

The Effect of Climate Change in Rajshahi, Bangladesh: An Analysis of Seasonal Trends and Their Implications

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Received Date: April 05, 2025; Published Date: May 12, 2025

Abstract

Climate change has intensified the frequency and severity of extreme weather events, particularly heat waves, which have significant consequences for public health, agriculture, and the economy. This study examines the impact of climate change on heat waves in Rajshahi, Bangladesh, focusing on past, present, and future trends. Using temperature data from the Bangladesh Meteorological Department (BMD) and Weather Spark, we analyzed historical trends from 1990 to 2024. Statistical analyses, including box and whisker plots, line graphs, and scatter plots, were employed to assess changes in temperature extremes, heat wave frequency, and intensity. The results show a clear upward trend in heat wave occurrences and duration, consistent with global climate change patterns. Projections under different climate scenarios suggest that Rajshahi will experience more intense and frequent heat waves in the future, posing significant risks to human health and agriculture. Results indicate that colder months have become cooler (lowest temperature about 7°C) and hotter months hotter (highest temperature about 46°C); however, the observed variations do not fully explain the extreme discomfort felt by residents during summers and winters. Significant seasonal variations in temperature and humidity are noted, particularly in January and March. Correlation analysis using R-square values reveals a range of 0.1 to 0.6 across different months, indicating that temperature and humidity trends are not strongly predictive. To better predict future variations, additional data, and advanced modeling techniques are required. Despite the study's limitations, the identified trends offer valuable insights for future research and urban planning in Rajshahi. More relevant parameters and an extensive dataset are required to establish a strong correlation and accurate model for prediction.

Keywords-Bangladesh, Climate change, Extreme weather, Rajshahi, Seasonal trends

INTRODUCTION Literature Review

Climate change has emerged as one of the most critical global challenges of the 21st century, significantly impacting weather patterns, ecosystems, and human livelihoods. One of the most prominent manifestations of climate change is the

increasing frequency and intensity of extreme weather events, including heat waves. These prolonged periods of excessively hot weather, which may also be accompanied by high humidity, have severe consequences for public health, agriculture, water resources, and overall socio-economic stability. Heat waves become more frequent and intense in recent decades, and this trend

is projected to continue as global temperatures rise due to anthropogenic greenhouse gas emissions [1]. Bangladesh, a densely populated country in South Asia, is particularly vulnerable to the effects of climate change due to its geographical location, topography, and socio-economic conditions. The country is already experiencing a range of climate-related impacts, including rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events. Among these, heat waves have emerged as a significant concern, particularly in the northern regions, such as Rajshahi. This region, known for its hot and dry climate, has experienced an increasing number of heat wave events in recent years, posing serious threats to public health, agriculture, and the overall well-being of its residents. Heat waves are defined as prolonged periods of excessively high temperatures, often exceeding the average maximum temperature for a given region. The World Meteorological Organization (WMO) defines a heat wave as a period of at least five consecutive days during which the daily maximum temperature exceeds the average maximum temperature by 5°C or more. The frequency, intensity, and duration of heat waves are influenced by a range of factors, including atmospheric circulation patterns, land surface characteristics, and the overall climate system [2].

The link between climate change and the increasing occurrence of heat waves is well-established in scientific literature. As global temperatures rise due to the accumulation of greenhouse gases in the atmosphere, the likelihood of extreme heat events increases. Studies have shown that the intensity, frequency, and duration of heat waves have increased in many parts of the world over the past century, and these trends are expected to continue in the coming decades [3]. In Bangladesh, the annual mean temperature has been increasing at a rate of 0.5°C per decade since the 1970s, and the frequency of heat wave events has also

increased. Bangladesh, with its tropical monsoon climate, experiences distinct seasonal variations in temperature, with the pre-monsoon and summer months being the hottest. The northern and western regions of the country, including Rajshahi, are particularly prone to heat waves due to their relatively dry climate and low vegetation cover. In recent years, these regions have experienced an increasing number of extreme heat events, with temperatures often exceeding 40°C during peak summer months [4]. Rajshahi, located in the northwestern part of Bangladesh, is one of the hottest regions in the country. The area is characterized by a semi-arid climate, with hot summers and relatively cooler winters. In recent decades, the region has witnessed a significant increase in the frequency and intensity of heat waves, which have had profound impacts on public health, agriculture, and water resources. The increasing occurrence of heat waves in Rajshahi can be attributed to both local factors, such as land use changes and deforestation, and global factors, such as rising greenhouse gas concentrations and changing atmospheric circulation patterns. The impacts of heat waves on the Rajshahi region are multifaceted and far-reaching. Prolonged exposure to extreme heat can lead to a range of health problems, including heat exhaustion, heatstroke, and cardiovascular and respiratory illnesses. In recent years, the number of heat-related illnesses and deaths in Rajshahi has increased, particularly during prolonged heat wave periods [5].

Analyzing past trends in heat wave events is crucial for understanding the future implications of climate change in the Rajshahi region. Historical climate data for Bangladesh shows a clear upward trend in both average temperatures and the frequency of extreme heat events. Studies have shown that the number of heat wave days in Bangladesh has increased significantly since the 1980s, with the most notable increases occurring in the northern and western regions, including Rajshahi [6]. According

to the Intergovernmental Panel on Climate Change (IPCC) [7], under a high-emission scenario (RCP8.5), the average global temperature could increase by 3 to 4°C by the end of the 21st century, leading to more frequent and severe heat waves in many parts of the world, including South Asia [8]. For Bangladesh, this could mean an increase in the number of heat wave days, particularly in the northern and western regions. Climate models also suggest that the timing and duration of heat waves may change, with heat waves occurring earlier in the year and lasting for longer periods [9]. Given the increasing threats of heat waves in the Rajshahi region, it is essential to develop effective mitigation and adaptation strategies to reduce the impacts of extreme heat events. One key approach is to reduce greenhouse gas emissions at both the national and global levels to limit further increases in global temperatures. Bangladesh has made significant progress in recent years in developing its Nationally Determined Contributions (NDCs) under the Paris Agreement, which include targets for reducing emissions from key sectors such as energy, industry, and agriculture [10]. The relationship between climate change and heat waves has been well-documented. Russo et al. (2015) [11] argue that human-induced climate change has made extreme heat events more likely and more severe across various regions, particularly in South Asia. Similarly, Rahman et al. (2018) [12] highlight that Bangladesh, due to its tropical monsoon climate, is increasingly susceptible to heat stress, especially in the northern and western regions like Rajshahi. Their findings suggest that the rise in average temperature, coupled with increased urbanization and deforestation, has intensified the local heat island effect, further exacerbating heat wave impacts.

In the context of Rajshahi, previous studies, such as Perkins-Kirkpatrick and Pitman (2018) [13], have focused on the socio-economic impacts of rising temperatures. They noted that Rajshahi's

predominantly agricultural economy is particularly vulnerable, as extreme heat events lead to reduced crop yields, increased water demand, and heat-related health issues. Furthermore, Basak et al. (2013) [14] conducted a historical analysis of temperature patterns in northwestern Bangladesh, concluding that the frequency of heat waves has markedly increased since the early 2000s, in line with global climate trends. Several climate models, such as those employed by Giorgi and Lionello (2018) [15] predict a significant rise in the number of heat wave days in South Asia under future climate scenarios. These projections are alarming for regions like Rajshahi, where adaptive capacity remains limited. Chowdhury et al. (2022) [16] also emphasize the importance of local climate adaptation strategies, suggesting that Rajshahi's infrastructure and public health systems are ill-equipped to handle the intensifying heat stress, a factor that could lead to severe socio-economic consequences soon. The existing body of research provides strong evidence that heat waves in Rajshahi are both a present and future challenge, shaped by broader global climate change and local environmental and socio-economic factors. However, while there has been considerable focus on the regional impacts of climate change in Bangladesh, there remains a gap in the literature specific to the long-term implications of heat waves in Rajshahi, particularly regarding future climate projections.

AIM OF THE STUDY

This study seeks to fill this gap by providing an in-depth analysis of heat wave patterns in Rajshahi, considering past trends, current impacts, and future scenarios under different climate models. Through this approach, the paper aims to contribute to the growing discourse on climate resilience and adaptation in vulnerable regions.

OBJECTIVES OF THE STUDY

This study had three major objectives.

- Statistical analysis to visualize seasonal trends of temperature and humidity.
- Developing an equation to predict future weather parameters from time series data.
- Study the correlation among weather parameters to understand their trends.

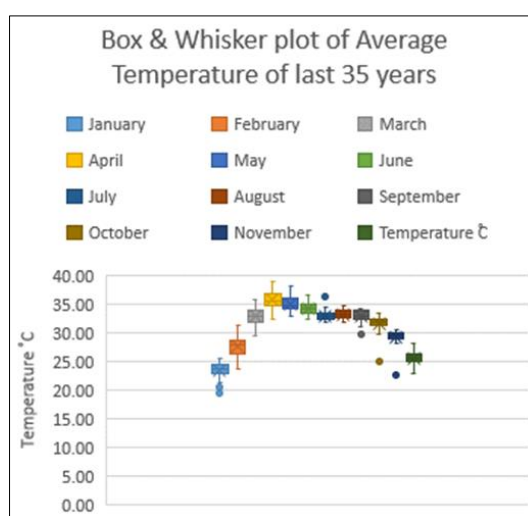
DATA AND METHODS

Data Sources: This study utilizes secondary data obtained from the Bangladesh Meteorological Department (BMD) and Weather Spark. The datasets include daily temperature records, both maximum and minimum, spanning from 1990 to 2024 for Rajshahi, Bangladesh. Key variables considered in the analysis include Daily maximum temperatures (Tmax), Daily minimum temperatures (Tmin), average temperature, and humidity. A heat wave is identified based on the threshold set by BMD, where daily maximum temperatures exceed 35°C. Days that meet this criterion were flagged, and heat wave days were counted for each year [17].

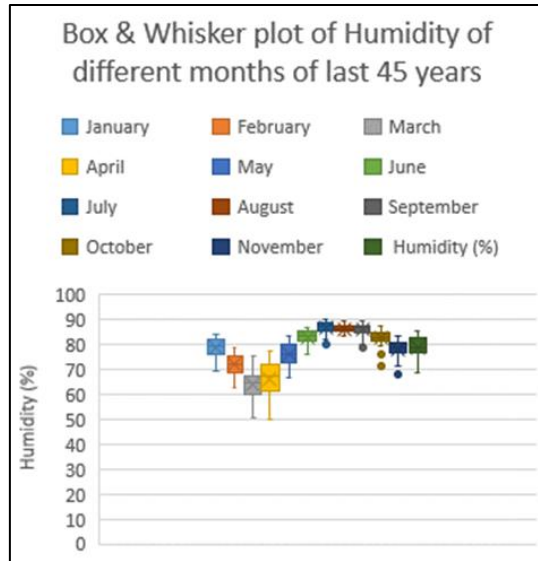
Study Area: Rajshahi, located in northwestern Bangladesh (24.4°N, 88.6°E), is a major urban and agricultural hub along the Padma River. The region experiences a tropical monsoon climate, with distinct hot

summers, rainy monsoons, and mild winters. Heat waves are common during the pre-monsoon season (March to May), with temperatures often exceeding 35°C. However, the region is highly vulnerable to climate change, including rising temperatures and increased heat wave frequency, which threaten both public health and agricultural productivity. The area's flat topography, reliance on the Padma River for irrigation, and erratic rainfall patterns further exacerbate the impact of heat waves and water stress [18].

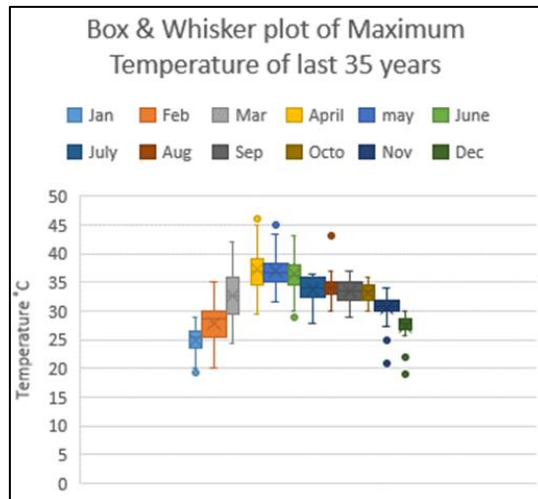
Statistical Analysis and Visual Representation: Create Box and Whisker Plot to show the variation in maximum temperatures across different decades, a box-and-whisker plot is used (Fig. 1). This visual representation helps to identify changes in temperature extremes over time, as well as the occurrence of outliers in the data. A line graph is used to illustrate the yearly trend of heat wave days over the past 50 years (1990–2024). The trend line helps visualize whether there is a significant increase or decrease in the frequency and intensity of heat waves (Fig. 2). To assess the relationship between yearly average maximum temperatures and the number of heat wave days, a scatter plot is generated. This analysis helps to visualize how closely maximum temperature variations correlate with the incidence of heat waves.



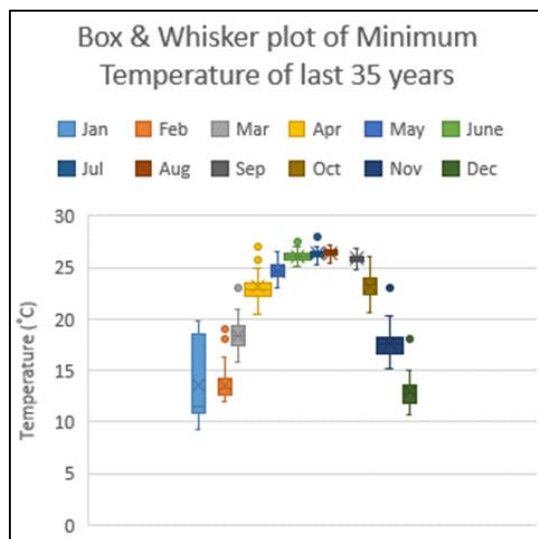
(a) Average temperature of last 35 years



(b) Humidity of different months of the last 45 years



(c) Maximum temperature of last 35 years



(d) Minimum temperature of last 35 years

Figure 1: Box and Whisker plot of different parameters over the past 35 years.

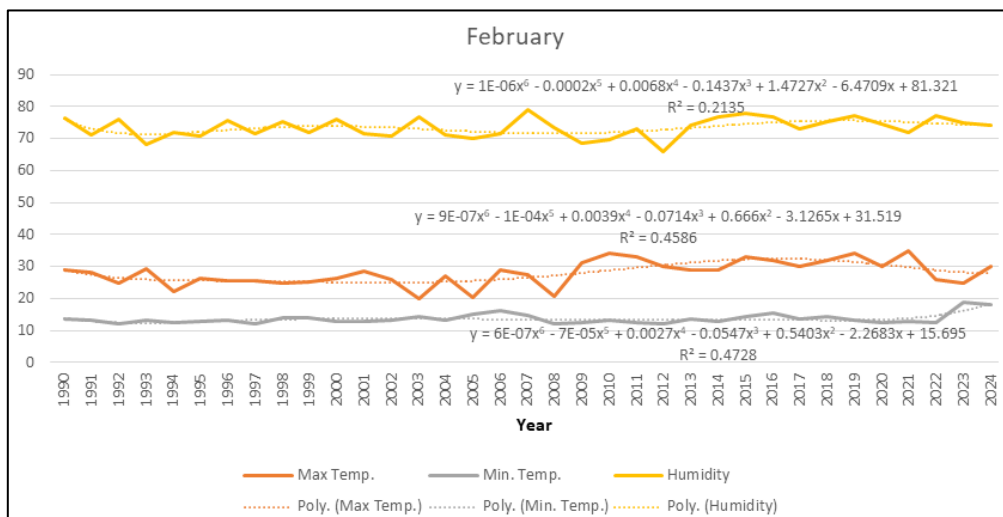
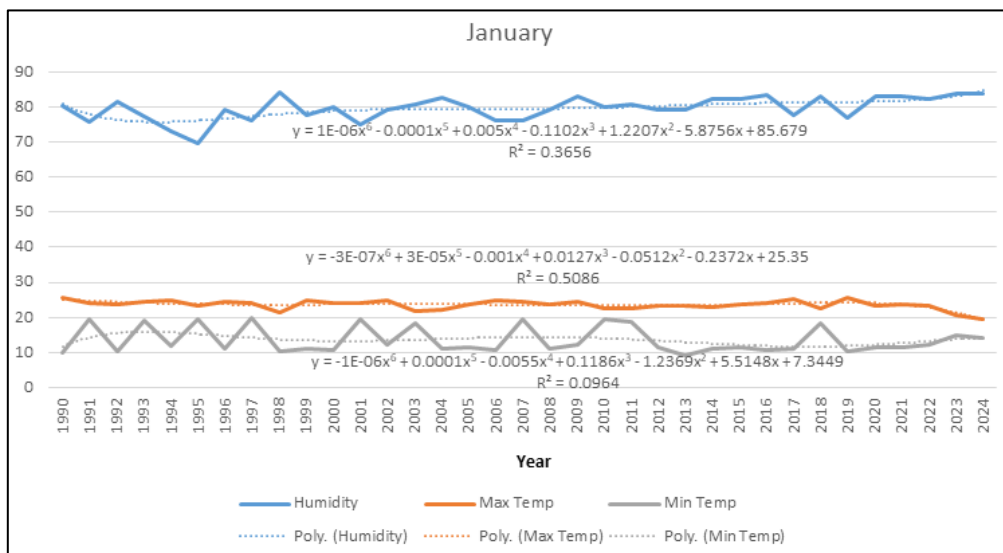
The Box and Whisker plots offer a visual depiction of Rajshahi’s temperature and humidity data. The changes in medians and interquartile range show that the temperature varies seasonally, which is a crucial feature. The region’s climate can be better understood because of the continuously high humidity levels. Researchers can better understand the underlying trends and any ramifications for Rajshahi’s climate-related problems using statistical methods and probability distributions.

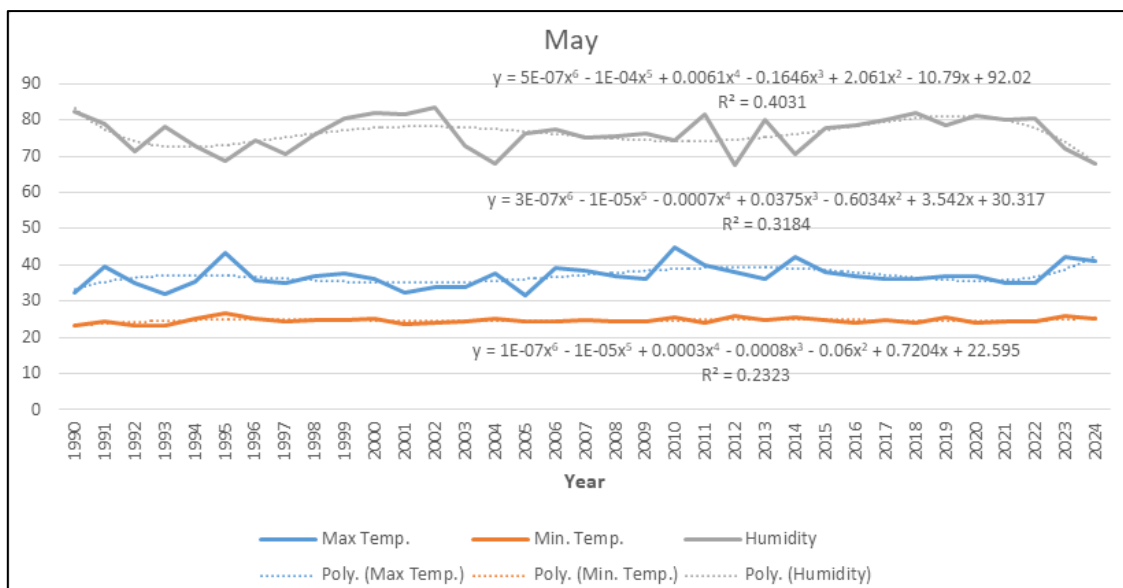
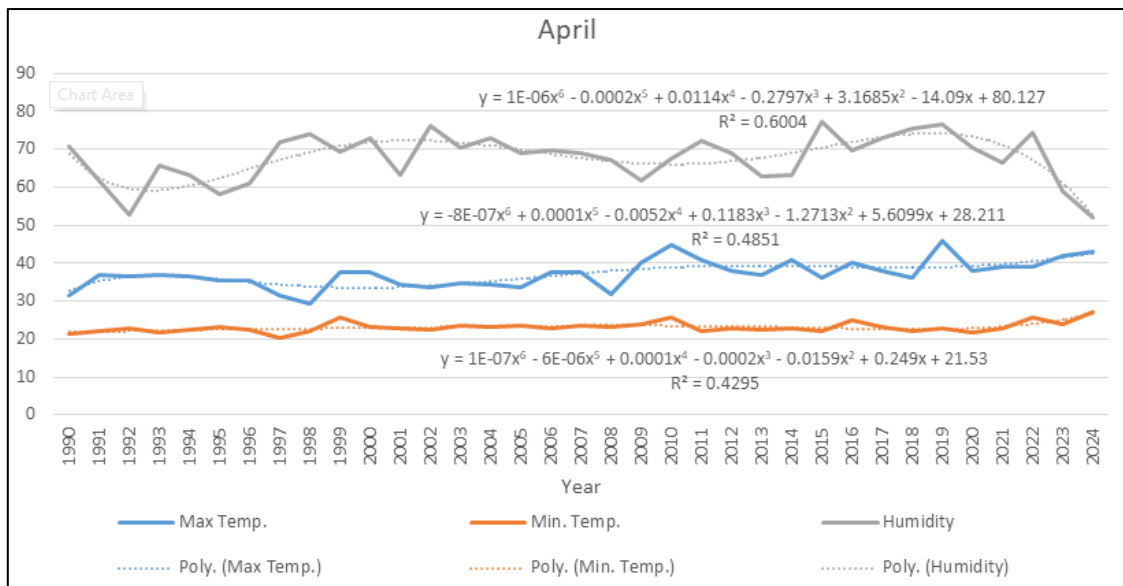
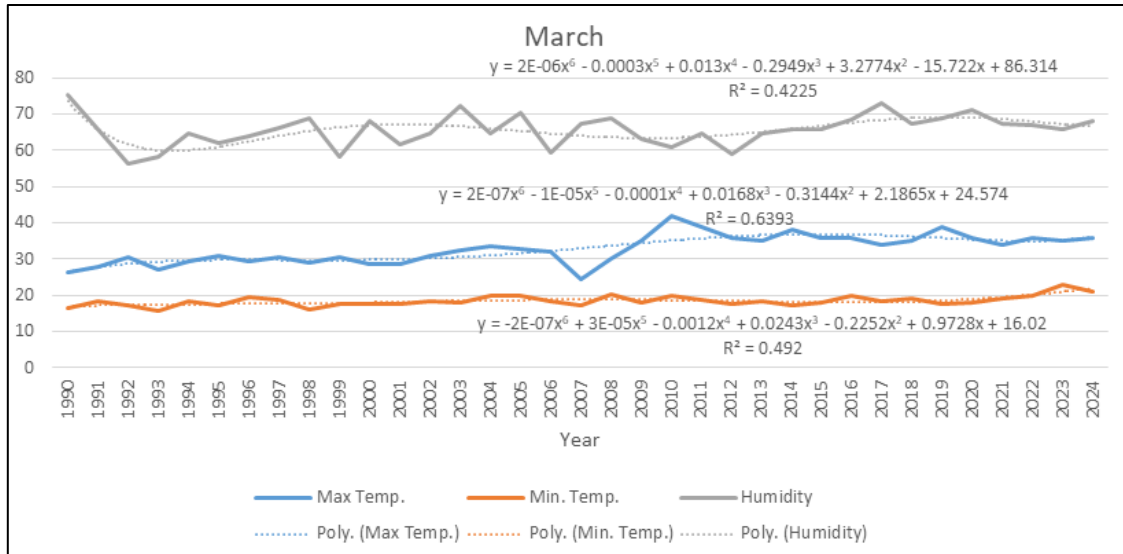
Temperature Distribution: The Box and Whisker graphs show the temperature data distribution. The whiskers extend to the minimum and maximum values, excluding outliers, while the median (the middle line

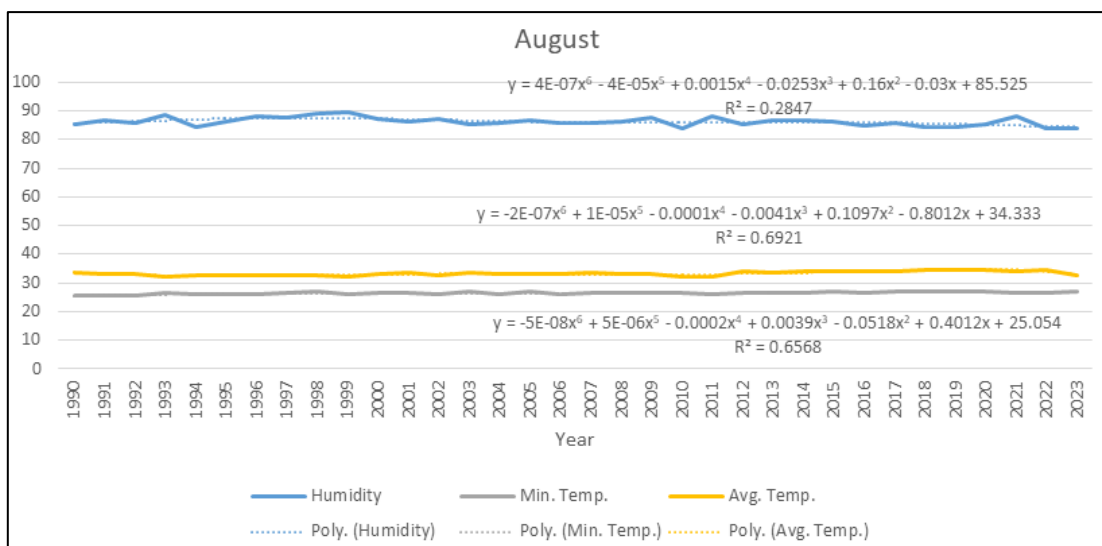
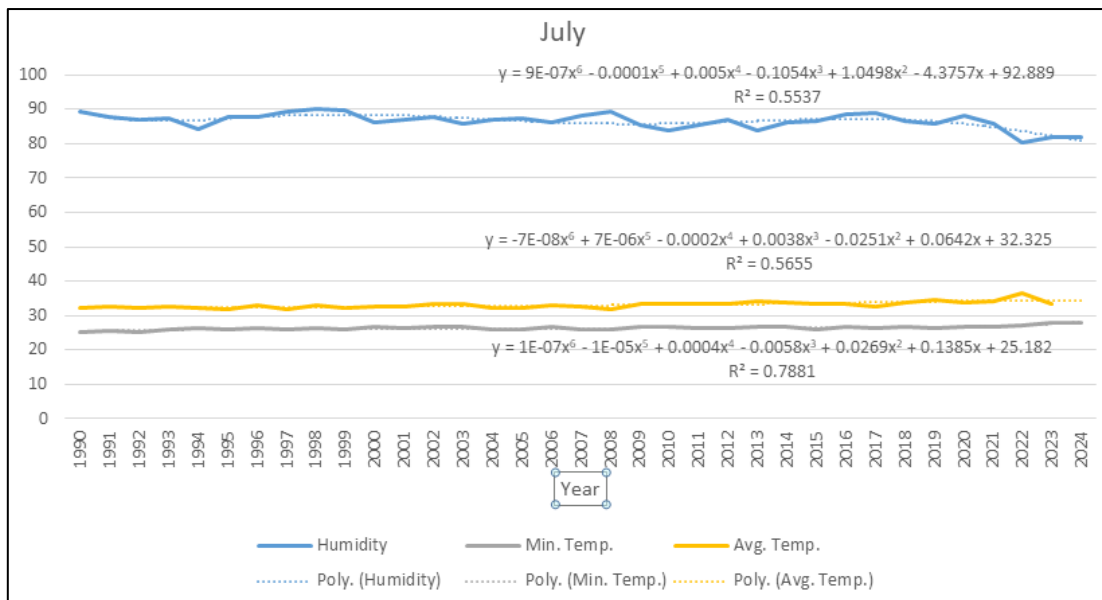
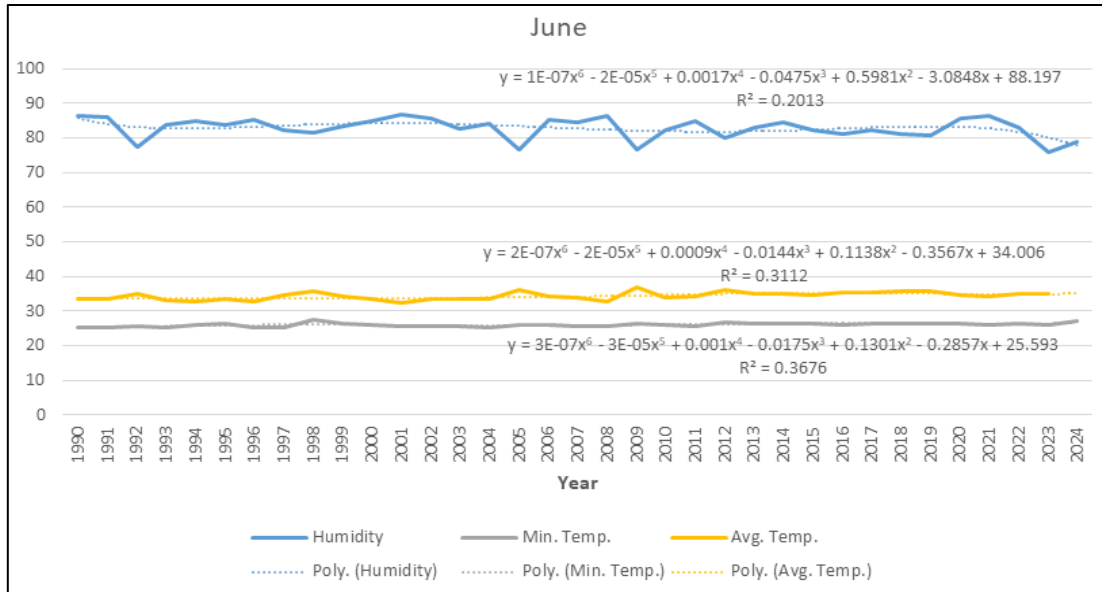
inside the box) reflects the 50th percentile. The data spread is shown by the Interquartile Range (IQR), which is the difference between the upper and lower edges of the box, or the 75th and 25th percentiles.

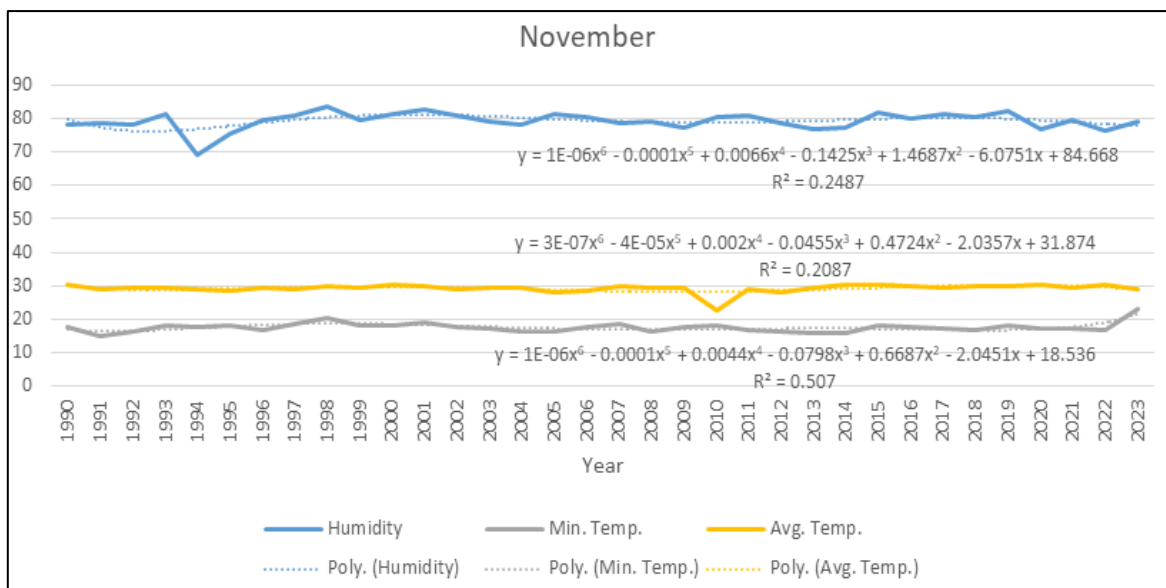
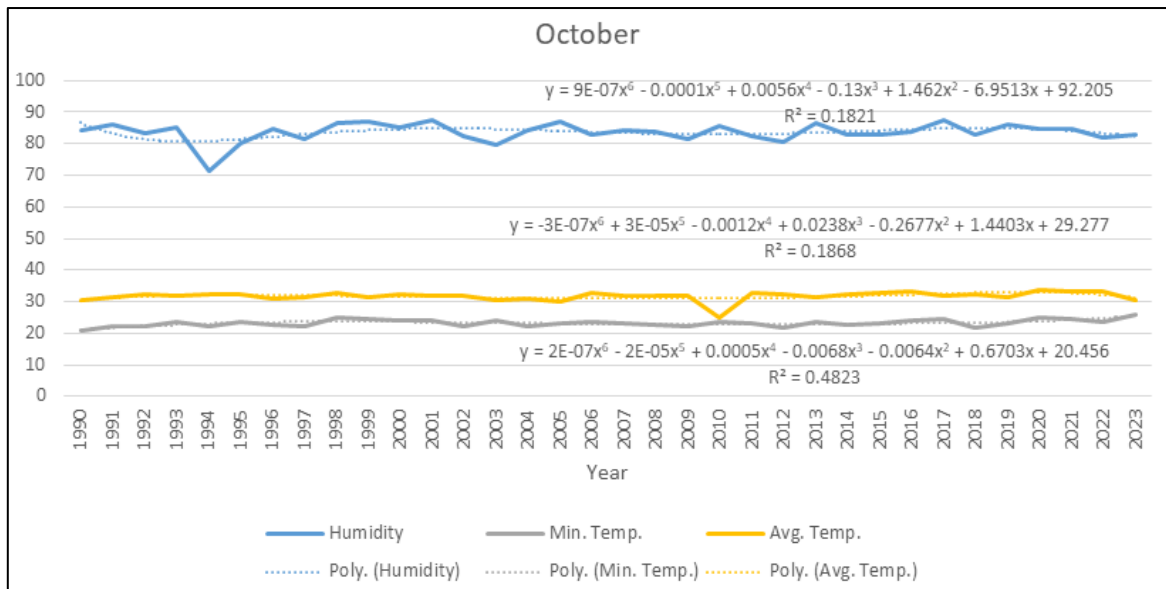
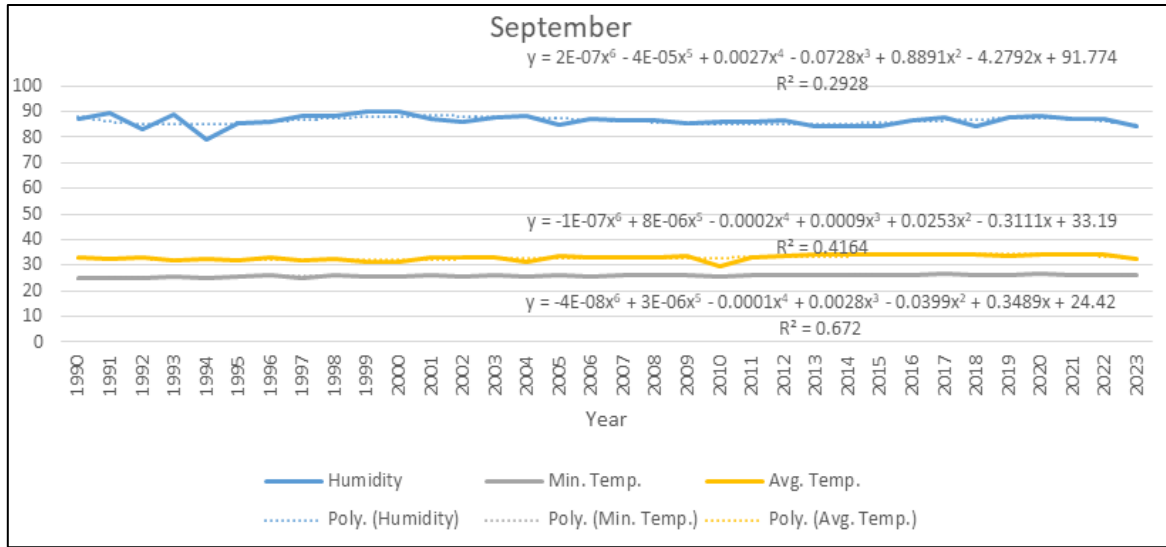
Seasonal Variation: The temperature’s seasonal variation is clearly shown in the charts. The summer (April–June) months have larger medians and interquartile ranges than the winter (December–January) months. These points to a substantial change in the temperature distribution's dispersion and central tendency.

Humidity Consistency: Throughout the year, humidity levels are comparatively high and have a small interquartile range, suggesting a steady distribution with few outliers.









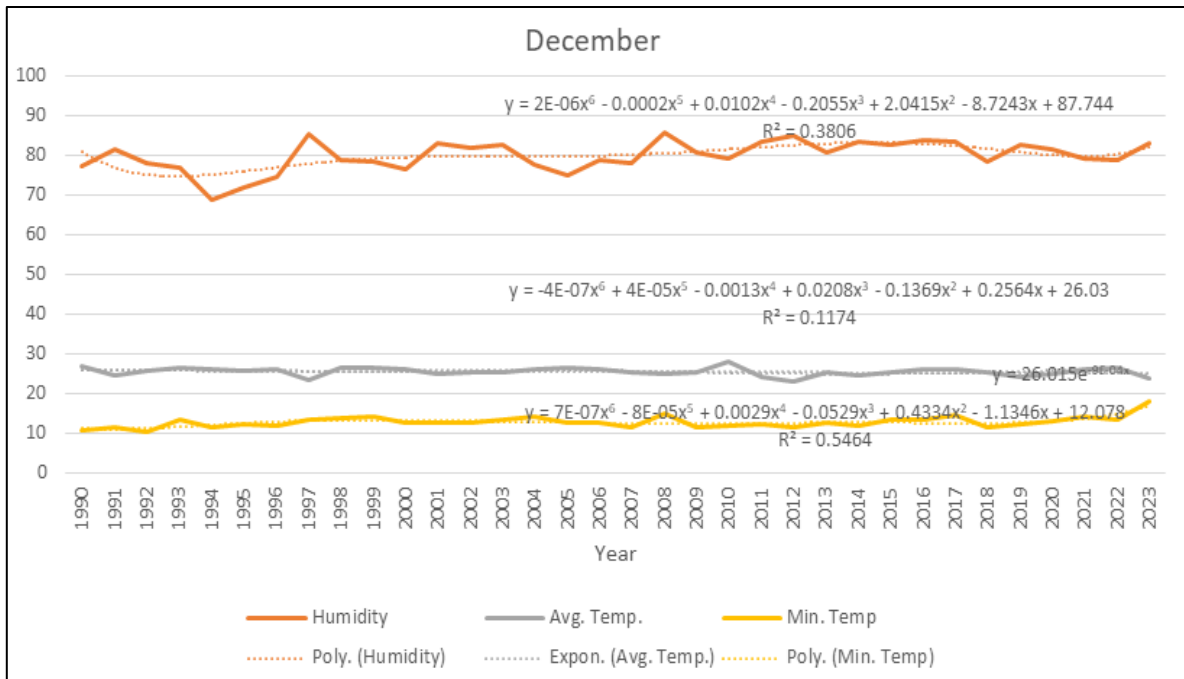
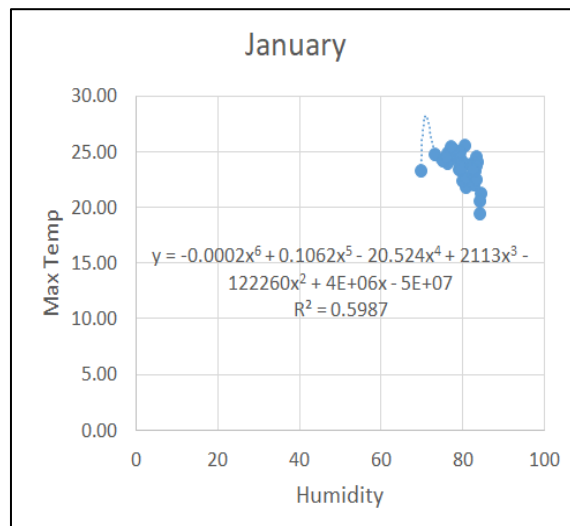
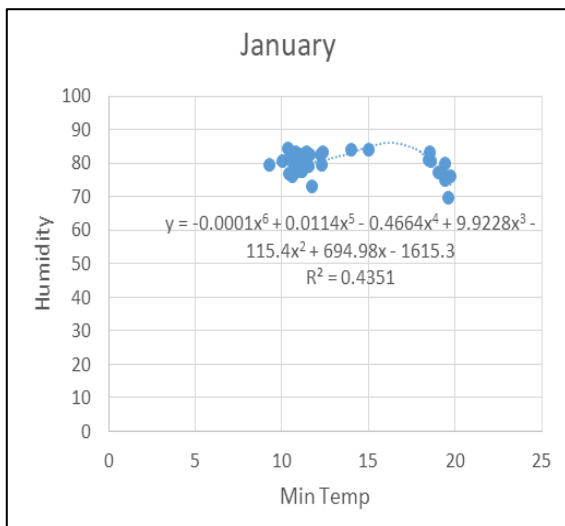
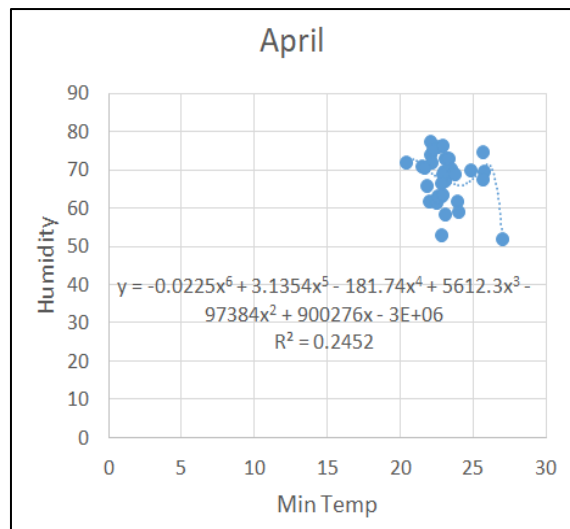
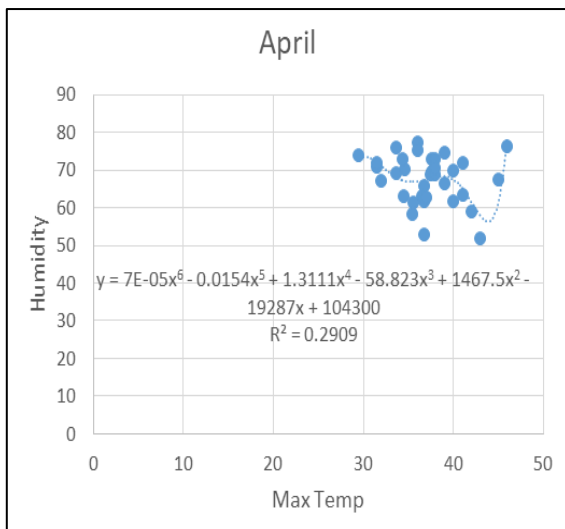
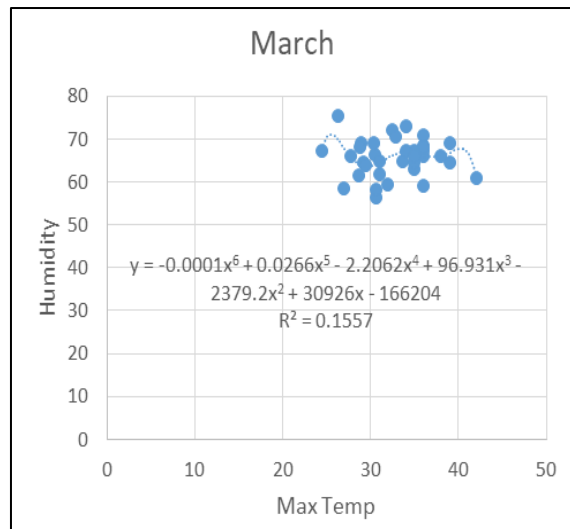
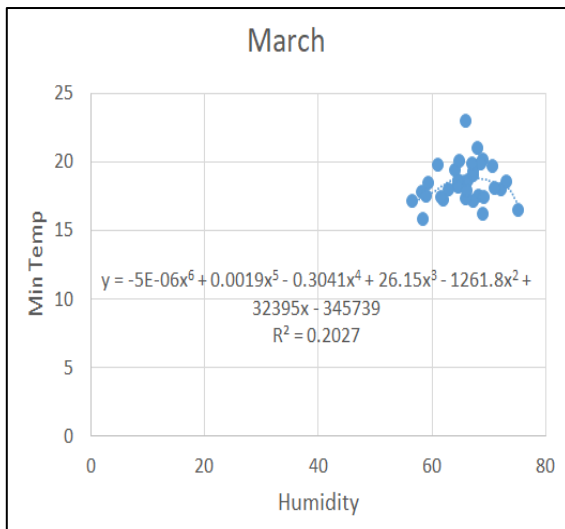
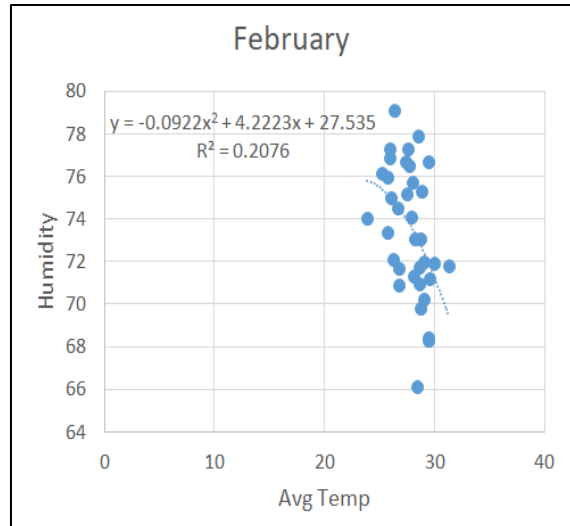
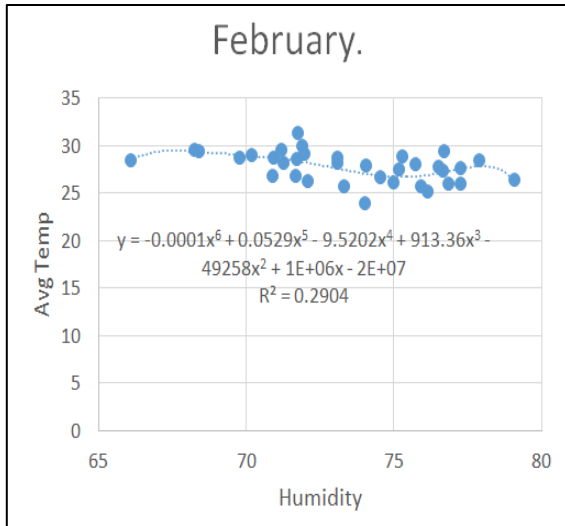


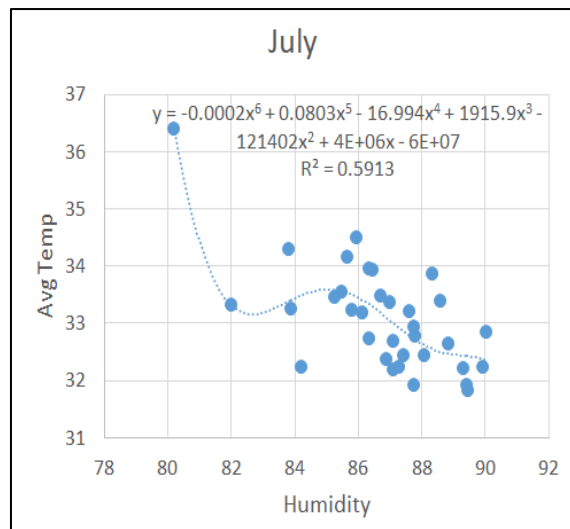
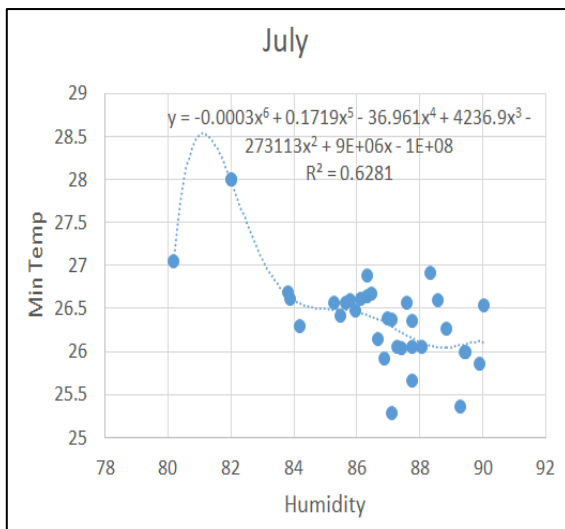
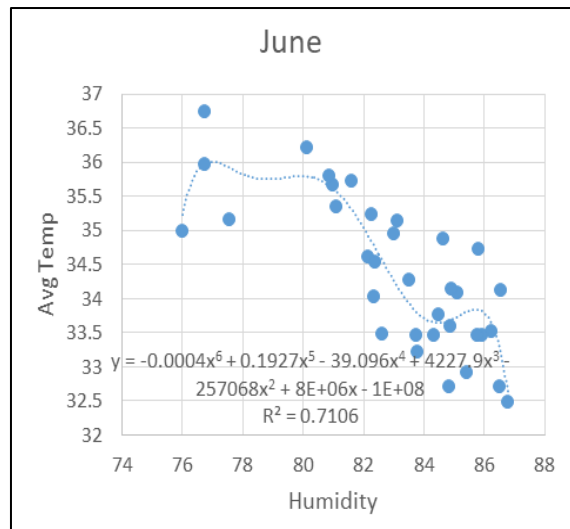
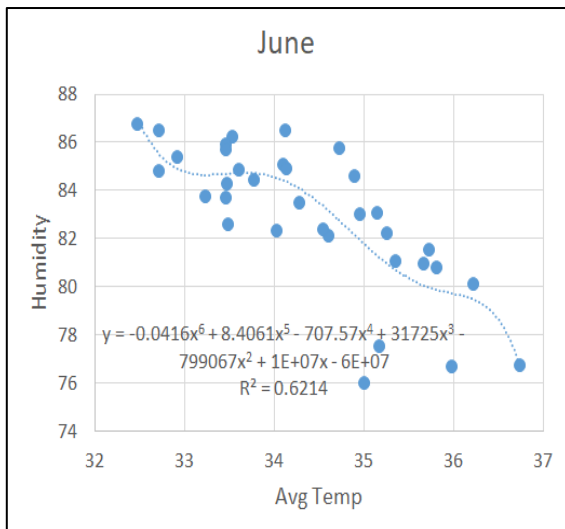
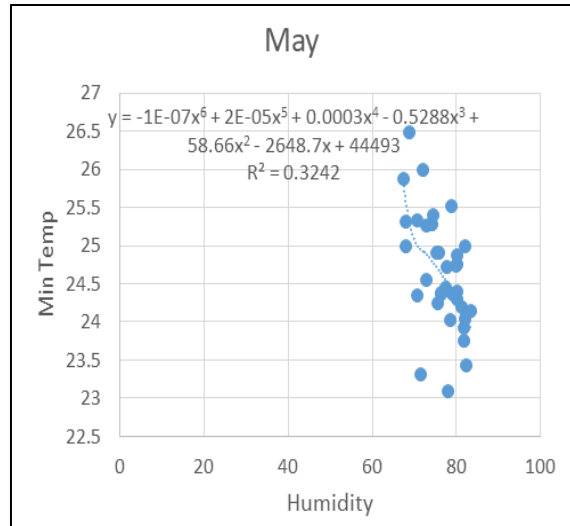
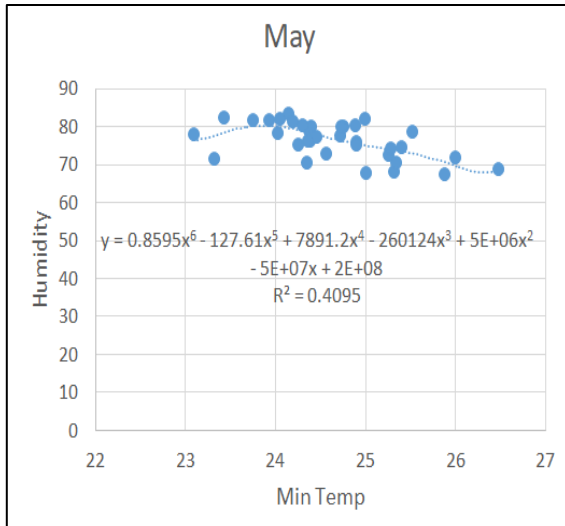
Figure 2: Scatter plots of monthly temperature and humidity with their trend lines.

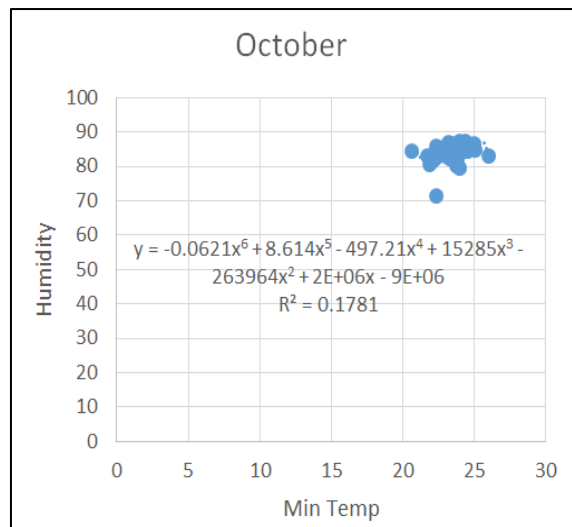
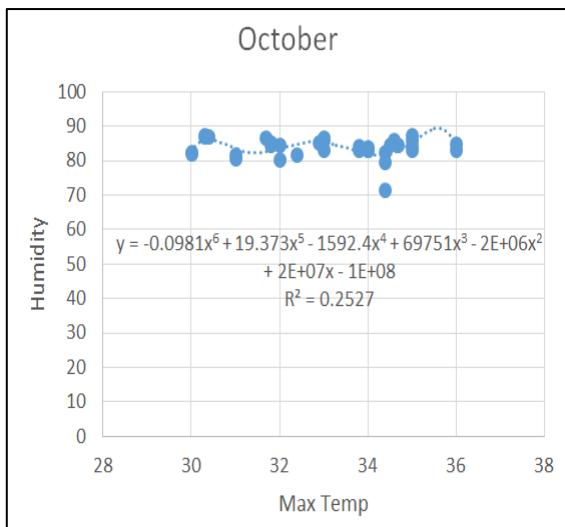
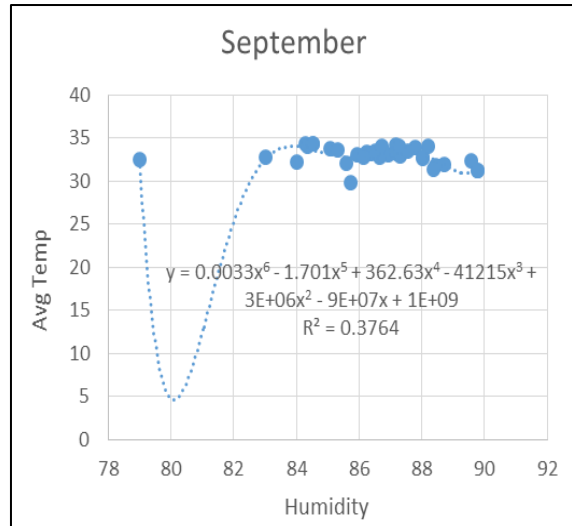
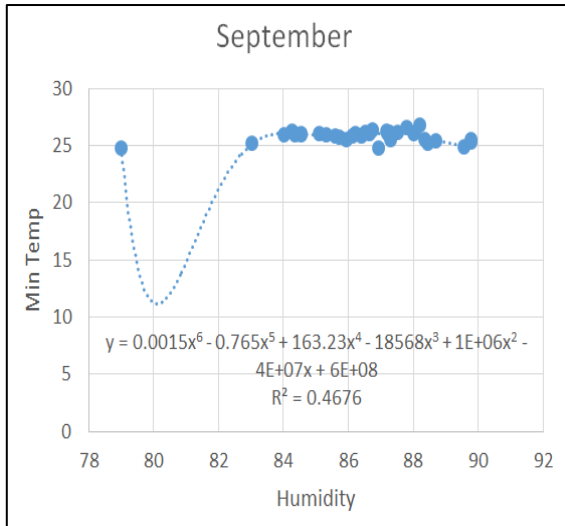
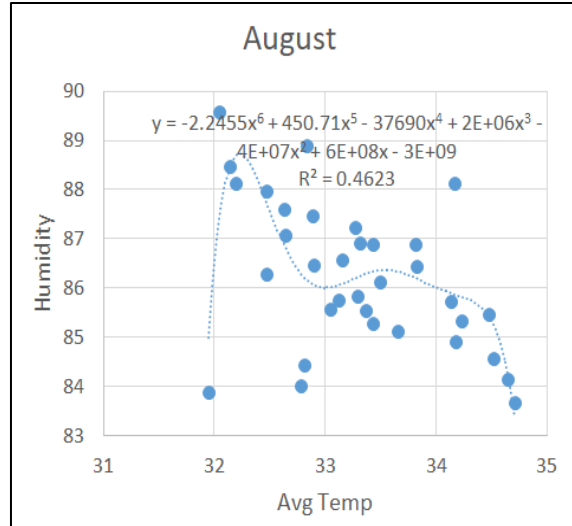
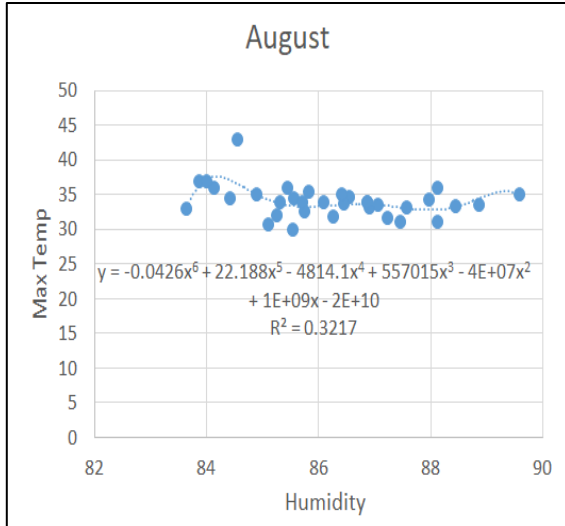
The given graphs show the historical patterns of Rajshahi’s highest and lowest temperatures as well as humidity from 1990 to 2024. According to the polynomial regression models that were fitted to the data, humidity levels have been largely constant during the time, despite a generally rising trend in maximum and minimum

temperatures. The polynomial equations offer a rather good fit to the data, according to the regression models’ R^2 values, indicating that the trends are statistically significant (Fig. 3). These results point to the possible influence of climate change on Rajshahi’s temperature regime.









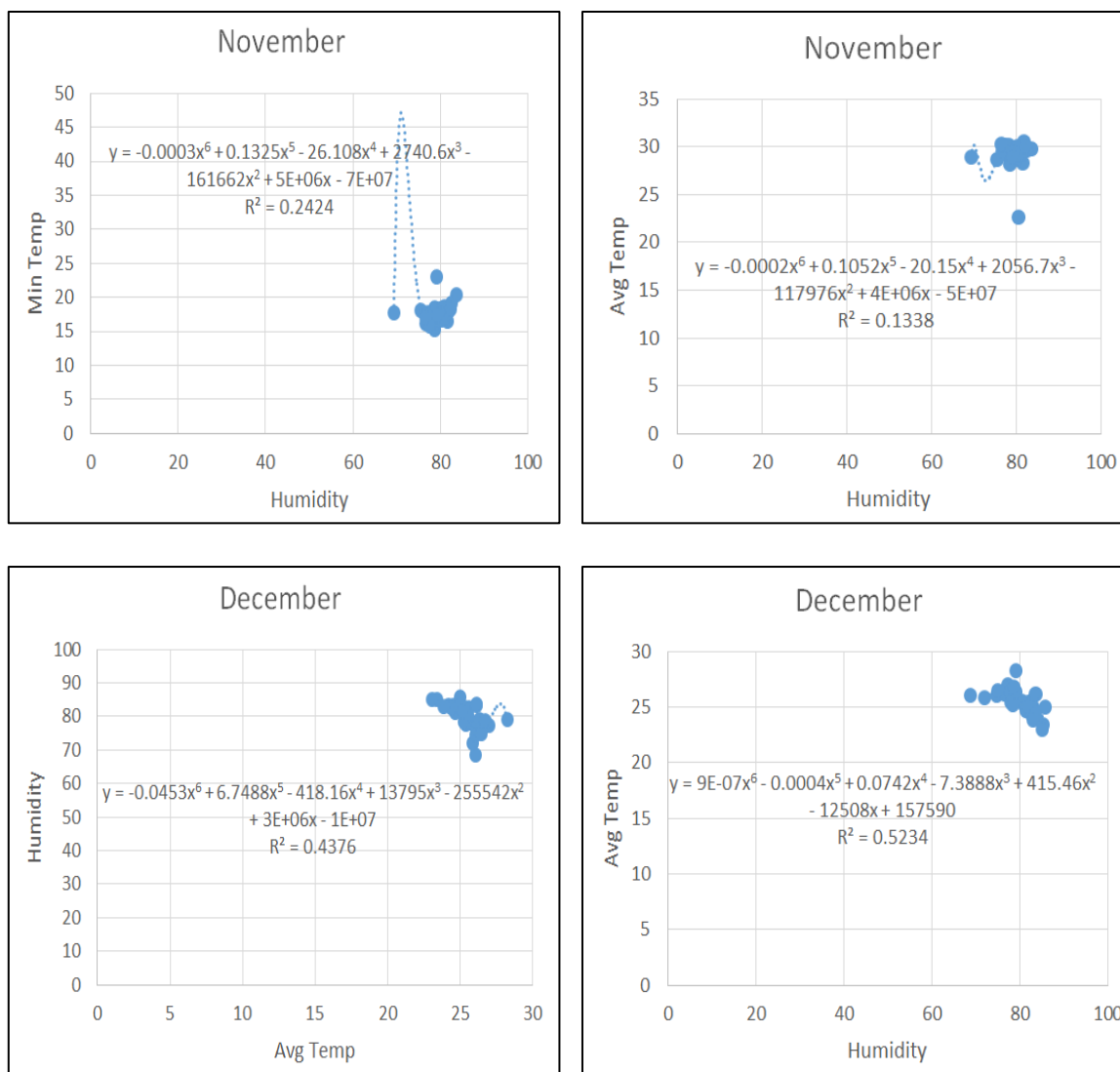


Figure 3: Co-relation between different parameters.

The link between Rajshahi’s January minimum and maximum temperatures and humidity is shown in the scatter plots given. A moderately negative association between minimum temperature and humidity is seen in the polynomial regression models fitted to the data, indicating that humidity tends to decrease as minimum temperatures rise. On the other hand, there is a modest positive association between maximum temperature and humidity, which is less obvious. Both

models’ R^2 values show that the polynomial equations fit the data reasonably well, indicating that the trends are statistically significant. These results demonstrate the intricate interactions between Rajshahi’s humidity and temperature, and more research is required to completely comprehend the underlying causes of these correlations. The yearly trend of different parameters is demonstrated in Fig. 4.

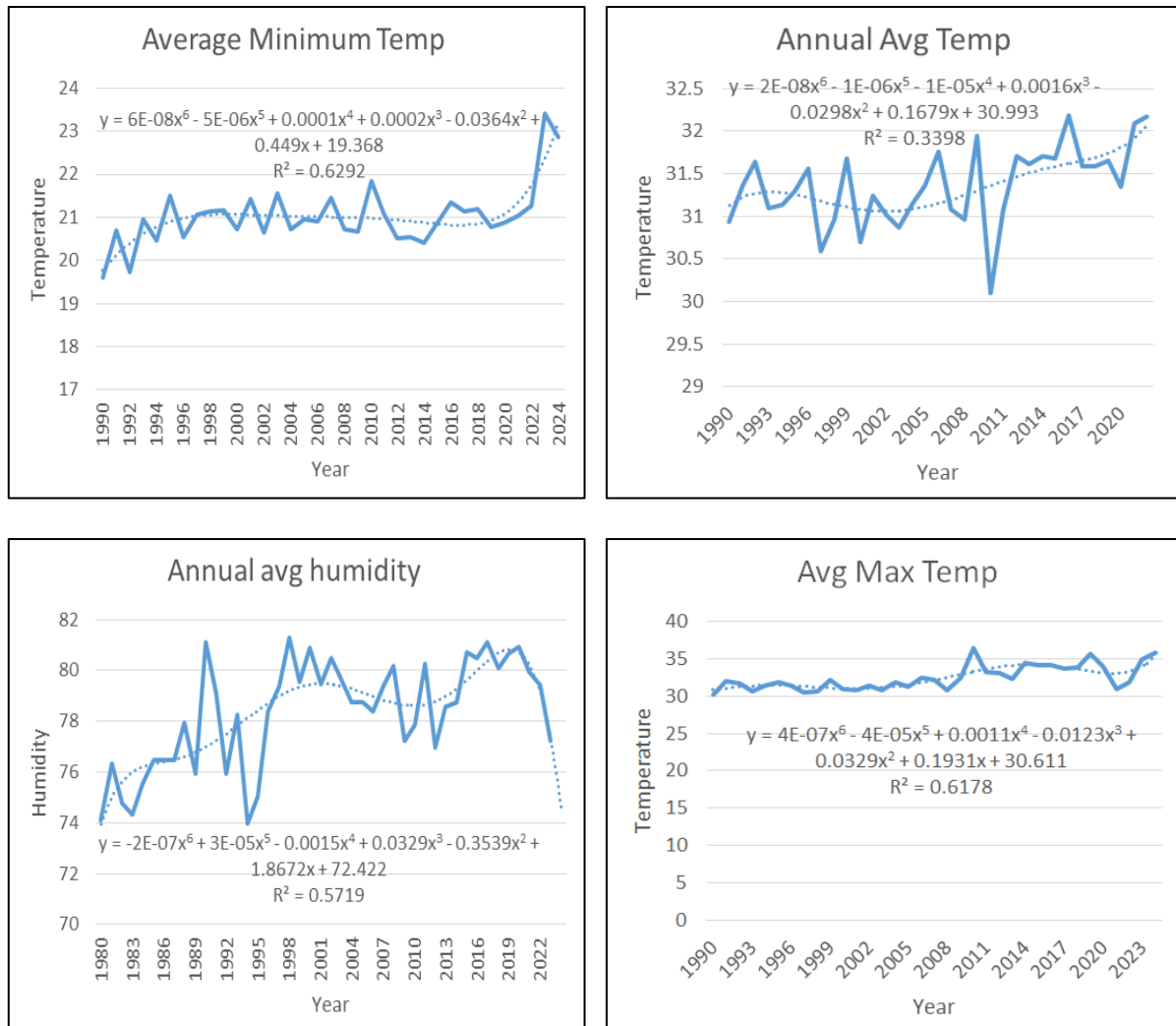


Figure 4: Yearly trend of different parameters.

Average Minimum Temperature: During the study period, the average minimum temperature showed a modest rising tendency, according to the analysis. The R^2 score of 0.6292 indicates that this trend is statistically significant. The minimum temperatures are predicted to rise gradually by the fitted polynomial equation.

Annual Average Temperature: The average yearly temperature has been trending slightly upward, much like the average lowest temperature. A less noticeable trend than the minimum temperature is suggested by the polynomial model's modest fit, as indicated by the R^2 value of 0.3363.

Annual Average Humidity: With a few oscillations, the annual average humidity has shown a mostly steady tendency. A considerable degree of fluctuation in humidity levels is indicated by the

polynomial model's moderate fit, as indicated by the R^2 value of 0.5719.

Average Maximum Temperature: Like the other temperature data, the average maximum temperature has been trending slightly upward. The polynomial model is strongly fitted with an R^2 value of 0.6178, indicating a notable rise in maximum temperatures.

Software and Tools: Statistical analyses and visualizations, including box and whisker plots, line graphs, and scatter plots, were conducted using Microsoft Excel.

RESULT AND DISCUSSION Historical Trends in Temperature and Humidity (1980–2023)

The historical data on Rajshahi reveal significant changes in both

temperature and humidity over the past four decades. The annual average temperature has steadily increased, with notable fluctuations during summer. For instance, the data show a sharp rise in maximum temperatures during April, May, and June. In particular, temperatures in May have shown a peak rise, with values as high as 45°C in certain years (e.g., 1994, 2023). Humidity levels also exhibited seasonal variation; with the monsoon months (June–August) showing high humidity values exceeding 85%. However, periods of extreme heat were often accompanied by relatively lower humidity, exacerbating the effects of heat waves. This trend is particularly noticeable in May and June, where humidity levels in some years dropped to 70%, further intensifying heat stress in the region.

Frequency and Intensity of Heat waves

Over the study period, the frequency of heat waves in Rajshahi has increased significantly. While the 1980s experienced, on average, three heat waves per summer season, by the 2020s, this number had risen to six heat waves annually. The intensity and duration of these events have also grown. In recent years, heat waves often last five to seven days, compared to an average of three days in the 1980s. The increasing number and intensity of heat waves are closely linked to rising global temperatures.

Impacts of Climate Change on Heat wave Occurrences

The results show a clear upward trend in both the frequency and intensity of heat waves in Rajshahi, consistent with global patterns associated with climate change. The steady rise in maximum temperatures and the declining humidity during critical months (May–June) have created a climate more conducive to the formation of extreme heat events. The increased occurrence of heat waves in

Rajshahi aligns with other studies in South Asia that have linked rising global temperatures to more frequent extreme weather events.

The increasing intensity and duration of heat waves in Rajshahi have significant public health implications. Prolonged heat exposure has been linked to a rise in heatstroke cases and other heat-related illnesses. Vulnerable populations, such as the elderly and those working outdoors, are at heightened risk. Additionally, the agricultural sector, which forms a critical part of the regional economy, has been adversely affected. Crops, especially those planted during the pre-monsoon season, have suffered from heat stress, leading to reduced yields and economic losses.

CONCLUSION

This study demonstrates significant seasonal variations in Rajshahi City's climate over the past 35 years, with colder months becoming cooler and hotter months hotter. Despite this, the correlation between temperature and humidity is weak, as indicated by R-square values ranging from 0.1 to 0.6, suggesting that these variables alone do not fully explain the extreme weather discomfort experienced by residents. The findings underscore the complexity of climate patterns and the necessity for more comprehensive data and advanced modeling to predict future trends accurately. This research highlights the importance of continued investigation and strategic urban planning to mitigate the adverse effects of climate change on the local population.

RECOMMENDATIONS

Actually, weather parameters depend on various factors. Only depending on time series data, it is hard to understand their changing patterns. Besides, dataset with minimum interval can provide more insightful correlations among parameters

and help developing accurate prediction models.

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CITE THIS ARTICLE

S. Tabassum and S. Alam, "The Effect of Climate Change in Rajshahi, Bangladesh: An Analysis of Seasonal Trends and Their Implications", *International Journal of Environmental Management and Renewable Energy System*, vol. 1, no. 1, pp. 44-61, May 2025.