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Analysis of Precipitation Concentration Index and Rainfall Prediction in various Agro-Climatic Zones of Andhra Pradesh, India

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Abstract

Enhanced anthropogenic activities over the last few decades have led to significant changes in climate world over. This paper mainly focuses on the assessment of changes occurring in the temporal distribution of rainfall with 30-years database of monthly precipitation for identifying the Monthly, Seasonal and Annual distributions, variations and trends in ten districts of AP. Regression analysis is done to examine the effect of weather parameters on change in climatic conditions. The slope values obtained from regression was calculated for the ten districts, showed the highest negative value for Karimnagar (-1.2) and highest positive value for the Guntur districts (1.3). Precipitation Concentration Index was analyzed at annual and seasonal scale to identify the pattern of rainfall in the study area for the period of 1981-2010 which showed an irregular distribution of rainfall with values in the range of 16 to 35. Prediction of rainfall for the year 2011 to 2015 is done by using the Climate Predictability Tool for the Karimnagar and Prakasam districts. The results indicated that the values of prediction of rainfall for Karimnagar showed that for the years 2006, 07, 08 and 11 the prediction was fairly consistent showing an error within the range of ±5%. Prakasam showed highly erratic values between the forecasted and predicted and actual data. This is attributed to the diverse agro-climatic regions in Prakasam when compared to Karimnagar which falls into a single agro-climatic zone.

Keywords: Regression analysis, climate predictability tool, precipitation concentration index.

Introduction

Rainfall is one of the important variables associated with monsoons in any part of world and the quantity of rainfall within a week or month varies widely. The monsoon season is fairly organized spatially over seasons on a large scale but this is not true for smaller scale domains[1]. The optimum time and space scales for rainfall are not well studied in the local domain and therefore it becomes important for one to understand the dynamics of the rainfall seasonally and annually. The increase in temperature and consequently the changes in precipitation are having an impact on the ecosystems across the world and thereby on the human population[2]. The IPCC-2007 study has for the period 1900–2005 in the region of north of 30^0latitude, identified that an increase in precipitation has occurred [3]. A study carried out in the tropical and subtropical areas has shown a decrease in precipitation from 1970s which has led to subsequent drought in the region[4]. There are indications of changes in rainfall taking place both on the global and regional scales[5]. Changes in the patterns of rainfall and its impact on vegetation and animal life including humans, is an important climatic problem which need to be address on priority[6]. Africa has often shown rainfall variability and associated droughts leading to food shortages[7,8]. It is reported that a 10% deviation of seasonal rainfall from the long term average rainfall leads to a 4.4% decrease in food production in Africa[9]. The trends reported by the IPCC on India's climate have been in conformity with the observations of the Indian Meteorology Department and the Indian Institute of Tropical Meteorology. In India, there has always been an erratic trend to the monsoon rainfall during the last century, although there have been some regional patterns emerging. The areas of west coast, north Andhra Pradesh and north west India have been experiencing increasing rainfall while those in east Madhya Pradesh and adjoining areas, north east India and parts of Gujarat and Kerala (–6 to –8% of normal over 100 years) have been reporting decreasing rainfall trends. The IPCC-2007 suggests the there is a need for detailed analyses of the sub-regional variability in precipitation. Detailed spatial datasets having multiple decades of information are required to carry out this kind of a study[10]. This paper aims to study the distribution of rainfall across various agro-climatic zones in 10 districts of Andhra Pradesh, India. Decadal analyses of the rainfall patterns in the study area were attempted. Analysis of the Precipitation Concentration Index (PCI) trends was carried out in 10 districts. Based on the results obtained from PCI the prediction of rainfall for next five years was done in two districts of Karimnagar and Prakasam in Andhra Pradesh.

Material and Methods

Study Area: The State of Andhra Pradesh has been divided into 23 administrative districts and lies between 12°41' and 22°N latitude and 77° and 84°40'E longitude. The State has different geographical regions and the climate changes in each of these regions. The temperature in summer, in the coastal plain is generally higher than the rest of the geographical regions in the State and varies between 20°C and 41°C. From July to September which is typical South West Monsoon, contributes maximum to the rainfall in the State. Based on soil characteristics, rainfall distribution, cropping pattern and other ecological characteristics, the state Andhra Pradesh has been classified into seven agro-climatic zones. In the present study 10 districts of Andhra Pradesh namely East Godavari, Guntur, Krishna, Kadapa, Karimnagar, Mahabubnagar, Prakasam, Visakapatnam, Warangal and West Godavari under different agro-climatic regions are chosen. The study area map shows the 10 districts of AP figure 1(a), while the agro-climatic zones in the 10 districts of Andhra Pradesh is shown in figure 1(b). The rainfall data for the 10 districts was collected from Directorate of Economics and Statistics [DES] Government of AP and the analysis of data were carried for a period 1981-2010 both at district and mandal / block level.

Methodology: The statistical analysis of the rainfall was computed for all the ten districts to identify the existence of trend in monthly, seasonal and annual rainfall pattern by using SYSTAT 7.0.1 software to understand the rainfall distribution in the period 1981-2010. Linear Regression test was done to identify the existence of any trend or persistence in the rainfall series. The monthly actual average rainfall in millimeters (mm) was analyzed at the district level for all the ten districts and normal values, mean, Standard Deviation (SD), Coefficient of Variation (CV) and Percent Deviation (%D) were calculated.

Modified version of Precipitation Concentration Index (PCI) was used to estimate the monthly heterogeneity of rainfall [11]. Through PCI the data related to the long term variability in the amount of rainfall received is obtained and was calculated using equation (1) on annual scale:

$$PCI_{annual} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p\,i\right)^2} \cdot 100 \qquad (1)$$

where pi is the monthly precipitation in month i.

The seasonal scale of Precipitation Concentration Index was calculated using equation (2)

$$PCI_{seasonal} = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} p\,i\right)^2} \cdot 25 \qquad (2)$$

According to Oliver's classification[11]: i. PCI < 10 indicates uniform precipitation distribution (low precipitation concentration), ii. PCI >11 and <15 indicates moderate precipitation concentration; iii. PCI >16 and < 20 indicates irregular distribution, iv. PCI > 20 indicates a strong irregularity (i.e., high precipitation concentration).

The PCI index was calculated for the period 1981-2010 to understand the changes with time. The t test with different levels of probability exceptionally likely ($p < 0.01$); extremely likely ($p < 0.05$); very likely ($p < 0.10$); very low probability ($p > 0.10$) for the different years was assessed to identity its statistical significance. The study also attempted to predict the rainfall for the period 2011-2015 using climate models at district level. Climate Predictability Tool (CPT) Version 11.03 is used to detect prediction, by downscaling of GCM output, and also using the statistical predictions using sea-surface temperatures. The model can construct the forecasts based on the given historic data. It further validates and then gives the forecasts. The rainfall for the period 2011-2015 is forecasted using the validation methods of CPT like Canonical Correlation, which is used to construct the model and validate.

Results and Discussion

The state of Andhra Pradesh is divided into 23 districts and each district is divided into several administrative blocks called mandals. Each of these mandals has rain gauges which record the rainfall on a daily basis. Rainfall data is collected on 24 hour daily basis in the various mandals of the 10 districts of Andhra Pradesh. The districts are divided into 7 agro-climatic zones and the distribution of mandals into various agro-climatic zones in the 10 districts is given in table 1.

Based on the daily rainfall collected the data is presented as monthly, seasonal and annual basis for the period 1981 to 2010. The percentage deviation of the annual average rainfall was calculated for three decades i.e., 1981-1990, 1991-2000 and 2001-2010 in the ten districts. An analysis of the data shows an increasing trend towards deficit and scanty rainfall in 50% of the selected districts in the last decade. These districts include East Godavari, Krishna, Visakapatnam, West Godavari, Prakasam and Karimnagar (table 2).

Significant changes in rainfall patterns but with an alternating sequence of multi-decadal periods of thirty years having frequent droughts and flood years are observed in the all India monsoon rainfall data [12]. A study on rainfall time series data in 211 gauges stations over a time period of 1918–1999 showed the potential trends in rainfall and helped in assessing their significance[13].

An analysis of the daily rainfall data of 37 years of Pantnagar, India on daily, weekly, monthly and annual basis, the data showed that the annual daily maximum rainfall received at any time ranged between 49.32mm (minimum) to 229.40mm (maximum) indicating a very large range of fluctuation during the period of study[14]. In order to identify the trends in rainfall the entire period was divided into sub-periods of 1974-1983, 1979-1988 and 1999-2008. The results indicated that the months June and October were drier than normal for the years 1974-1983 and 1999-2008[15]. Further analysis of decadal data shows that the highest negative percent deviation values are observed in all the selected districts except for Kadapa in the last decade of 2000-2010. The districts of West Godavari, Krishna, Guntur, East Godavari, Warangal and Visakapatnam has shown the largest negative percent deviation in the year 2002-2003 while that for Karimnagar, Prakasam and Mahabubnagar in the year 2004-2005. An analysis of the seasonal data i.e., South West Monsoon and North East Monsoon was carried out in the 10 districts for 30 years and the results presented in table 3.

Table-1
Number of mandals in various Agro-Climatic Zones

Districts	Krishna-Godavari Zone (800-1100mm)	SouthernZone (700-1100mm)	Southern Telangana Zone (700-900mm)	High altitude and tribal areas (>1400mm)	North Coastal Zone (1000-1100mm)	North Telangana Zone(900-1500mm)	Scarce Rainfall Zone (500-750mm)	Total number of mandals in districts
East Godavari	2	-	-	6	51	-	-	59
Guntur	57	-	-	-	-	-	-	57
Krishna	50	-	-	-	-	-	-	50
Kadapa	-	9	-	-	-	-	41	50
Karimnagar	-	-	-	-	-	57	-	57
Mahabubnagar	-		33	-	-	-	27	60
Prakasam	33	22	-	-	-	-	2	57
Visakapatnam	-	-	-	2	41	-	-	43
Warangal	-	-	33	-	-	17	-	50
West Godavari	46	-	-	-	-	-	-	46
Total Number of mandals	188	31	66	8	92	74	88	-

Table-2
Decadal analysis of rainfall showing number of years with positive and negative deviation

	1981-1990		**1991-2000**		**2001-2010**	
Districts	**Positive**	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**
East Godavari	4	6	4	6	2	8
Guntur	5	5	6	4	7	3
Krishna	3	7	4	6	5	5
Kadapa	2	8	5	5	5	5
Karimnagar	3	3	3	7	2	8
Mahabubnagar	7	3	5	5	5	5
Prakasam	3	7	6	4	2	8
Visakapatnam	6	4	4	6	2	8
Warangal	5	5	4	6	6	4
West Godavari	3	7	4	6	2	8

Table-3
Number of years with negative deviation –season wise rainfall analysis

	Annual Rainfall				**South West Monsoon (SWM)**				**North East Monsoon (NEM)**				
Districts	**E**	**N**	**D**	**S**	**E**	**N**	**D**	**S**	**E**	**N**	**D**	**S**	
East Godavari	6	4	5	14	5	11	0	17	4	11	5	9	30 YEARS
Guntur	2	15	2	10	6	10	5	8	3	10	4	12	
Krishna	3	8	3	15	6	7	4	15	3	7	3	16	
Kadapa	3	9	2	15	4	6	2	18	5	6	3	15	
Karimnagar	4	4	10	7	4	2	2	14	3	2	2	18	
Mahabubnagar	4	13	4	9	5	5	2	12	4	5	5	15	
Prakasam	7	4	5	13	4	2	2	13	7	2	4	16	
Visakapatnam	3	9	5	12	2	6	3	20	4	6	6	13	
Warangal	4	10	3	12	2	9	3	12	4	9	4	12	
West Godavari	2	7	0	20	1	10	0	17	3	10	4	12	

E- Excess; **N**- Normal ; **D**- Deficit ; **S**- Scanty, Excess years: Actual rainfall, SWM, NEM > mean + SD, Deficit years: Actual rainfall, SWM, NEM < mean - SD

The excess and deficit years for annual rainfall and for two seasons during the period 1980-2009 are identified using mean and Standard Deviation [S.D]. In the study, the summer period shows a positive trend, while the annual and the seasonal scale analyses show a predominantly negative trend. In the present study it can be observed that the annual rainfall distribution into excess, normal, deficit and scanty is influenced predominantly by South West Monsoon. Basin wise trend analysis across India in 15 basins has shows a decreasing trend in the annual rainfall, one of which showed at 15% confidence level. A similar trend is seen in annual and seasonal rainfall along with the rainy days in almost all the basins in the country[16]. Regression analysis was applied for 30 years of annual average rainfall in the ten districts as shown in table 4. The slope was calculated for all the 10 districts (figure 2) and it was found that the value for Karimnagar was the most negative (-1.2) and the Guntur is the most positive (1.35). The values of R^2 varied in the range of 0.013 to 0.169. The changes in rainfall using data from 134 stations in 13 watersheds within Ethopia in the period 1960 and 2002 and there was a significant decrease in rainfall in the watershed region[17].

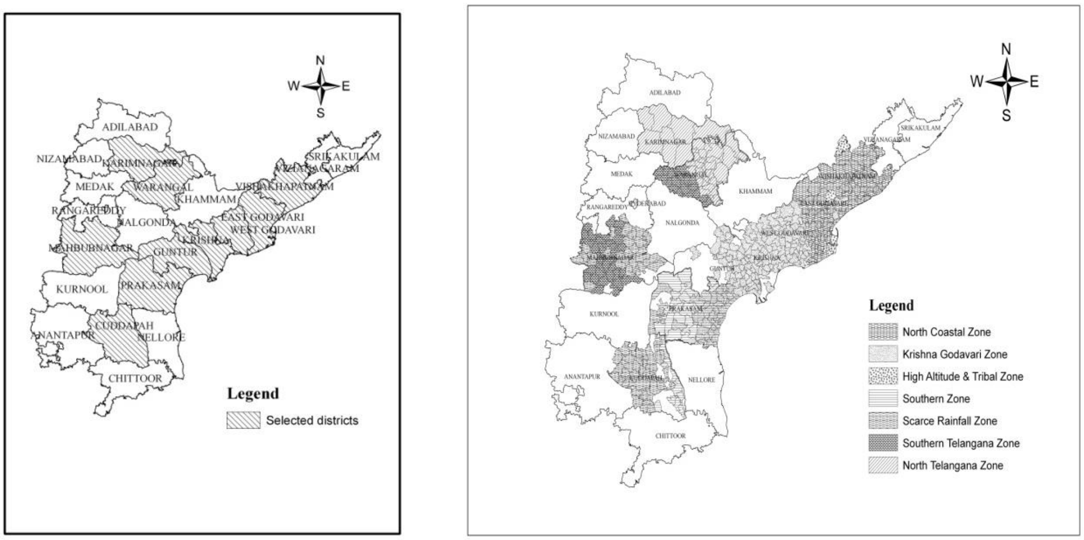

Figure 1(a) Figure 1(b)

Figure-1
Maps showing (a) 10 districts of Andhra Pradesh selected for the study (b) Agro-Climatic zones in 10 districts of Andhra Pradesh

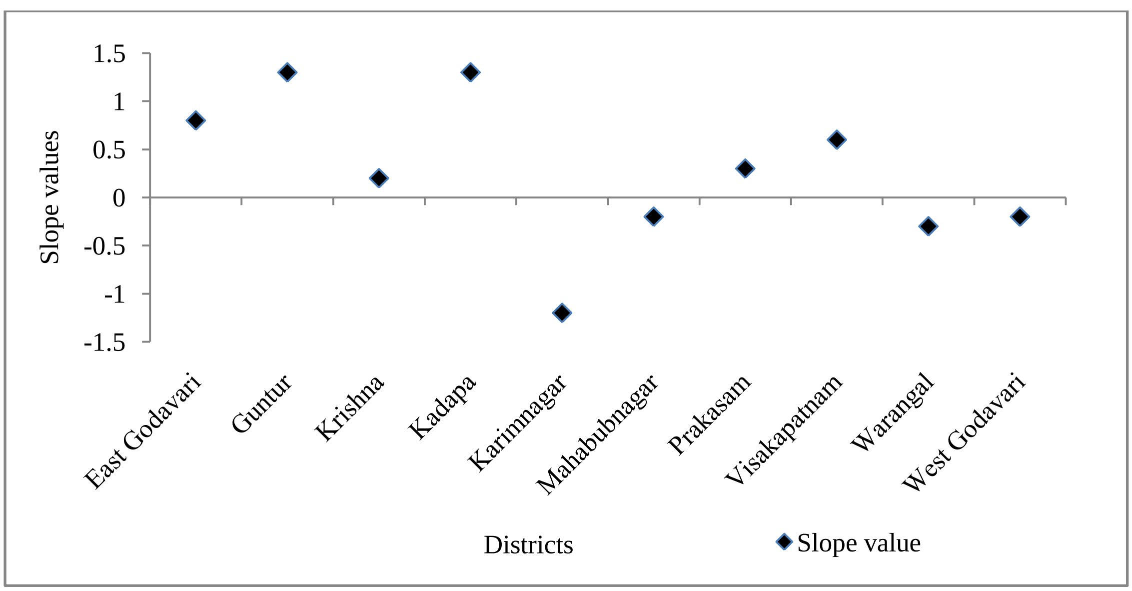

Figure-2
Graph showing values of slope of Regression analysis

The Precipitation Concentration Index values for the 10 districts of Andhra Pradesh were calculated based on the equations (1 and 2) given by Oliver 1980. The results are presented in table 5 and indicate highly irregular distribution of rainfall is occurring in all the 10 districts. The highest irregularity was observed for the period 2001-2010 as seen in table 5.

A study on the variability in space and time of the Precipitation Concentration Index trends in the Mediterranean fringe of Iberian Peninsula shows that higher values were obtained in the south and south-eastern parts, which indicated more trends towards irregularity in rainfall[18]. Dereje Ayalew et al.[19] calculated the annual and seasonal patterns of the rainfall and examined for all 10 stations based on inter-seasonal spread of the rainfall using PCI which showed a decline in the period of September to December. A study on the calculation of annual, seasonal, wet and dry periods between the years 1946-1975 and 1976-2005 in Spain has shown increase in precipitation concentration in the wet season on the annual scale. However the seasonal changes are localized[20]. A calculation of the % number of years with values of PCI > 16 in the present study, in various agro-climatic regions shows that Prakasam district is affected maximum with 62% of years in the North East Monsoon period. Similar analysis of the annual data shows all agro-climatic regions lie in the range of 29 to 45% highly irregular rainfall distribution. Hence it can be concluded that the PCI is complex and effect the local precipitating conditions and is also related to the global atmospheric features in the region. The trends and consequently the variability in rainfall both annual and seasonal was analyzed for annual and seasonal data. The statistical significance as shown by the t-test (figure 3) indicates that for the annual PCI values the probability is in all cases >0.10 which is classified as very low probability. Hence it can be mentioned that by regressing annual rainfall for the 30 year period and PCI, results from the *t* -test showed significant changes in rainfall.

Based on results obtained for Karimnagar and Prakasam districts it was found that the rainfall pattern was erratic and hence the Climate Predictability Tool [CPT] was used to predict the rainfall for the years from 2011 to 2015. The data obtained for 2011 was used to cross verify with the actual rainfall received during the year. The models applied for the forecasting are like multiple regression models, principal component regression, statistical ensemble model etc. The relationship of all India summer monsoon rainfall and sea surface temperatures (SSTs) over Arabian sea region from 1951 to 1980 was studied so as to get a useful predictor for the monsoon rainfall. It was found that the best correlation coefficient (0.4) was obtained for lag-1(MAM) and 0.63 for the tendency parameter MAM-DJF[21]. A study predicted the JJAS (June to September) rainfall Ethiopia using CCA (canonical correlation analysis) of Climate predictability Tool (CPT) using gridded global SST as predictor field[22]. The tool is run twice first using May SST to predict JJAS and then use JAS SST to predict JJAS. The canonical correlation of May SSTs and JJAS is observed to be 0.55 and with JAS SSTs it is 0.70.

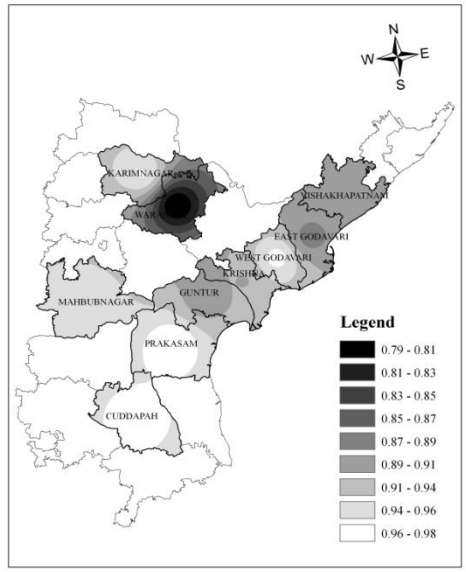

Figure-3
Map showing t-test significant level for 10 districts

Based on the above studies on the ISMR using SST, the rainfall prediction for Karimnagar and Prakasam districts were done using two different predictors by running data using CPT. First predictor is SST anomalies of February and March of the period 1984-2011 of South East tropical Indian Ocean (SETIO) of spatial domain Latitudes 20^0S to 10^0S and Longitudes 100^0E to 120^0E. The other predictor used is Arabian Sea (AS) SSTs (spatial domain Latitudes 4^0S to 24^0N and Longitudes 56^0E to 72^0E) for the months of March, April and May of the period 1984-2011. The data for the two predictors is taken from the ERSST v2 (1984-2009) of 2^0 X 2^0 grid (average values are available for the spatial domains considered is available in CPT supporting file format) and from ERSST v3b 2^0 X 2^0 data (only grid data is available) for the years 2010 to 2011. The simple arithmetic mean of ERSST v3b is taken. The predictant used is the seasonal southwest monsoon rainfall data collected from the DES for the period 1984-2010. The forecast is done for the JJAS (June to September). Using the SETIO SSTs anomalies composite of March and February as predictor (period 1984-2011) and JJAS actual rainfall is used as predictant. Seasonal and monthly rainfall is predicted for the year 2011. The other Predictor used is the Arabian Sea composite of March, April and May (MAM) SSTs of the period 1984-2011 and this predictor is used to predict one lead month's rainfall i.e. June month. Predictant used is June month actual rainfall, CCA is used to construct the model and the cross-validated option is used to validate the model.

Based on the South East Tropical Indian ocean SST anomalies of the months February and March taken for the Latitudes 20^0S to 10^0S and Longitudes 100^0E to 120^0E, the data is available as averages of the 67 grids that fall in the above said spatial domain. The composite of February and March SST anomalies are used as predictor and JJAS actual average rainfall as predictant. The model is constructed and CCA is used, the goodness index is observed to be 0.05 and correlation coefficient is 0.05, RMS error 219.81 and canonical correlation is 0.31. The forecasted JJAS rainfall for the year 2011 is 756.46 mm and the figures 4 and 5 shows the hind cast plot along with forecasts shows forecasted and observed rainfall for Karimnagar and Prakasam districts respectively.

The composite is used with June month actual average rainfall as predictant and goodness index of 0.238 and Pearson correlation is 0.29 with RMS error 61.91 and Canonical correlation is 0.44. The forecasted June rainfall for the year 2011 is 140.67mm. The composite February and March SST anomalies has resulted negative correlation with July, August and September month actual average and thus forecasts are not done. The data used for predictors is coupled GCM output. CCA is used to train the CPT with the goodness index 0.57. The second predictor Arabian Sea SST of the months March, April and May (MAM) composite are used and the June actual average rainfall is used as predictant, a negative Pearson correlation is observed, which indicates that the model cannot fit that data. Out of the two predictors, for seasonal predictions the indicator February and March SST anomalies of SETIO have shown a better predictive skill in both the districts. Table 6 shows the forecasted and observed values for the years 2005 – 2011. The results indicated that the values of prediction of rainfall for Karimnagar showed that for the years 2006, 07, 08 and 11 the prediction was fairly consistent showing an error within the range of ±5%. Prakasam showed variation between the values of observed and predicted rainfall and more erratic between the forecasted and predicted and actual data. This is attributed to the diverse agro-climatic regions in Prakasam when compared to Karimnagar which falls into a single agro climatic zone.

Table-4
Regression values of 10 districts

Districts	Y value	R square value
East Godavari	y = 0.840x - 26.88	$R^2 = 0.088$
Guntur	y = 1.352x - 20.76	$R^2 = 0.172$
Krishna	y = 0.287x - 13.67	$R^2 = 0.013$
Kadapa	y = 1.318x - 29.62	$R^2 = 0.147$
Karimnagar	y = -1.210x + 8.742	$R^2 = 0.169$
Mahabubnagar	y = -0.216x + 5.473	$R^2 = 0.004$
Prakasam	y = 0.379x - 18.37	$R^2 = 0.024$
Visakapatnam	y = 0.699x - 19.59	$R^2 = 0.047$
Warangal	y = -0.328x + 2.441	$R^2 = 0.019$
West Godavari	y = -0.243x - 6.333	$R^2 = 0.006$

Table-5
Annual and seasonal Precipitation Concentration Index (PCI) Values of ten districts in their respective agro climatic zones

Districts	Annual PCI				SWM PCI			NEM PCI			
	<10	<16	>16	% no. of years with PCI >16 (2001-2010)	<10	<16	>16	<10	<16	>16	% no. of years with PCI >16 (2001-2010)
Krishna Godavari Zone											
Guntur	00	3	27	33.3	27	1	00	1	15	12	42.8
Krishna	00	3	27	29.6	28	00	00	1	14	15	40
West Godavari	00	3	27	33.3	27	1	00	1	12	17	41.1
Southern Zone											
Prakasam	1	4	25	32	25	3	00	3	19	8	62.5
Southern Telangana Zone											
Mahabubnagar	00	00	30	33.3	28	00	00	3	10	17	35.2
Warangal	00	1	29	34.4	27	1	00	3	10	17	47
North Coastal Zone											
East Godavari	00	4	26	38.4	28	00	00	1	13	16	37.5
Visakapatnam	00	10	20	45	28	00	00	1	9	20	35
North Telangana Zone											
Karimnagar	00	00	25	40	24	1	00	2	6	18	44.4
Warangal	00	1	29	34.4	27	1	00	2	9	17	47
Scarce Rainfall Zone											
Kadapa	00	5	25	36	25	3	00	8	19	3	100
Mahabubnagar	00	00	30	33.3	28	00	00	3	10	17	35.2

Table-6
The observed and forecasted JJAS actual average rainfall from 2005-2011 for Karimnagar and Prakasam districts

Years	Forecasted Rainfall (mm)	Observed Rainfall (mm)
Karimnagar - North Telangana Zone - 57 mandals		
2005	811	800
2006	696	934
2007	760	750
2008	783	742
2009	720	532
2010	733	995
2011	756	756
Prakasam - Krishna- Godavari zone - 33 mandals; Southern Zone - 22 mandals; Scarce Rainfall Zone -2 mandals		
2005	420	338
2006	351	274
2007	389	598
2008	404	288
2009	365	282
2010	374	601
2011	387	569

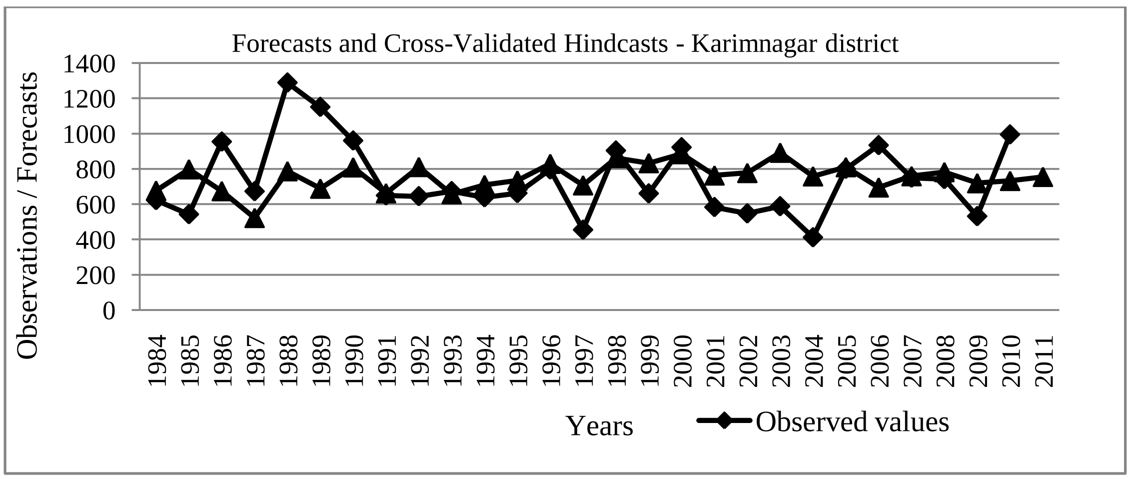

Figure-4
Graph showing the forecasted value and cross validated hindcasts using F and M SST anomalies – Karimnagar district

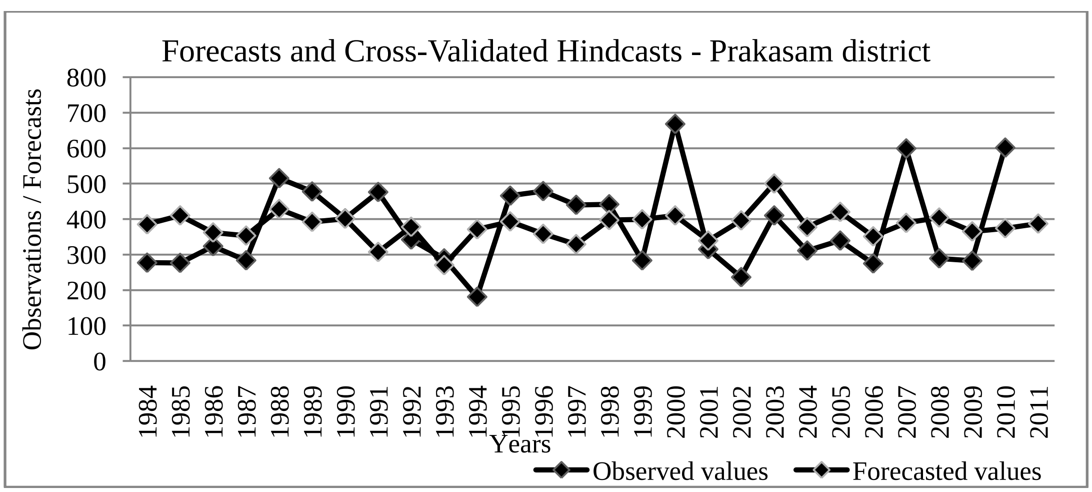

Figure-5
Graph showing the forecasted value and cross validated hindcasts using F and M SST anomalies – Prakasam district

Conclusion

Climatic variations are observed in almost most regions at the global and regional level. The present study attempts to analyze the changes occurring in the temporal distribution of rainfall in 10 districts of Andhra Pradesh, India for a period from 1981 to 2010. Statistical evaluations including regression analysis was carried out using rainfall data at district and mandal level. The analysis of the data shows an increasing trend towards deficit and scanty rainfall in 50% of the selected districts in the last decade. The precipitation concentration index calculated at annual and seasonal level showed values >16 in the last decade of 2001 to 2010. A calculation of the % number of years with values of PCI >16 in the present study, in various agro-climatic regions shows that Prakasam district is affected maximum with 62% of years in the North East Monsoon period. The Climate Predictability tool was used to forecast the rainfall in the districts of Karimnagar and Prakasam. It can be concluded that the tool works within the error limits of ±5% for Karimnagar district which could be attributed to the single agro climatic zone [North Telangana Zone] where as the tool is erratic for Prakasam which falls into three agro climatic zones. The overall analysis of the data for the last 30 years in the districts of Andhra Pradesh clearly indicates significant changes in rainfall patterns especially during the last decade.

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