Issue 5 volume 4, July-August 2015
ISSN 2249-9954

Future trend assessment of Regional Climate Variability screening past 20 years meteorological status

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ABSTRACT

The tasks of providing multi-decadal climate projections and seasonal climate predictions are of significant societal interest and pose major scientific challenges. The present study describes the global climate system context in which to interpret Nagpur and surrounding region environmental change to support planning and implementation of various strategies in the face of climate change. Here the classification and analysis of various climatic and meteorological parameters has been undertaken that have been proposed as relevant for understanding variations in climatic conditions of the Nagpur region (21.15˚N, 79.09˚E). The statistical and numerical analysis of past two decades data has been done. Two patterns of season stand out in our analysis i.e. the winter (December, January, February) and pre-monsoon (March, April, May). Some thermodynamic parameters (CAPE, CIN and sensible heat flux), rainfall, and surface evaporation along with planetary boundary layer have been studied in this work. The results obtained from the statistical analysis of past decades data are being utilized for predicting the future scenario using various trend projection techniques. These experiments, however, are only preliminary, and form the first stage of a wider study into how the climate variability occurs due to such meteorological parameters and in the future under various scenarios of future climate change.

Key words: Climate variability, climatic trend, Rainfall, Surface evaporation, Planetary boundary layer, Sensible heat flux

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INTRODUCTION

Many studies addressing climate variability and its causes and effects have been undertaken by the researchers worldwide. In recent years there has been increasing concern about climate change and variability and its influence on man and his activities. This concern has been formally expressed in a WMO statement on climate change and variability [1]. The present study concentrates on In this paper we concentrate on investigating climatic variability of Nagpur and surrounding region through an analysis of various meteorological parameters such as convective available potential energy (CAPE), Convective inhibition (CIN), sensible heat flux (SHF) as an elements of temperature, Surface Evaporation (SE), Rainfall and Planetary Boundary Layer (PBL) over the time series of two decades. As these variables form the dominant dynamic components of climate, our emphasis on them is well justified. Here the focus is on the atmospheric component of the climate system and on multi decadal & seasonal time-scales. Many studies concerning climate change have been undertaken. Most studies have concentrated on long term trends in temperature [2, 3, 4]. Other quantities have received some attention, notably snow and ice cover [5]. A survey was performed and article presents a large variety of observed climatic parameters. The article deals with zonal and time averaged quantities and is directed towards identifying trends. Indeed it is possible that climate change could be manifested at least in part by changes in the nature and amplitude of the variability. Thus it is important to improve both our understanding and our predictive capability of climate variability [6].

In general, an increasing trend in temperature has been observed in southern and central India in recent decades in all seasons and over all of India in the post monsoon seasons. This warming has generally been accompanied by increases in diurnality except over northern India in the winter, pre-monsoon and post-monsoon seasons [7]. There was observed increase in trends of annual mean, maximum and minimum temperatures south of 23 ◦N and cooling trends north of 23 ◦N [8]. The diurnal temperature range (DTR) shows an increasing trend in all the seasons over most of peninsular India. This is in contrast to many other land regions of the northern hemisphere [9]. The trends in potential evapo-transpiration (PE) for 10 stations in India including stations in arid and semi-arid tropics were analyzed. In the monsoon and post-monsoon seasons, PE was found to have decreased over the last 15 yr over the whole country, whereas in the winter and pre-monsoon seasons the trends are less consistent. The decreasing trend in PE is up to a maximum of about 0.3 mm day^{-1} decade^{-1} over west-central India in the monsoon and post-monsoon seasons. These trends are generally lower than for surface evapo-transpiration (Ep) and represent a reduction in PE of less than 3% per decade. Changes in PE were most strongly associated with changes in relative humidity, particularly in the winter and pre-monsoon seasons [10]. The potential impact of the anthropogenic heat flux on global climate has recently been discussed and summarized. It showed that the total amount of energy released by human activity is relatively small compared to the solar energy intercepted by the earth, but the human energy emissions are concentrated in the relatively small percentage of the earth's surface making up urban areas. The potential impact of the flux of anthropogenic heat on local climatology in human populated areas may therefore be large [11].

A successful weather and air quality forecast is critically dependent on the determination of the Planetary Boundary Layer (PBL) height. The planetary boundary layer is the lowest layer of the troposphere, ranging from several hundred meters to a few kilometers in depth. Directly affected by surface conditions, it is distinguishable from the free troposphere by differences in flow, thermodynamic properties, and chemical content. The last of these is critical to surface air quality [12] because the PBL depth determines a finite but varying volume into which pollutants can disperse. Over land, diurnal surface heating produces a clear cycle in the PBL depth [13], with convective boundary layers as high as 5 km possible under extreme conditions. If insolations stops during the day, as during the solar, the PBL top height decreases just as it typically does in the evening. Elsewhere, the PBL depends more strongly on synoptic conditions, but still changes significantly over time scales of hours [14].

While the importance of identifying and understanding historical trends in the climatic record is clear, some measure of "variability" also demands examination. There appears to be a general belief that the climate has become more "variable" in recent times [15]. In a related study, statistical methods were used to explore relationships of local surface temperature and precipitation data with regionally averaged values of surface temperature, precipitation, sea level pressure, and 700-mb height for a 32-station network over the state of Oregon. They found that despite difficulties of comparing near-surface mean values, it is possible to obtain useful local information by examining the large scale variability [16]. In this paper, we report results from two decades i.e. from 1994 to 2014 of the two seasons, winter and pre-monsoon of the various climatic parameters of Nagpur region. The satellite data were collected for PBL, surface evaporation and sensible heat flux from Giovanni-MERRA. The MERRA is a NASA reanalysis for the satellite era using a major new version (V5) of the Goddard Earth Observing System

(GEOS) Data Assimilation System (DAS). The MERRA focuses on historical analyses of the hydrological cycle on a broad range of weather and climate time scales. The rainfall data is collected from the report of Indian Institute of Tropical Meteorology. The CAPE and CIN which are the elements of temperature are derived from the data provided by University of Wyoming, Department of Atmospheric Science. All the data is statistically analyzed for justifying the present climate variability in relation with various above parameters and to predict the future trends of variation.

MATERIALS AND METHODS

The location of the study area is the Nagpur region, Maharashtra (21.15˚N, 79.09˚E), situated in the central part of India. In this location data are collected and necessary computations are made for the winter season (Dec, Jan, Feb) and pre-monsoon season (Mar, Apr, May) during the year 1994-95 to 2014. The data sets consist of monthly mean Planetary Boundary Layer (PBL), Surface Evaporation (SE) and Sensible Heat Flux (SHF) during study period derived from derived from Modern Era-Retrospective Analysis for Research and Applications (MERRA). The MERRA is a NASA reanalysis for the satellite era and products are generated using Version 5.2.0 of the Goddard Earth Observing System Data Assimilation System (GEOS-5 DAS) with the model and analysis each at 1/2x2/3 degrees resolution. The MERRA production is being conducted in 3 separate streams, 1979 - 1989; 1989 - 1998; 1998 - present. The monthly mean Rainfall is collected from the Tropical Rainfall Measuring Mission (TRMM). It is a joint mission between NASA and the Japan Aerospace Exploration Agency designed to monitor and study tropical rainfall. TRMM is a research satellite designed to improve our understanding of the distribution and variability of precipitation within the tropics as part of the water cycle in the current climate system. By covering the tropical and sub-tropical regions of the Earth, TRMM provides much needed information on rainfall and its associated heat release that helps to power the global atmospheric circulation that shapes both weather and climate. Twenty years winter and pre-monsoon dataset of radiosonde measurements from the Nagpur region is analyzed in this study. Atmospheric Sounding Datasets are obtained from the University of Wyoming (www.weather.uwyo.edu). The study used the radiosonde data parameters that are the functions of temperature i.e. Convective Available Potential Energy (CAPE) and Convective Inhibition (CIN).
The correlation co-efficient method was used to examine the association between the parameters such as PBL, rainfall, CAPE, CIN, surface evaporation and sensible heat flux. A correlation coefficient is a statistical measure of the degree to which changes to the value of one variable predict change to the value of another. In positively correlated variables, the value increases or decreases in tandem. In negatively correlated variables, the value of one increases as the value of the other decreases. Correlation coefficients are expressed as values between +1 and -1. A coefficient of +1 indicates a perfect positive correlation. A coefficient of -1 indicates a perfect negative correlation. A coefficient of zero indicates there is no discernable relationship between fluctuations of the variables.

A linear regression model that contains more than one predictor variable is called a *multiple linear regression model*. Multiple linear regression (MLR) attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Every value of the independent variable x is associated with a value of the dependent variable y. MLR models were employed to examine the association of Planetary Boundary Layer (PBL) and Rainfall with Surface Evaporation (SE), Sensible Heat Flux (SHF), Convective Available Potential Energy (CAPE) and Convective Inhibition (CIN) results in formulation of a 1st order equations like;

$$y = c + mx_1 + mx_2 + mx_3 + mx \quad (1)$$

In (Eqn. 1) m_i (where 1 = 0, 1, 2…) is the slope of the line and c is the y-intercept, y and x are the variables.

The output of this MLR was used to predict the values of PBL and rainfall compare them with the observed values. The error matrix was also being performed with the values of errors such as Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Standard Error (SE) found during the MLR.

The Autoregressive (AR) Model was used to forecast the various parameters such as surface evaporation, sensible heat flux, and CAPE and CINS results in the formulation of 1st order autoregressive time series equation like;

$$\sum_{i=0}^{p} \rho_i X_{k-i} = \varepsilon_k \qquad k = 0, \pm 1, \pm 2, \ldots \tag{2}$$

In (Eqn. 2) $\rho_0 \neq 0$, $\rho_P \neq 0$ and the ε_t are typically assumed to be uncorrelated (0, σ^2) random variables (i.e. E(ε_0) = 0, E(ε_0^2) = σ^2).

The output from this AR for various above four parameters was used to in MLR equation to predict the rainfall and PBL for future scenario.

RESULTS

As the changes in rainfall and planetary boundary layer which are the meteorological parameters responsible for climate variability can be appraised by the sensible heat flux, surface evaporation, convective available potential energy and convective inhibition and offers good supportive information. Table (1) shows the average of observations with minimum and maximum values for the winter and pre-monsoon seasons of various meteorological parameters. It is observed that the rainfall and planetary boundary layer is high in the pre-monsoon season than the winter over the observed site. Table (2) shows correlation coefficient between various parameters for both the seasons. There observed good positive correlation between SHF and PBL and negative correlation between SHF and RF, PBL and SE for both the season while poor correlation for RF and CAPE and RF and CIN. A good negative correlation is observed between PBL and CIN for pre-monsoon season

Table 1: Observed Seasonal Average Of Various Parameters With Their Minimum And Maximum Values (a) For Winter Season (b) For Pre-Monsoon Season During The Year 1994-95 To 2014.
(a) Winter Season

Parameters	Mean	Range
Rainfall (mm)	124.28	Min. = 2.16 Max. = 493.66
Planetary Boundary Layer (m)	1104.69	Min. = 949.86 Max. = 1217.7
Surface Evaporation (KG/m^2/s)	2.18	Min. = 1.03 Max. = 4.25
Sensible Heat Flux (W/m^2)	94.84	Min. = 76.11 Max. = 109.03
Convective Available Potential Energy (J/Kg)	292.18	Min. = 79.69 Max. = 538.82
Convective Inhibition (J/Kg)	-318.18	Min. = -327.81 Max. = -150.86

(b) Pre-Monsoon Season

Parameters	Mean	Range
Rainfall (mm)	87.72	Min. = 0.162 Max. = 405.33
Planetary Boundary Layer (m)	535.39	Min. = 424.35 Max. = 610.06
Surface Evaporation (KG/m^2/s)	2.86	Min. = 1.85 Max. = 4
Sensible Heat Flux (W/m^2)	37.20	Min. = 18.84 Max. = 49.88
Convective Available Potential Energy (J/Kg)	66.21	Min. = 5.08 Max. = 240.21
Convective Inhibition (J/Kg)	-53.12	Min. = -164 Max. = 0

Table 2: Correlation coefficient between various meteorological parameters studied (a) for winter season and (b) for pre-monsoon season.

(a) Winter season

	CAPE	CIN	SHF	SE	RF	PBL
CAPE	1	-0.13123	-0.08824	-0.2629	0.180638	-0.05764
CIN	-0.13123	1	0.366675	-0.294	-0.25739	0.2725
SHF	-0.08824	0.366675	1	-0.459	-0.56275	0.938355
SE	-0.26298	-0.29407	-0.45909	1	0.14452	-0.42448
RF	0.180638	-0.25739	-0.56275	0.14452	1	-0.60036
PBL	-0.05764	0.2725	0.938355	-0.4244	-0.60036	1

(b) Pre-monsoon season

	CAPE	CIN	SHF	SE	RF	PBL
CAPE	1	0.043089	-0.30088	0.074934	0.265383	-0.25109
CIN	0.043089	1	-0.37351	0.218783	-0.03612	-0.47717
SHF	-0.30088	-0.37351	1	-0.52844	-0.59748	0.897712
SE	0.074934	0.218783	-0.52844	1	0.217583	-0.49633
RF	0.265383	-0.03612	-0.59748	0.217583	1	-0.51131
PBL	-0.25109	-0.47717	0.897712	-0.49633	-0.51131	1

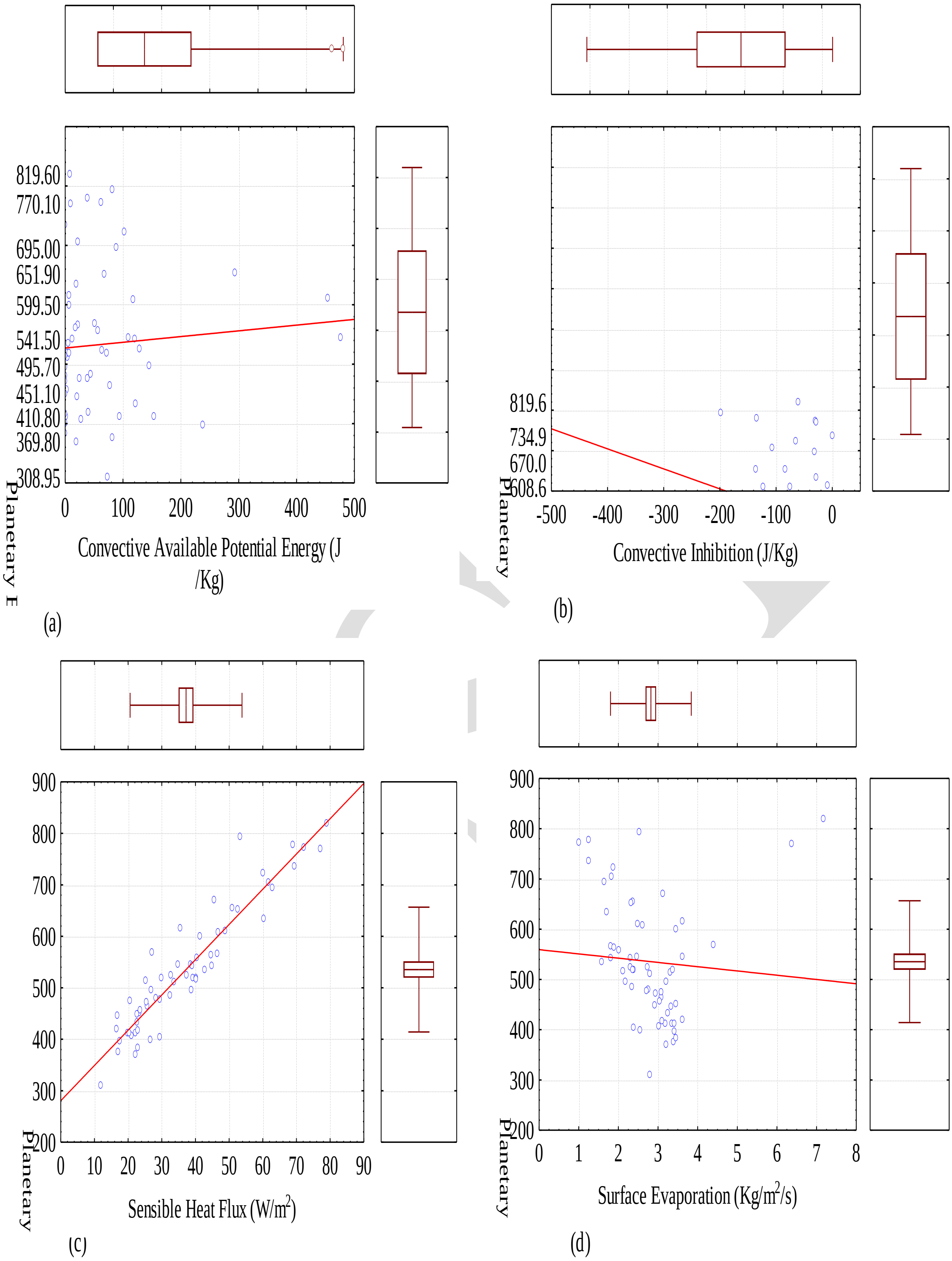


Figure 1: Showing the box-whisker and scatter plots of (a) PBL & CAPE (b) PBL & CIN (c) PBL & SHF and (d) PBL & SE for the winter season during year 1994-95 to 2014

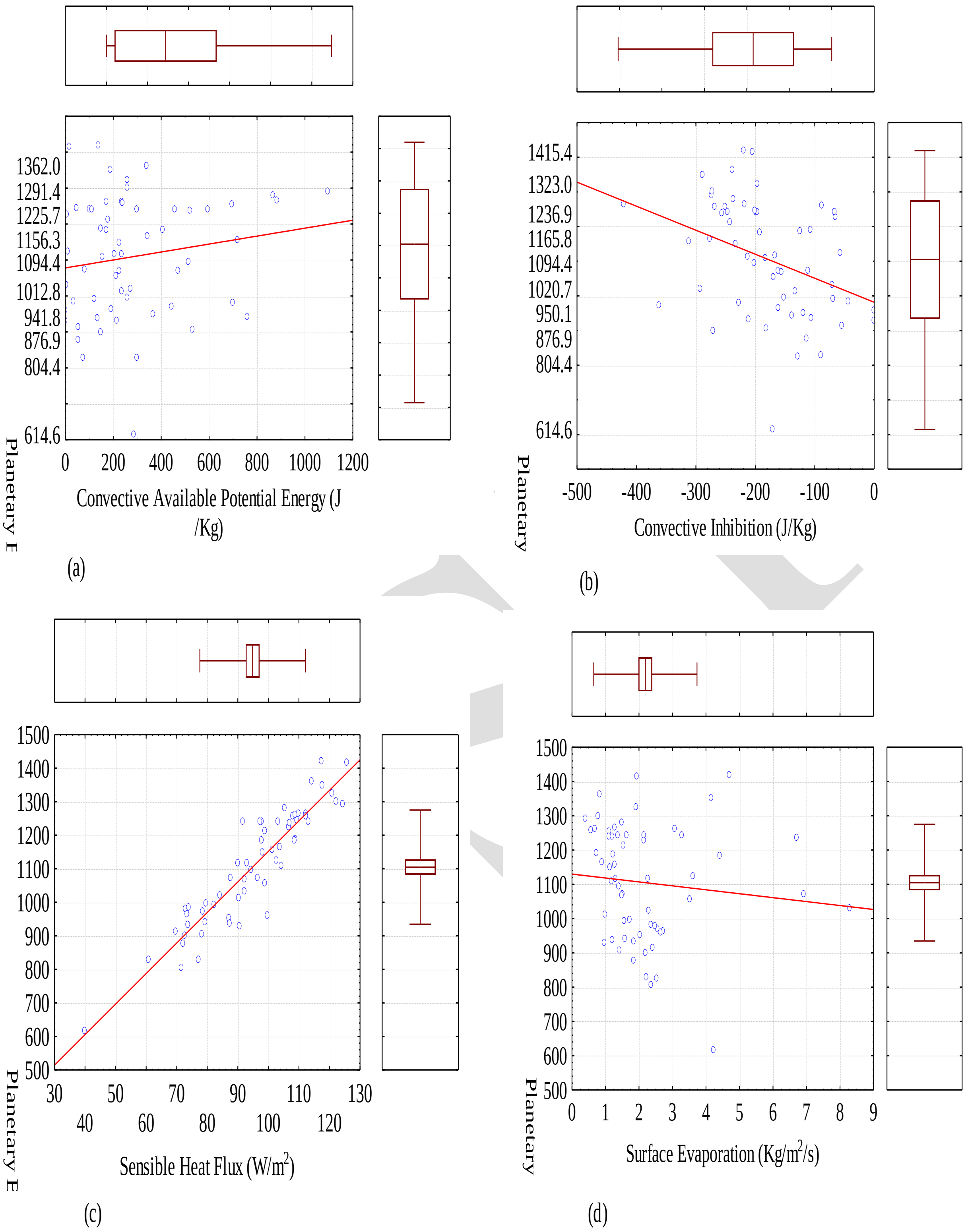


Figure 2: Showing the box-whisker and scatter plots of (a) PBL & CAPE (b) PBL & CIN (c) PBL & SHF and (d) PBL & SE for the pre-monsoon season during year 1995 to 2014.

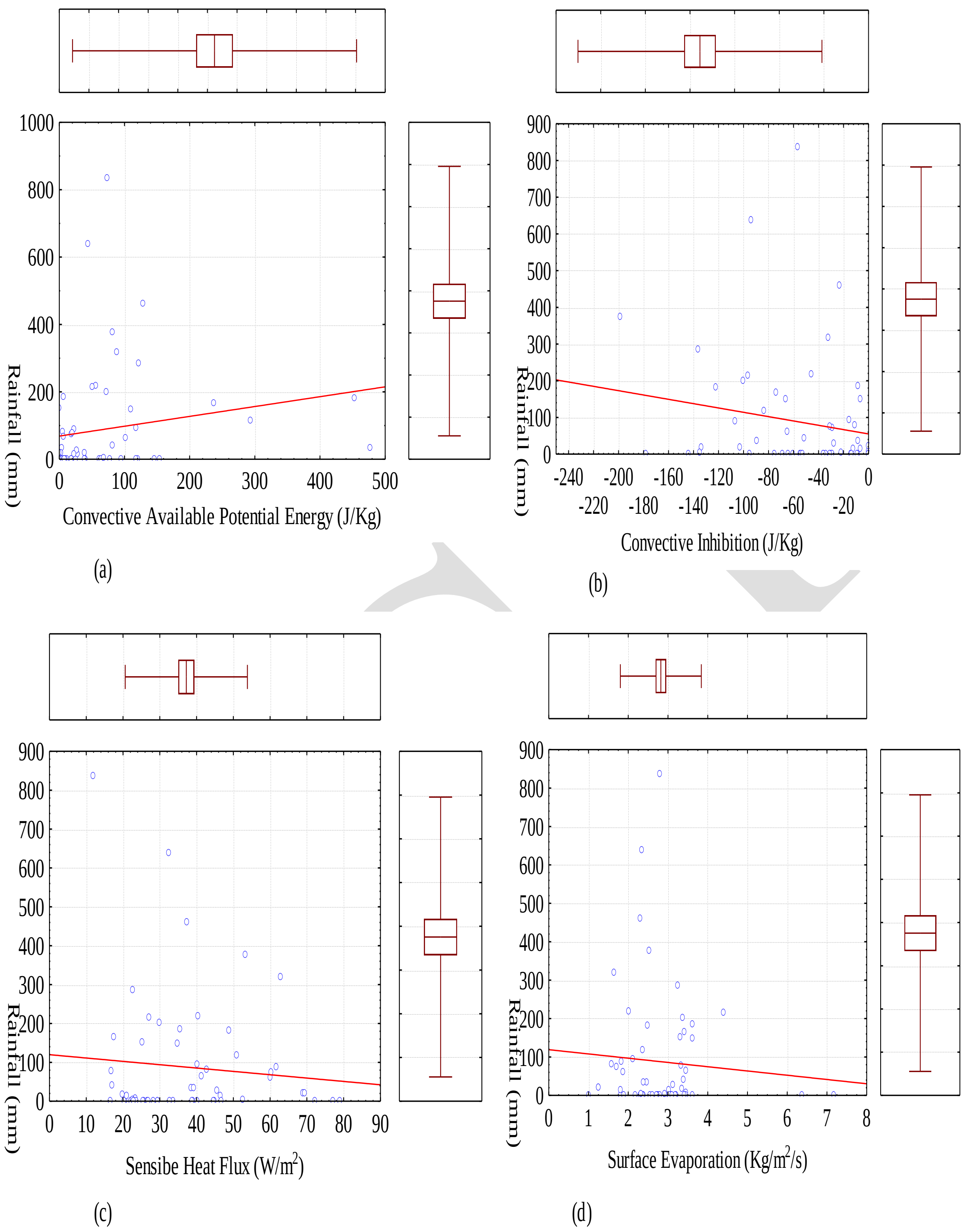


Figure 3: Showing the box-whisker and scatter plots of (a) Rainfall & CAPE (b) Rainfall & CIN (c) Rainfall & SHF and (d) Rainfall & SE for the winter season during year 1994-95 to 2014.

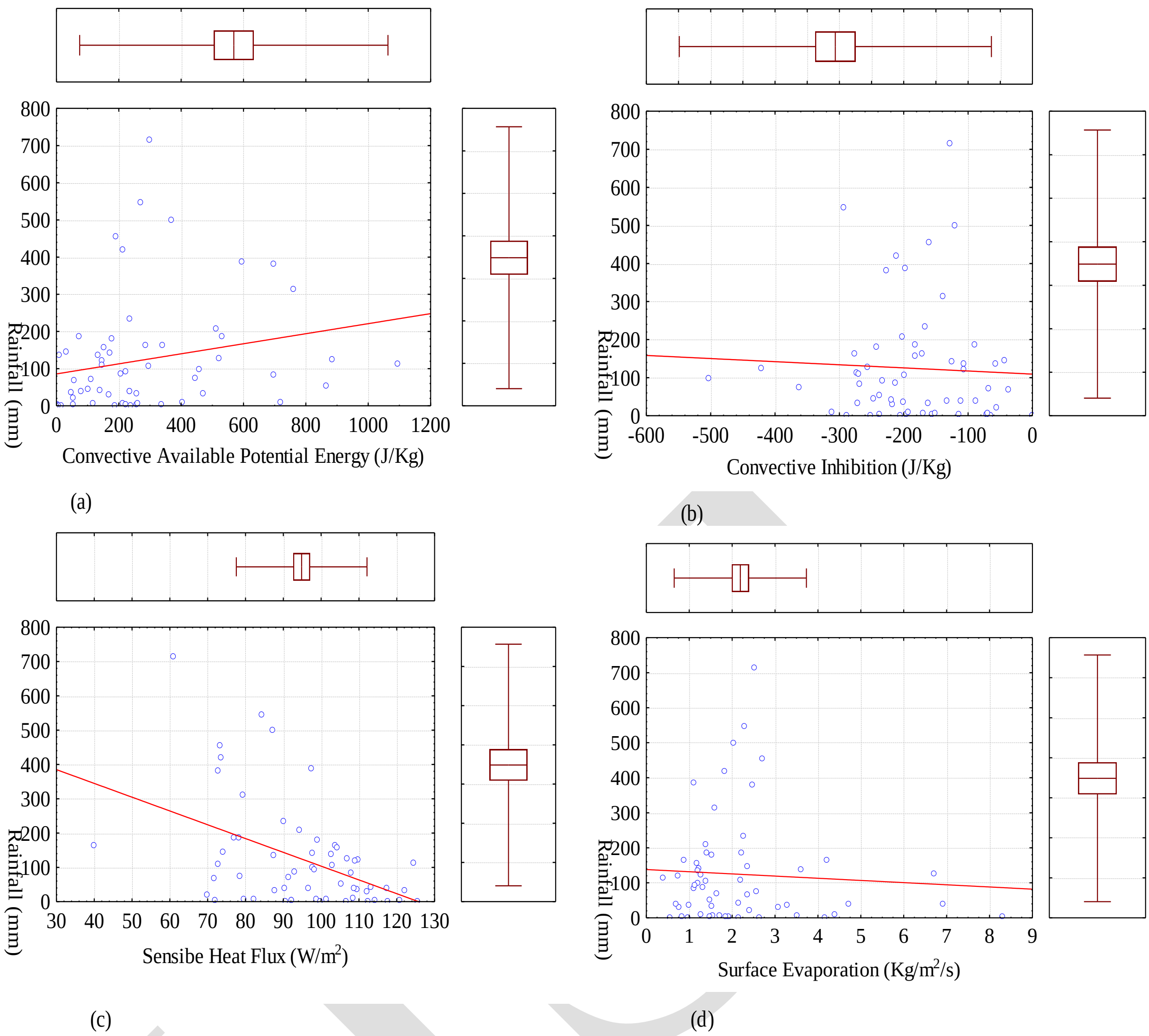


Figure 4: Showing the box-whisker and scatter plots of (a) Rainfall & CAPE (b) Rainfall & CIN (c) Rainfall & SHF and (d) Rainfall & SE for the pre-monsoon season during year 1995 to 2014.

The impact of different parameters (viz. CAPE, CIN, SHF and SE) on Planetary Boundary Layer and Rainfall are tested using a set of multiple linear equations. In this statistical analysis PBL and Rainfall are assigned as dependent variable while CAPE, CIN, SHF and SE are the independent variables. The sets of equations with different dependent variable with the respective season are shown below;

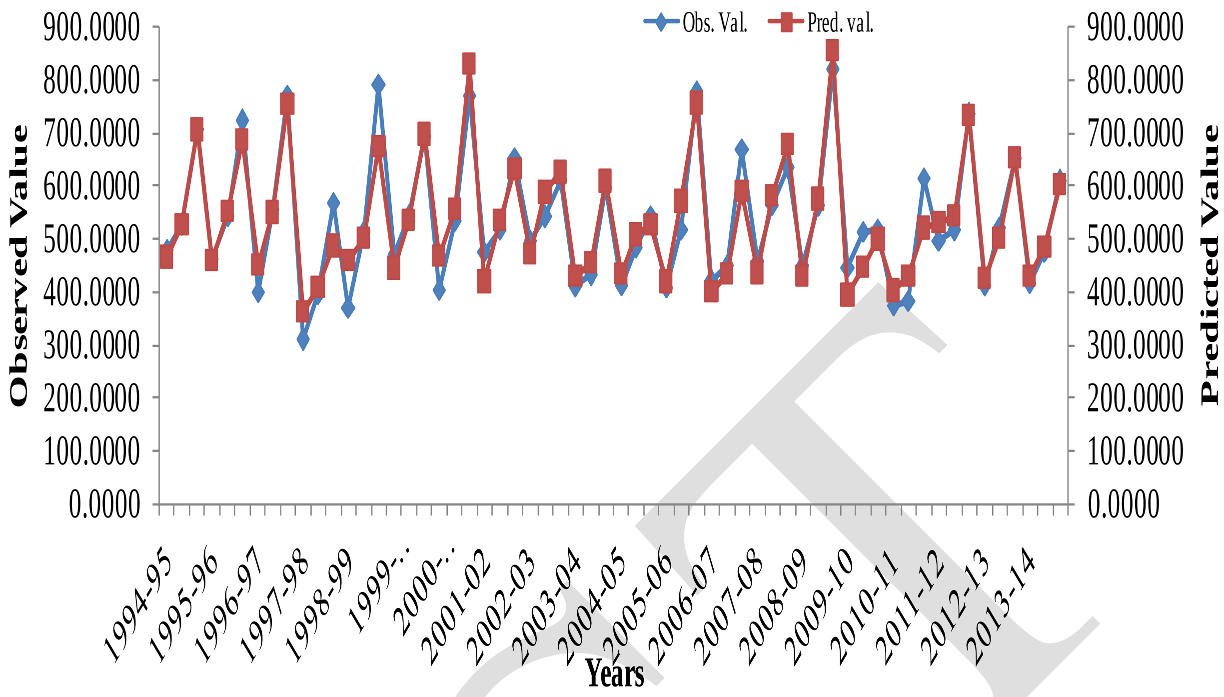
$$PBLwin = 248.97 + (0.001) \times CAPE + (-0.09) \times CIN + (0.936) \times SHF + (0.063) \times SE \quad (3)$$

$$PBLpm = 239.55 + (0.01) \times CAPE + (-0.16) \times CIN + (0.876) \times SHF + (0.01) \times SE \quad (4)$$

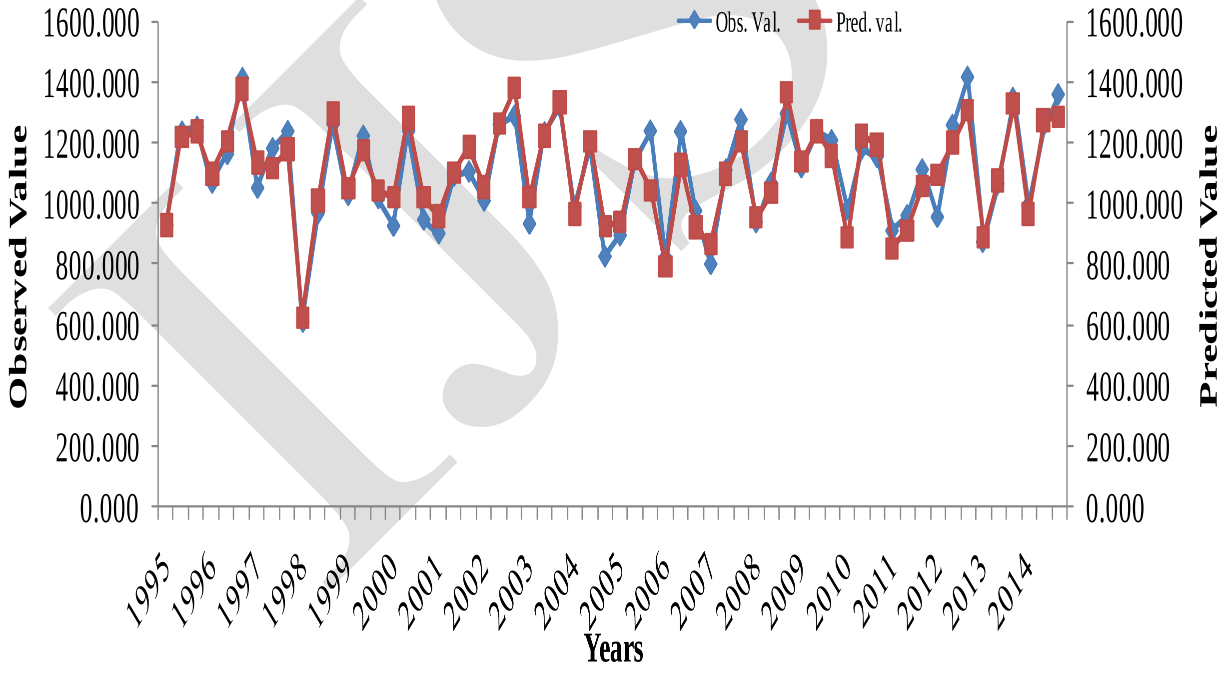
$$RFwin = 129.96 + (0.120) \times CAPE + (-0.19) \times CIN + (0.13) \times SHF + (0.09) \times SE \quad (5)$$

$$RFpm = 497.56 + (0.226) \times CAPE + (-0.07) \times CIN + (0.50) \times SHF + (0.04) \times SE \quad (6)$$

The predicted values obtained from the above four MLR equations with the values obtained from actual observation are presented in Figure (5) and (6).



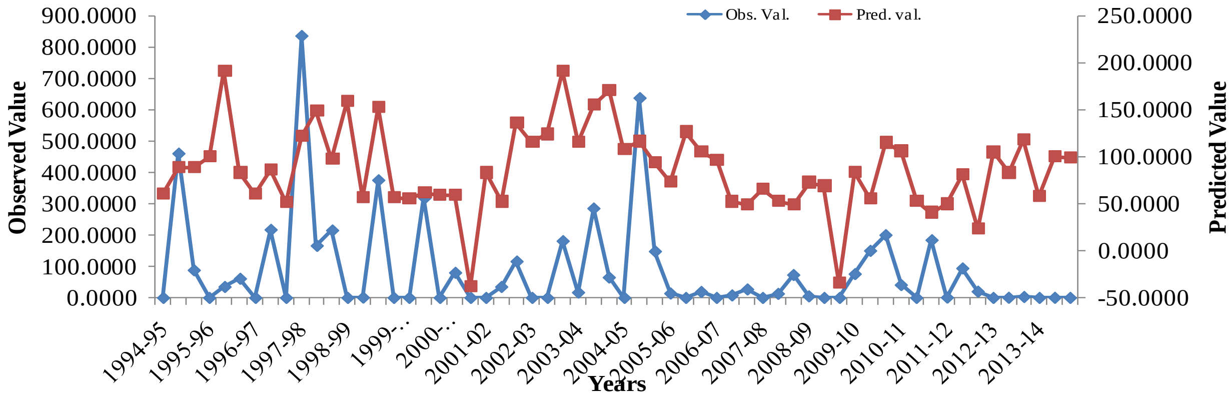
(a)



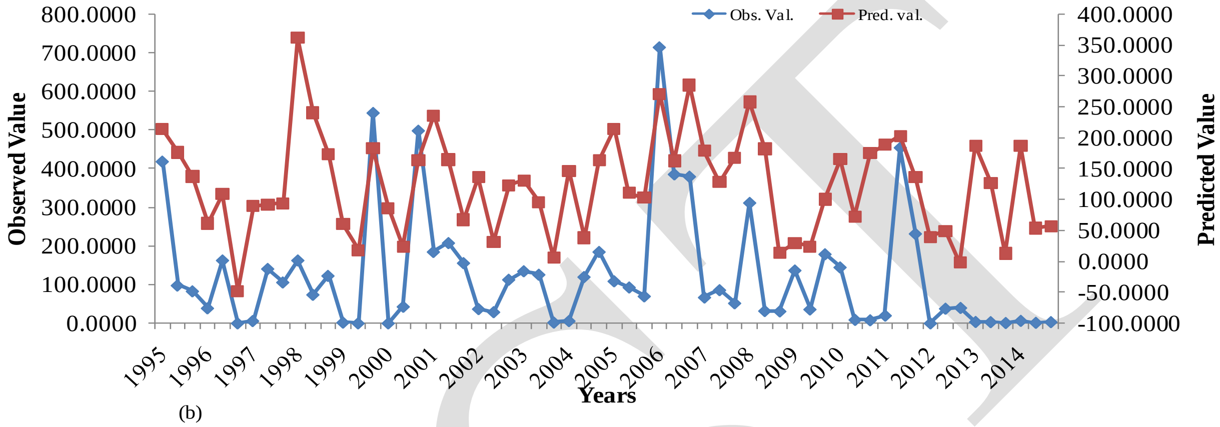
(b)

Figure 5: Observed and predicted value variation of Planetary Boundary Layer using different MLR equations (a) for winter season (b) for pre-monsoon season over the site during 1994-95 to 2014.

Issue 5 volume 4, July-August 2015
ISSN 2249-9954



(a)



(b)

Figure 6: Observed and predicted value variation of Rainfall using different MLR equations (a) for winter season (b) for pre-monsoon season over the site during 1995 to 2014.

Those predicted values incurred from equations (3) and (4) for Planetary Boundary Layer has more closeness to actual observations. Those predicted values incurred from equations (5) and (6) for Rainfall shows slight fluctuation from the actual observations. Mean Absolute Error (MAE), Standard Error (SE) and Root Mean Squared Error (RMSE) are computed using the following equations and represented in Figure (7).

$$MAE = \frac{1}{n}\sum_{n=1}^{n}\left|Y_{obs} - Y_{P}\right| \quad (7)$$

$$SE = \frac{s}{\sqrt{n}} \quad (8)$$

$$RMSE = \sqrt{\frac{\sum_{n=1}^{n}\left(Y_{obs} - Y_{P}\right)^2}{n}} \quad (9)$$

Where n is the number of observations, Y_{obs} and Y_p are the observed and predicted values respectively and s is the sample standard deviation.

The Autoregressive model was used for forecasting the various parameters viz. SHF, SE, CAPE and CIN. Value of immediate past is analyzed and projected for immediate future following the equation (2). Figure (8) and (9) shows the observed and the future trend of the parameters such as SE, SHF, CAPE and CIN (for next 10 years, up to 2024). The results obtained for various parameters are used in equations (3), (4), (5) and (6) for predicting the Rainfall and Planetary Boundary Layer for future trend of respective seasons. Figure (10) shows the observed and the future trend of Rainfall and Planetary Boundary Layer for the next 10 years.

It is observed that there are no much fluctuations in future projected values of both winter and pre-monsoon season and general trend is constant in with actual observed value.

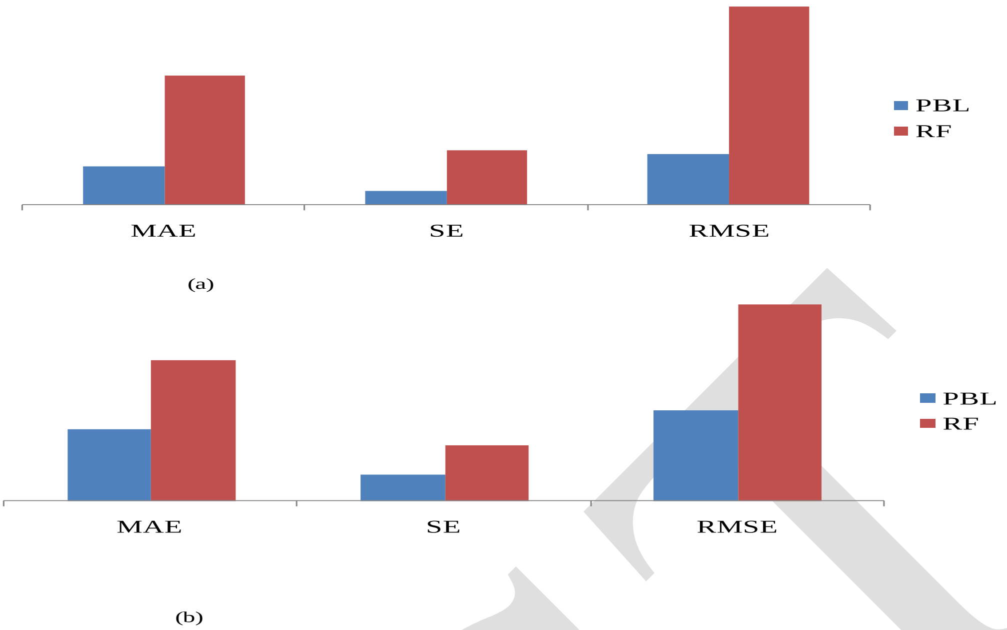


Figure 7: MAE, SE and RMSE values obtained from the four MLR equations of PBL and rainfall (a) for winter season (b) for pre-monsoon season.

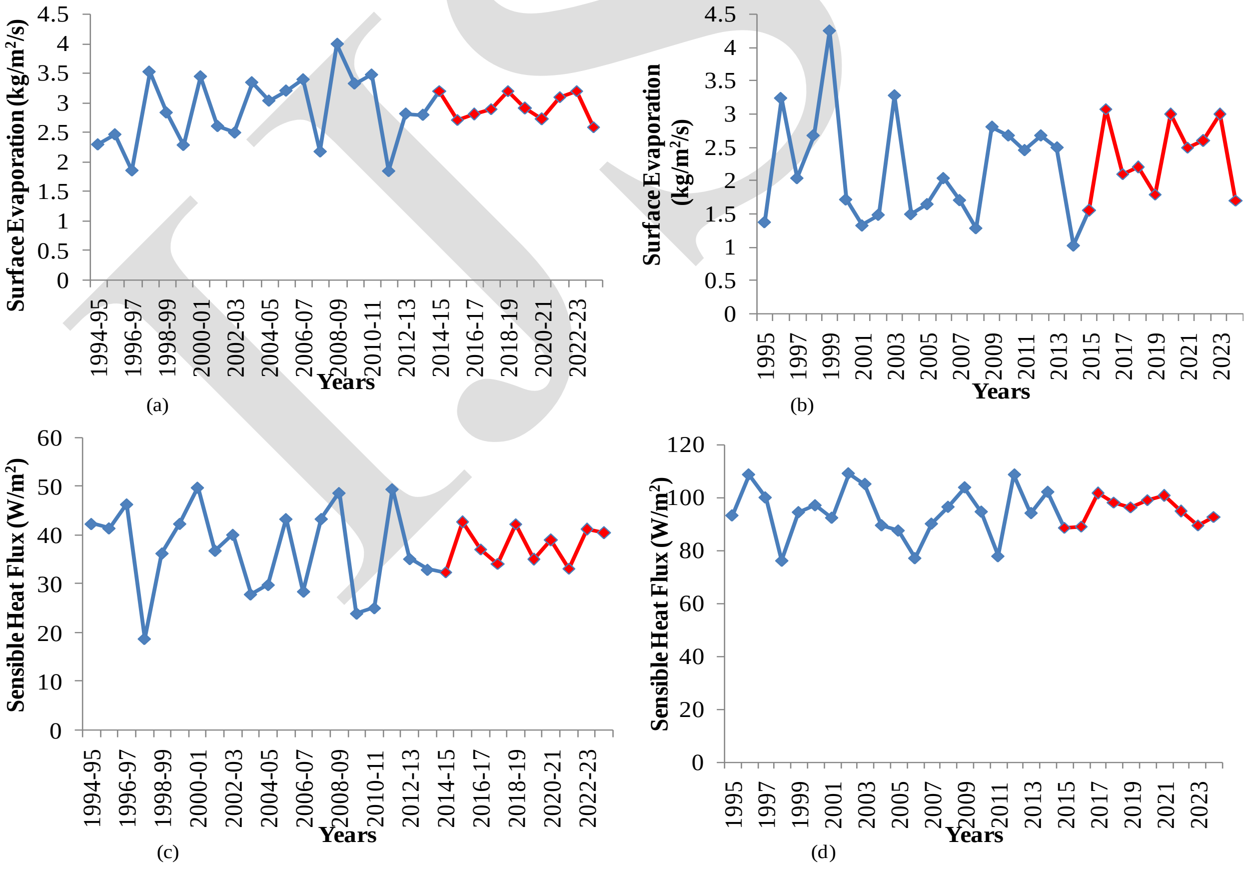


Figure 8: Observed and future trend (up to year 2024) of (a) SE for winter season (b) SE for pre-monsoon (c) SHF for winter season and (d) SHF for pre-monsoon season over the selected location.

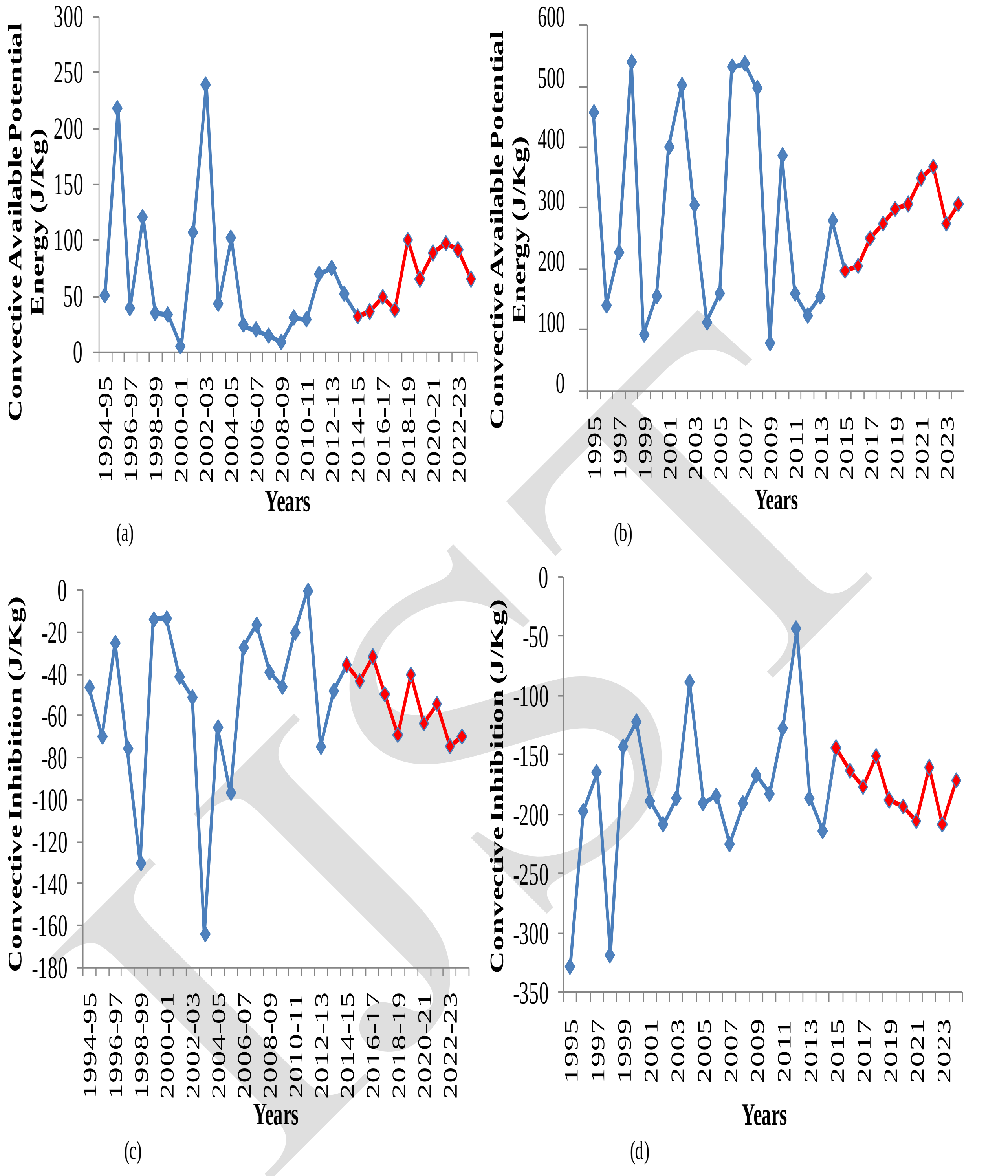


Figure 9: Observed and future trend (up to year 2024) of (a) CAPE for winter season (b) CAPE for pre-monsoon (c) CIN for winter season and (d) CIN for pre-monsoon season over the selected location.

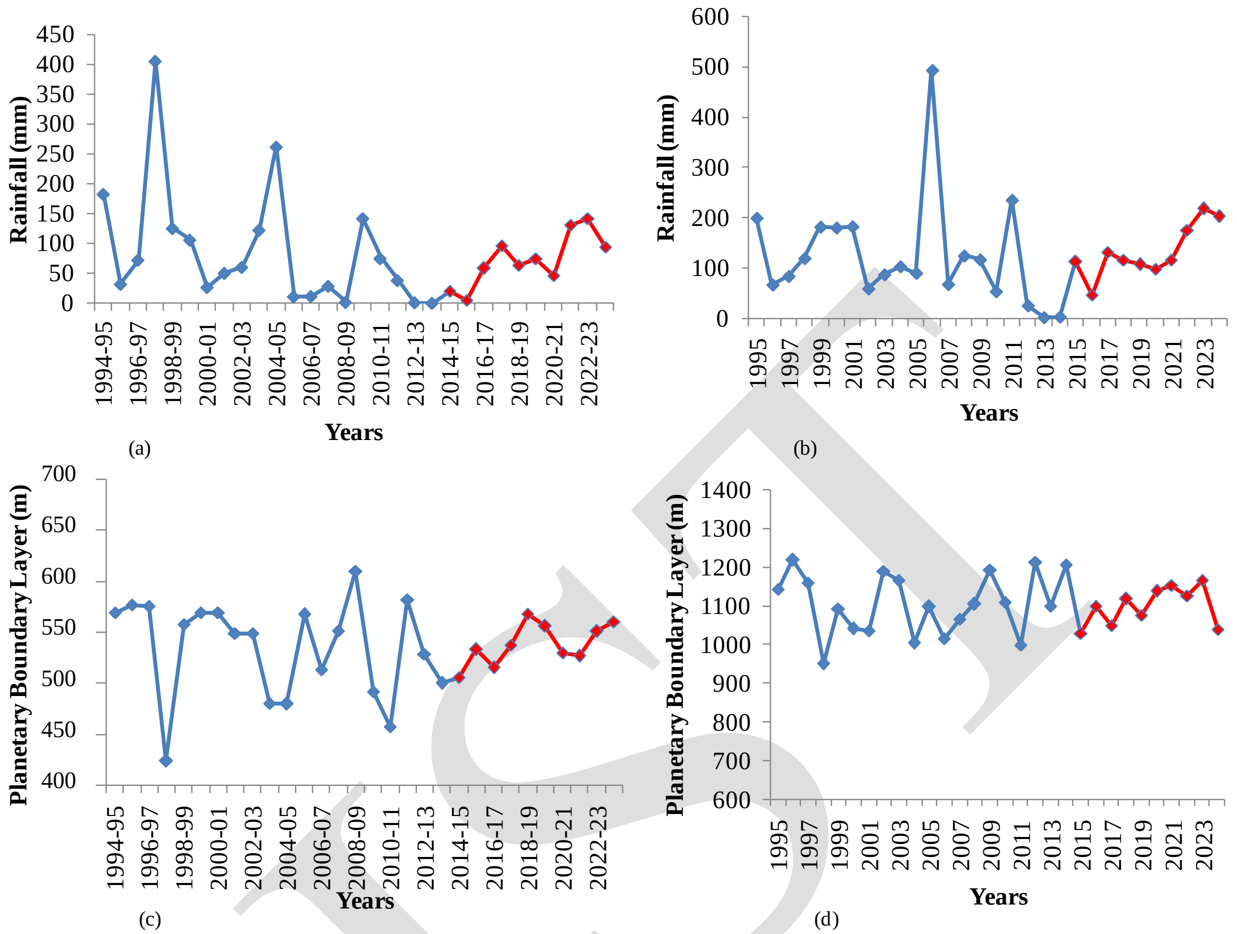


Figure 10: Observed and future trend (up to year 2024) of (a) Rainfall for winter season (b) Rainfall for pre-monsoon (c) PBL for winter season and (d) PBL for pre-monsoon season over the selected location.

CONCLUSION

The consequences of increase or decrease in the Planetary Boundary Layer or Rainfall in the atmosphere have great impact on climate variability. Realization of various climatic feedbacks in this regard can be obtained upon analysis. Winter and pre-monsoon analysis of the past twenty years of planetary boundary layer shows the exact similarity between actual observation and predicted value. The slight fluctuation is found between actual observation and predicted value of the rainfall for both the seasons which may enhance the climatic variability. Multiple Linear Regression analysis ascertains the decreasing trend of rainfall for the future which may affect the climate. The future trend of planetary boundary layer is increasing for winter season which will help in better mixing of the pollutants while in pre-monsoon PBL decreases resulting in polluted atmosphere and warming of the climate.

ACKNOWLEDGEMENT

Authors acknowledge Modern Era-Retrospective Analysis for Research and Applications (MERRA) of GEOS-5 DAS and Tropical Rainfall Measuring Mission (TRMM) for PBL, surface evaporation, sensible heat flux and rainfall data. University of Wyoming is also acknowledged for providing sounding data for the research. Authors are gratefully thankful to Dr. S. R. Wate, Director, National Environmental Engineering Research Institute (NEERI) for his kind encouragement.

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