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# Trend and Variability Analysis for Forecasting of Temperature in Bangladesh

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**Abstract**
An attempt was made to investigate the trend and variability pattern for decadal, annual and seasonal (three crop seasons) average dry bulb temperature (ADBT) for the six divisional stations of Bangladesh namely Dhaka, Khulna, Rajshahi, Barisal, Sylhet and Chittagong. The monthly ADBT for 2009-2012 is forecasted using the univariate Box-Jenkin's ARIMA (autoregressive integrated moving average) modelling technique. The rates of linear trend for annual average dry bulb temperature (ADBT) were found negative for Rajshahi and Barisal but positive for Dhaka, Khulna, Sylhet and Chittagong. The rates for Seasonal ADBT were positive for all the three seasons for Dhaka and Chittagong, but negative for all the three seasons for Barisal while positive for Kharif and Rabi seasons and negative for Prekharif seasons for Khulna and Sylhet. The rates were positive for Kharif season but negative for Prekharif and Rabi seasons for Rajshahi.

**Key words**: Forecasting, Temperature

## Introduction

Temperature refers to intensity aspects of heat and energy, which creates speed of molecules in a body. The variation in temperature affects crops in different forms and ways. Plant's growth and yield is highly dependent on temperature. In case of optimum temperature for optimum growth, plants absorb $CO_2$ for photosynthesis and convert it to sugar for its energy and growth. Increased temperature can elevate the transpiration rate and reduce the moisture level for plant's growth, crop yield may also be reduced due to increased temperature. Excess temperature causes heat injury, retards growth, irreparable damage to cells and cytoplasms, retards growth of fruit formulation and maturity. On the other hand, low temperature causes 1ess growth and death of tissues, prevents formation of chlorophyll and yellowing of leaves, freezing of plant tissues and finally leads to their death (Lenka, 1998). Many bacterial and fungal diseases reach to their severe levels with increased temperature and precipitation. Stem growth, flowering and fruit development depends on temperature regimes. It is thought that each crop requires a definite summation of temperature units from its sowing to harvesting i.e. crop maturity depends on total temperature units. Higher daily temperature shortens the crop duration and vise-versa. In this paper, the annual and seasonal average dry bulb temperatures (ADBT) were analyzed to find out the intra and inter-annual temperature variability, where the univariate Box-Jenkin's autoregressive integrated moving average (ARIMA) models are developed for monthly ADBT. Box-Jenkin's ARIMA model is widely used as an alternative model for forecasting climatic data. ARIMA models provide maximum likelihood estimators that are unbiased when the data are seasonal and autocorrelated, and when a variable is lagged on itself. In intra-annual variability analysis, the maximum, mean and minimum ADBT and the coefficient of variation (CV) were used in detecting the pattern of temperature variability in annual and seasonal aspects for a year. But in inter-annual variability analysis, the trend lines were estimated to investigate the year-to-year variations among various stations.

## Sources of Data and Methodology

***Sources of data***
Data were taken from Bangladesh Meteorological Department, Dhaka. The monthly ADBT in degree centigrade were taken for Dhaka, Rajshahi, Khulna, Barisal, Sylhet and Chittagong during 1953-2008, 1964-2008, 1948-2008, 1949-2008, 1956-2008 and 1949-2008, respectively. The missing data were filled in by the median of the corresponding years. The seasonal data for the three crop seasons namely Kharif, Prekharif and Rabi were derived by averaging the monthly data taken from June - October, March - May and November - February, respectively.

***Validation of data***

In this study, the linear trend for annual and seasonal ADBT were fitted with the least square method taking the following form of equation -

$$Y = a + bX$$

where, $Y$ - ADBT, $X$ - time, $a$ and $b$ - parameters

Stationarity of residuals for ADBT trend was tested using autocorrelation function (ACF) and partial autocorrelation function (PACF) display and the normality was checked by normal probability plot. The value of classical 't' test was used for the identification of significant ADBT trend, when residuals follow the normality and stationarity pattern.

Univariate Box-Jenkin's ARIMA model was fitted to forecast the monthly ADBT data for January 2009 - December 2012. After confirming that the series was stationary, an effort was made for an ARIMA model to express each observation as a linear function of the previous value of the series (autoregressive parameter), and of the past error effect (moving average parameter). The available data were divided into training, validation and test sets. The training set was used to build up the model, the validation set was used for parameter optimization and the test set was used to evaluate the model. The adequacy of the above model was checked by comparing the observed data with the forecasted results. The data for the last ten years were used to compare with the fitted model forecasts for the years and the models were selected for the minimum root mean square forecasting error of the data set of mentioned time range. The diagnostic techniques namely histogram of residuals, normal probability plot of residuals, ACF and PACF display of residuals, times series (TS) plots for residual versus fitted values and TS plots for residual versus order of the data were used for checking residuals of ARIMA models. Box-Cox transformation was used for variance stabilization and the transformation of the data to get stationary series from nonstationary series (Pankraiz, 1991). The software package 'Minitab 13' was used to fit the ARIMA univariate models. A detailed description of the nonseasonal and seasonal ARIMA models and the standardized notation used is set in the Appendix 1.

***Box Jenkins modelling strategy and ARIMA Model***

Box Jenkins (1976) formalized the ARIMA modeling framework in three steps: (i) Identification, (ii) Estimation and (iii) Verification. In the identification stage, it was tried to identify that how many terms to be included based on the ACF and PACF of the differenced and/or transformed time series. In the estimation stage, the coefficients of the model were estimated by the maximum likelihood method. The verification of the model was done through diagnostic checks of the residuals (histogram or normal probability plot of residuals, standardized residuals, ACF and PACF of the residuals). The performance of the ARIMA models was often tested through comparison of prediction with observation not used in the fitted model. An appropriate ARIMA model provides minimum mean squared error forecasts among all linear univariate models with fixed coefficients. It might produce point forecasts for each time period and interval forecasts constructing a confidence interval around each point forecast. To have the 95% interval for each forecast the formulae $f \pm 2s$ was used, where $f$ denotes 'forecast' and $s$ was it's 'standard error'. The forecasts for a stationary model converge to the mean of the series and the speed of converging movement depends on the nature of the model. For nonstationary model the forecasts did not converge to the mean.

## Results and Discussions

***a) Decadal variability***

The decadal averages for annual and seasonal ADBT for six divisions of Bangladesh are presented in Table 1. The annual and seasonal ADBT in the last decades were higher as compared to 1981-90 in all the six stations.

**Table 1.** Decadal average ADBT for the six stations

| | Dhaka | | | | | Rajshahi | | | | | Khulna | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | A | K | PK | R | Period | A | K | PK | R | - | A | K | PK | R |
| - | - | - | - | - | - | - | - | - | - | 1948-50 | 25.75 | 28.25 | 27.78 | 21.10 |
| 1953-60 | 25.18 | 27.81 | 27.68 | 20.0 | - | - | - | - | - | 1951-60 | 25.77 | 28.16 | 28.64 | 20.63 |
| 1961-70 | 25.59 | 27.80 | 27.93 | 21.1 | 1964-70 | 25.37 | 28.16 | 28.56 | 19.48 | 1961-70 | 26.06 | 28.13 | 29.13 | 21.18 |
| 1971-80 | 25.39 | 28.00 | 27.36 | 20.7 | 1971-80 | 25.80 | 28.45 | 28.53 | 20.45 | 1971-80 | 26.48 | 28.56 | 29.09 | 21.92 |
| 1981-90 | 25.81 | 28.45 | 27.50 | 21.2 | 1981-90 | 25.06 | 28.21 | 27.41 | 19.34 | 1981-90 | 25.65 | 28.41 | 27.74 | 20.63 |
| 1991-00 | 25.78 | 28.52 | 27.80 | 20.8 | 1991-00 | 25.12 | 28.31 | 27.71 | 19.17 | 1991-00 | 25.91 | 28.61 | 28.26 | 20.78 |
| 2001-08 | 25.96 | 28.48 | 27.97 | 21.3 | 2001-08 | 25.22 | 28.44 | 27.66 | 19.37 | 2001-08 | 26.14 | 28.71 | 28.56 | 21.12 |

A = Annual K = Kharif PK = Prekharif R = Rabi

**Table 1.** continued

| | Barisal | | | | | Sylhet | | | | | Chittagong | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | K | PK | R | | A | K | PK | R | | A | K | PK | R |
| 1949-50 | 25.91 | 28.22 | 28.05 | 21.43 | | | | | | 1949-50 | 25.96 | 28.64 | 27.20 | 21.68 |
| 1951-60 | 25.84 | 28.15 | 28.45 | 21.00 | 1956-60 | 24.53 | 27.01 | 25.64 | 20.60 | 1951-60 | 25.57 | 27.64 | 27.50 | 21.53 |
| 1961-70 | 26.06 | 28.15 | 28.25 | 21.80 | 1961-70 | 24.44 | 27.01 | 25.69 | 20.28 | 1961-70 | 25.37 | 27.40 | 27.34 | 21.36 |
| 1971-80 | 25.35 | 27.86 | 27.40 | 20.66 | 1971-80 | 24.39 | 27.14 | 25.55 | 20.07 | 1971-80 | 25.49 | 27.55 | 27.16 | 21.65 |
| 1981-90 | 25.37 | 28.03 | 27.48 | 20.47 | 1981-90 | 24.37 | 27.21 | 25.18 | 20.21 | 1981-90 | 25.66 | 27.84 | 27.06 | 21.88 |
| 1991-00 | 25.48 | 28.11 | 27.71 | 20.50 | 1991-00 | 24.62 | 27.39 | 25.50 | 20.49 | 1991-00 | 25.94 | 28.22 | 27.55 | 21.87 |
| 2001-08 | 25.55 | 28.12 | 27.82 | 20.64 | 2001-08 | 24.84 | 27.68 | 25.75 | 20.62 | 2001-08 | 26.07 | 28.10 | 27.75 | 22.26 |

A = Annual K = Kharif PK = Prekharif R = Rabi

### *b) Intra-annual variability*

The intra-annual variability for annual and seasonal ADBT for the six stations are presented in Table 2. The highest average ADBT was 28.4 in Khulna but (27.2) lowest in Sylhet. The highest annual average ADBT was 29.5 in Dhaka but lowest 24.5 in Sylhet. The highest maximum ADBT was 29.5 in Dhaka but lowest 25.7 in Sylhet while the highest minimum ADBT was 25.1 in Chittagong but lowest 23.9 in Sylhet. The average ADBT was highest in Kharif season but lowest in Rabi season except Khulna where it was highest in Prekharif season but lowest in Rabi season. The CV was highest in Rabi season but lowest in Kharif season.

**Table 2.** Within-Year variability for annual and seasonal ADBT

| Period | Dhaka | | | | Khulna | | | | Rajshahi | | | | Barisal | | | | Sylhet | | | | Chittagong | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | max | ave | min | cv | max | ave | min | cv | max | ave | min | cv | max | ave | min | cv | max | ave | min | cv | max | ave | min | cv |
| Annual | 29.5 | 29.5 | 24.8 | 2.6 | 27.4 | 26 | 24.9 | 1.8 | 26.6 | 25.3 | 24.6 | 1.9 | 28 | 25.6 | 25 | 2.1 | 25.7 | 24.5 | 23.9 | 1.8 | 26.8 | 25.7 | 25.1 | 1.4 |
| Kharif | 29.1 | 28.2 | 27.5 | 1.4 | 29.2 | 28.4 | 26.5 | 1.4 | 29 | 28.3 | 27.8 | 1 | 28.8 | 28.1 | 27.5 | 1.1 | 28.2 | 27.2 | 26.5 | 1.4 | 29.4 | 27.8 | 27.1 | 1.5 |
| Prekharif | 32.4 | 27.7 | 26.1 | 3.3 | 30.6 | 28.5 | 26.1 | 3 | 30.6 | 27.9 | 25.9 | 3.6 | 29.6 | 27.9 | 26.4 | 2.5 | 27.5 | 25.5 | 24.3 | 2.6 | 28.3 | 27.4 | 26 | 1.8 |
| Rabi | 29.6 | 20.9 | 19 | 6.5 | 23.6 | 21 | 19.6 | 3.5 | 21.5 | 19.6 | 18.3 | 3.9 | 27 | 20.9 | 19.6 | 5.2 | 24.3 | 20.3 | 19.3 | 4.8 | 23.8 | 21.7 | 20.8 | 2.5 |

Max = Maximum ave = Average min = Minimum cv = Coefficient of Variation

### *c) Inter-annual variability*

#### *Annual and seasonal ADBT*

The rates obtained from linear trend (LT) for annual and seasonal ADBT are shown in Table 3. Stationarity and normality features of ADBT were also examined and pointed out against each trend value for annual, Kharif, Prekharif and Rabi seasons. The growth rates for annual ADBT were significantly positive for Chittagong (+0.010*); approximately significant for Sylhet (+0.007) and fairly high positive for Dhaka (+0.0149) and Khulna (+ 0.003) with nonnormal and/or nonstationary residual, but fairly high negative for Rajshahi (– 0.011) and Barisal (– 0.009) with nonnormal and/or nonstationary residual.

During Kharif season, the growth rates for ADBT were found significantly positive for Dhaka (+ 0.018*) and Sylhet (+ 0.013*); fairly high and positive for Khulna (+ 0.011) and Chittagong (+ 0.010) with nonnormal and stationary residual and for Rajshahi (– 0.003) with normal and stationary residual but less negative for Barisal (– 0.001) with normal and stationary residual too.

During Prekharif season, the rates for ADBT were less positive for Dhaka (+ 0.004) with nonnormal and stationary residual and fairly high and positive for Chittagong (+ 0.004) with normal and stationary residual. But significant negative rates were for Rajshahi (– 0.026*) and Barisal (– 0.013*); and fairly high but negative for Khulna (– 0.006) with nonstationary residual and very low and negative for Sylhet (– 0.001).

During Rabi season, the rates for ADBT were significantly positive for Chittagong (+ 0.014*); fairly high and positive for Dhaka (+0.0183) and less positive for Khulna (+ 0.001) and Sylhet (+ 0.005) with nonnormal and/or nonstationary residual while fairly high but negative for Rajshahi (– 0.0182) and Barisal (– 0.017) with nonnormal and/or nonstationary residual.The growth rates for annual ADBT were negative for Rajshahi and Barisal but positive for Dhaka, Khulna, Sylhet and Chittagong. The growth rates for Seasonal average ADBT were found positive for all the three seasons for Dhaka and Chittagong, and negative for all the three seasons for Barisal but the rates were positive for Kharif and Rabi seasons and negative for Prekharif seasons for Khulna and Sylhet. The rates were positive for Kharif season but negative for Prekharif and Rabi seasons for Rajshahi.

**Table 3.** Rates obtained from L T for annual and seasonal ADBT and residual's stationarity and normality

| Station | Annual | Kharif | Prekharif | Rabi |
|---|---|---|---|---|
| Dhaka | + 0.0149 ( t=2.92, NN, S) | + 0.018* (t=9.01, N, S) | + 0.004 (t=0.63, NN, S) | + 0.0183 (t=1.66, NN, S) |
| Rajshahi | – 0.011 ( t=-2.14, N, NS ) | + 0.003 (t=1.00, N, S) | – 0.026* (t=-2.37, N, S) | – 0.0182 (t=-2.18, N, NS) |
| Khulna | + 0.003 ( t=1.01, N, NS) | + 0.011 (t=4.50, NN, S) | – 0.006 (t=-1.12, N, NS) | + 0.001 (t=0.27, N, NS) |
| Barisal | – 0.009 ( t=-2.52, NN, NS) | – 0.001 (t=-0.52, N, S) | – 0.013* (t=-2.63, N, S) | – 0.017 (t=-2.24, NN, NS) |
| Sylhet | + 0.007 ( t= 1.82, Ap.N, S ) | + 0.013* (t= 4.72, Ap.N, S) | – 0.001 (t=-0.27, N, S) | + 0.005 (t= 0.64, NN, S) |
| Chittagong | + 0.010* (t=4.38, N, S) | + 0.010 (t=3.53, NN, Ap. S) | + 0.004 (t= 1.33, N, S) | + 0.014* (t=3.80, Ap.N, S) |

***CVs of annual and seasonal ADBT***

The rates obtained from LT for CV of annual and seasonal ADBT are shown in Table 4. The rates for CV of annual ADBT are found significant positive for Chittagong (+0.010*); approximately significant for Sylhet (+0.007) and fairly high positive for Dhaka (+0.0149) and Khulna (+ 0.003) with nonnormal and/or nonstationary residual, but fairly high negative for Rajshahi (– 0.011) and Barisal (– 0.009) with nonnormal and/or nonstationary residual. During Kharif season, the rates is fairly positive for Rajshahi (+ 0.013) and less positive for Barisal (+ 0.004) with normal and stationary residual but fairly negative.

**Table 4.** Rates obtained from L T for CVs of annual and seasonal ADBT and residual's stationarity and normality

| Station | Annual | Kharif | Prekharif | Rabi |
|---|---|---|---|---|
| Dhaka | – 0.0335* (t = -3.38, Ap.N, S) | – 0.003 (t = -0.53 , N, S) | – 0.017 (t = -0.82, Ap. N, S) | - 0.003 (t = -0.12, NN, S) |
| Rajshahi | + 0.0302 (t = 1.70, N, S) | + 0.013 (t = 1.10, N, S) | – 0.022 (t = -0.67, N, S) | + 0.073* (t = 3.04, N, S) |
| Khulna | + 0.00549 (t = 0.57, N, S) | – 0.012 (t = -1.01, NN, S) | – 0.017 (t = -1.00, N, S) | + 0.054* (t = 4.28, N, S) |
| Barisal | + 0.0255* (t = 2.80 ,N, S) | + 0.004 (t = 0.85, N, S) | + 0.001 (t = 0.08, N, S) | + 0.049 (t = 2.28, NN, S) |
| Sylhet | – 0.0349* (t = -2.89, N, S) | – 0.011 (t = -1.38 , N, S) | + 0.026 (t = 1.31, N, S) | – 0.058 (t = -1.16 NN, S) |
| Chittagong | – 0.0142 (t = -1.98 , N, S) | – 0.020 (t = -2.35, NN, S) | – 0.014 (t = -1.27, N, S) | + 0.027* (t = 2.16, N, S) |

The growth rates for CV of annual ADBT were negative for Dhaka, Sylhet and Chittagong but positive for Rajshahi, Khulna and Barisal. The growth rates for CV Seasonal Average ADBT were negative for all the three seasons for Dhaka but positive for all the three seasons for Barisal. The rates were positive during Kharif and Rabi seasons but negative for Prekharif season for Rajshahi while negative during Kharif and Rabi seasons and positive during Prekharif seasons for Sylhet. The rates were negative during Kharif and Prekharif season but positive for Rabi seasons for Khulna while positive during Kharif and Prekharif season but negative for Rabi seasons for Chittagong.

***Model fitting and forecasting***

As the next step, an attempt was made to fit univariate Box-Jenkin's ARIMA models to forecast the monthly ADBT for January 2009 to December 2012 for those six stations where ARIMA models were fitted for replacing the detected outliers in the models. ARIMA model derived equation for replacing outliers of monthly ADBT in Sylhet and Chittagong are presented in Table 5. The outliers and the corresponding forecasted values for 1997 in Sylhet are presented in Table 6. Estimated ARIMA model derived equations for six stations are presented in Table 7. The ACF displayed for residual autocorrelations for the estimated models were fairly small relative to their standard errors for all the variables. The histograms of the residuals were symmetrical suggesting that the shocks might be normally or approximately normally distributed. The normal probability plots of the residuals did not deviate badly from straight lines (is fairly close to a straight line), again suggesting that the shocks were normal. Point and interval forecasted values for the models of the ADBT are displayed in Table 8. The plots for point and interval forecasts and some residual plots are shown in Fig. 1.

The data 37.8 for November 1966 in Sylhet was detected as outlier and it was replaced by 22.81 from the fitted model ARIMA(200)(111)$_{12}$ for 1967-1997 (reversing the years) where 1969-1997 was taken as the training set and 1967-68 was taken as validation set.

The data 37.8 for February 1956 in Sylhet was detected as outlier and it was replaced by 19.94 from the fitted model ARIMA(200)(111) $_{12}$ for 1957-1997 where 1959-1997 was taken as the training set and 1957-1958 was taken as validation set.

The data for the twelve months for 1997 in Sylhet were detected as outliers and those were replaced by the following forecasted values from the fitted model ARIMA(111)(111) $_{12}$ for 1956-1996 where 1956-1995 was taken as the training set and 1995-1996 was taken as the validation set.

The data 34.7 for August 1949 was detected as outlier for Chittagong and it was replaced by 27.54 from the fitted model ARIMA(101)(111) $_{12}$ for 1948-2008 (reversing the years) where 1946-2008 was taken as the training set and 1947-48 was taken as validation set.

**Table 5.** ARIMA models for replacing outliers of monthly ADBT in Sylhet and Chittagong

| Variable | Model | Derived Equation of Model ARIMA | **MRMSFE** | MS |
|---|---|---|---|---|
| Sylhet 1967-1997 | ARIMA (200)(111) $_{12}$ | $(1 - 0.0821B)(1 - 0.0691B^2)(1 + 0.0527B^{12})\ \nabla_{12}\ y_t = -0.01149 + (1-0.9617B^{12})\ \varepsilon_t$ <br> se of coeff. (0.0462) (0.0463) (0.0492) (0.003078) (0.0258) | 0.610761 | 0.541 |
| Sylhet 1957-1997 | ARIMA (200)(111) $_{12}$ | $(1 - 0.1370B)(1 - 0.1141B^2)(1 - 0.0135B^{12})\ \nabla_{12}\ y_t = -0.004188 + (1-0.9552B^{12})\ \varepsilon_t$ <br> se of coeff. (0.0414) (0.0416)(0.0446)(0.002508) (0.0196) | 0.651 | 0.587 |
| Sylhet 1956-1996 | ARIMA (111)(111) $_{12}$ | $(1 - 0.1294B)(1 + 0.0011B^{12})\ \nabla\nabla_{12}\ y_t = 0.000109 + (1-0.922B)(1-0.9426B^{12})\ \varepsilon_t$ <br> se of coeff. (0.05) (0.0502) (0.000258) (0.0199) (0.0217) | 0.638 | 0.587 |
| Chittagong 1948-2008 | ARIMA (101)(111) $_{12}$ | $(1 - 0.7097B)(1 - 0.0168B^{12})\ \nabla_{12}\ y_t = -0.0030212 + (1 - 0.4756B)(1 - 0.9545B^{12})\ \varepsilon_t$ <br> se of coeff. (0.0766) (0.0404) (0.0008344) (0.0955)( 0.0151) | 0.741 | 0.393 |

SQ R T =square root transformed, RMSFE=root mean square forecasting error, SS=sum of square
DF= degrees of Freedom , MS=mean square error, se of coeff.=standard error of coefficient

**Table 6.** The outliers and the corresponding forecasted values for 1997 in Sylhet

| | Jan-97 | Feb-97 | Mar-97 | Apr-97 | May-97 | Jun-97 | Jul-97 | Aug-97 | Sep-97 | Oct-97 | Nov-97 | Dec-97 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DO | 26.2 | 19 | 24.5 | 24.4 | 26.9 | 26.8 | 27.9 | 28.5 | 26.5 | 25.9 | 23.4 | 19.2 |
| FV | 18.53 | 20.55 | 24.38 | 26.23 | 27.02 | 27.71 | 27.95 | 28.28 | 27.82 | 26.50 | 23.36 | 19.74 |

DO- Detected outlier FV- Forecasted values

**Table 7.** Results of ARIMA models for monthly ADBT in six stations

| Variable | Model | Derived Equation of Model ARIMA | **RMSFE** | MS |
|---|---|---|---|---|
| Dhaka | ARIMA $(101)(011)_{12}$ | $(1 - 0.4599B)\nabla_{12}\ y_t = 0.010087 + (1 - 0.2825\ B)(1 - 0.9599B^{12})\ \varepsilon_t$ se of coeff. (0.1703) (0.001241) (0.1838) (0.0135) | 0.743 | 0.550 |
| Rajshahi | ARIMA $(101)(011)_{12}$ | $(1 - 0.5298B)\nabla_{12}\ y_t = -0.00461 + (1 - 0.2082B)(1 - 0.9522B^{12})\ \varepsilon_t$ se of coeff. (0.1036) (0.002243) (0.1186) (0.0179) | 0.842 | 0.833 |
| Khulna | ARIMA $(111)(011)_{12}$ | $(1 - 0.3143B)\nabla\nabla_{12}\ y_t = 0.0000216 + (1 - 0.9597B)(1 - 0.9319B^{12})\ \varepsilon_t$ se of coeff. (0.0359) (0.000136) (0.0008) (0.0139) | 0.631 | 0.583 |
| Barisal | ARIMA $(200)(111)_{12}$ | $(1 - 0.3033B)(1 - 0.1745\ B^2)(1 - 0.1271\ B^{12})\nabla_{12}\ y_t = -0.00396 + (1 - 0.9665B^{12})\ \varepsilon_t$ se of coeff. (0.0374) (0.0372) (0.0391) (0.001418) (0.0138) | 0.673 | 0.531 |
| Sylhet | ARIMA $(101)(111)_{12}$ | $(1 - 0.7926\ B)(1 - 0.0023B^{12})\nabla_{12}\ y_t = 0.002384 + (1 - 0.6229B)(1 - 0.9612\ B^{12})\ \varepsilon_t$ se of coeff. (0.0744) (0.0429) (0.000677)( 0.0953)( 0.017) | 0.761 | 0.565 |
| Chittagong | ARIMA $(101)(011)_{12}$ | $(1 - 0.7179B)\nabla_{12}\ y_t = 0.00294 + (1 - 0.4954B)(1 - 0.9593B^{12})\ \varepsilon_t$ se of coeff. (0.0759) (0.000691) (0.0948) (0.014) | 0.752 | 0.394 |

SQ R T =Square root transformed, RMSFE=Root mean square forecasting error, SS=sum of square
DF= Degrees of Freedom , MS=Mean square error, se of coeff.=Standard error of coefficient

## Conclusions

The foregoing analyses indicate that the growth rates for annual ADBT were found significant positive for Chittagong (+0.010*); approximately significant for Sylhet (+0.007) and fairly high and positive for Dhaka (+0.0149) and Khulna (+ 0.003) with nonnormal and/or nonstationary residual, but fairly high but negative for Rajshahi (– 0.011) and Barisal (– 0.009) with nonnormal and/or nonstationary residual.

During Kharif season, the growth rates for ADBT were significantly positive for Dhaka (+ 0.018*) and Sylhet (+ 0.013*); fairly positive for Khulna (+ 0.011) and Chittagong (+ 0.010) with nonnormal and stationary residual and for Rajshahi (– 0.003) with normal and stationary residual but slightly negative for Barisal (– 0.001) with normal and stationary residual too.

During Prekharif season, the rates for ADBT were less positive for Dhaka (+ 0.004) with nonnormal and stationary residual and fairly positive for Chittagong (+ 0.004) with normal and stationary residual. But significant negative rates were for Rajshahi (– 0.026*) and Barisal (– 0.013*); and fairly high but negative for Khulna (– 0.006) with nonstationary residual and very low but negative for Sylhet (– 0.001).

During Rabi season, the rates for ADBT were significantly positive for Chittagong (+ 0.014*); fairly high and positive for Dhaka (+0.0183) and less positive for Khulna (+ 0.001) and Sylhet (+ 0.005) with nonnormal and/or nonstationary residual while fairly high but negative for Rajshahi (– 0.0182) and Barisal (– 0.017) with nonnormal and/or nonstationary residual.

The growth rates for CV of annual ADBT were negative for Dhaka, Sylhet and Chittagong but positive for Rajshahi, Khulna and Barisal. The growth rates for CV Seasonal Average ADBT were negative for all the three seasons for Dhaka but positive for all the three seasons for Barisal. The rates were positive during Kharif and Rabi seasons but negative for Prekharif season for Rajshahi while negative during Kharif and Rabi seasons and positive during Prekharif seasons for Sylhet. The rates were negative during Kharif and Prekharif season but positive for Rabi seasons for Khulna while positive during Kharif and Prekharif season but negative for Rabi seasons for Chittagong.
The models ARIMA$(1,0,1)(0,1,1)_{12}$, ARIMA$(1,0,1)(0,1,1)_{12}$, ARIMA$(1,1,1)(0,1,1)_{12}$, ARIMA$(2,0,0)(1,1,1)_{12}$, ARIMA$(1,0,1)(1,1,1)_{12}$ and ARIMA$(1,0,1)(0,1,1)_{12}$ were selected for monthly ADBT of Dhaka, Rajshahi, Khulna, Barisal, Sylhet and Chittagong where forecasting errors were minimum, and residuals showed both stationarity and normality.

The findings supported that the climate of Bangladesh is changing in terms of annual and seasonal ADBT and this may affect agricultural crop production. So, agricultural planners should set their policy taking the necessary steps with the changing pattern of ADBT.

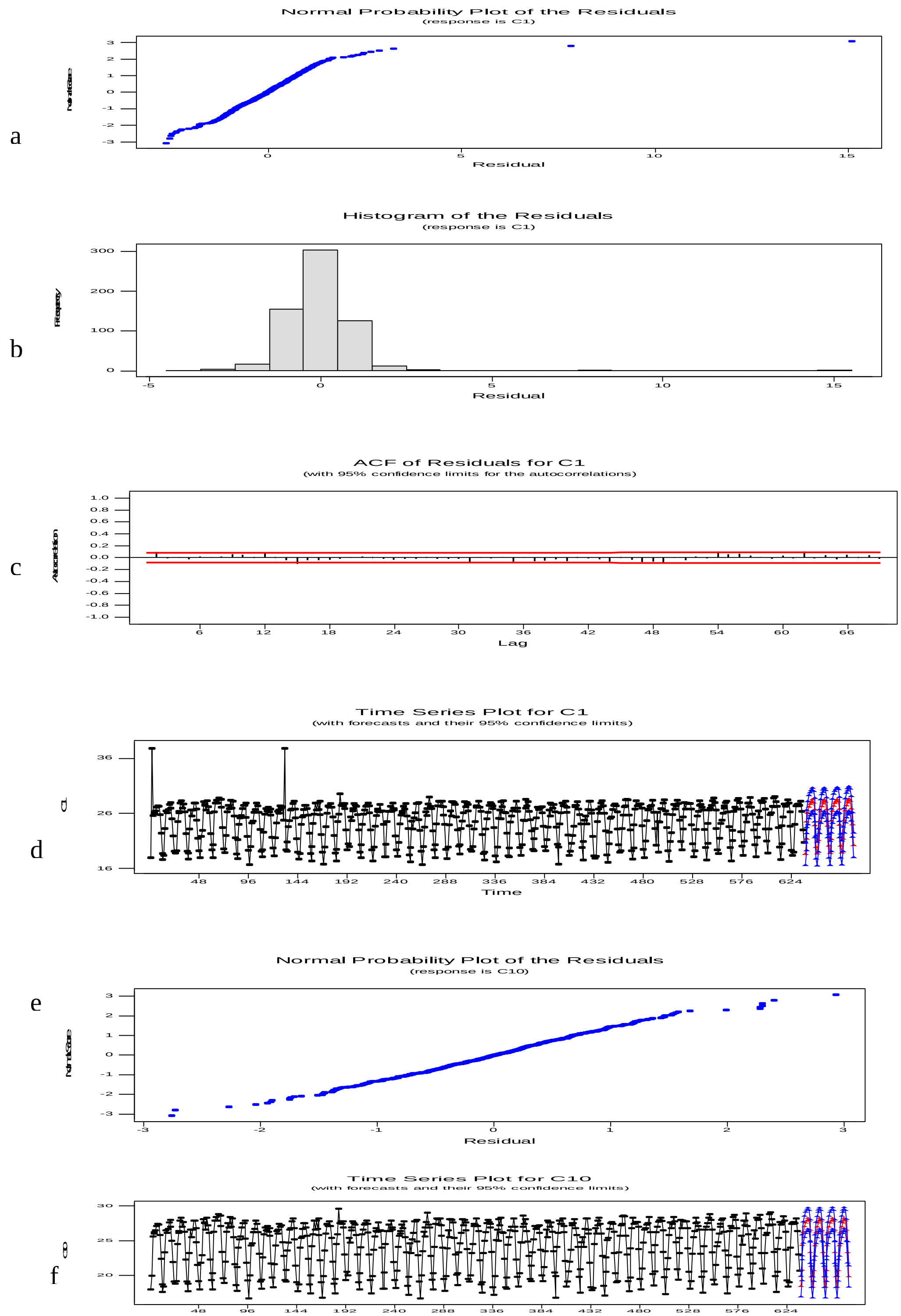


**Fig. 1.** Graph for original ADBT in Sylhet: (a) NP plot for residuals (b) Histogram for residuals (c) ACF display for residuals (d) TS plot of data with point and interval forecasts with outlier (Red line - Indication of point estimate and blue line - Indication of 95% confidence interval) (e) NP plot for residuals after replacing the outlier (f) TS plot of data with point and interval forecasts after replacing the outlier

**Table 8.** Point and interval forecasts of ADBT for 2009

| | Dhaka for 2009 | | | Rajshahi for 2009 | | | Khulna for 2009 | | | Barisal for 2009 | | | Sylhet for 2009 | | | Chittagong for 2009 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) |
| **January** | 18.8 | 17.3 | 20.2 | 16.9 | 15.1 | 18.7 | 18.7 | 17.2 | 20.2 | 18.2 | 16.8 | 19.6 | 18.4 | 17.0 | 19.9 | 19.8 | 18.6 | 21.0 |
| **February** | 22.1 | 20.6 | 23.6 | 20.1 | 18.2 | 22.0 | 22.1 | 20.6 | 23.7 | 21.3 | 19.8 | 22.8 | 20.8 | 19.3 | 22.3 | 22.4 | 21.2 | 23.7 |
| **March** | 26.5 | 25.0 | 28.0 | 25.0 | 23.1 | 27.0 | 26.6 | 25.0 | 28.2 | 25.9 | 24.4 | 27.4 | 24.4 | 22.9 | 25.9 | 25.9 | 24.6 | 27.2 |
| **April** | 28.7 | 27.2 | 30.2 | 28.8 | 26.9 | 30.8 | 29.2 | 27.6 | 30.9 | 28.3 | 26.7 | 29.8 | 26.2 | 24.7 | 27.7 | 28.1 | 26.8 | 29.4 |
| **May** | 29.1 | 27.6 | 30.6 | 29.2 | 27.3 | 31.1 | 29.9 | 28.3 | 31.5 | 29.0 | 27.4 | 30.5 | 27.0 | 25.5 | 28.6 | 28.9 | 27.6 | 30.2 |
| **June** | 29.1 | 27.6 | 30.6 | 29.0 | 27.1 | 30.9 | 29.4 | 27.8 | 31.0 | 28.4 | 26.8 | 29.9 | 27.6 | 26.1 | 29.1 | 28.4 | 27.1 | 29.7 |
| **July** | 28.9 | 27.4 | 30.4 | 28.5 | 26.6 | 30.4 | 28.8 | 27.2 | 30.5 | 27.9 | 26.4 | 29.5 | 27.9 | 26.4 | 29.4 | 28.0 | 26.7 | 29.3 |
| **August** | 29.1 | 27.6 | 30.6 | 28.7 | 26.8 | 30.6 | 29.0 | 27.4 | 30.6 | 28.1 | 26.5 | 29.7 | 28.2 | 26.7 | 29.8 | 28.1 | 26.8 | 29.4 |
| **September** | 28.8 | 27.3 | 30.3 | 28.2 | 26.3 | 30.1 | 28.7 | 27.1 | 30.4 | 28.0 | 26.5 | 29.6 | 27.9 | 26.3 | 29.4 | 28.3 | 27.0 | 29.6 |
| **October** | 27.6 | 26.1 | 29.1 | 26.5 | 24.6 | 28.5 | 27.7 | 26.1 | 29.3 | 27.0 | 25.4 | 28.6 | 26.5 | 25.0 | 28.0 | 27.8 | 26.5 | 29.0 |
| **November** | 24.1 | 22.6 | 25.6 | 22.5 | 20.6 | 24.4 | 24.2 | 22.6 | 25.8 | 23.4 | 21.9 | 25.0 | 23.3 | 21.8 | 24.8 | 24.8 | 23.5 | 26.1 |
| **December** | 20.2 | 18.7 | 21.7 | 18.2 | 16.3 | 20.1 | 20.0 | 18.3 | 21.6 | 19.4 | 17.8 | 20.9 | 19.8 | 18.3 | 21.4 | 21.2 | 19.9 | 22.5 |

PE-Point estimate IE (L)-Interval estimate(lower limit) IE (U)- Interval estimate(upper limit)

**Table 8.** continued

| | Dhaka for 2010 | | | Rajshahi for 2010 | | | Khulna for 2010 | | | Barisal for 2010 | | | Sylhet for 2010 | | | Chittagong for 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) |
| **January** | 18.8 | 17.3 | 20.3 | 16.6 | 14.7 | 18.5 | 18.5 | 16.8 | 20.1 | 18.0 | 16.4 | 19.6 | 18.3 | 16.8 | 19.9 | 19.9 | 18.6 | 21.2 |
| **February** | 22.1 | 20.6 | 23.6 | 19.9 | 18.0 | 21.9 | 22.1 | 20.5 | 23.7 | 21.3 | 19.7 | 22.9 | 20.7 | 19.2 | 22.3 | 22.5 | 21.2 | 23.8 |
| **March** | 26.5 | 25.0 | 28.0 | 25.0 | 23.0 | 26.9 | 26.6 | 24.9 | 28.2 | 25.8 | 24.2 | 27.3 | 24.3 | 22.8 | 25.8 | 26.0 | 24.7 | 27.3 |
| **April** | 28.7 | 27.3 | 30.2 | 28.8 | 26.9 | 30.7 | 29.2 | 27.6 | 30.9 | 28.2 | 26.6 | 29.8 | 26.2 | 24.6 | 27.7 | 28.2 | 26.9 | 29.5 |
| **May** | 29.1 | 27.6 | 30.6 | 29.2 | 27.3 | 31.1 | 29.9 | 28.3 | 31.6 | 28.9 | 27.3 | 30.4 | 27.0 | 25.5 | 28.5 | 28.9 | 27.6 | 30.2 |
| **June** | 29.1 | 27.6 | 30.6 | 29.0 | 27.1 | 30.9 | 29.4 | 27.8 | 31.1 | 28.4 | 26.8 | 30.0 | 27.6 | 26.0 | 29.1 | 28.4 | 27.2 | 29.7 |
| **July** | 28.9 | 27.4 | 30.4 | 28.5 | 26.5 | 30.4 | 28.9 | 27.2 | 30.5 | 27.9 | 26.4 | 29.5 | 27.9 | 26.4 | 29.4 | 28.0 | 26.8 | 29.3 |
| **August** | 29.1 | 27.7 | 30.6 | 28.7 | 26.8 | 30.6 | 29.0 | 27.3 | 30.7 | 28.0 | 26.5 | 29.6 | 28.2 | 26.7 | 29.8 | 28.1 | 26.9 | 29.4 |
| **September** | 28.8 | 27.3 | 30.3 | 28.2 | 26.3 | 30.1 | 28.8 | 27.1 | 30.4 | 28.0 | 26.4 | 29.6 | 27.8 | 26.3 | 29.4 | 28.3 | 27.0 | 29.6 |
| **October** | 27.6 | 26.1 | 29.1 | 26.5 | 24.6 | 28.5 | 27.7 | 26.1 | 29.4 | 27.0 | 25.4 | 28.6 | 26.5 | 25.0 | 28.0 | 27.8 | 26.5 | 29.1 |
| **November** | 24.1 | 22.6 | 25.6 | 22.5 | 20.6 | 24.4 | 24.2 | 22.6 | 25.9 | 23.4 | 21.9 | 25.0 | 23.3 | 21.8 | 24.8 | 24.8 | 23.5 | 26.1 |
| **December** | 20.2 | 18.7 | 21.7 | 18.2 | 16.3 | 20.1 | 20.0 | 18.3 | 21.6 | 19.3 | 17.7 | 20.9 | 19.8 | 18.3 | 21.4 | 21.2 | 19.9 | 22.5 |

PE-Point estimate IE (L)-Interval estimate (lower limit) IE (U)- Interval estimate(upper limit)

**Table 8.** continued

| Period | Dhaka **for 2011** | | | Rajshahi **for 2011** | | | Khulna **for 2011** | | | Barisal **for 2011** | | | Sylhet **for 2011** | | | Chittagong **for 2011** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) |
| January | 18.8 | 17.3 | 20.3 | 16.6 | 14.6 | 18.5 | 18.5 | 16.8 | 20.2 | 18.0 | 16.4 | 19.6 | 18.3 | 16.8 | 19.9 | 19.9 | 18.6 | 21.2 |
| February | 22.1 | 20.7 | 23.6 | 19.9 | 18.0 | 21.9 | 22.1 | 20.4 | 23.8 | 21.3 | 19.7 | 22.9 | 20.7 | 19.2 | 22.3 | 22.5 | 21.2 | 23.8 |
| March | 26.5 | 25.0 | 28.0 | 24.9 | 23.0 | 26.9 | 26.6 | 24.9 | 28.3 | 25.7 | 24.1 | 27.3 | 24.3 | 22.8 | 25.9 | 26.0 | 24.7 | 27.3 |
| April | 28.8 | 27.3 | 30.2 | 28.8 | 26.9 | 30.7 | 29.3 | 27.6 | 31.0 | 28.2 | 26.6 | 29.7 | 26.2 | 24.6 | 27.7 | 28.2 | 26.9 | 29.5 |
| May | 29.1 | 27.7 | 30.6 | 29.2 | 27.2 | 31.1 | 29.9 | 28.2 | 31.6 | 28.8 | 27.3 | 30.4 | 27.0 | 25.5 | 28.5 | 28.9 | 27.6 | 30.2 |
| June | 29.1 | 27.6 | 30.6 | 29.0 | 27.1 | 30.9 | 29.4 | 27.7 | 31.1 | 28.4 | 26.8 | 30.0 | 27.6 | 26.1 | 29.1 | 28.5 | 27.2 | 29.7 |
| July | 28.9 | 27.5 | 30.4 | 28.4 | 26.5 | 30.4 | 28.9 | 27.2 | 30.6 | 27.9 | 26.3 | 29.5 | 27.9 | 26.4 | 29.4 | 28.1 | 26.8 | 29.3 |
| August | 29.2 | 27.7 | 30.6 | 28.7 | 26.7 | 30.6 | 29.0 | 27.3 | 30.7 | 28.0 | 26.5 | 29.6 | 28.2 | 26.7 | 29.8 | 28.2 | 26.9 | 29.5 |
| September | 28.8 | 27.4 | 30.3 | 28.2 | 26.3 | 30.1 | 28.8 | 27.1 | 30.5 | 28.0 | 26.4 | 29.6 | 27.9 | 26.3 | 29.4 | 28.4 | 27.1 | 29.6 |
| October | 27.6 | 26.1 | 29.1 | 26.5 | 24.6 | 28.4 | 27.7 | 26.0 | 29.5 | 27.0 | 25.4 | 28.6 | 26.5 | 25.0 | 28.1 | 27.8 | 26.5 | 29.1 |
| November | 24.1 | 22.7 | 25.6 | 22.5 | 20.6 | 24.4 | 24.2 | 22.5 | 26.0 | 23.4 | 21.8 | 25.0 | 23.3 | 21.8 | 24.9 | 24.8 | 23.5 | 26.1 |
| December | 20.2 | 18.7 | 21.7 | 18.2 | 16.3 | 20.1 | 20.0 | 18.3 | 21.7 | 19.3 | 17.7 | 20.8 | 19.8 | 18.3 | 21.4 | 21.3 | 20.0 | 22.5 |

PE-Point estimate IE (L)-Interval estimate(lower limit) IE (U)- Interval estimate(upper limit)

**Table 8.** continued

| Period | Dhaka**2012** | | | Rajshahi **2012** | | | Khulna **2012** | | | Barisal**2012** | | | Sylhet**2012** | | | Chittagong**2012** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) | PE | IE (L) | IE (U) |
| January | 18.8 | 17.3 | 20.3 | 16.5 | 14.6 | 18.5 | 18.5 | 16.8 | 20.2 | 18.0 | 16.4 | 19.6 | 18.4 | 16.8 | 19.9 | 19.9 | 18.6 | 21.2 |
| February | 22.2 | 20.7 | 23.6 | 19.9 | 18.0 | 21.8 | 22.1 | 20.4 | 23.9 | 21.3 | 19.7 | 22.9 | 20.7 | 19.2 | 22.3 | 22.5 | 21.2 | 23.8 |
| March | 26.5 | 25.0 | 28.0 | 24.9 | 23.0 | 26.9 | 26.6 | 24.8 | 28.3 | 25.7 | 24.1 | 27.3 | 24.3 | 22.8 | 25.9 | 26.0 | 24.7 | 27.3 |
| April | 28.8 | 27.3 | 30.3 | 28.8 | 26.8 | 30.7 | 29.3 | 27.5 | 31.0 | 28.2 | 26.6 | 29.7 | 26.2 | 24.6 | 27.7 | 28.2 | 26.9 | 29.5 |
| May | 29.2 | 27.7 | 30.6 | 29.2 | 27.2 | 31.1 | 30.0 | 28.2 | 31.7 | 28.8 | 27.2 | 30.4 | 27.0 | 25.5 | 28.6 | 28.9 | 27.7 | 30.2 |
| June | 29.1 | 27.7 | 30.6 | 29.0 | 27.1 | 30.9 | 29.4 | 27.7 | 31.2 | 28.4 | 26.8 | 30.0 | 27.6 | 26.1 | 29.1 | 28.5 | 27.2 | 29.8 |
| July | 29.0 | 27.5 | 30.4 | 28.4 | 26.5 | 30.4 | 28.9 | 27.1 | 30.6 | 27.9 | 26.3 | 29.5 | 27.9 | 26.4 | 29.4 | 28.1 | 26.8 | 29.4 |
| August | 29.2 | 27.7 | 30.7 | 28.6 | 26.7 | 30.6 | 29.0 | 27.3 | 30.8 | 28.0 | 26.4 | 29.6 | 28.3 | 26.7 | 29.8 | 28.2 | 26.9 | 29.5 |
| September | 28.9 | 27.4 | 30.4 | 28.2 | 26.3 | 30.1 | 28.8 | 27.0 | 30.6 | 28.0 | 26.4 | 29.6 | 27.9 | 26.3 | 29.4 | 28.4 | 27.1 | 29.7 |
| October | 27.6 | 26.1 | 29.1 | 26.5 | 24.6 | 28.4 | 27.8 | 26.0 | 29.5 | 27.0 | 25.4 | 28.6 | 26.5 | 25.0 | 28.1 | 27.8 | 26.5 | 29.1 |
| November | 24.2 | 22.7 | 25.7 | 22.5 | 20.5 | 24.4 | 24.3 | 22.5 | 26.0 | 23.4 | 21.8 | 25.0 | 23.3 | 21.8 | 24.9 | 24.8 | 23.5 | 26.1 |
| December | 20.2 | 18.8 | 21.7 | 18.2 | 16.3 | 20.1 | 20.0 | 18.2 | 21.8 | 19.3 | 17.7 | 20.8 | 19.9 | 18.3 | 21.4 | 21.3 | 20.0 | 22.6 |

PE-Point estimate IE (L)-Interval estimate(lower limit) IE (U)- Interval estimate(upper limit)

## References

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**Appendix 1: Standardized ARIMA Notations**

The ARIMA models have a general form of p, d, q where p is the order of the standard autoregressive term AR, q is the order of the standard moving average term MA, and d is the order of differencing AR describes how a variable $y_t$ such as temperature depends on some previous values $y_{t-1}$, $y_{t-2}$ etc. while MA describes how this variable $y_t$ depends on a weighted moving average of the available data $y_{t-1}$ to $y_{t-n}$. For example, for a one step ahead forecast (suppose: for t being September) with an AR-1, all weight is given to the temperature in the previous month (September), while with an AR-2 the weight is given to the temperature of the two immediately previous months (September and August). By contrast, with a MA-1, MA-2, a certain weight is given to the temperature of the immediately previous month (September), a smaller weight is given to the temperature observed two months ago (August) and so forth, i.e., the weights decline exponentially.

The combined multiplicative seasonal ARIMA (p, d, q) $\times$ 12 (P, D, Q) model gives the following:

$$\phi_p(B)\Phi_p(B^s)\nabla_s^D\nabla^d z_t = C + \theta_q(B)\Theta_Q(B^s)\varepsilon_t$$

The standard expression of ARIMA model where B denotes the backward shift operator where

- $\phi_p(B) = 1 - \phi_1 B - \phi_2 B^2 - ... - \phi_p B^p$

The standard autoregressive operator of order p

- $\Phi_p(B^s) = 1 - \Phi_1 B - \Phi_2 B^2 - ... - \Phi_p B^{ps}$

The seasonal autoregressive operator of order p

- $\nabla_s^D$ is the seasonal differencing operator of order D
- $\nabla^d$ is the differencing operator of order d
- $y_t$ is the value of the variable of interest at time t
- $C = \mu\phi_p(B)\Phi_p(B^s)$ is a constant term, where μ is the true mean of the stationary time series being modeled. It was estimated from sample data using the approximate likelihood estimator approach.
- $\theta_q(B) = 1 - \theta_1 B - \theta_2 B^2 - ... - \theta_q B^q$

The standard moving average operator of order q

- $\Theta_Q(B^s) = 1 - \Theta_1 B^1 - \Theta_2 B^2 - ... - \Theta_Q B^{QS}$

The seasonal moving average operator of order Q

- $\phi_1, \phi_2, ......, \phi_p$ ; $\Phi_1, \Phi_2, ..., \Phi_p$ ; $\theta_1, \theta_2, ..., \theta_q$ ; $\Theta_1\ \Theta_2, ..., \Theta_Q$ are unknown coefficients that are estimated from sample data using the approximate likelihood estimator approach.
- $\varepsilon_t$ is the error term at time at time t
- S is the annual period, i,e. 12 months

Thus, the multiplicative seasonal modeling approach with the general form of ARIMA (p, d, q) $\times$ S (P, D, Q) has been used in this paper. In this form, p is the order of the seasonal autoregressive term (ARS), Q is the order of the seasonal moving average term, D is the order of the seasonal differencing and s is the annual cycle (e.g, s = 12 using the monthly data). ARS describes how the variable y depends on $y_{t-12}$ (ARS-1), $y_{t-24}$ (ARS-2), etc., while MAS describes how y depends on a weighted moving average of the available data $y_{t-12}$ to $y_{t-12n}$. For example, for a one step ahead forecast (suppose: for t being September and with an ARS-1, all weight is given to the temperature in the previous September while with an ARS-2, the weight is given to the September temperature 1 and 2 years ago. By contrast, with a MAS-1, MAS-2, the model gives a certain weight to September temperature 1 year ago, to the September temperature 2 years ago, and so on. These weights decline exponentially.