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Research Article

SARIMA Model-Based Maximum Temperature Forecasting in Bangladesh: A Data-Driven Evaluation from 1981 to 2024

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Abstract

Bangladesh is a tropical nation where there are notable seasonal temperature changes. The Seasonal Autoregressive Integrated Moving Average (SARIMA) model is used in this study to forecast Bangladesh's maximum temperature from 2023 to 2042. The objective is to assess how rising temperatures can affect public health, energy consumption, and agriculture. Autocorrelation and partial autocorrelation analysis will be used to improve the model. Analysis was done using historical maximum temperature data spanning from 1981 to 2022. Forecasts were produced using the SARIMA model, whose parameters were chosen in accordance with plots of the autocorrelation function (ACF) and partial autocorrelation function (PACF). The model SARIMA (1,1,2)(0,0,1) is selected based on AIC. In order to account for forecast uncertainty, forecasts were created for the years 2023–2042. 95% prediction ranges were then calculated. Bangladesh's maximum temperatures are predicted by the SARIMA model to rise gradually, from roughly 33.75 ℃ in 2023 to 34.17 ℃ in 2042. With some degree of uncertainty, the 95% prediction intervals show a steady increasing trend between 33.53 ℃ and 34.51 ℃. The anticipated increase in the highest temperatures has major consequences for Bangladesh. These results highlight how crucial it is to create adaptation plans and laws in order to lessen the effects of warming temperatures and increase resilience.

Keywords

SARIMA Model, Maximum Temperature Forecast, Climate Change, Bangladesh, Temperature Trends

1. Introduction

One of the biggest environmental issues of our time is climate change, having a huge impact on economies, ecosystems, and populations all over the world. One of the most obvious effects of climate change is rising temperatures, which have a significant impact on a number of industries, including public health, energy, and agriculture.

Bangladesh, a heavily populated nation in South Asia's low-lying delta region, is one of the countries most affected by climatic instability and extreme weather occurrences. It is known for being vulnerable to cyclones, flooding, and rising temperatures, that is facing greater threats to infrastructure, public health, agriculture, and general socioeconomic stabil-

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ity. Rising temperatures have been reported in South Asia, particularly in Bangladesh, in recent years, owing to a combination of human activity and variability in nature [1]. In spite of this, exact and realistic temperature forecasting becomes essential for developing plans for effective climate adaptation and mitigation.

Forecasting maximum temperatures is very important since it has a direct impact on many different areas, such as public health, energy consumption, agriculture, and water resource management. For example, prolonged periods of high heat can cause crop failures, raise the energy needed for cooling, and increase the number of heat-related illnesses.

To estimate and anticipate temperature fluctuations, many statistical and machine learning techniques have been used over the years. The capacity of the Seasonal Autoregressive Integrated Moving Average (SARIMA) model to extract the seasonal and trend components included in time series data has made it stand out among the others. According to research by Hyndman and Athanasopoulos (2018), the model is a good option for predicting weather patterns because of its ability to handle seasonal data well [2]. The SARIMA model was used to forecast maximum temperatures in a number of Indian cities, proving its effectiveness in capturing both short- and long-term trends. According to the study's findings, SARIMA models are especially helpful in areas like the Indian subcontinent that have prominent seasonal climate patterns. For example, Ghosh and Mujumdar (2006) emphasized the usefulness of the model in monsoonal climate regions by modeling precipitation patterns in India using SARIMA [3].

Although SARIMA models have been widely used in many different climate zones, there are still few thorough studies assessing their effectiveness in Bangladesh. SARIMA was used in a study by Rahman et al. (2017) to forecast temperature in Dhaka city, showcasing the model's capacity to account for seasonal fluctuations [4]. Nevertheless, the depth of this study was limited because it only looked at one city and had a brief forecast horizon. Islam et al. (2014) conducted a noteworthy investigation that used time series analysis to analyze temperature patterns in Bangladesh; nevertheless, the study did not concentrate on long-term forecasts [5]. Again In another study the selected SARIMA models give two-year predicted monthly maximum and minimum temperatures that can help decision makers to establish priorities for preparing themselves against forthcoming weather fluctuations [6]. A notable gap in the literature is the absence of long-term, national studies employing SARIMA, especially considering the significance of precise temperature forecasting for Bangladesh's climate adaption plans. The research has importance as it has the potential to improve Bangladesh's temperature forecasts' predictive accuracy. This would in turn promote evidence-based decision-making concerning resource management and climate adaption. In order to close these gaps, a thorough assessment of the SARIMA model for predicting Bangladesh's maximum temperatures between 1981 and 2041 is being carried out in this work. The project seeks to give a more accurate and region-specific forecast by utilizing a large dataset and concentrating on long-term trends. This will add to the body of knowledge on climate modeling in Bangladesh and inform climate resilience measures.

2. Materials and Methods

2.1. Data Source

Data on maximum temperatures collected from the Bangladesh Meteorological Department are used in the study from year 1981 to 2022, a period of 42 years. The dataset has extensive geographical and temporal coverage, encompassing several meteorological stations located throughout Bangladesh.

2.2. Methods

Time series data having seasonal components can be handled using the Seasonal Autoregressive Integrated Moving Average (SARIMA) model, which is why it was chosen.

An expansion of the ARIMA (Autoregressive Integrated Moving Average) model that takes into account seasonality in addition to the non-seasonal components is called SARIMA (Seasonal Auto-Regressive Integrated Moving Average). While SARIMA models are especially made to handle data with seasonal trends, ARIMA models are commonly utilized for time series analysis and forecasting.

Natural phenomena such as temperature, rainfall etc. was strong components corresponding to seasons. Hence, the natural variability of many physical, biological and economic processes tends to match with seasonal fluctuations [7].

SARIMA Model is represented as

$$ARIMA\ (p, d, q)(P, D, Q)_n$$

Where,
p=Number of non-seasonal AR terms;
d=Number of non-seasonal differences;
q=Number of non-seasonal MA terms;
P= Number of seasonal AR terms;
D= Number of seasonal differences;
Q= Number of seasonal MA terms;
n= number of periods per season.

2.3. Materials

Statistical software tools sigmaXL and OriginPro was used to develop the SARIMA model.

3. Results

Our data, which is the highest temperature recorded at meteorological stations throughout Bangladesh between 1981 and 2022, must first be checked for non-stationarity before fitting a suitable model can be applied. The ARIMA model summary and statistics from Tables 1 and 2 show that the SARIMA(1,1,2)(0,0,1) model is suitable for this study, and that Model selection and validation are carried out using statistical metrics like the Akaike Information Criterion (AIC).

Table 1. *SARIMA Model summary.*

ARIMA Model Summary	
AR Order (p)	1
I Order (d)	1
MA Order (q)	2
SAR Order (P)	0
SI Order (D)	0
SMA Order (Q)	1
Seasonal Frequency	4
Include Constant	1
No. of Predictors	0
Model Selection Criterion	AIC
Box-Cox Transformation	Rounded Lambda
Lambda	0
Threshold	0

Table 2. *ARIMA model statistics.*

ARIMA Model Statistics	
No. of Observations	42
DF	36
StDev	0.003302916
Variance	1.09093E-05
Log-Likelihood	172.4809266
AICc	-330.491265
AIC	-332.9618533
BIC	-322.6804209

Tables 3 and 4 indicates forecast accuracy and parameter estimations. These tables shows that aside from other pertinent statistical metrics, MAPE and RMSE are used to assess the model's performance.

Table 3. *Forecast Accuracy.*

Metric	**In-Sample (Estimation) One-Step-Ahead Forecast**
N	41
RMSE	0.112134686
MAE	0.07812542
MAPE	0.2323724
MASE	0.556754964

Table 4. *Parameter estimation.*

Term	**Coefficient**	**SE Coefficient**	**T**	**P**
AR_1	-0.320499718	0.322653049	0.993326	0.3272
MA_1	0.116379184	0.289675857	0.401757	0.6902
MA_2	0.865069025	0.279552583	3.094477	0.0038
SMA_1	0.798604076	0.282023659	2.831692	0.0075
Const: Trend	0.000511282	3.27672E-05	15.60347	0.0000

As seen in Figure 1 through Figure 5 given below, the SARIMA model accurately depicts the historical temperature trends with few residual errors. The seasonal and non-seasonal components of the SARIMA model were determined using Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots. The model's proper representation of the underlying temperature trends is ensured by the lag values selected in accordance with the guidance provided by the ACF and PACF displays.

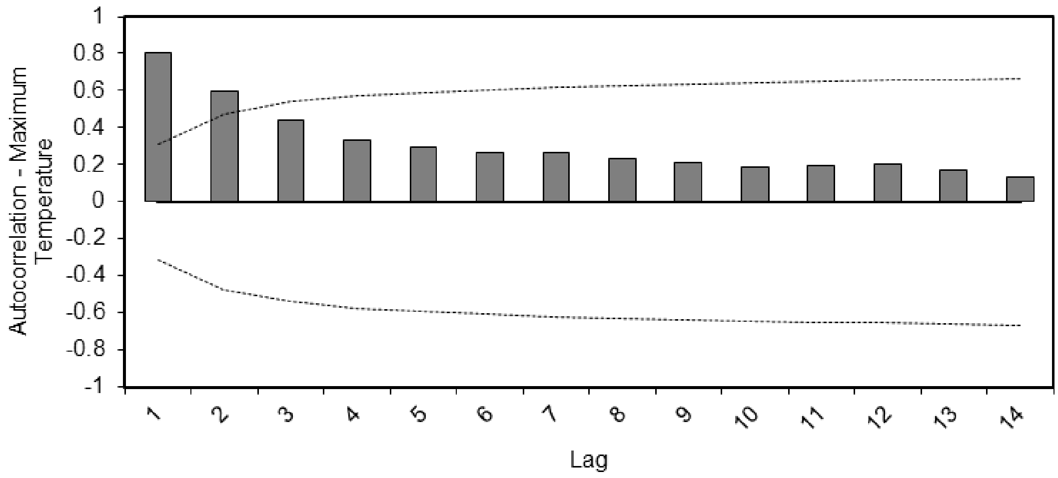

Figure 1. *Autocorrelation Function (ACF) Plot Significance Limit Alpha = 0.05.*

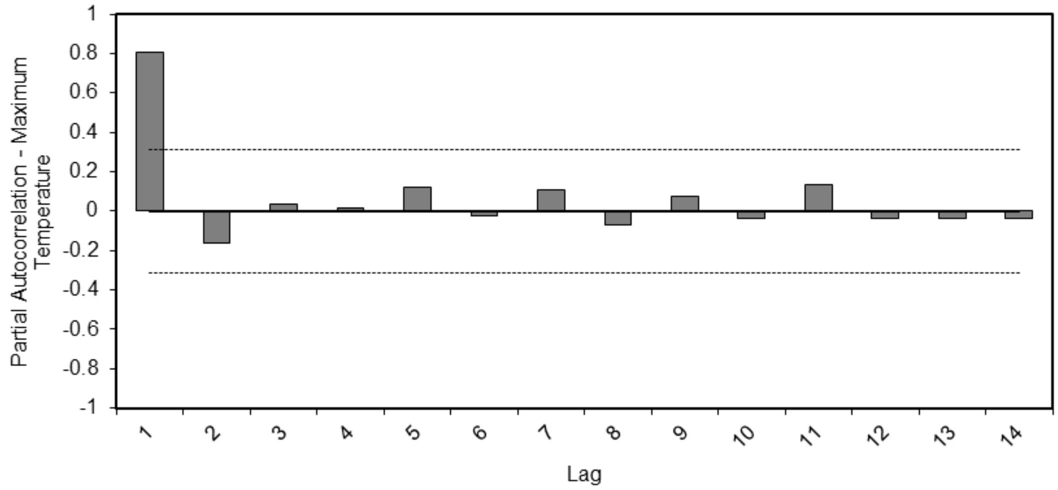

Figure 2. *Partial Autocorrelation Function (PACF) Plot Significance Limit Alpha = 0.05.*

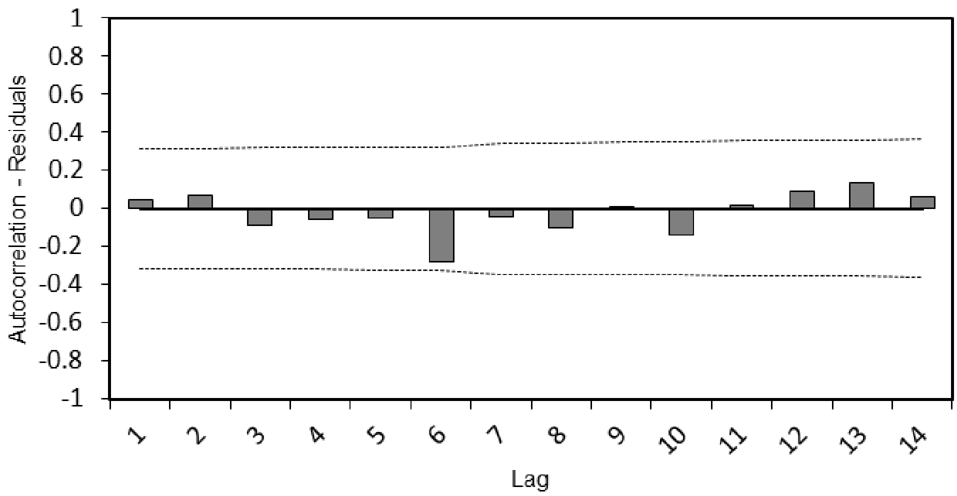

Figure 3. *Autocorrelation Function (ACF) Plot – Residuals Significance Limit Alpha = 0.05.*

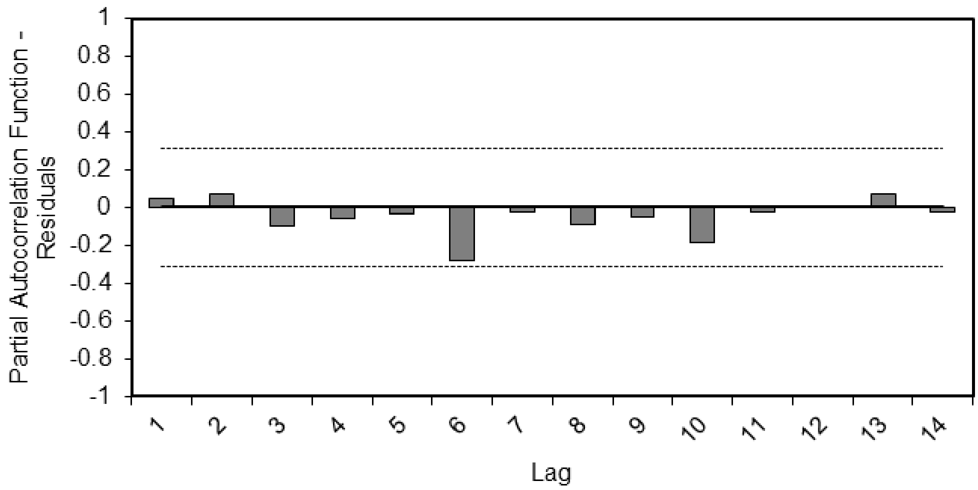

Figure 4. *Partial Autocorrelation Function (PACF) Plot –Residuals Significance Limit Alpha = 0.05.*

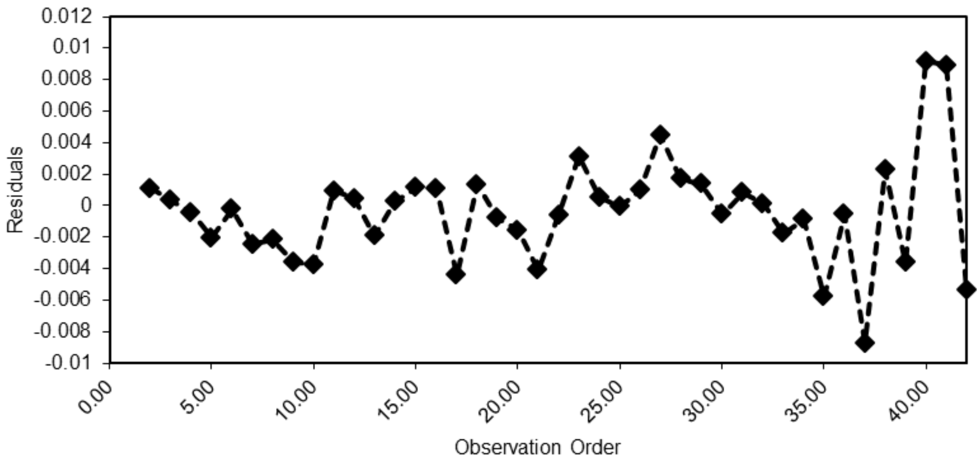

Figure 5. *Residuals vs Data Order for: Maximum Temperature.*

Table 5 and Figure 6 displays Forecast table of anticipated maximum temperatures over the next 20 years and forecasting chart accordingly.

Table 5. *Forecast table.*

Period	One-Step-Ahead Forecast	Lower 95.0% PI	Upper 95.0% PI
2023	33.75065484	33.52627455	33.97653683
2024	33.74756774	33.49020739	34.0069058
2025	33.47343764	33.21564916	33.73322682
2026	33.94965421	33.68771756	34.21362752
2027	34.00628604	33.68759764	34.32798927
2028	33.89133434	33.55939269	34.22655928
2029	33.95104819	33.61700358	34.28841213
2030	33.95481525	33.62060258	34.29235023
2031	33.97653931	33.64209075	34.31431274

Period	One-Step-Ahead Forecast	Lower 95.0% PI	Upper 95.0% PI
2032	33.99251747	33.65791141	34.33044998
2033	34.01034992	33.67556693	34.34846113
2034	34.02759951	33.6926463	34.36588264
2035	34.04504775	33.70992211	34.38350503
2036	34.06244404	33.72714657	34.40107486
2037	34.07986875	33.74439915	34.41867342
2038	34.09729611	33.76165435	34.43627466
2039	34.11473439	33.77892037	34.45388692
2040	34.13218095	33.79619458	34.47150754
2041	34.14963663	33.81347782	34.48913738
2042	34.16710117	33.83076984	34.50677617

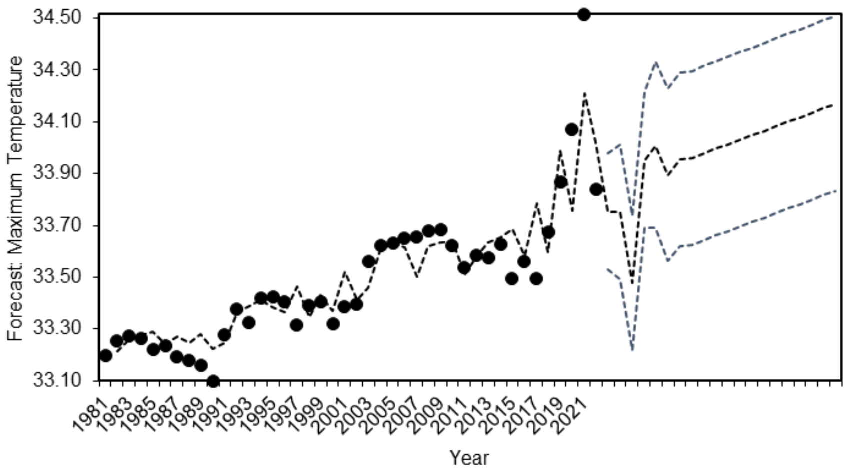

Figure 6. *ARIMA Time Series Forecasting Chart 95.0% Prediction Intervals.*

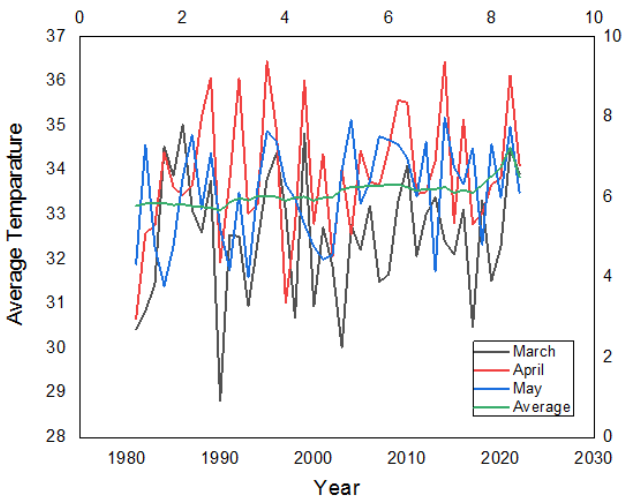

Figure 7. *Average temperature of annual time series data.*

Figure 7 indicates the average temperature of annual time series data which is given below,

4. Discussion

The results of the analysis show that, from 1981 to 2022, Bangladesh's maximum temperatures showed a distinct and significant increasing trend. The effects of climate change on Bangladesh's climatic system are highlighted by the average increase of 1 ℃ per decade, which is consistent with larger regional and global warming patterns. The seasonal and long-term trends in the historical temperature data were effectively captured by the SARIMA model, which was created through thorough statistical research. The model is a reliable instrument for temperature forecasting, as shown by its strong validation metrics (e.g., MAPE, RMSE, and AIC) and low residuals.. Over the next 20 years, the SARIMA model predicts that maximum temperatures will continue to rise. In comparison to the baseline period of 1981–2022, a rise of around 1 ℃ is predicted in the average maximum temperature by 2041. The results of the one-step-ahead forecast show that the maximum temperature in Bangla-desh would continue to rise from 2023 to 2042. The highest temperature expected in 2023 is roughly 33.75 ℃, and by 2042, it will have risen gradually to 34.17 ℃. A range of uncertainty is shown by the 95% prediction intervals, with 33.53 ℃ as the lower bound and 33.98 ℃ as the upper bound of the forecast for 2023. This range changes by 2042, with the lower bound being 33.83 ℃ and the top bound being 34.51 ℃. These forecasts align with the patterns in global warming shown in comparable South Asian research, which show a continuous rise in local temperatures brought on by rising greenhouse gas emissions [8]. According to these forecasts, temperatures will climb steadily, which is consistent with the region's overall observations of global warming trends. Bangladesh's agriculture is expected to be significantly impacted by the predicted temperature increase, especially for crops that are susceptible to heat stress. Rice yields can be significantly reduced by even small temperature rises during critical growth periods [9, 10]. The progressive increase from 33.75 ℃ in 2023 to 34.17 ℃ in 2042 indicates that peak energy demand during the summer months may increase over time. This growing demand would put further strain on Bang-ladesh's energy infrastructure, demanding investments in energy efficiency and renewable energy development. The predicted temperatures also highlight the significance of incorporating climate projections into long-term energy planning to guarantee that the country can meet its future energy demands responsibly. Rising temperatures can cause a noticeable spike in electricity consumption as homes and businesses use air conditioning and cooling systems more frequently [11]. Furthermore, there could be an increase in the frequency and severity of heatwaves, which would increase the risks to public health. Research has indicated that elevated temperatures are linked to a higher frequency of heat-related ailments, including dehydration, heatstroke, and cardiovascular events. This is particularly true for susceptible groups like the elderly and those with pre-existing medical conditions [12].

Although the forecast produced by the SARIMA model is dependable, it is crucial to take into account the inherent uncertainties in long-term climate projections. As a result of errors in the model and the underlying data, the prediction intervals show a range of potential outcomes. Variations from the predicted temperatures could be caused by a number of factors, including changes in greenhouse gas emissions worldwide, changes in the local environment, and unforeseen meteorological phenomena. Furthermore, any non-linearities in climate responses—which can intensify as temperatures rise—are not taken into consid-eration by the model. More intricate models or ensemble methods could be useful in future research to capture a greater variety of possible circumstances. Moreover, abrupt changes in temperature patterns brought on by intricate climatic interactions may not be properly captured by the linear structure of the SARIMA model [2, 13].

Future research should examine the socioeconomic effects of rising temperatures, with a focus on Bangladesh's vulnerable people. To lessen the effects of rising temperatures, research into adaptive solutions is also necessary in the fields of energy, agriculture, and public health. Furthermore, combining regional climate models with SARIMA projections may offer a more thorough comprehension of the geographical variety of temperature variations throughout the nation. To improve the accuracy of future climate estimates, more research might concentrate on the interactions between rising temperatures and other climatic factors, such as humidity and precipitation [14].

5. Conclusions

The maximum temperatures predicted by the SARIMA model for Bangladesh between 2023 and 2042 show a consistent trend, with important ramifications for public health, energy, and agriculture. After refining the model with historical temperature data from 1981 to 2022 and ACF and PACF plots, the SARIMA projections showed a steady and progressive increase in maximum temperatures, from roughly 33.75 ℃ in 2023 to 34.17 ℃ by 2042. The findings of this study suggest that Bangladesh would continue to face serious issues as a result of climate change. The results emphasize the necessity of proactive mitigation and adaptation plans to deal with the problems caused by climate change. In order to provide a more thorough knowledge of climate consequences, future study could build on these findings by including additional climate variables, such as humidity and precipitation. In addition, including non-linear models may result in longer-term climate forecasts with higher accuracy. In order to maintain Bangladesh's socioeconomic stability and environmental sustainability, it will be essential to incorporate accurate climate forecasts into national planning as the country experiences continuous temperature rises. Also, policymakers must include these estimates into national climate programs.

Abbreviations

SARIMA	Seasonal Autoregressive Integrated Moving Average
ARIMA	Autoregressive Integrated Moving Average
AIC	Akaike Information Criterion
ACF	Autocorrelation Function
PACF	Partial Autocorrelation Function

Author Contributions

Nur Hosain Md. Ariful Azim: Conceptualization, Project administration, Supervision

Sofi Mahmud Parvez: Data curation, Formal Analysis, Investigation, Resources, Visualization

Mumtahin Taharima: Methodology, Writing – original draft

Md. Sabbir Ahmed Ruman: Data curation, Resources, Writing – review & editing

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Data Availability Statement

We obtained the Annual Maximum Discharge data (m^3/s) for the 23 between 2000 and 2022 years that were recorded for the SW266 Kanairghat station on the Meghna River in Sylhet district. Not applicable.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Nur Hosain Md. Ariful Azim was born in Rangpur, Bangladesh in1976. He completed B.Sc. and M.Sc. in Mathematics from the University of Dhaka. After that He completed M. Phil. and Ph. D in Mathematics from Bangladesh University of Engineering and Technology. NHM. A. Azim has wide experience in teaching and administrative in both Business and Science schools. In 2001, he joined International Islamic University Chittagong (Bangladesh) as a lecturer in the Department of Business Administration. In 2005, he joined Southeast University (Bangladesh) as an Assistant Professor in Southeast Business School (SBS) and promoted as an Associate Professor in Mathematics in 2014. He has joined in the Department of Electrical and Electronics Engineering of Southeast University in 2018 and working there till the date. His research interest mostly on computational fluid dynamics and heat transfer. Besides, he has keen interest on standard statistical analysis and numerical modelling. The author is a life member of BMS and BSPUA and also connected with several charitable organizations.

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Md. Sabbir Ahmed Ruman was born Brahmanbaria I hold a Bachelor of Science in Environmental Science from Noakhali Science and Technology University and a Master of Science in Meteorology from the University of Dhaka in 2019 and 2022 respectively.