551.509.3 : 551.553.2 : 551.577 (540.63)

MR MODEL FOR THE PREDICTION OF SUB DIVISIONAL SOUTHWEST MONSOON SEASONAL RAINFALL OF SUB DIVISIONS FROM ANDHRA PRADESH AND TELANGANA

1. Following the disastrous famine in 1877, Blandford (1884) made first attempt to forecast the Southwest monsoon seasonal rainfall (Normand, 1953). Walker (1923) identified global scale surface pressure oscillations across Pacific Ocean named as “Southern Oscillation” in short SO. Bjerkens (1969) through his study linked equatorial east Pacific Sea Surface Temperatures (SSTs) with SO and both are inversely related. Angell (1981) correlated Indian summer monsoon rainfall and SST anomalies over Equatorial Pacific and found that there existed a strong negative correlation between these two when SST positive anomalies were present. Normand (1953) observed that India is too large to be treated as a single unit and some regional rainfalls are negatively correlated with others. Weare (1979) found an associated between positive equatorial eastern Pacific and high Indian region SSTs. However, Shukla & Mishra (1977) found weak positive correlations between Arabian Sea SSTs and June to September rainfalls over some portions of India. Saji *et al.* (1999) reported an analysis of observational data over the past 40 years, showing a dipole mode in the Indian Ocean: a pattern of internal variability with anomalously low sea surface temperatures off Sumatra and high sea surface temperatures in the western Indian Ocean, with accompanying wind and precipitation anomalies. Ashok & Saji (2007) studied the relative impacts of the ENSO and Indian Ocean dipole (IOD) events on Indian summer (June-September) monsoon rainfall at sub-regional scales using Global Sea-Ice and Sea Surface Temperatures (GISST) dataset from 1958 to 1998 which is now superseded by Hadley Sea-Ice and Sea Surface Temperature (HADISST) data set along with Willmott and Matsuura gridded rainfall data (Willmott & Matsuura, 1995), all India summer monsoon rainfall data from India Meteorological Department, and homogeneous and sub-regional Indian rainfall datasets (Parthasarathy *et al*., 1993; 1995). In their study the spatial distribution of partial correlations between the IOD and summer rainfall over India indicated a significant impact on rainfall along the monsoon trough regions, parts of the southwest coastal regions of India. Mooley & Parthasarathy (1983) examined the relationship between El Nino events and the all India & Sub-divisional rainfalls for the period 1871-1978 and found statistically significant association between events and drought/ deficient rainfalls over sub-divisions west of 80° E and north of 12° N. Therefore, in this paper an attempt has been made to generate a multiple regression model to forecast meteorological sub divisional summer monsoon rainfall for three sub-divisional namely Coastal Andhra Pradesh, Rayalaseema & Telanaga using the three oceanic

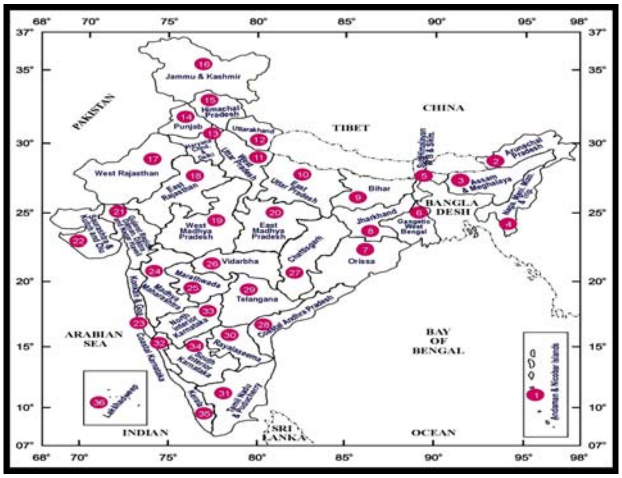

Fig. 1. Meteorological sub-division map of India

parameters and one atmospheric parameter, *viz.*, IODMI, SOI, MEI & ONI. The sub-divisions considered in this study are shown in Fig. 1.

The average rainfall figures (1958-2009) are 529.3, 444.8 & 717.9 mm for CAP, RYSM & TLNG respectively. In the 52 years period from 1958-2009, it is seen that CAP has seen 11/27/14, RYSM has seen 11/28/13 and TLNG has seen 8/30/14 Excess/ Normal/Deficient years. In other words, the percentage of Excess/Normal/Deficient years were 21%/52%/27%, 21%/54%/25% & 15%/58%/17% for CAP, RYSM & TLNG respectively based on the percentage departures calculated with base period of 1958-2009. The standard deviations for SW monsoon rainfall are 123.2/125.7/174.5 mm for CAP/RYSM/TLNG respectively with the same base period as shown in Table 1. The average negative deviations during the period (1958-2009) are 18/18/20 and average positive deviations are 20/27/18 for CAP/RYSM/ TLNG respectively. The correlation coefficients between the three meteorological sub-divisions are shown in Table 2. The correlation coefficients are strong & statistically significant at 0.05 significant levels.

2. The strength of the Indian Ocean Dipole (IOD) is represented by Dipole Mode Index (DMI) that indicates anomalous Sea Surface Temperature gradient between the western equatorial Indian Ocean (50° E - 70° E and 10° S-10° N) and the south eastern equatorial Indian Ocean (90° E – 110° E and 10° S - 0° N. The positive IODMI corresponds to positive IOD and negative IODMI corresponds to negative IOD. IOD is a coupled ocean-atmosphere phenomenon it can also be represented by Pressure or OLR (Outgoing Long wave Radiation). In this paper monthly Sea Surface Temperature IODMI dataset derived from HadISST dataset (1958-2009) has been used (Rayner *et al.* 2003). The SST data are taken from the

TABLE 1

Rainfall statistics based on 1958-2009

Statistics/Sub-divisions	CAP	RYSM	TLNG
Mean (mm)	529.3	444.8	717.9
standard deviation	123.2	125.7	174.5
No. of Excess years (percentage)	11 (21)	11 (21)	8 (15)
No. of Normal years (percentage)	27 (52)	28 (54)	30 (58)
No. of Deficient years (percentage)	14 (27)	13 (25)	14 (27)
Average negative deviations	18	18	20
Average positive deviations	20	27	18

TABLE 2

Correlation coefficients between three meteorological sub-divisions

Sub-divisions	CAP	RYSM	TLNG
CAP	1	0.78	0.71
RYSM	0.78	1	0.51
TLNG	0.71	0.51	1

Met. Office Marine Data Bank (MDB) from 1982 onwards also includes data received through the Global Telecommunications System (GTS). In order to enhance data coverage, monthly median SSTs for 1871-1995 from the Comprehensive Ocean-Atmosphere Data Set (ICOADS) were also used where there were no MDB data. From May 2007 the data set of *in situ* measurements used in HadISST has changed. The monthly Southern Oscillation Index (SOI) values have been taken from the archival of Bureau of Meteorology, Government of Australia (1958-2009). There are a few different methods of to calculate the SOI. The method used by the Australian Bureau of Meteorology is the Troup SOI which is the standardised anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin. The Multivariate ENSO index values (Wolter, 1987; Wolter & Timlin, 1993) have been taken from the Physical Sciences Division, Earth System Research Laboratory, National Oceanic Atmospheric Administration (NOAA), USA. The Oceanic Nino Index (ONI) values were taken from the Climate Prediction Centre (CPC), NOAA for the period 1958-2009. The Oceanic Niño Index (ONI) is computed as a 3 month running mean of Extended Reconstruction Sea Surface Temperatures (ERSST.v3b) (Smith *et al.*, 2008) SST anomalies in the Niño 3.4 region 5° N - 5° S, 120° - 170° W), based on centred 30-year base periods updated every 5 years and warm/cold events are identified by using a threshold value of ± 0.5 °C. The monthly sub-divisional rainfall data has been taken from the data

TABLE 3

Correlation between sub-divisional SW monsoon seasonal rainfalls and various indices

Index/Sub-division	CAP	RYSM	TLNG	T-Statistic		
				CAP	RYSM	TLNG
IODMI	-0.19	-0.22	-0.12	-1.33965*	-1.52751*	-0.85269#
SOI	0.42	0.36	0.39	2.993886***	2.530198***	2.742147***
MEI	-0.31	-0.24	-0.36	-2.17272***	-1.68071**	-2.50843***
ONI	-0.41	-0.41	-0.41	-2.91535***	-2.91535***	-2.87929***

* Not statistically siginificant at 0.05 significant level but significant at 0.1 for one sided, # at 0.2 for one sided; ** statistically significant at 0.05 significant level for one sided; *** statistically significant at 0.05 significant level or less for two sided

archival "Homogeneous Indian Monthly Rainfall Data Sets (1871-2012)" of Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Government of India (Mooley *et al*., 1981; Parthasarthy *et al*., 1993; 1995). Firstly using the data sets considered correlations between all these have been computed and then finally, Analysis of Variance (ANOVA) and multiple regression methods employed for prediction of the sub divisional seasonal southwest monsoon rainfalls. The general purpose of multiple regression, a time honoured technique, is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable. In the social and natural sciences multiple regression procedures are very widely used in research. In general, multiple regression allows the researcher to know which is the best predictor after all. Later the multiple regression model has been validated using next four years rainfall data from 2004 to 2013. The training period for the multiple regression model is 52 years and the independent test period is 10 years. The correlation coefficients between the predictors (IOD, SOI, MEI & ONI) and predictand (Southwest monsoon rainfall) for coastal Andhra Pradesh are -0.2, 0.4, -0.3 & -0.4, for Rayalaseema are -0.2, 0.4, -0.2 & -0.3 and for Telangana -0.1, 0.4, -0.4 & -0.4 in the same order as predictors during training period. The correlation coefficients are statistically significant at 0.05 significant level except one between Telangana and IOD.

3. The relationship between the Indian summer monsoon and the El Niño-Southern Oscillation (ENSO) has been subjected to numerous studies and has demonstrated that the Indian monsoon rainfall tends to be below normal in the developing phase of ENSO (Rasmusson and Carpenter, 1983; Lau *et al*., 2000; Wang *et al*., 2001 & 2003). During the five strong El Nino years 1877, 1899, 1911, 1918 and 1972 many areas of India suffered large rainfall deficiencies and severe droughts. There are four moderate El Nino years 1887, 1914, 1953 and 1976 when the suffering was marginal. The simultaneous correlation between the SW monsoon rainfall and June NINO3 is about -0.5. The warmer SSTs over NINO 3 region modulate the Walker Circulation and cause reduction in the Indian summer monsoon rainfall due to subsidence (Palmer *et al*., 1992; Soman and Slingo, 1997). Many earlier studies indicated that drought years in India are associated with El Nino years and flood years are associated with La Nina years. However, in the later years there has been some change in the association and all the El Nino years were not drought years and especially the year 1997 which was a strong El Nino year and in that year the Indian Summer Monsoon Rainfall was more than normal indicating that the relationship between the Indian monsoon and ENSO had weakened in the recent decades (Kumar *et al*., 1999). Kumar *et al*., 2002 in their study showed that of the 22 (19) large negative (positive) Indian Summer Monsoon Rainfall anomalies that occurred during 1871-2001, only 11(8) were associated with El Nino (La Nina).

TABLE 4

Correlations between various indices

INDICES	IODMI	SOI	MEI	ONI
IODMI	1.00	-0.59	0.52	0.50
SOI	-0.59	1.00	-0.85	-0.83
MEI	0.52	-0.85	1.00	0.86
ONI	0.50	-0.83	0.86	1.00

All correlations statistically significant at 0.05 significant level for two sided

In this study, the correlations calculated are -0.19, -0.22 & -0.12 between IODMI, 0.42, 0.36 & 0.39 between SOI, -0.31, -0.24 & -0.36 between MEI and -0.41, -0.41 & -0.41 between ONI and Coastal Andhra Pradesh, Rayalaseema & Telangana respectively. The SOI has shown a strong positive correlation with all the three sub-divisional monsoon rainfall as mentioned above with

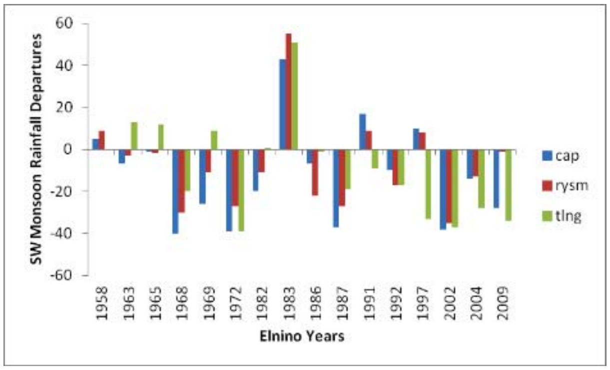

Fig. 2. Showing SW monsoon rainfall percentage departures during El Nino years

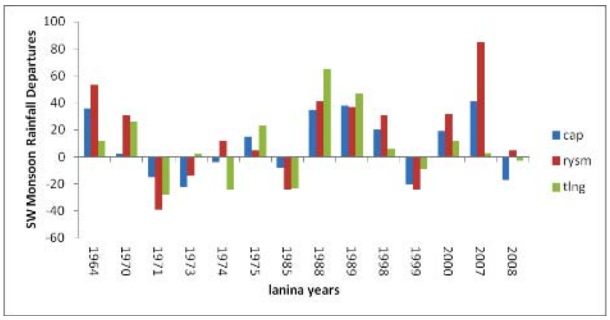

Fig. 3. Showing SW monsoon rainfall percentage departures during La Nina years

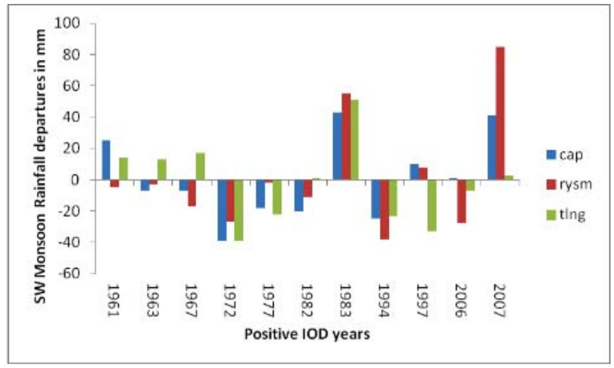

Fig. 4. Showing SW monsoon rainfall percentage departures during positive IOD years

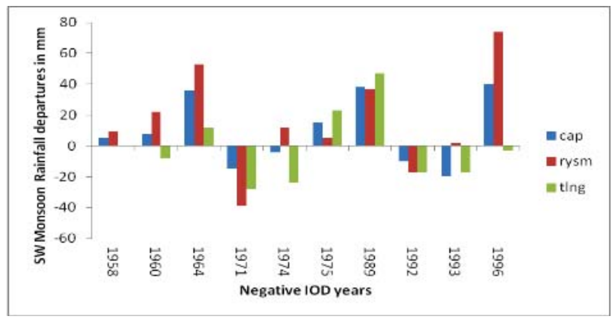

Fig. 5. Showing SW monsoon rainfall percentage departures during negative IOD years

remaining three indices showing negative correlations as mentioned above. The correlations with T-statistic are shown in Table 3. From Table 4 it can be seen that IODMI has strong positive correlations with MEI & ONI and strong negative relationship with SOI and SOI showing strong negative correlations with ONI & MEI. During the data period 1958-2009 based on ONI, there were 16/14/22 El Nino /La Nina/neutral years. In the years 1968, 1972 & 2002 all the sub-divisions received deficient rains. In the years 1958, 1963, 1965, 1991 & 1992 all the sub-divisions received normal rains. In the remaining years at least one sub-division got deficient rain. The Coastal Andhra Pradesh got 7/1/8, Rayalaseema got 5/1/10 and Telangana 6/1/9 deficient/excess/normal years out of 16 El Nino years. Out of 22 NEUTRAL years Coastal Andhra Pradesh got 5/5/12, Rayalaseema got 5/3/14 and Telangana 5/2/15 deficient/excess/ normal years. Similarly, during 14 La Nina years Coastal Andhra Pradesh got 2/5/7, Rayalaseema got 3/7/4 and Telangana 3/4/7 deficient/excess/normal years. Clearly the results indicated that during La Nina & NEUTRAL years the number of excess or Normal years is more. During El Nino years the deficient years are more in comparison with La Nina & NEUTRAL years. The performance of SW monsoon sub-divisional rainfalls in case of El Nino & La Nina years are presented in Figs. 2 and 3 respectively. During positive IOD (11) years, Coastal Andhra Pradesh got 3/3/5, Rayalaseema got 3/2/5 and Telangana got 4/1/6 deficient/excess/normal rainfall years. During negative IOD (10) years the Coastal Andhra Pradesh got 1/3/6, Rayalaseema got 1/4/5 and Telangana got 2/2/6 deficient/excess/normal rainfall years. It is therefore can be said that during positive IOD the number of deficient rainfall years is more. The performance of southwest monsoon during positive & negative IOD years is shown in Figs. 4 and 5. In the study period there were 13 SOI years and out of which coastal Andhra Pradesh got 6/0/7, Rayalaseema got 5/0/8 and Telangana got 6/0/7 deficient/excess/normal rainfall years. From this it can be said that no excess rainfall year was observed during Southern Oscillation year in the three sub-divisions considered in this study. The performance of southwest Monsoon during southern oscillation years is presented in Fig. 6.

It is also seen that out of 11 Positive IOD years 5(5) positive IOD years occurred during El Nino (NEUTRAL) years and only one positive IOD year occurred during La Nina year. Therefore, it can be said that mostly positive IOD years are associated with El Nino or NEUTRAL years. Out of 10 Negative IOD years 5/2/3 years occurred during La Nina / El Nino / NEUTRAL years. Therefore, positive IOD years are El Nino years and negative IOD

TABLE 5

Relationship between El Nino/Neutral/La Nina, drought, floods, IOD years (1958-2009)

El Nino years	Neutral years	La Nina years	Drought CAP/RYSM/TLNG	Floods CAP/RYSM/TLNG	Postive IOD	Negative IOD	X
16	22	14	7/10/7	8/10/7	11	10	X
El nino Years	X	X	6/4/5	1/1/1	5	2	X
Neutral Years	X	X	1/5/1	4/2/3	5	3	X
La Nina Years	X	X	0/1/1	4/6/3	1	5	X
X	X	X	1/2/1	2/2/1	X	X	Postive IOD
X	X	X	0/1/1	2/2/1	X	X	Negative IOD

Legend : ENL - El Nino/Neutral/La Nina; +IOD - Positive phase of IOD; -IOD - Negative phase of IOD; DF - Drought/Flood.

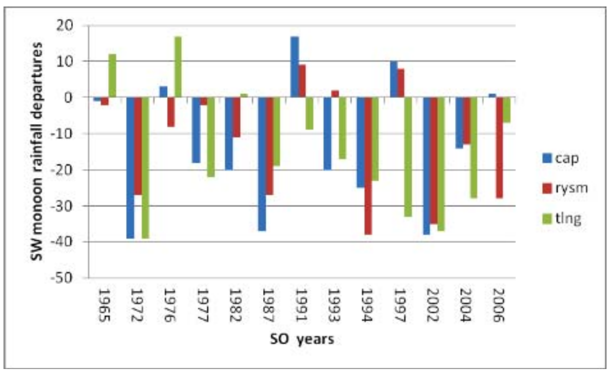

Fig. 6. Showing SW monsoon rainfall percentage departures during SO years

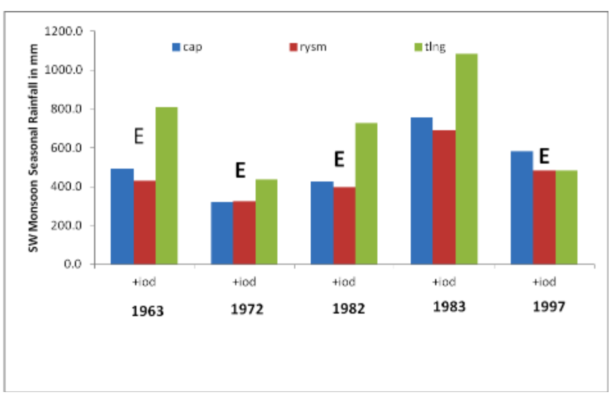

Fig. 7. Showing SW monsoon rainfalls during El Nino and positive IOD years

years are La Nina years and NEUTRAL years can be mostly positive IOD years. Therefore, the performance of southwest monsoon during El Nino & positive IOD is shown in Fig. 7.

In this paper, the flood year is defined as the year in which the rainfall excess was in between 26% to 50% and drought year is defined as the year in which the rainfall deficiency was in between -26% to -50%. The number of Flood (Drought) years are 8(7), 10(10) and 7(7) for Coastal Andhra Pradesh, Rayalaseema and Telangana respectively during the period of study. Out of 16 El Nino years 6(1), 4(1) & 5(1) are drought (flood) years for coastal Andhra Pradesh, Rayalaseema and Telangana respectively. Out of 22 NEUTRAL years 4(1), 2(5) & 3(1) are flood (drought) years for coastal Andhra Pradesh, Rayalaseema and Telangana respectively. Out of 14 La Nina years 4(0), 7(1) & 3(1) are flood (drought) years for coastal Andhra Pradesh, Rayalaseema and Telangana respectively. Therefore, it can't be surely said that El Nino years are often associated with drought years and La Nina years are associated with flood years and NEUTRAL years can go either way. However, droughts occurred during El Nino years and floods during La Nina or NEUTRAL years. It is also seen that Floods (Droughts) 2(2), 2(2) & 1(1) occurred equally during positive as well as negative IOD years in coastal Andhra Pradesh, Rayalaseema & Telangana. Floods are more than Droughts during negative IOD years and also during positive IOD years. The figures are shown in Table 5.

Further from the analysis of the data the ANOVA & Regression analysis was carried out. The training period for the multiple regression is 52 years and the independent test period is 10 years. The Multiple correlation coefficients (MCC) /Root Mean Square Error (RMSE) for the model during test period are 0.5/114.8 for Coastal Andhra Pradesh, 0.4/128.6 for Rayalaseema and 0.7/116.1 for Telangana. The MCC are statistically significant at 0.05 significance level. The analysis done provided statistically very significant multiple R and the obtained regression coefficients are used to generate a regression equation that can be used to forecast and diagnose the three sub divisional southwest monsoon seasonal rainfalls (Tables 7 & 8). The observed and forecasted sub-divisional rainfalls have been plotted and shown

TABLE 6

Regression statistics, anova, regression coefficients (1958-2009)

Parameters	CAP	RYSM	TLNG
Multiple R	0.479217192*	0.41872*	0.44001*
R Square	0.229649118	0.17532	0.19361
Adjusted R Square	0.16408734	0.10514	0.12498
Standard Error	112.6183313	118.901	163.198
F	3.502789693	2.498	2.82111
Significance F	0.013904053	0.0552	0.03533
Intercept	531.4636617	444.457	727.167
IODMI	8.683683122	-1.8935	24.5508
SOI	6.980355485	6.15445	5.70201
MEI	55.76551163	63.2031	13.1774
ONI	-68.18974821	-65	-77.586

*significance level 0.05

TABLE 7

Regression equations of SW monsoon rainfalls for three meteorological sub-divisions (base period 1959-2009)

Sub-division	Regression equations
CAP	531.5+8.68*IODMI+6.98*SOI+55.77*MEI-68.19*ONI
RYSM	444.5-1.89*IODMI+6.15*SOI+63.20*MEI-65.00*ONI
TLNG	727.2+24.55*IODMI+5.70*SOI+13.18*MEI-77.59*ONI

in Figs. 8, 9 & 10 for three sub-divisions studied. The model simulation also show that the decrease in the Indian summer monsoon rainfall during ENSO phases is associated with a descending motion of anomalous Walker circulation and the increase in the Indian summer monsoon rainfall during IOD phase is associated with the ascending branch of anomalous regional Hadley circulation because El Nino is associated with negative SOI that means Walker Circulation becomes weak and in case of positive IOD the Hadley circulation becomes stronger. During coexisting ENSO and IOD years, however, the fate of Indian summer monsoon is dictated by the combined influence of both of them (Samer Pokre *et al*., 2012).

4. (*i*) The results indicated that during La Nina & NEUTRAL years the number of excess or Normal years is more.

(*ii*) During El Nino years the deficient years are more in comparison with La Nina & NEUTRAL years.

(*iii*) Droughts occurred during El Nino years and floods during La Nina or NEUTRAL years.

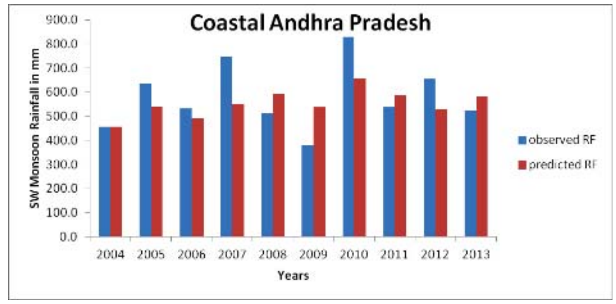

Fig. 8. Observed and predicted SW monsoon rainfalls for coastal Andhra Pradesh

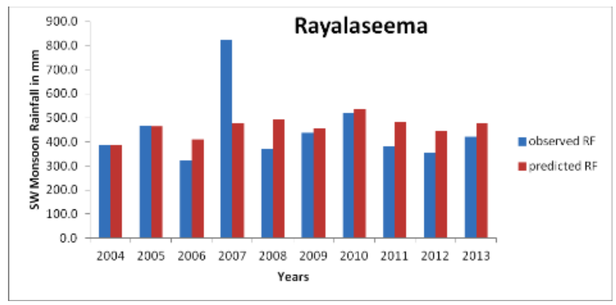

Fig. 9. Observed and predicted SW monsoon rainfalls for Rayalaseema

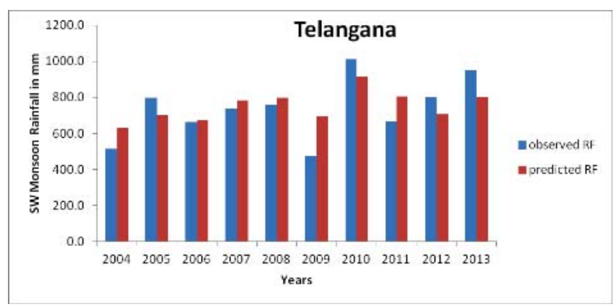

Fig. 10. Observed and predicted SW monsoon rainfalls for Telangana

(*iv*) During positive IOD the number of deficient rainfall years is more.

(*v*) No excess rainfall year was observed during Southern Oscillation year in the three sub-divisions considered in this study.

(*vi*) The Multiple Correlation Coefficients (MCC)/Root Mean Square Error (RMSE) for the model during test period are 0.5/114.8 for Coastal Andhra Pradesh, 0.4/128.6 for Rayalaseema and 0.7/116.1 for Telangana. The MCC are statistically significant at0.05 significance level.

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