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Modeling of Climate Change Prediction and its Impact on the Tea Production in Sylhet District, Bangladesh

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Abstract

Climate change, one of the most pressing issues, poses the greatest threat to human existence on our planet ever understanding the underlying structure, function and forecasting the future behavior has become considerable apparatus in numerous applications like metrological phenomena and production pattern of any observations. This study was conducted to model and forecast micro climatic variables in Sylhet district. The weather data for humidity, maximum temperature, minimum temperature, light duration, wind speed and monthly rainfall for the period 2005 to 2017 in Moulvibazar and Sylhet was collected for this study. Using Box-Jekins methodology, seasonal ARIMA model has been applied and models have also been verified. The best models were selected mainly based on AIC criterion. The best fitted SARIMA models for in Moulvibazar for humidity, maximum temperature, minimum temperature, light duration, wind speed and rainfall are ARIMA(1,0,1)(2,1,0)[12], ARIMA(1,0,0) (2,0,0)[12], ARIMA(2,0,1)(2,1,0)[12], ARIMA(1,1,1)(1,0,0)[12], ARIMA(4,0,1)(2,1,0)[12] and ARIMA(2,0,3)(1,1,2)[12] and in Sylhet ARIMA(0,0,1)(1,1,0)[12], ARIMA(0,0,0)(2,0,0)[12], ARIMA(0,0,0)(2,0,0)[12], ARIMA(0,1,2)(2,0,0)[12], ARIMA(3,0,1)(1,0,0)[12] and ARIMA(1,0,0)(2,1,1)[12], respectively. This model can help to predict the climatic condition earlier, which could enhance the estimation of tea production in the next preceding years.

Keywords: AIC criterion, ADF, ARIMA, KPSS and SARIMA.

Introduction

In Bangladesh, tea stands as a crucial crop significantly bolstering both the national economy and public health. Following jute, tea ranks as the country's second-largest cash crop, contributing approximately 1% to the national GDP (BBS, 2023). With substantial economic significance, tea cultivation is on the rise, with the current number of tea gardens standing at 172, spanning 279 thousand acres, covering nearly 0.91% of the nation's arable land (BTB, 2022). By December 2021, tea production had reached almost 96.51 million kilograms, surpassing the 74.14 million kg production target. Bangladesh garnered 14999 million taka from exporting 680000 kg of tea globally. While the exact domestic consumption for 2021 remains undisclosed, tea consumption in 2019 stood at 95200000 kg, reflecting an average annual increase of 4.61% (BTB, 2022). Hence, enhancing this sector holds paramount importance in earning foreign exchange and catering to domestic demand.

Tea manufacturing in Bangladesh benefits greatly from the country's warm, humid environment. In addition, tea plants develop more quickly with increased or decreased annual rainfall (Chy et al., 2022; Islam et al., 2021). Therefore, steep places are the best location for tea cultivation. As a result, Sylhet, Moulvibazar, Habiganj, and Chittagong in Bangladesh, which are the country's four primary mountainous regions, produce the most tea (Anonymous, 2022). Bangladesh's average annual rainfall is 203 cm, and its average annual temperature is 26.01 degrees Celsius, all of which are favorable for growing tea (Farukh et al., 2020; Islam et al., 2021). Bangladesh's environment and climate are conducive to the growth of the tea business, which is why the country's tea production is rising (Mila et al., 2022; Rahman, 2022). However, global warming is a significant challenge for Bangladesh's tea industry. The amount of tea leaves produced, and the quality of the tea are both decreased by contaminated weather and extreme heat (Ali et al., 2014; Islam et al., 2021). Interestingly, Bangladesh receives exceptional rainfall from April to October each year, ensuring the yield and quality of tea leaves (Ali et al., 2014; Rahman, 2022;

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Tabassum et al, 2023). Nonetheless, recent strong rains, hailstorms, thunderstorms, sporadic droughts, and increasing air humidity in Bangladesh because of the effects of global warming result in low tea yields (Anonymous, 2022; Haque et al., 2017). The growth of the tea business in Bangladesh is further hampered by the time of year when there is no rain, extreme heat, and dust, which restrict plant yield (Islam et al., 2021). Thus, to reduce the effect of global warming, research on climatic seasonal variation on tea would be one of the best solutions to minimize yield losses.

The country's leading tea-producing region is Sylhet, a divisional city in the northeast of Bangladesh. Geographically, Sylhet region is the best place for tea production due to the favorable environment of its growth and development. The pH of the soil in Sylhet is 4.80, making it slightly acidic by nature (Paul et al., 2021; Rahman et al., 2015). According to previous reports on various crops, acidic soil typically reduces production losses by up to 30% in Sylhet region (Hossain et al., 2017; Momin et al., 2023; Monshi et al., 2015; Sarker et al., 2022a;), however, its acidic nature of soil is one of the best encouraging factors for quality tea production (Chy et al., 2022). A better understanding of crop adaptation and management would result from the screening of genotypes for low pH tolerance (Malek et al., 2012; Sajid et al., 2022; Sarker et al., 2022b; Sumi et al., 2022), a vigorous tea genotypes can boost up its production upto the marks. Meanwhile, research has been done on the growing performance of several crop plants (Roy et al., 2016; Sarkar et al., 2021; Tabassum et al., 2015; Upoma et al., 2024), but research on existing tea genotypes for the selection of environmentally suitable genotypes would be the best option for its improvement. Thus, to understand the physiological underpinnings of yield variance of different crop genotypes (Bhuiyan et al., 2021; Islam et al., 2022; Yesmin et al., 2022), it is critical for measuring the growth factors and other pertinent climatic variables that are important for crop development.

Microclimatic factors, particularly rainfall, play a significant role in tea production. Extreme weather and climatic phenomena have been occurring in Bangladesh for many years (Atikunnaher et al., 2017; Hossain et al., 2009; Malek et al., 2010). To measure and forecast such climatic data, a statistical analysis model called ARIMA (Autoregressive Integrated Moving Average) uses time series data to either forecast future trends or provide a better understanding of the current data set (Kotu and Deshpande, 2019). Basically, it is the most useful statistical model which can forecast future values using data from the past (Kibria et al., 2022). In the meantime, many researchers have been successfully conducted climatic data and forecasting using ARIMA model to analyses monthly rainfall in tea (Nury et al., 2014), forecast the production of sugarcane, tea, and garlic (Hossain and Abdulla, 2015; Islam et al., 2020; Mila et al., 2019; Rahman, 2017), monthly temperature in tea (Nury et al., 2011) etc. in Bangladesh. There has also been conducted plenty of research on climate change using this ARIMA model in global or country scale (Deka et al., 2021; Mehmood et al., 2023; Niranjan et al., 2022). However, it is necessary to examine the changes of climate in small scale in Sylhet division in Bangladesh. The present study was conducted to build a SARIMA model for the detection of climatic variables in Sylhet division and to make a short-term prediction for these climatic variables.

Materials and Methods

Study Area

There are 172 tea estates in Bangladesh, in which 143 are in the Sylhet region, and the headquarter of the Bangladesh Tea Research Institute (BTRI) in this region gives more attention to tea production. In general, the choice of study region relies on the study's objectives; in this case, we selected Sylhet and Moulvibazar districts as the mother of tea production area. Geographically, Sylhet is the North-Eastern part of Bangladesh comprises 12,298.40 sq km land area, located between 23°58' and 25°12' North latitudes and 90°56' and 92°30' East longitudes. Moreover, tea production data of the studied area of a total of 102 tea estates under Moulvibazar and Sylhet districts (Figure 1) were considered. The climatic information as well as cultivation reports of the studied areas were used based on data availability for the period of 2005 to 2017 and later, we predicted the forecasting climatic condition and production of tea using ARIMA model for the year 2023 to 2028.

Methods of Data Collection

The present study was conducted based on the secondary data collected from the different tea estates in the study area. The relevant climatic data like light duration, wind speed, rainfall, maximum and minimum temperature were collected from two weather stations Srimangal and Sylhet under the Bangladesh Metrological Department (BMD). Tea production data also collected from Bangladesh Tea Board, Bangladesh Tea Research Institute and from different report of Bangladesh Tea Board. This analysis was completely done by statistical programming based open-source Software named as R with the version R×64 3.6.1.

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ARIMA Models

ARIMA (p, d, q) is the acronym for an auto-regressive integrated moving average model. The three terms to be estimated in the model are auto-regressive (p), integrated (trend d), and moving average (q). A stationary time series (Y_t) is said to follow an autoregressive moving average model of orders p and q, denoted by ARMA (p, q) if it satisfies the difference equation:

$$Y_t = \phi_1 Y_{t-1} + .. + \phi_p Y_{p-p} - \theta_1 \varepsilon_{t-1} - \cdots - \theta_q \varepsilon_{t-q} + \varepsilon_t$$

Where ε_t is white noise process.

Equation can be written as $\phi(L)Y_t = \theta(L)\varepsilon_t$. Where $\phi(L)$ and $\theta(L)$are AR and MR polynomial of orders p and q defined as

$$\phi(L) = 1 - \alpha_1 L - \alpha_2 L^2 - \ldots - \alpha_p L^p$$
$$\theta(L) = 1 + \beta_1 L + \beta_2 L^2 + \ldots + \beta_q L^q$$

Here, L is the backshift operator defined by $L^k Y_t = Y_{t-k}$ For stationary, the zeros of $\phi(L)$= 0 must lie outside the unit circle. Similarly, for invertibility, the zeros of $\theta(L)$ = 0 must lie outside the unit circle. If the time series (Xt) is non-stationary as is often the case, Box and Jenkins (1976) made a proposal that differing to an appropriate degree could make the series to be stationary. If the minimum degree to which the series is differenced to attain stationary is d then if the differenced series denoted by ($\nabla^d Y_t$) satisfies (1), the original series is said to follow an autoregressive integrated moving average model or orders p, d and q and designated ARIMA (p, d, q). Here the difference operator ∇= 1 – L. If the series Y_t Y_t has seasonal period s then it could be written as SARIMA(p,d,q)(P,D,Q)s

$$\varphi_{AR}(L)\ \varphi_{SAR}(L^s)\ \nabla^d\ \nabla^D{}_s Y_t = \theta_{MA}(L)\ \theta_{SMA}(L^s)\ \varepsilon_t$$

Where s = number of periods per season, φ_{AR}= non-serasonal autoregressive parameter, θ_{MA} = non-seasonal moving average parameter, φ_{SAR}= serasonal autoregressive parameter, θ_{SMA} = seasonal moving average parameter. The operator ∇_s is the seasonal difference operator defined by $\nabla_s = 1 - L^s$ and D is the seasonal difference order. Verification of the model has also been done using Akaike information criterion (AIC), The Bayesian Information Criterion (BIC), The Augmented Dickey Fuller Test (ADF), Kwiatkowski–Phillips–Schmidt–Shin (KPSS) is unit root test for stationary has also be done to check the of the data set. Ljung Box test (sometimes called the modified Box-Pierce, or just the Box test) is a way to test for the absence of serial autocorrelation.

Results and Discussion

Seasonal Variation of Climatic Variables

To see the variation of climatic variables, the maximum, minimum and average values along with ADF, KPSS test for all the six variables in both Moulvibazar and Sylhet district are given in Table 1. The maximum relative humidity was recorded in Sylhet as 89.30% and minimum amount was also in Sylhet 59.60%. Average relative humidity in Moulvibazar was 80.95% and in Sylhet was 77.88%. From the two areas, it was found that maximum values of humidity (89.30%), minimum temperature (26.30°C), sunshine (6.7hours), wind speed ($9.60 m.s^{-1}$) and rainfall (1288mm) were recorded in Sylhet. The highest temperature was observed in Moulvibazar (35.10°C). The lowest value of maximum temperature (23.70°C) and minimum temperature (7.50°C) were also recorded in Moulvibazar. And the lowest value of humidity (59.60%), sunshine (0.6 hours) and wind ($2.20 m.s^{-1}$) was observed in Sylhet. In both areas, the average maximum temperature was approximately the same. But in Moulvibazar, average humidity (80.95%), maximum temperature (30.91°C), sunshine (3.3hours) and wind speed ($5.5 m.s^{-1}$) was comparatively better than Sylhet. Benti et al. (2022) stated that maximum temperatures above 23.03°C and below 26.35°C, tea clones produced more fruit and required fewer plucking rounds, but temperatures above 28.34°C and below 10.38°C were detrimental to leaf quality and fruit production.

This study was performed mainly to build up model for climate change and to see the impact of climate on tea production for the two mother of tea producing areas like Moulvibazar and Sylhet using time series analysis for 13 years (2005-2017) data set of climatic variables and tea production for these two areas. The time series plot of all the six climatic variables (relative humidity, maximum temperature, minimum temperature, light duration, wind speed and rainfall) were shown in Figure 2. Using seasonal ARIMA model (SARIMA), the best fitted model for all the six variables were given in Table 2. The result of SARIMA model shows the changing patterns of climatic variables were not same for the two regions. From the Moulvibazar and Sylhet districts, it is seen that the highest amount of relative humidity was recorded in Sylhet (89.30%) and the lowest amount of humidity was in Moulvibazar (63.30%). The best fitted model for relative humidity in Moulvibazar ARIMA (1,0,1)(2,1,0)[12] and in Sylhet was ARIMA(0,0,0)(2,0,0)[12] with AIC (689.2 and 816.4). Tea production is mostly influenced by relative humidity along with appropriate management of fertilizers (Ali et al., 2014.; Dhekale et al., 2014; Siamba et al., 2023).

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Table 1. ADF, KPSS test, maximum, minimum, and average values for relative humidity, maximum temperature, minimum temperature, light duration, wind speed and rainfall in Moulvibazar and Sylhet district

Climatic Variables	Maximum value		Minimum value		Average value		ADF test				KPSS test			
							Test statistics		p-value		Test statistics		p-value	
	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet
Humidity	88.20%	89.30%	63.20%	59.60%	80.95%	77.88%	-8.3583	-10.241	0.01	0.01	0.2070	0.0711	0.1	0.1
Maximum temp	35.10ºC	35.00ºC	23.70ºC	24.10 ºC	30.91ºC	30.81ºC	-8.5608	-8.365	0.01	0.01	0.0467	0.0544	0.1	0.1
Minimum temp.	25.80ºC	26.30ºC	7.50ºC	11.60ºC	19.67ºC	21.06ºC	-11.38	-11.242	0.01	0.01	0.0147	0.0134	0.1	0.1
Sunshine hrs.	5.3hrs	6.7hrs	2.0hrs	0.6hrs	3.3hrs	2.9hrs	-8.5999	-5.6483	0.01	0.01	0.0288	0.8985	0.1	0.1
Wind speed	9.0m.s^{-1}	9.6m.s^{-1}	2.8m.s^{-1}	2.2m.s^{-1}	5.9m.s^{-1}	5.76m.s^{-1}	-6.5995	-8.791	0.01	0.01	0.1543	0.0520	0.1	0.1
Rainfall	925mm	1288mm	0mm	0mm	198mm	343mm	-11.092	-12.263	0.01	0.01	0.1120	0.0684	0.1	0.1

Table 2. Diagnostics of the best fitted models in Moulvibazar and Sylhet district

	Humidity		Maximum temperature		Minimum temperature		Light duration		Wind speed		Rainfall	
	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet	Moulv.	Sylhet
Model	ARIMA(1,0,1) (2,1,0)[12]	ARIMA(0,0,1) (1,1,0)[12]	ARIMA(1,0,0) (2,0,0)[12]	ARIMA(0,0,0) (2,0,0)[12].	ARIMA(2,0,1) (2,1,0)[12]	ARIMA(0,0,0) (2,0,0)[12]	ARIMA(1,1,1) (1,0,0)[12]	ARIMA(0,1,2) (2,0,0)[12]	ARIMA(4,0,1) (2,1,0)[12]	ARIMA(3,0,1) (1,0,0)[12]	ARIMA(2,0,3) (1,1,2)[12]	ARIMA(0,0,2) (2,1,1)[12]
∂^2	6.419	13.32	1.064	1.459	1.109	0.658	0.228	0.5631	1.048	1.756	14524	29168
Log-likelihood	-339.60	-393.24	-211.08	-234.74	-212.69	-176.40	-104.89	-177.14	-208.41	-263.20	-883.29	-953.28
AIC	689.20	792.47	430.16	477.48	437.37	358.81	217.78	364.29	432.82	540.40	1784.57	1920.57
AICc	689.64	792.64	430.45	477.77	437.99	358.98	218.04	364.69	433.89	541.16	1785.96	1921.39
BIC	704.05	801.38	442.04	489.36	455.19	367.72	229.95	379.51	456.58	561.75	1811.05	1941.35
ME	0.3030346	0.2569115	0.03282773	0.034637	0.0390	0.0252186	-0.002176	-0.1019181	-0.0248	-0.00654	13.5725	-8.474554
RMSE	2.400154	3.624173	1.020543	1.195438	0.9942	0.8055237	0.4713027	0.7382899	0.9595	1.299252	112.308	160.6313
MAE	1.72145	2.722618	0.8006767	0.9561913	0.6596	0.5936928	0.3551699	0.6596138	0.7158	1.033442	79.1381	107.9461
MPE	0.3009631	2.733178	-0.09852216	NA	-0.1779	NA	-1.779808	-11.88372	-4.4940	-6.86482	NA	NA
MAPE	2.193184	77.71369	2.409778	NA	0.7455	NA	10.69506	23.62704	13.5600	20.97434	NA	NA
MASE	0.7516336	0.513419	0.4893024	0.4739664	0.3640	0.460714	0.6967911	0.9487859	0.66160	0.795380	0.48892	0.6816752
ACF1	-0.0144778	0.0838818	-0.00046237	-0.009961	0.0058	0.0715420	0.02954813	-0.0316990	-0.0055	-0.0131324	0.01181	-0.00825723

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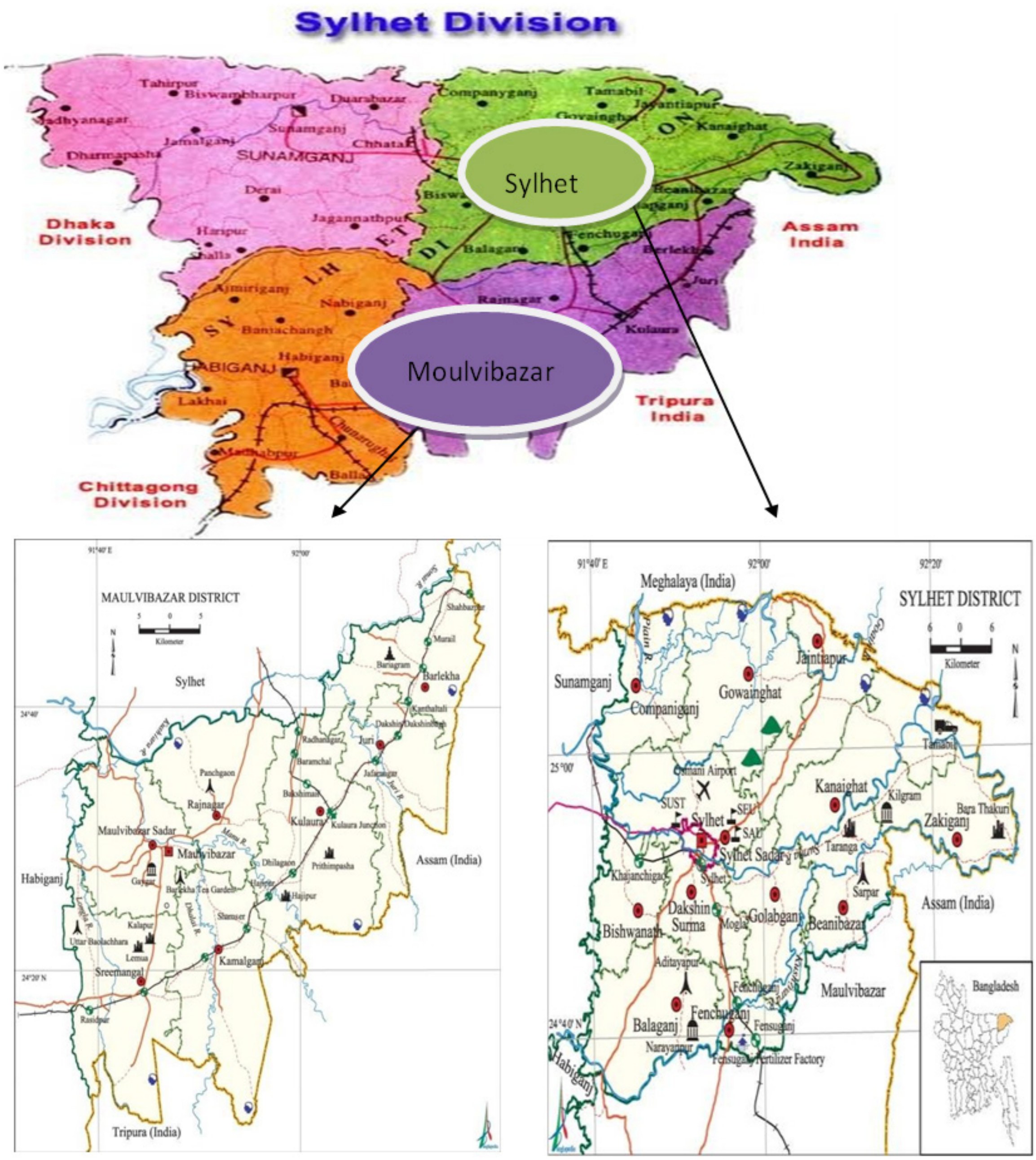

Figure 1. Map of Sylhet, Sylhet and Moulvibazar District

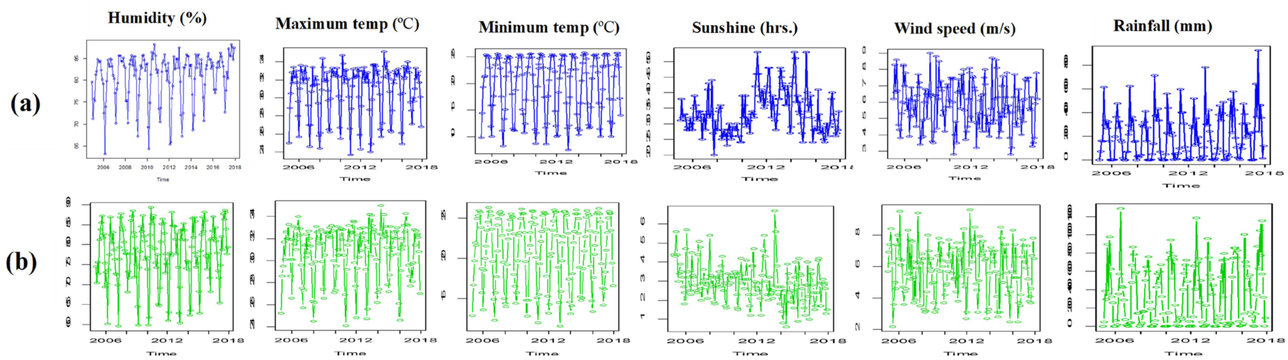

Figure 2. Plots of original series of humidity, maximum, minimum temperature, light duration, wind speed and rainfall in Moulvibazar (blue color), and Sylhet district (green color).

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In this study, the highest amount of maximum temperature was 35.10°C and it was same for the two stations. The average maximum temperature for the two areas is approximately the same. That means the maximum temperature for the two regions slightly differs from each other. The lowest amount of maximum temperature was in Moulvibazar district 23.70°C. The best fitted model for maximum temperature in Moulvibazar was ARIMA (1,0,0)(2,0,0)[12] and in Sylhet was ARIMA(1,0,0)(2,0,0)[12] with AIC (430.16 and 477.48). Similarly for minimum temperature, the highest amount was recorded in Sylhet 26.30°C and the lowest degree of minimum temperature was comparatively very low in Srimangal at 7.50°C. The best selected model for minimum temperature in Moulvibazar and Sylhet station was ARIMA (2,0,1)(2,1,0)[12] and in Sylhet ARIMA(0,0,0)(2,0,0)[12] with AIC (437.37, 358.81), respectively. The light duration was highest in Sylhet 6.7hours and lowest was only 2.0hours in Moulvibazar. The best fitted model for sunshine in Moulvibazar was ARIMA (1,1,1)(1,0,0)[12] and Sylhet ARIMA(0,1,2)(2,0,0)[12] with AIC (217.77 and 364.29). Wind speed in Moulvibazar varies between 9 $m.s^{-1}$ to 2.8$m.s^{-1}$ and in Sylhet was 9.6$m.s^{-1}$ to 2.2$m.s^{-1}$. The average wind speed was approximately the same for the two stations. The best fitted model for wind speed in Moulvibazar and Sylhet was ARIMA (4,0,1)(2,1,0)[12] and in Sylhet was ARIMA(3,0,1)(1,0,0)[12] with AIC value (432.82 and 540.40). The best fitted model rainfall in Moulvibazar was ARIMA (2,0,3)(1,1,2)[12] (ADF test p-value=0.01, KPSS test p-value=0.1) and in Sylhet was ARIMA(1,0,0)(2,1,1)[12] (ADF test with p value= 0.01 and KPSS test with p-value=0.1) with AIC (1784.57, 1906.4). Mila et al. (2022) suggested the best fitted models ARIMA (0,1,0), ARIMA (0,2,2), and ARIMA (1,1,2) for tea production, consumption, and export, respectively.

According to the modeling, the data set exhibits seasonality, and there appears to be a constant trend of growing and falling values. The Augmented Dickey-Fuller Test with Pr(≥-8.3583)<.01 and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root test with Pr(≥ 0.20704)>0.1 at 5% level of significance adequately declared that the data set is stationary and there is no unit root problem. But the positive and negative ACF (Autocorrelation Function) and PACF (Partial Auto correlation Function) plot in Figure 3 confirmed that seasonal variation exists in data set. So, the original series were different at lag 12 to vanish the seasonal impact. ACF and PACF after differencing has been shown in Figure 3 also seem to be well because most of all the values within the bounded lines (dotted lines). The ACF indicates the moving average process and PACF indicates the autoregressive part. The ACF with significant spike at lag 1 and PACF with significant spike at lag 2 imply that first order moving average and second order autoregressive are effective on relative humidity and similar pattern were also effective for the other seasonal climatic variables. Keeping in mind the lower AIC value the best selected ARIMA model for relative humidity was ARIMA (1,0,1)(2,1,0)[12] in Moulvibazar. The residual plot of ACF and PACF of relative humidity in Figure 3 shows that there is no autocorrelation. P-value of Box-Ljung test is (=3.0651) with high value 0.9951 indicating that the residuals are indeed white noise (Table 3). That means the data set is stationary and the fitted model is best model for relative humiditry in Moulvibazar district. The histogram with normal curve and normal Q-Q plot of residual in Figure 4 shows that almost all the points are close to Q-Q lines which suggests that the residuals follow the normal distribution Till to date, several researchers have been demonstrated the feasibility and importantness of the ARIMA models in different crops (Hamjah et al., 2014; Mila et al., 2022; Rahman et al., 2022; Siamba et al., 2023). Therefore, the fitted ARIMA models for all the six variables are appropriate for seasonal climatic variation analysis.

Table 3. Ljung-Box test for residuals of the fitted models in Moulvibazar and Sylhet district with residuals of tea area, production, and yield.

	Ljung-Box								
	Humidity (%)	Maximum temperature (ºC)	Minimum temperature (ºC)	Light duration (hrs)	Wind speed ($m.s^{-1}$)	Rainfall (mm)	Area (ha)	Production (ton)	Yield (ton)
Moulvibazar									
χ^2_{12}	3.07	4.95	10.32	10.79	5.35	5.83	6.48	6.03	6.95
p-value	0.99	0.96	0.587	0.56	0.53	0.92	0.77	0.81	0.86
Sylhet									
χ^2_{12}	4.73	1.91	10.22	0.16	1.10	3.68	5.26	2.80	1.27
p-value	0.97	0.99	0.59	0.79	0.95	0.61	0.87	0.99	0.99

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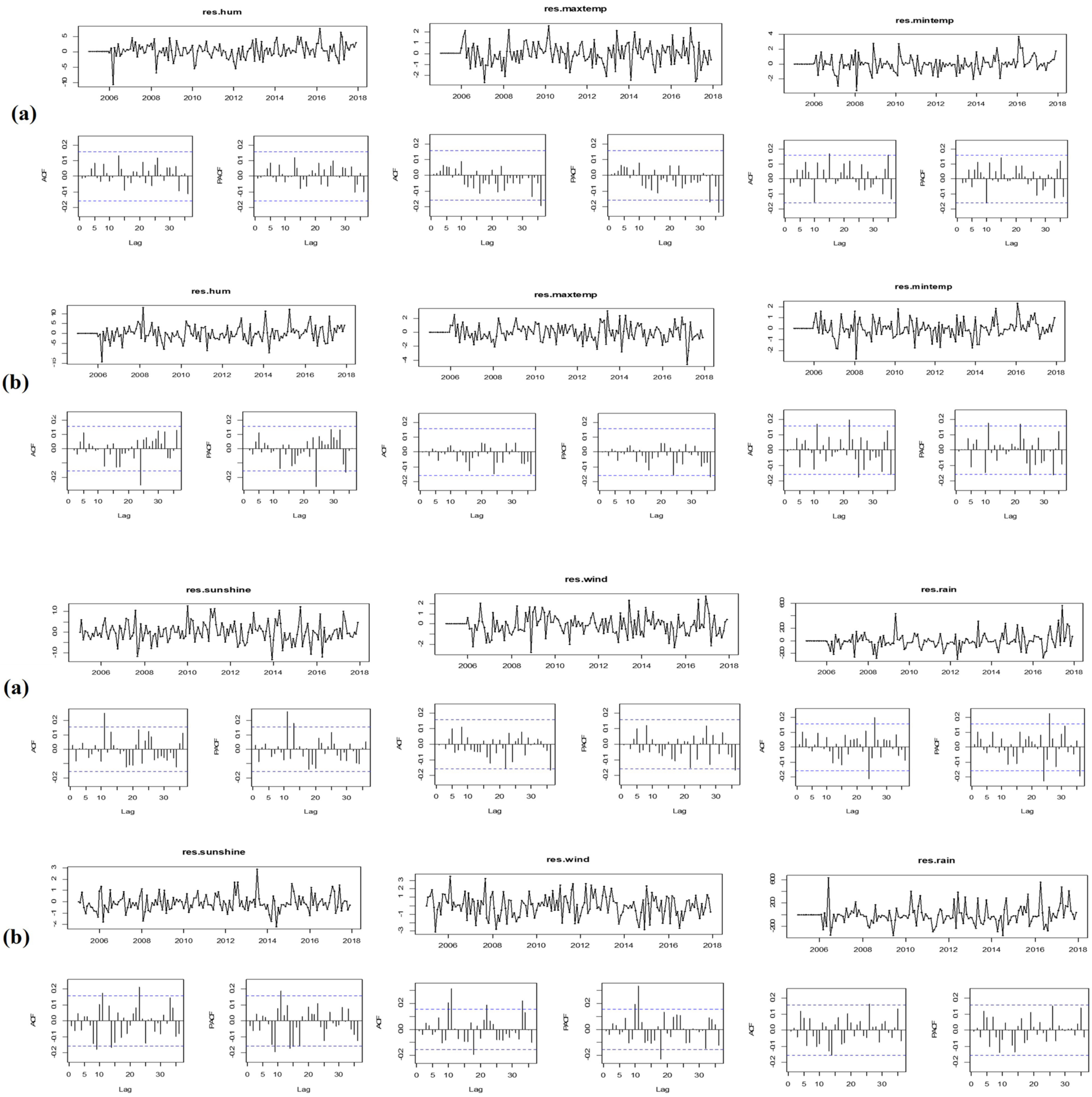

Figure 3. ACF and PACF plot of residuals for relative humidity, maximum temperature, minimum temperature, light duration, wind speed and rainfall in (a) Moulvibazar, and (b) Sylhet district.

Table 4. Maximum, minimum, average values, KPSS test statistics for tea production, area, yield in Moulvibazar and Sylhet district

	Maximum value	Minimum value	Average value	KPSS test	
				Test statistics	P-value
Moulvibazar					
Area (ha)	32843	30487	31621	0.21335	0.1
Production (ton)	60439	34261	38611		0.1
Yield (kg.ha^{-1})	1840	1082	1219	0.27135	0.1
Sylhet					
Area (ha)	5116	4799	4957	0.12592	0.1
Production (ton)	11804	4876	5432	0.31176	0.1
Yield (kg.ha^{-1})	2307.4	995.5	1195.3	0.26614	0.1

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In Moulvibazar district, the highest amount of tea production was about 60439 tons for the year 2017 and the lowest amount was 34261 tons for the year 2011 with an average production 38611 tons using under 31621 ha lands (Table 4). The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root test with Pr(≥ 0.33027 > 0.1) at 5% level of significance infer that the data set is stationary. Same test has also been applied after difference and the p value is greater than 0.05 Pr(≥ 0.35215 > 0.09778) which the difference is sufficient. To select the best fitted model with minimum value of AIC and BIC criteria some fitted model with their AIC and BIC was given in Table 5. Considering AIC and BIC the best fitted model for tea production in Moulvibazar is ARIMA (1,1,1). The diagnostics of this model were presented in Table 6. This method is well supported with Rahman (2017) the appropriate model of ARIMA (1,1,2) for forecasting the production of tea in Bangladesh. Similarly, tea production in Sylhet KPSS test was 0.31176 with p-value 0.1 indicating the data set is stationary. The AIC and BIC values of different ARIMA models for tea area and production in Moulvibazar and Sylhet district were given in Table 5 along with some fitted ARIMA models for tea production. The best fitted model tea production was selected as ARIMA (0,1,0) with (AIC=380.51 and BIC=381). Similarly for tea area the same procedure has also been applied and the best fitted model for tea area keeping in mind with least AIC. For the tea area the KPSS test is 0.51887 with p value 0.03742 indicating that the data set is not stationary. After taking the first difference the KPSS test 0.12592 with p value 0.1 shows that the difference was sufficient. The best fitted model has been selected for tea production and area and as ARIMA (0,1,0) with (AIC=380.51 and BIC=381), ARIMA (1,1,1) with (AIC=128.18 and BIC=129.63), respectively and their diagnostics was presented in Table 6. Box-Lung test statistics in Table 3 with high p-value shows the residuals are indeed white noise. The Q-Q normal plot and forecast plot was presented in Figure 5. The best selected ARIMA model for tea production and tea production area in Sylhet division was about ARIMA (1,1,1) with AIC (306.52), BIC (307.97) and ARIMA (0,1,0) AIC (63.19), BIC (63.68). This study is also well supported by Hussain and Abdullah (2015) the ARIMA (0,2,1) model with AIC=714.68 and BIC=778.06 is the best selected model for forecasting the garlic production in Bangladesh. Dhekale et al. (2014) in West Bengal fitted ARIMA (2,1,1) without considering factors of production with (0.98) and lower values of AIC, Log likelihood, and ARIMA (2,1,1) model with considering the factors of production provides (0.97) and lower AIC, Log likelihood.

The trend forecasts suggest an expansion in tea cultivation areas in Moulvibazar and increased production in the Sylhet regions. Although both areas have seen an increase in tea cultivation, the production in these regions has not exhibited a consistent

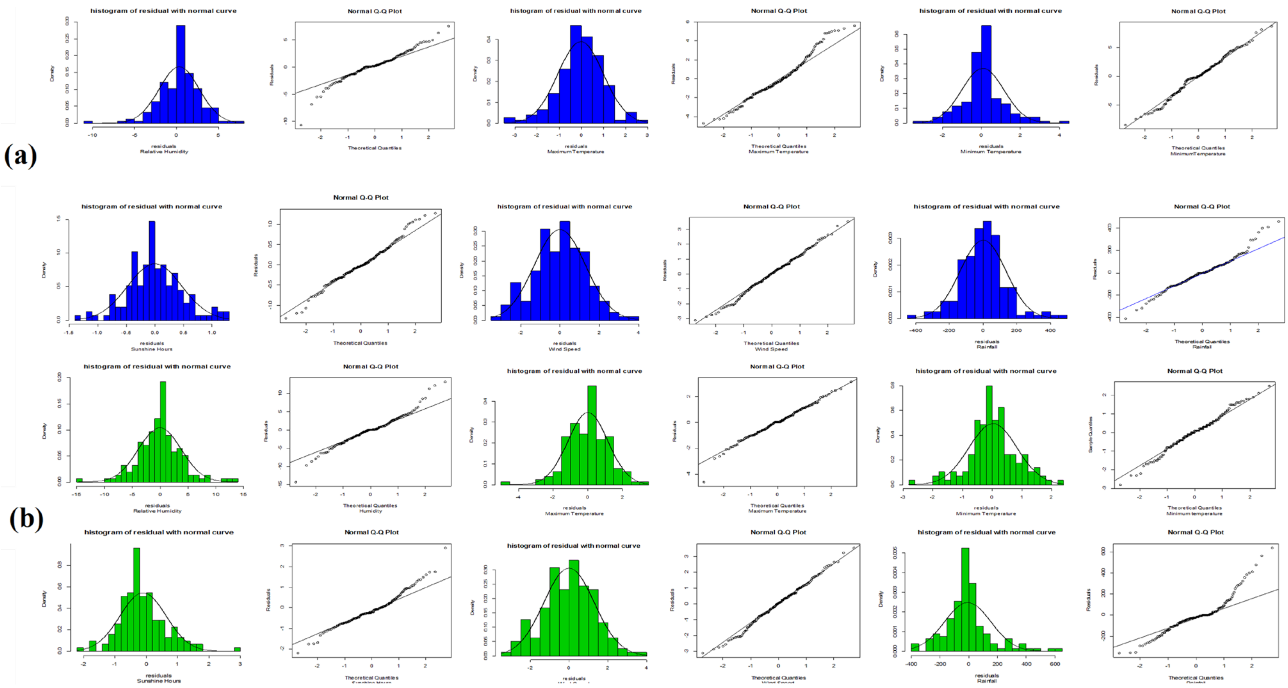

Figure 4. Histogram with normal cure and normal Q-Q plot of residuals of humidity, maximum and minimum temperature, light duration, wind speed and rainfall in (a) Moulvibazar, and (b) Sylhet district.

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upward trajectory, with fluctuations observed since 2015. The forecasted figures indicate a relatively stable tea production in both Moulvibazar and Sylhet districts from 2023 to 2028. Additionally, Mila et al. (2022) conducted a forecast on tea production and consumption spanning 2019 to 2028, revealing an upward trend in both tea production (rising from 83.40 to 94.88 million kg) and consumption (increasing from 94.35 to 131.71 million kg).

Impact of Climatic Variables and Forecasting on Tea Production

The selected climatic variables have large impact on tea production. The seasonal monsoon also greatly affects the tea production (Farukh et al., 2020). In the

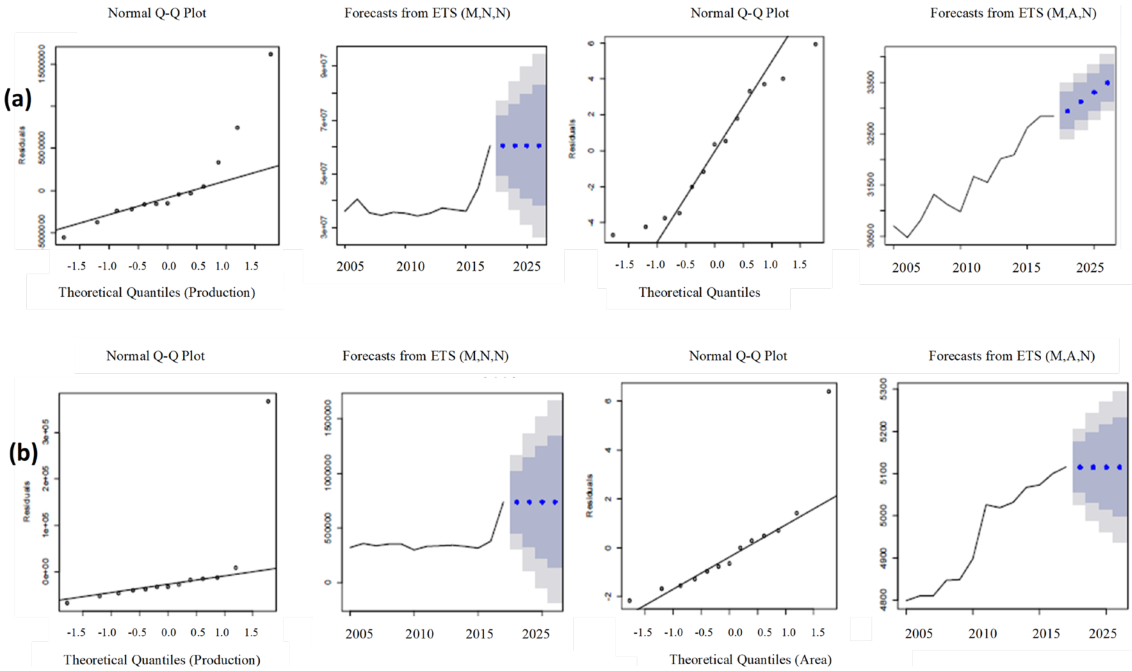

Figure 5. Residuals Q-Q plot and forecast plot of tea production with area in (a) Moulvibazar, and (b) Sylhe district.

Table 5. AIC and BIC values of different ARIMA models for tea area and production in Moulvibazar and Sylhet district.

Area			Production		
Model	AIC	BIC	Model	AIC	BIC
Moulvibazar district					
ARIMA(0,0,1)	207.20	208.89	ARIMA(1,0,0)	447.46	449.16
ARIMA(1,0,1)	199.05	201.31	ARIMA(0,0,1)	445.97	447.67
ARIMA(1,1,1)	180.73	182.18	ARIMA(0,0,2)	444.19	446.45
ARIMA(1,0,0)	197.07	198.77	ARIMA(0,1,0)	409.08	409.56
ARIMA(2,0,2)	196.04	199.43	ARIMA(1,0,1)	444.85	447.11
ARIMA(2,0,0)	199.04	201.30	ARIMA(1,1,1)	407.70	409.16
Sylhet district					
ARIMA(0,0,1)	154.58	156.28	ARIMA(0,1,0)	380.51	381.00
ARIMA(1,0,1)	144.28	146.54	ARIMA(0,0,1)	414.88	416.58
ARIMA(1,1,1)	128.18	129.63	ARIMA(1,0,1)	416.49	418.75
ARIMA(2,0,2)	147.06	150.45	ARIMA(1,1,1)	407.70	409.16
			ARIMA(2,0,2)	418.94	422.33

Notes: AIC= Akaike Information Criterion, BIC= Bayesian Information Criterion

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selected two areas there was significant relationship with tea production and climatic variables considering others factors of production remains constant. In Moulvibazar, the best fitted ARIMAX model was ARIMA(1,0,2) for tea and climatic parameters (Figure 6). From the Table 7, it can be seen that humidity, maximum temperature and light duration and wind speed has a positive impact whereas minimum temperature and rainfall has negative impact with tea production. The diagnostics of the model ARIMA (1,0,2) has been given in Table 6 and showed that relative humidity, maximum temperature, minimum temperature, light duration and rainfall has statistically significant impact on tea production in Moulvibazar district. And wind speed has no direct impact on the tea production in Moulvibazar district. Rahman et al. (2022) observed that the mixed ARIMA (0,2,3) model outperforms the univariate ARIMA (0,2,2) model when taking the potato's surface area into account. In comparison to the ARIMA model, the 95 percent confidence range for the forecast value of the mixed model is smaller. Similarly in Sylhet district, the best selected ARIMAX model was found ARIMA (0,0,1). The relative humidity, maximum temperature and wind speed has a positive relation with tea production, while minimum temperature, light duration and rainfall have negative impact with tea production. It means that if relative humidity, maximum and wind speed are good then tea production will also be good and vice versa. And if the minimum temperature, light duration, and rainfall is higher than optimum amount then the production will reduce. In the Sylhet area, relative humidity, maximum temperature, light duration, and wind speed have statistically significant impact on tea production. In Sylhet Division the best fitted ARIMAX model was ARIMA(1,1,1) with AIC=364.72 and BIC=369.57 (Table 5).

The relative humidity, maximum temperature, minimum temperature, light duration, and rainfall have statistically significant and positive relation with the tea production. But in Sylhet division wind speed has no direct impact on tea production. Nury et al. (2011) has also fitted the models for Moulvibazar and Sylhet as ARIMA (0,1,1)(1,1,1)[12] and in Sylhet was (1,1,1)(0,1,1)[12] with AIC (914.27, 1810.38)

Table 6. Summary coefficients of model ARIMA (1,0,2) for Moulvibazar and model ARIMA (0,0,1) for Sylhet district.

Coefficients	Estimates	Std error	z value	P value
Model ARIMA (1,0,2) for Moulvibazar district				
AR1	-0.237	0.304	-0.780	0.435
MA1	0.000	0.263	0.0000	0.999
MA2	-1.000	0.263	-3.800	0.0001 ***
Intercept	-13270	13383251	-9.915	< 2.2e-16 ***
Area	35502.436	1337.629	26.541	< 2.2e-16 ***
Humidity	1398862.2	217251.7	6.438	1.203e-10 ***
Maximum temperature	1389908.6	321219.3	4.327	1.512e-05 ***
Minimum temperature	-1401281.3	605369.5	-2.314	0.0206 *
Light duration	780670.5	321752.4	2.426	0.0152 *
Wind speed	251795.5	188261.9	1.337	0.181
Rainfall	-1923.691	619.132	-3.107	0.0018 **
Model ARIMA (0,0,1) for Sylhet district				
MA1	-1.0000	0.201	-4.956	7.163e-07 ***
Intercept	-9376869	5085174	-1.844	0.065189
Area	5165.796	72.292	71.457	< 2.2e-16 ***
Humidity	88656.600	43063.94	2.0587	0.0395 *
Maximum temperature	202267.680	99105.67	2.040	0.0412 *
Minimum temperature	-244115.670	86361.31	-2.826	0.0047**
Light duration	-377710.0	105033.7	-3.596	0.0003 ***
Wind speed	432824.11	95369.62	4.538	5.669e-06 ***
Rainfall	-56.0210	47.1733	-1.187	0.235007

Note: Significance level: '***' for 0.001, '**' for 0.01 and '*' for 0.05.

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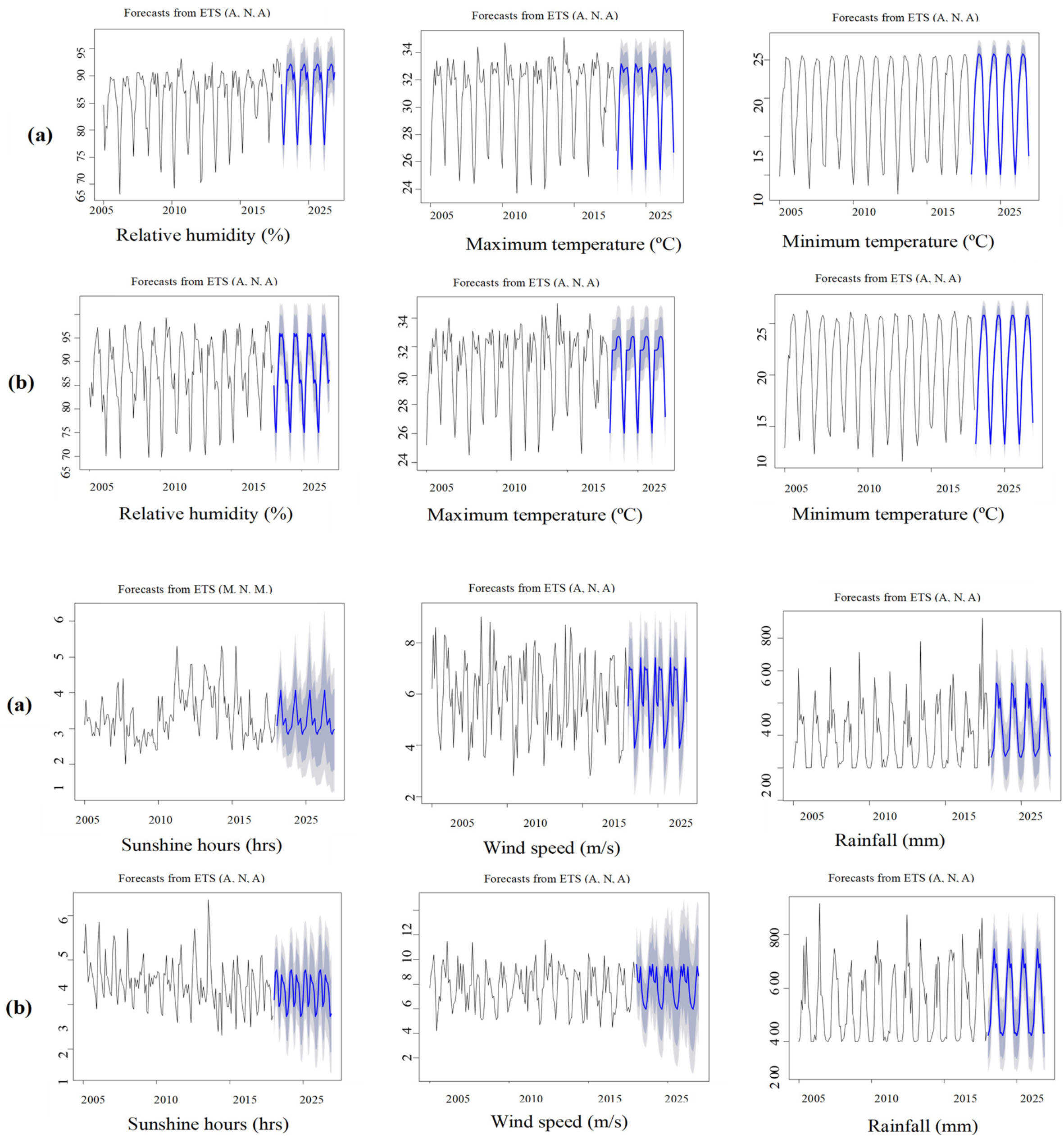

Figure 6. Forecast time series of humidity, maximum temperature, minimum temperature, sunshine hours, wind speed and rainfall in (a) Moulvibazar, and (b) Sylhet district.

Table 7. The best fitted models for tea area, production and yield with their diagnostics in Moulvibazar and Sylhet district.

Model	σ^2	log likelihood	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1
Moulvibazar									
ARIMA(1,1,1)	2.124e+13	-200.85	1099754	4042205	2984814	2.1364	7.45712	0.86075	-0.1829
ARIMA(1,1,1)	145972	-87.36	166.6136	335.0912	273.08	0.5191695	0.8626	0.9407	-0.3108
ARIMA(0,0,0)	30543	-78.99	55.5225	174.77	113.74	100	100	0.9187	0.261
Sylhet									
ARIMA(0,0,0)	2.927e+12	-189.26	549854.3	1710744	805861.6	100	100	0.8553917	0.1380002
ARIMA(0,1,0)	1327	-59.64	0.3671053	33.51107	22.53916	0.00528	0.4540137	0.8099841	-0.1266533
ARIMA(1,1,1)	24557	-77.07	35.14661	137.4416	99.81113	2.109394	7.805529	0.8775569	-0.1397973

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and they checked their models appropriateness only by checking at the ACF and PACF plot of residuals. While in this study to check the model's appropriateness the diagnostic checking was not only looking forward to ACF and PACF plot along with Box-Lung test probability value, histogram with curve and normal Q-Q plot of residuals. Siamba et al. (2023) also demonstrated the importance of the ARIMA and hybrid ARIMA model in tuberculosis incidences in the children in Kenya. Hamjah and Chowdhury (2014) also suggested the best fitted ARIMAX model for cash crop like tea, cotton, sugarcane and tobacco and production are ARIMAX (0,1,1), ARIMAX (1,1,0), ARIMAX (0,1,1) and ARIMAX(0,1,1), respectively.

Both in Moulvibazar and Sylhet area, the relative humidity, the maximum temperature, and wind speed has positive impact with tea production while minimum temperature and rainfall has negative impact with tea production. In Moulvibazar, relative humidity was statistically significant at 0.01% level of significant while in Sylhet humidity was significant at 5% level of significant. But in Sylhet division, except wind speed all the selected variables have significant and positive impact on the tea production. Hamjah (2014) documented that relative humidity in summer had a significant impact on tea production in Bangladesh.

Average humidity for the two areas was 80.93% and 77.87%. Ali et al. (2014) found that average humidity in Sylhet was 75.85 of last 10 years and humidity was perfect for tea production. The tea plant needs between 1150 mm and 1400 mm of yearly rainfall as a minimum, and between 2500 mm and 3000 mm as a maximum (Jayasinghe et al., 2020, Jayasinghe and Kumar, 2021). According to Chen et al. (2019), an increase in sunshine hour resulted in higher the number of leaves and weight of tea shoots as well as the final tea output. Temperature is the most important climatic variable for tea production. Both the maximum and minimum temperature has a significant impact on tea production. The highest tea production lied within 31.50 to 30.10ºC maximum temperature with minimum temperature 20.50ºC to 19.20ºC in Moulvibazar. In Sylhet, it was 21.60 to 20.80ºC on average. The optimum maximum temperature for tea production was 30.82ºC and average minimum temperature was 19.67ºC (Table 1). Han et al. (2017) observed that an increase in temperature might result in a higher yield in a place or season with low temperatures. However, Ali et al. (2014) did not find any significant relation of temperature with tea production of selected four tea estates. The maximum tea production in the two areas lied in 4 to 2.7 hours in Moulvibazar and 3.2 to 2.2 hours in Sylhet. The average light duration for the two areas was 3.3 hours and 2.9 hours. Hamjah (2014) found that sunshine hour in summer has a significant impact on tea production. In Moulvibazar, wind speed has no significant impact on tea production. But in Sylhet it has statistically significant impact on tea production with tea production at 0.01% level of significance. The maximum production tea maintaining 6.4 to 3.5m.s^{-1} wind speed in Moulvibazar and Sylhet 6.1 to 5.3m.s^{-1} .The average wind speed for the two years was 5.7m.s^{-1} and 5.9m.s^{-1} (Table 1).

The maximum tea production in Moulvibazar was 6044 tons with 2404mm rainfall, whereas in Sylhet the maximum production was 11804 tons with maintaining 4115mm rainfall (Table 4). This study is compared with Ali et al. (2014) where they found that rainfall was positively related with tea production in Lackatoorah, Malnichera and Burjan tea estate without considering the impact of tea area. Rahman (2022) also suggested the adopting of organic tea farming practices which can combat climate change as well as enhance socioeconomic value. Farukh et al. (2020) demonstrated a greater volume of tea was produced in Sylhet and Sreemangal because of severe precipitation intensity. The original and anticipated series comparison revealed the same trends, indicated that the fitted model is statistically sound and suitable for forecasting tea production in Bangladesh (Islam et al., 2020).

Conclusion

We used a seasonal time series data set to study the variation of climatic variables of relative humidity, maximum temperature, minimum temperature, light duration, wind speed and rainfall in Moulvibazar and Sylhet. The result of SARIMA model shows the changing patterns of climatic variables were not same for the two regions. As prescribed in SARIMA procedure the best fitted models by looking lower AIC and BIC criterion have been checked diagnostically for their appropriateness. The histogram with normal curve and normal Q-Q plots shows that the fitted models are statistically well to forecast the relative humidity, maximum temperature, minimum temperature, light duration, and rainfall for the two regions during and beyond the estimation period. This model can help to predict the climatic variable conditions earlier, which could enhance the estimation of tea production in the next preceding years in the different regions of the country.

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