Global NEST Journal, Vol 18, No 3, pp 494-507, 2016


# TIME SERIES MODELS OF MONTHLY RAINFALL AND TEMPERATURE TO DETECT CLIMATE CHANGE FOR JORHAT (ASSAM), INDIA

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Received: 07/08/2015
Accepted: 07/05/2016
Available online: 31/05/2016

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**ABSTRACT**

In the present study, monthly rainfall, maximum temperature and minimum time series models were developed for Jorhat (Assam) situated in northeast India using monthly rainfall, maximum temperature and minimum temperature data from the year 1965 to 2000. A trend free time series of rainfall and temperature was obtained by eliminating the trend component in the original time series, and then was used in identifying the periodic component. Fourier series analysis was used to identify periodic component. First five harmonics explained total variance of 79.4, 72.6 and 73.7% for monthly rainfall, maximum temperature and minimum temperature respectively. In the stochastic dependent component modelling, Autoregressive (AR) models of order 12 were found suitable on the basis of minimum value of AICC and BIC statistics. Portmanteau test formulated by McLeod and Li was carried out for checking the independence of stochastic dependent component which indicated that series consist of independent and identically distributed variables. Independent stochastic components were further modelled using normal distribution function. Nash-Sutcliffe coefficient also indicated high degree of models fitness to the observed data. Developed time series models were validated using eight years (2001-2008) data. Using the developed time series models, monthly rainfall, maximum temperature and minimum temperature were forecasted up to the year 2050. Assessment of changes in monthly rainfall, maximum temperature and minimum temperature in generated series (2009 to 2050) were predicted using linear regression which indicated no significant trend, i.e., the climate at Jorhat (Assam) in next four decades will remain more or less stable.

**Keywords:** Time series modelling, Rainfall, Temperature, AR Model, climate change.

## 1. Introduction

Weather refers to short-term changes in atmospheric conditions, while climate deals with events happening over a much longer period. Climate change of a place refers to gradual variations in the average weather conditions over a long time period. Analysis of climatic parameters would enable the farmers to adopt agricultural practices that minimize the adverse effect (Jhajharia *et al.*, 2007). Earth's surface air temperature has increased during the 20$^{th}$ century and the century's ten warmest years occurred during the last fifteen years (EPA, 2000). In India, several studies report changes in temperature and rainfall and its association with climate change (Hingane *et al.*, 1985; Sinha Ray *et al.*, 1997). An increasing trend in mean annual temperature was reported at the rate of 0.57°C per hundred years over India (Pant and Kumar, 1997). Warming was found to be mainly contributed by the post-monsoon and winter seasons in

India. In monsoon season, no significant trend was witnessed in air temperature in any part of India except for significant negative trend over northwest India. However rainfall fluctuations have been largely random over a century, with no systematic change detectable in annual or seasonal time scales over India. The west coast, north Andhra Pradesh and northwest India, witnessed increasing trend in seasonal rainfall, while East Madhya Pradesh, Orissa, Northeast India, and parts of Gujarat and Kerala witnessed decreasing trends in seasonal rainfall (MOEF, 2004). Sinha Ray and De, (2003) have also concluded that all India rainfall and surface pressure shows no significant trend except some periodic behavior.

Time series analysis is one of the important and major tools in applied hydrology. A data sequence ordered in time is called a time series and it is used either for building mathematical models to generate synthetic hydrologic records or to forecast the occurrence of hydrologic events. A time series model can be divided into two components-deterministic and stochastic. The deterministic component is used for prediction of the time and chance independent future events, while the stochastic component is used for determination of the chance and chance dependent effects. Deterministic component are either periodic or non-periodic in nature. The non-periodic component is characterized by its trend and jump characteristics. Any variation in trend or jump characteristic of a data series is caused mainly because of changes in physical characteristics of watershed or sudden variation in any of the watershed characteristics. The period of nature of a deterministic component is characterized by its cyclic pattern, which exhibits an oscillatory movement and is repeated over a fixed interval of time. However, a stochastic component consists of irregular oscillation and random effects, which are not accountable physically, and is described by probabilistic concepts (Das, 2009). A time series represents a set of observations that measure the variation in time of some dimension of a phenomenon, such as, precipitation, evaporation, wind speed, river flow, etc. Various researchers, namely, Sinha Ray *et al.*, (1997); Reddy and Kumar, (1999); Toth *et al.*, *(*2000); Jha *et al.*, (2003); Raja Kumar and Kumar, (2004 and 2007), Mishra and Desai, (2005); Bhakar *et al.*, (2006); Dabral *et al.*, (2008); Sherring *et al.*, (2009); Kumar and Kumar, (2010) and Dabral *et al.*, (2014) used time series for modelling various hydrological parameters.

The north-eastern (NE) region of India, one of most important bio-diversity rich regions of world, contains about 8000 species of flowering plants and more than 500 spices of orchids (Rao, 1994; Jhajharia and Singh, 2011). The region is mostly a tropical wetland and annual rainfall varies in the range of 2000 mm over parts of Assam to 12000 mm over a few hillocks in Meghalaya (Jhajharia *et al.*, 2012). In the present study, Jorhat (Assam state) is selected to study the time series analysis for two main climatic parameters, i.e., temperature and rainfall, because rainfall and temperature has great influence on climate variability. The variability of these two parameters may be modelled accurately using time series approach. Therefore, the present study is carried out with the following objectives: (i) to develop time series models of monthly rainfall and temperature for humid environments of northeast India; (ii) to validate and generate future value using developed time series model; and finally to assess the change of monthly rainfall and temperature in generated time series. Results of this study will help the planners and the government development agencies to include the impact of climate change into decision-making of protecting precious natural resources, such as, forest, environment, soil and water, etc. in the bio-diversity rich region of northeast India in general, and particularly the state of Assam including Jorhat. This is mainly due to the relentless pressure for the release of forestland from agriculture, industries, power and irrigation project, housing, urban development and various others uses in Assam, one of the most important seven-sister states of NE India.

## 2. Methods and Material

### *2.1 Study Area and Collection of Data*

NE India is a unique transitional zone between the Indian, Indo-Malayan and Indo-Chinese bio-geographical zones (Rao, 1994). Jorhat (26.75°N, 94.22°E and elevation 116 metres) is situated in the state of Assam in northeast India. The location map of Jorhat site is shown in Fig. 1. Jorhat district spreads over geographical area of 2,851 km$^2$ and the economy of the district depends mainly on tea, silk, paddy and fruit crops. Monthly rainfall and temperature data were collected from Tocklai Tea Research Association, Jorhat (Longitude 94° 12'E and Latitude 26° 47'N) from the year 1965 to 2008. The average annual temperature and rainfall of the station is about 26°C and about 2,029 mm, respectively. Monthly rainfall and temperature data for 36 years were used in the time series analysis from 1965 to 2000. Monthly data for 8 years from 2001 to 2008 were considered during the validation of the developed model.

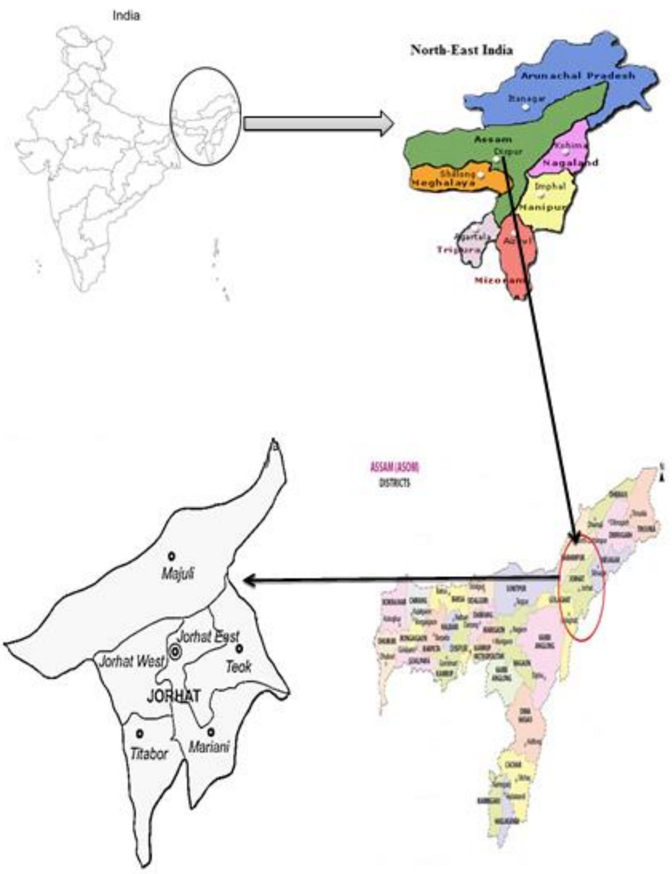


**Figure 1.** Location map of Jorhat (Assam)

*2.2. Time series analysis*

Mathematically, a discrete time series is denoted by $X_t$, where t=1, 2, 3… etc., and $X_t$ are at equidistant time interval and decomposed by additive type. The additive form provides a reasonable model in most cases, and is expressed as:

$$X_t = T_t + P_t + S_t + a_t \qquad (1)$$

where, $T_t$ = Deterministic trend component, $P_t$= Deterministic periodic component, $S_t$= Stationary stochastic dependent component and $a_t$= Stationary stochastic independent component, t = 1,2,3……N, where N= total number of values and $X_t$=Monthly rainfall, maximum temperature and minimum temperature data.

Since, the model is applied to stochastic component, which is treated as random variable, the trend and periodic components were first removed from the time series. The identification and detection of each component is necessary in order to obtain representative stochastic model of the time series. Each of the model components have been analysed and determined through the following steps.

*2.3 Trend Component ($T_t$)*

The trend is the steady and regular movement in a time series through which the values are, on an average, either increasing or decreasing. To find out the presence of trend in time series Turning point test details of which are described in the works of Dabral *et al.*, (2008) and Dabral *et al.*, ( 2014).

If the trend exist, then modeling of ($T_t$) was done by linear regression. After removing the trend, a trend free series was obtained as:

$$Y_t=X_t-T_t = P_t+S_t + a_t \qquad (2)$$

*2.4 Periodic Component($P_t$)*

Using harmonic analysis, the periodic component in the series $Y_t$ was determined The periodic component of mean monthly rainfall, maximum temperature and minimum time series ($Y_t$)was estimated by following equation:

$$\mu_\tau = m_x + \sum_{j=1}^{m}\left[A_j \mathrm{Cos}\left(\frac{2\pi j\tau}{w}\right) + B_j \mathrm{Sin}\left(\frac{2\pi j\tau}{w}\right)\right] \qquad (3)$$

Where, $\mu_\tau$ = periodic component in mean monthly value, $m_x$ = mean of the series $Y_t$, =1,2,3….,N with N as the total number of discrete values of rainfall and temperature data, $A_j$ and $B_j$= Fourier coefficients of mean series, τ=1,2,3…w with w as basic period of the series=1,2,3…m with m as member of significant harmonics and *w* =12 for monthly rainfall and temperature data.

The parameters Aj and Bj were estimated as described in the works of Dabral *et al.*, (2008) and Dabral *et al.*, (2014). Periodic component in the standard deviation was estimated by using the similar relationship (Eq. 3). Fourier coefficients for mean and standard deviation were determined up to six harmonics as suggested by Mutreja, (1986). The actual numbers of significant harmonics to be fitted in the series $X_t$ were determined through an analysis of variance. Variance $h_t$ explained by each harmonic is given in the form of the written equation below:

$$h_j = \left(A_j^2 + B_j^2\right)/2 \qquad (4)$$

$$\Delta p_j = \left(\text{variance of } h_j\right)/s^2 \qquad (5)$$

Where, *s*= variance of the standard deviation of the monthly data. After deciding the number of harmonics to be fitted to the 12 estimated values of periodic mean and periodic standard deviation, the periodicity of the series $Y_t$ was removed and the standardized stochastic component was obtained as described in the works of Dabral *et al.*, (2008) and Dabral *et al.*, (2014).

*2.5 Stochastic Component*

The stochastic component is constituted by various random effects, which cannot be estimated exactly. Application of autoregressive model has been attractive because, in the autoregressive form, the value of variable available at present time depends on the value of previous time and they are the simplest model to use. Therefore, stochastic models in autoregressive (AR) form were used for presentation of time series. The $p^{th}$ order autoregressive mode AR (P), representing the variable St is generally written as:

$$S_t = \sum_{i=1}^{p} \emptyset_i S_{t-1} + a_t \qquad (6)$$

Where $S_t$ = stationary stochastic dependent component, $\Phi_i$ = autoregressive model parameter and $a_t$ = independent random effect at time *t* or residual.

In the present study, model parameters were estimated using ISTM2000- V7.1 and SPSS-16 softwares. The autocorrelation and partial autocorrelation functions were also computed for the series $S_t$ along with their standard error using the same software and plotted against lag K. By visual inspection of the plots, tentative order of the model was decided. AICC/BIC statistics were also estimated. The order of the AR model was identified on the basis of the minimum value of AICC/ BIC statistics.

Independent stochastic Component series ($a_t$) was obtained using the following equation:

$$a_t=S_t-\sum_{i=1}^{p}\emptyset_i S_{t-1} \tag{7}$$

To check the independence of $a_t$, the Portmanteau test formulation by Mcleod and Li, (1983) was carried out. For modelling the independent stochastic component ($a_t$), normal probability distribution function was fitted to $a_t$ series as suggested by Chow *et al.*, (1988). The transformed $a_t$ series, in terms of $R_t$ series, can be represented as:

$$R_t=\mu_t+\sigma_t z_t \tag{8}$$

Where, $R_t$ = transformed $a_t$ series, $\mu_t$ = mean of the $R_t$ series, $\sigma_t$ = standard deviation of the $R_t$ series and $z_t$ = a random component with zero mean and unit variance.

*2.6 Evaluation of Regeneration Performance*

Results of the time series model were evaluated quantitatively to assess the regeneration performance. Statistical parameters such as mean, standard deviation were used to assess the fitting of the model. The models were evaluated through several statistical measures, such as, absolute error, relative error, Nash–Sutcliffe coefficient ($E_{NS}$), which are expressed as follows.

$$\text{Absolute error}= |\text{Generated value}-\text{Historical value}| \tag{9}$$

$$\text{Relative error}=\frac{\text{Absolute error}}{\text{Historical value}}\times 100 \tag{10}$$

$$E_{NS}1-\frac{\sum_{i=1}^{n}\left[X_{ob(t)}-X_{cal}(t)\right]^2}{\sum_{i=1}^{n}\left[X_{ob(t)}-X_{av}(t)\right]^2} \tag{11}$$

Assessment of changes of monthly rainfall and temperature in generated series (2009-2050) was predicted using regression analysis (Y = m*t + C, where, t = time in month, m = slope coefficient, C = least square estimate of the intercept). The slope coefficient indicates the monthly average rate of change in rainfall and temperature characteristics. The sign of the slope gives the direction of the variable (increasing if sign is positive and decreasing if sign is negative). Student's t-test was used to identify the trends at the 5% level of significance.

## 3. Results and Discussion

*3.1 Deterministic modelling*

For identification of trend component in the monthly rainfall, maximum and minimum temperature series, turning point test was carried out. The hypothesis of trend in the series was formulated and checked. Using the test statistics, the results of turning point test are presented in Table 1. Results indicated the presence of trend component in the monthly rainfall, maximum temperature and minimum temperature series. The values of the test statistics have been found to fall within the limits at 1% level of significance. Therefore, all the observed monthly rainfall, maximum temperature and minimum temperature series data could not be considered to be trend free. Using regression analysis, equations of trend ($T_t$) were determined and given in Table 1. After removing the trend, a trend free series ($Y_t$) was obtained for monthly rainfall, maximum temperature and minimum temperature.

**Table 1**. Analysis of trend component for monthly rainfall, maximum and minimum temperature and equation of trend lines of different variables

| Station | Variable | Turning Point Test | | | | | Equation of Trend line |
|---|---|---|---|---|---|---|---|
| | | N | P | E(P) | Var(P) | Z | |
| Jorhat | Rainfall | 432 | 224 | 286.67 | 76.48 | -6.93717 | Tt=-0.036X+174.76 |
| | Maximum temperature | 432 | 147 | 286.67 | 76.48 | -15.9707 | Tt=-0.0004X+28.261 |
| | Minimum Temperature | 432 | 72 | 286.67 | 76.48 | -24.5469 | Tt=0.0014X+18.79 |

Autocorrelogram (for lag 1 to 170) of the series $Y_t$ was developed for identification of base period. The peak and trough of the autocorrelogram show that the series $Y_t$ for rainfall, maximum temperature and minimum temperature has a periodic component with a base period of 12 months.

Fourier decomposition of periodic component and cumulative periodogram of the monthly rainfall, maximum temperature, and minimum temperature series at Jorhat are shown in Table 2. First five harmonics for the monthly rainfall, maximum temperature and minimum temperature series explained a total variance of 79.37, 72.59 and 73.65% respectively for Jorhat station. Therefore, other harmonics were ignored. Periodic means and periodic standard deviation were computed. The periodicity of the series $Y_t$ was removed. The remaining $S_t$ Series was subjected to checks for stationary behavior and model identification.

**Table 2.** Fourier decomposition of periodic component of monthly rainfall, maximum temperature and minimum temperature at Jorhat

| Variable | Order | Aj | Bj | Explained variance (%) | Cumulative Explained Variance (%) |
|---|---|---|---|---|---|
| **Rainfall** | 1 | -164.153 | -27.7578 | 75.92821 | 75.93 |
| | 2 | -0.12636 | 24.44634 | 1.637188 | 77.57 |
| | 3 | 11.83911 | 11.03456 | 0.717526 | 78.29 |
| | 4 | -5.34006 | 11.50018 | 0.440418 | 78.72 |
| | 5 | 5.235834 | -14.4747 | 0.649058 | 79.37 |
| | 6 | 0.992667 | 0 | 0.002699 | 79.38 |
| **Maximum temperature** | 1 | -3.7408 | -1.46827 | 67.22 | 67.22 |
| | 2 | -0.7471 | -0.64305 | 4.04 | 71.26 |
| | 3 | -0.23904 | -0.41892 | 0.97 | 72.23 |
| | 4 | 0.162159 | -0.06807 | 0.13 | 72.36 |
| | 5 | -0.05228 | 0.234588 | 0.24 | 72.60 |
| | 6 | 0.000956 | 0 | 3.8E-06 | 72.60 |
| **Minimum temperature** | 1 | -164.153 | -27.7578 | 75.93 | 75.93 |
| | 2 | -0.12636 | 24.44634 | 1.64 | 77.57 |
| | 3 | 11.83911 | 11.03456 | 0.72 | 78.29 |
| | 4 | -5.34006 | 11.50018 | 0.44 | 78.73 |
| | 5 | 5.235834 | -14.4747 | 0.65 | 79.38 |
| | 6 | 0.992667 | 0 | 0.0027 | 79.3827 |

*3.2 Stochastic modelling*

It is observed that the first autocorrelation and partial auto correlation function at lag 1 to 12 crossed the 95% confidence limit (Figs. 2 to 7) for rainfall, maximum temperature and minimum temperature series. Therefore, $1^{st}$ to $12^{th}$ order autoregressive models were selected for application. Anderson, (1976), observed that with the help of Autocorrelogram and partial Autocorrelogram, the true identification of the actual process might not be possibly obtained. He, therefore, suggested that other models should be tried for the selection. Therefore, autoregressive models up to 12th order were tried in this study. The values of AICC/BIC statistics were found to be minimum in case of AR (12) model for all the monthly rainfall, maximum temperature and minimum temperature series. Therefore, the 12 order autoregressive model was considered as suitable (Table 3).

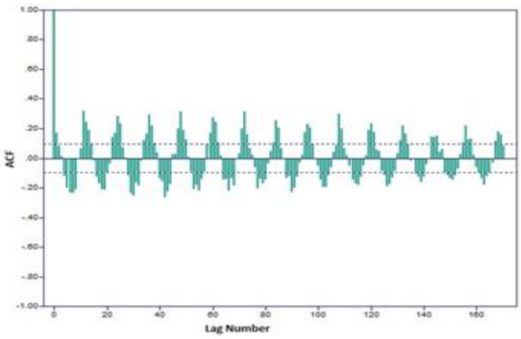


**Figure 2.** Autocorrelogram of series St (Rainfall) with S.E. limit

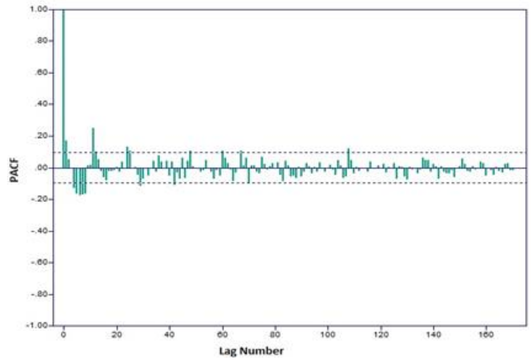


**Figure 3.** Partial autocorrelogram of series St (Rainfall) with S.E limit

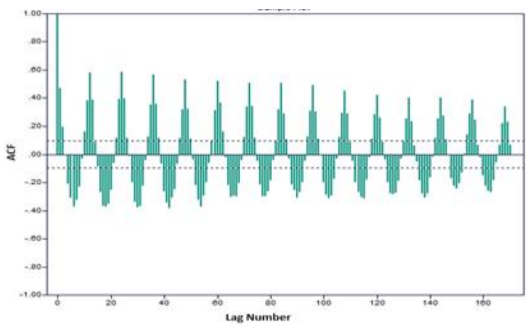


**Figure 4.** Autocorrelogram of series St (maximum temperature) with S.E. limit

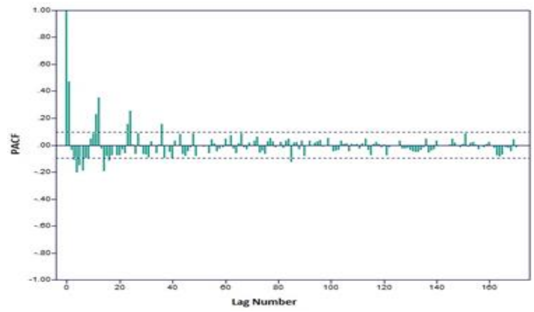


**Figure 5.** Partial autocorrelogram of series St (maximum temperature) with S.E. limit

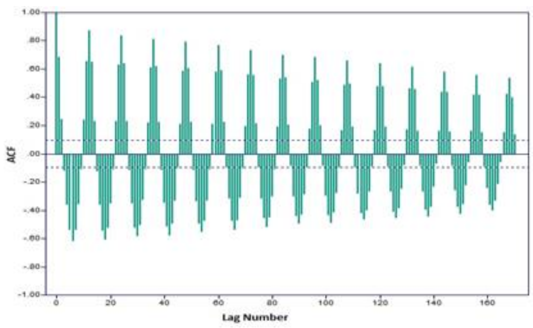


**Figure 6.** Autocorrelation of series St (minimum temperature) with S.E. limit

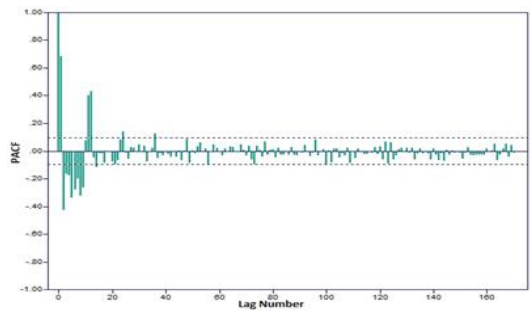


**Figure 7.** Partial autocorrelation of series St (minimum temperature) with S.E. limit

Portmanteau test formulated by Macleod and Li, (1983) indicated that all series (Rainfall, Maximum Temperature and Minimum temperature) consist of independent and identically distributed variables. For modelling the independent stochastic component, normal probability distribution function was fitted to $a_t$ series of monthly rainfall, maximum temperature and minimum temperature. Calculated chi square values were found to be 3.1, 5.2 and 6.6 for rainfall, maximum temperature, and minimum temperature $a_t$ series which are less than that of the tabular values at 5% level of significance. This indicates that $a_t$ series (for rainfall, maximum temperature, minimum temperature) is fitted to normal probability distribution function. The transformed a series, in terms of $R_t$ series, is represented as:

$$R_t=Z_t \tag{12}$$

**Table 3.** Best fit Autoregressive model for series $S_t$

| Variable | Description of model | AICC | BIC |
|---|---|---|---|
| Rainfall | $S_t = 0.01353\ S_{t-1} - 0.0006588\ S_{t-2} + 0.04338\ S_{t-3} - 0.03987\ S_{t-4} - 0.07761\ S_{t-5} - 0.1077\ S_{t-6} - 0.1204\ S_{t-7} - 0.1642\ S_{t-8} + 0.01002\ S_{t-9} + 0.001806\ S_{t-10} + 0.2563\ S_{t-11} + 0.1070\ S_{t-12}$ | 0.114675 x$10^4$ | 0.115812 x$10^4$ |
| Maximum Temperature | $S_t = 0.2685\ S_{t-1} - 0.01708\ S_{t-2} + 0.007452 S_{t-3} - 0.07002\ S_{t-4} - 0.01236\ S_{t-5} - 0.07863\ S_{t-6} - 0.02331 S_{t-7} - 0.07182\ S_{t-8} + 0.01342\ S_{t-9} + 0.01040 S_{t-10} + 0.1094\ S_{t-11} + 0.3581 S_{t-12}$ | 0.991874x$10^3$ | 0.101442x $10^4$ |
| Minimum Temperature | $S_t = 0.2707\ S_{t-1} - 0.1109 S_{t-2} - 0.1027\ S_{t-3} + 0.01995 S_{t-4} - 0.05237\ S_{t-5} - 0.09971\ S_{t-6} - 0.01244 S_{t-7} - 0.03527\ S_{t-8} - 0.07852 S_{t-9} - 0.05483\ S_{t-10} + 0.1846 S_{t-11} + 0.5016 S_{t-12}$ | 0.455982x$10^3$ | 0.494174x $10^3$ |

Time series for monthly rainfall, maximum temperature and minimum temperature were developed by substitution of the values of deterministic and stochastic Components in Eq. 1. The decomposition model of the time series ($X_t$) for rainfall, maximum temperature, minimum temperature is given in Table 4.

The qualitative assessment was made by the comparison of autocorrelation functions of the historical and regenerated series for rainfall, maximum temperature and minimum temperature.

**Table 4.** Decomposition of model of time series $X_t$

| | |
|---|---|
| Rainfall | $X_t = (174.6-0.0036X) + \{0.00104 + (-164.153) \text{Cos} (\frac{2\pi}{12}) \tau + (-27.7578) \text{Sin} (\frac{2\pi}{12}) \tau + (-0.12636) \text{Cos} (\frac{4\pi}{12}) \tau + (24.25563) \text{Sin} (\frac{4\pi}{12}) \tau + 11.8391 \text{Cos} (\frac{6\pi}{12}) \tau + (11.0346) \text{Sin} (\frac{6\pi}{12}) \tau\} + (-5.34006) \text{Cos} (\frac{8\pi}{12}) \tau + (11.5002) \text{Sin} (\frac{8\pi}{12}) \tau\} + 5.23583 \text{Cos} (\frac{10\pi}{12}) \tau + (-14.4747) \text{Sin} (\frac{12\pi}{12}) \tau\} + 0.01353\ S_{t-1} - 0.0006588\ S_{t-2} + 0.04338\ S_{t-3} - 0.03987\ S_{t-4} - 0.07761\ S_{t-5} - 0.1077\ S_{t-6} - 0.1204\ S_{t-7} - 0.1642\ S_{t-8} + 0.01002\ S_{t-9} + 0.001806\ S_{t-10} + 0.2563\ S_{t-11} + 0.1070\ S_{t-12} + Z_t$ |
| Maximum Temperature | $X_t = (28.261-0.0004X) + \{0.005785 + (-3.7408) \text{Cos} (\frac{2\pi}{12}) \tau + (-1.46827) \text{Sin} (\frac{2\pi}{12}) \tau + (-0.7471) \text{Cos} (\frac{4\pi}{12}) \tau + (-0.64305) \text{Sin} (\frac{4\pi}{12}) \tau + (-0.23904) \text{Cos} (\frac{6\pi}{12}) \tau + (-0.41892) \text{Sin} (\frac{6\pi}{12}) \tau\} + (0.162159) \text{Cos} (\frac{8\pi}{12}) \tau + (-0.06807) \text{Sin} (\frac{8\pi}{12}) \tau\} + (-0.05228) \text{Cos} (\frac{10\pi}{12}) \tau + (0.234588) \text{Sin} (\frac{12\pi}{12}) \tau\} + 0.2685\ S_{t-1} - 0.01708\ S_{t-2} + 0.007452 S_{t-3} - 0.07002\ S_{t-4} - 0.01236\ S_{t-5} - 0.07863\ S_{t-6} - 0.02331 S_{t-7} - 0.07182\ S_{t-8} + 0.01342\ S_{t-9} + 0.01040 S_{t-10} + 0.1094\ S_{t-11} + 0.3581 S_{t-12} + Z_t$ |
| Minimum Temperature | $X_t = (18.79+0.0014X) + \{0.000893 + (-6.37827) \text{Cos} (\frac{2\pi}{12}) \tau + (-2.44307) \text{Sin} (\frac{2\pi}{12}) \tau + (-1.26802) \text{Cos} (\frac{4\pi}{12} \tau) + (-0.95738) \text{Sin} (\frac{4\pi}{12}) \tau + (-0.4889) \text{Cos} (\frac{6\pi}{12}) \tau + (-0.0674) \text{Sin} (\frac{6\pi}{12}) \tau\} + (-0.02922) \text{Cos} (\frac{8\pi}{12}) \tau + (0.022063) \text{Sin} (\frac{8\pi}{12}) \tau\} + (-0.11342) \text{Cos} (\frac{10\pi}{12}) \tau + (0.019513) \text{Sin} (\frac{12\pi}{12}) \tau\}\ 0.2707\ S_{t-1} - 0.1109 S_{t-2} - 0.1027\ S_{t-3} + 0.01995 S_{t-4} - 0.05237\ S_{t-5} - 0.09971\ S_{t-6} - 0.01244 S_{t-7} - 0.03527\ S_{t-8} - 0.07852 S_{t-9} - 0.05483\ S_{t-10} + 0.1846 S_{t-11} + 0.5016 S_{t-12} + Z_t$ |

*3.3 Models assessment*

*3.3.1 Rainfall*

The mean and standard deviation of the generated series (1965–2000) are found to be 162.91 mm and 117.4 mm, which is close to the mean of 166 mm and standard deviation of 148 mm of the historical series. Nash–Sutcliffe coefficient was observed to be and 0.70 indicating a high degree of model fitness. Mean monthly values of rainfall from 1965 to 2000 of historical data and generated sequence were used for comparison. The respective relative and absolute errors of all the calendar months were calculated for comparison and are given in Table 5. The absolute error is in the range of 0.6 to 86.9. Relative errors are found to comparatively higher for the months January, February, March, April and August, September, October and November.

*3.3.2 Maximum temperature*

The mean and standard deviation of the generated series (1965–2000) are found to be 27.97 and 3.16 which is close to the mean of 28.17 and standard deviation of 3.5 of the historical series. Nash–Sutcliffe coefficient was observed to be 0.83 indicating a high degree of model fitness. Mean monthly values from 1965 to 2000 of historical data and generated sequence were used for comparison. The respective relative and absolute errors of all the calendar months were calculated for comparison and are given in Table 5. The absolute error and relative errors are found 0 and 0% respectively for all months.

**Table 5.** Mean monthly rainfall, maximum temperature and minimum temperature of historical and generated data series (1965-2000) along with errors

| Variable | Month | Mean of historical data(mm) | Mean of generated data(mm) | Errors | | Nash Sutcliff coefficient |
|---|---|---|---|---|---|---|
| | | | | Absolute ,mm | Relative,% | |
| Rainfall | January | 20.9 | 43.4 | 22.5 | 107.7 | 0.70 |
| | February | 39.5 | 77.5 | 38.0 | 96.2 | |
| | March | 62.9 | 107.9 | 45.1 | 71.6 | |
| | April | 199.8 | 237.8 | 37.9 | 19.0 | |
| | May | 252.1 | 274.7 | 22.6 | 8.9 | |
| | June | 309.1 | 308.5 | 0.6 | 0.2 | |
| | July | 379.4 | 357.6 | 21.9 | 5.8 | |
| | August | 323.2 | 236.2 | 86.9 | 26.9 | |
| | September | 259.6 | 215.4 | 44.2 | 17.0 | |
| | October | 118.3 | 79.1 | 39.1 | 33.1 | |
| | November | 23.8 | 2.6 | 21.2 | 89.2 | |
| | December | 14.7 | 14.1 | 0.6 | 3.9 | |
| Maximum Temperature | January | 22.3 | 22.3 | 0 | 0 | 0.83 |
| | February | 24.2 | 24.2 | 0 | 0 | |
| | March | 27.6 | 27.6 | 0 | 0 | |
| | April | 28.4 | 28.4 | 0 | 0 | |
| | May | 30.0 | 30.0 | 0 | 0 | |
| | June | 31.4 | 31.4 | 0 | 0 | |
| | July | 31.6 | 31.6 | 0 | 0 | |
| | August | 30.5 | 30.5 | 0 | 0 | |
| | September | 30.9 | 30.9 | 0 | 0 | |
| | October | 29.0 | 29.0 | 0 | 0 | |
| | November | 26.4 | 26.4 | 0 | 0 | |
| | December | 23.3 | 23.3 | 0 | 0 | |
| Minimum Temperature | January | 10.4 | 10.4 | 0.4 | 3.15 | 0.99 |
| | February | 12.4 | 13.1 | 0.7 | 5.41 | |
| | March | 16.2 | 17.1 | 0.9 | 5.81 | |
| | April | 19.7 | 20.5 | 0.8 | 4.30 | |
| | May | 22.5 | 22.6 | 0.1 | 0.58 | |
| | June | 24.8 | 24.5 | 0.3 | 1.30 | |
| | July | 25.3 | 25.0 | 0.2 | 0.87 | |
| | August | 25.4 | 21.5 | 3.8 | 15.08 | |
| | September | 24.5 | 24.2 | 0.3 | 1.19 | |
| | October | 21.5 | 20.4 | 1.2 | 5.55 | |
| | November | 16.0 | 15.1 | 0.9 | 5.80 | |
| | December | 10.8 | 10.5 | 0.3 | 3.07 | |

### *3.3.3 Minimum temperature*

The mean and standard deviation of the generated series (1965–2000) are found to be 18.73 and 5.16 for minimum temperature, which are close to the mean of 19.09 and standard deviation of 5.16 for minimum temperature of the historical series. Nash–Sutcliffe coefficient was observed to be 0.99 respectively indicating a high degree of model fitness. Mean monthly values from 1965 to 2000 of historical data and generated sequence were used for comparison. The respective relative and absolute errors of all the calendar months were calculated for comparison and are given in Table 5. The absolute error is in the range of 0.1to 3.8 for minimum temperature. Relative errors are found to be in the range of 1.19 to 15.08 %.

*3.4 Validation of the Developed Time Series Models*

*3.4.1 Rainfall*

Time series model was used for prediction of 8 years value. The predicted values of monthly rainfall along with the historical values for the year 2000 and 2008 are shown in Fig. 8. The annual mean of the predicted monthly rainfall series is 154 which close to the mean value of 151 of the historical value. Nash–Sutcliffe coefficient is observed to be 0.71 for rainfall respectively indicating a high degree of model fitness to the observed data (Table 6).

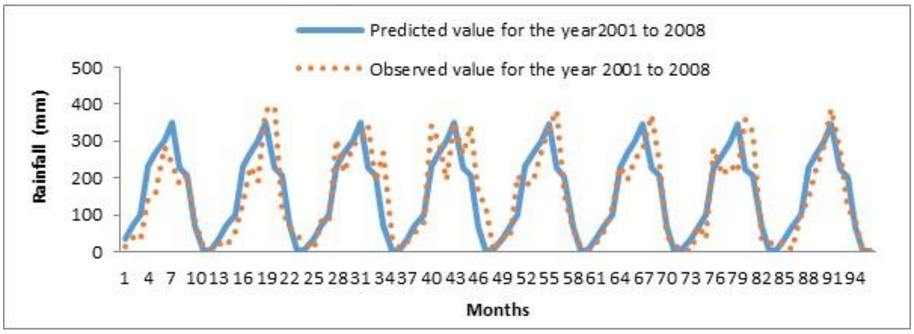


**Figure 8.** Observed and predicted value of rainfall for the years 2001 to 2008

*3.4.2 Maximum Temperature*

Time series model was used for prediction of 8 years value of maximum temperature i.e., for the years 2000 and 2008. The predicted values of monthly maximum temperature along with the historical values for the year 2000 and 2008 are shown in Fig. 9.

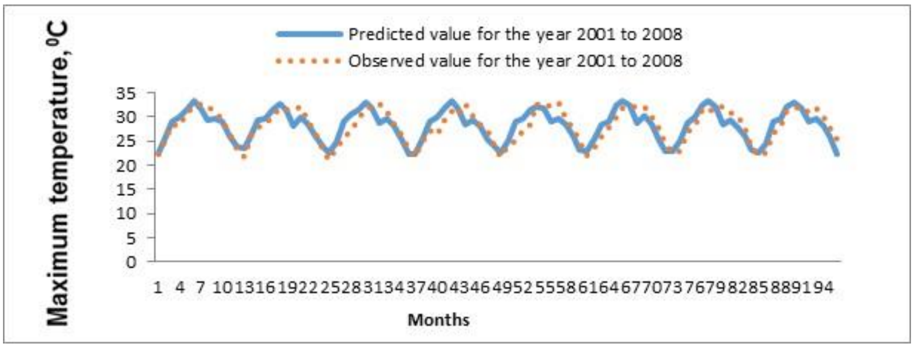


**Figure 9.** Observed and predicted value of monthly maximum temperature for the year 2001 to 2008

The annual mean of the predicted monthly maximum temperature is 28.33 which is close to the mean value of 28.21 of the historical value. Nash–Sutcliffe coefficient is observed to be 0.702 respectively indicating a high degree of model fitness to the observed data (Table 6).

*3.4.3 Minimum Temperature*

Time series model was used for prediction of 8 years i.e., for the years 2000 and 2008. The predicted values of monthly minimum temperature along with the historical values for the year 2000 and 2008 are shown in Fig. 10. The annual mean of the predicted monthly minimum temperature series is 18.93 which is close to the mean value of 19.45. Nash–Sutcliffe coefficient is observed to be 0.79 indicating a high degree of model fitness to the observed data (Table 6).

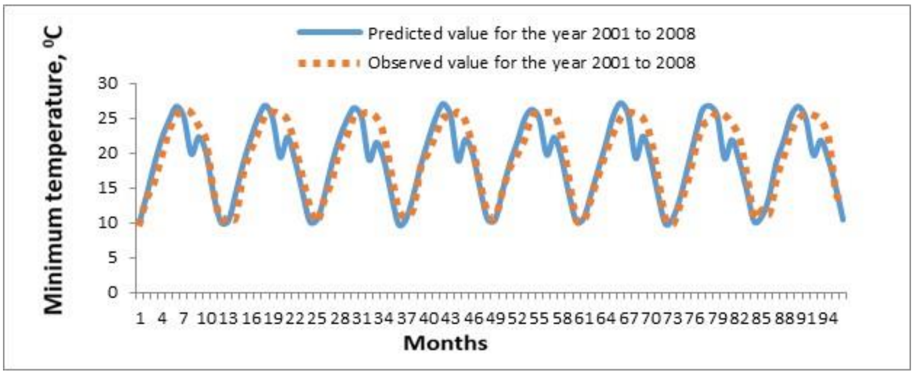


**Figure 10.** Observed and predicted value of monthly minimum temperature for the year 2001 to 2008

**Table 6.** Mean monthly rainfall, maximum temperature and minimum temperature of historical and generated data series (2000-2008) along with errors

| Variable | Month | Mean of historical data(mm) | Mean of generated data(mm) | Errors | | Nash Sutcliff coefficient |
|---|---|---|---|---|---|---|
| | | | | Absolute ,mm | Relative,% | |
| Rainfall | January | 20.4 | 35.0 | 14.6 | 71.6 | 0.71 |
| | February | 43.8 | 69.3 | 25.5 | 58.4 | |
| | March | 88.0 | 100.1 | 12.1 | 13.7 | |
| | April | 220.0 | 229.7 | 9.7 | 4.4 | |
| | May | 214.0 | 266.4 | 52.5 | 24.5 | |
| | June | 250.0 | 300.0 | 49.9 | 20.0 | |
| | July | 312.2 | 348.5 | 36.4 | 11.6 | |
| | August | 320.5 | 226.2 | 94.3 | 29.4 | |
| | September | 211.3 | 205.3 | 6.0 | 2.9 | |
| | October | 100.3 | 68.8 | 31.5 | 31.4 | |
| | November | 34.0 | 0 | 34.0 | 100.0 | |
| | December | 7.7 | 5.0 | 2.7 | 35.1 | |
| Maximum Temperature | January | 21.9 | 22.8 | 0.9 | 4.1 | 0.702 |
| | February | 24.1 | 25.1 | 1.1 | 0 | |
| | March | 26.8 | 29.0 | 2.2 | 0.1 | |
| | April | 27.7 | 29.8 | 2.1 | 0.1 | |
| | May | 30.2 | 31.9 | 1.7 | 0.1 | |
| | June | 31.8 | 33.0 | 1.3 | 0 | |
| | July | 31.9 | 31.9 | 0 | 0 | |
| | August | 32.1 | 28.7 | 3.4 | 0.1 | |
| | September | 31.6 | 29.7 | 1.9 | 0.1 | |
| | October | 29.5 | 28.3 | 1.2 | 0 | |
| | November | 27.1 | 25.8 | 1.4 | 0 | |
| | December | 24.0 | 23.2 | 0.8 | 0 | |
| Minimum Temperature | January | 10.5 | 10.5 | 0.1 | 0.6 | 0.79 |
| | February | 12.8 | 14.0 | 1.3 | 9.9 | |
| | March | 16.8 | 18.3 | 1.6 | 9.3 | |
| | April | 20.0 | 21.9 | 1.8 | 9.2 | |
| | May | 22.9 | 25.2 | 2.3 | 10.0 | |
| | June | 25.2 | 26.8 | 1.6 | 6.3 | |
| | July | 25.7 | 25.2 | 0.5 | 1.9 | |
| | August | 25.7 | 19.4 | 6.3 | 24.4 | |
| | September | 22.0 | 19.7 | 2.3 | 10.5 | |
| | October | 21.9 | 19.3 | 2.6 | 11.7 | |
| | November | 16.0 | 14.5 | 1.5 | 9.6 | |
| | December | 11.4 | 10.2 | 1.3 | 11.1 | |

*3.5 Assessment of the Change of Monthly Rainfall, Maximum Temperature and Minimum Temperature in Generated Series (2009-2050)*

Using the developed time series models (Table 4), monthly rainfall, maximum temperature and minimum temperature were forecasted for the year 2009 to 2050 (Figs. 11 to 13).

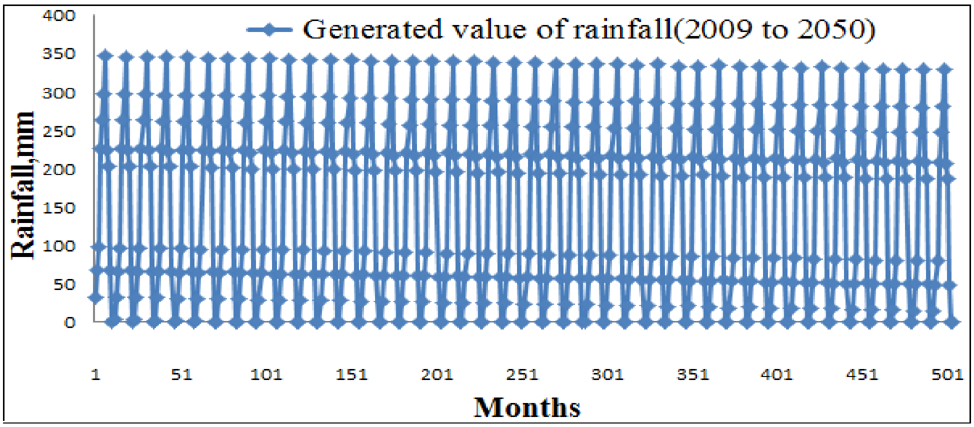


**Figure 11.** Generated value of rainfall (2009-2050)

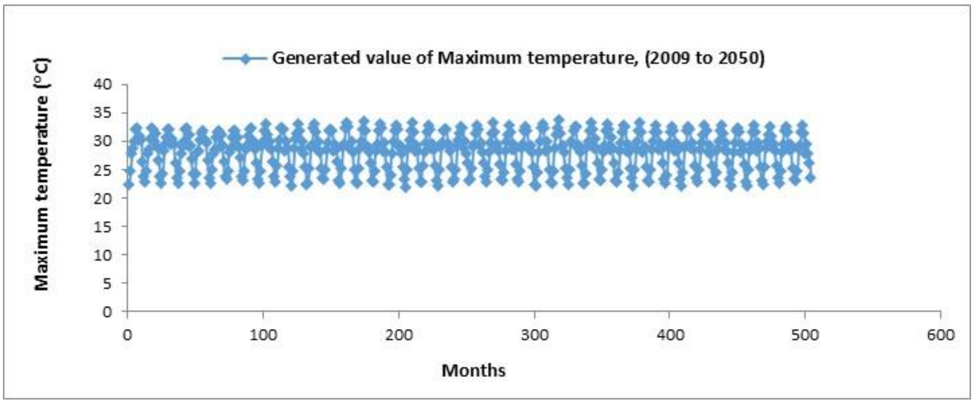


**Figure 12.** Generated value of maximum temperature (°C)

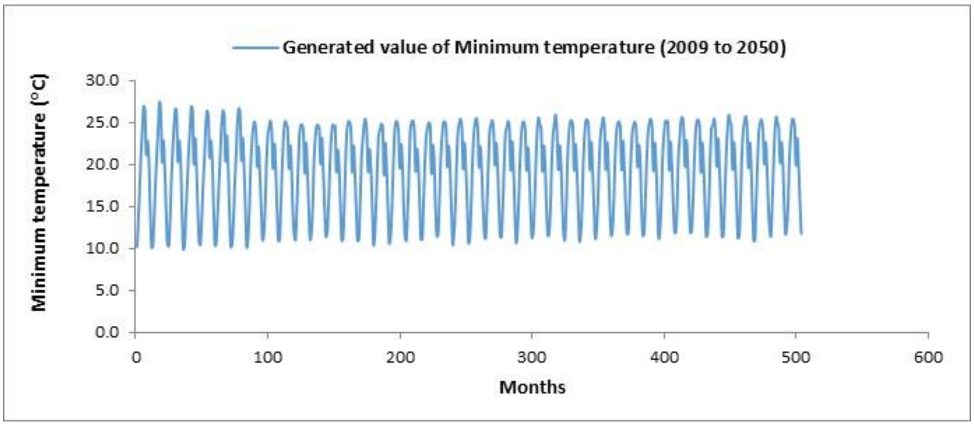


**Figure 13.** Generated value of minimum temperature (°C)

The linear regression analyses of monthly series of rainfall, maximum temperature and minimum temperature have not shown any significant trend (Table 7). This indicates that climate at Jorhat (Assam) in next four decades will remain more or less stable.

**Table 7.** Linear regression analysis

| S. No. | Parameter | Equation | Slope | Intercept |
|---|---|---|---|---|
| **1.** | Rainfall | $Y_t$=-0.039 t +152.853 | -0.039 | 152.853* |
| **2.** | Maximum Temperature | $Y_t$=-0.0004 t +28.262 | -0.0004 | 28.262* |
| **3.** | Minimum Temperature | $Y_t$=0.0014 t+18.998 | +0.0014 | 18.998* |

*= Significant at 5% probability level

## 4. Conclusions

Monthly rainfall, maximum temperature and minimum temperature series were found to have deterministic and stochastic components. Time series models for rainfall, maximum temperature and minimum temperature were obtained by adding deterministic (trend and periodic component) and stochastic component dependent and independent component. Nash-Sutcliffe coefficient also indicated a high degree of model fitting to the observed data. Validation of the time series models for rainfall, maximum temperature and minimum temperature were done using 8 years data (2001-2008). The Nash-Sutcliffe coefficient also indicated a high degree of model validation. The linear regression analyses of monthly series (generated 2009-2050) of rainfall, maximum temperature and minimum temperature have not shown any significant trend. This indicates that the climate at Jorhat (India) in next 04 decades will remain more or less stable.

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