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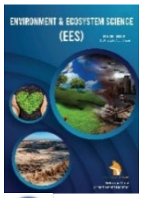

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RESEARCH ARTICLE

ANALYSIS OF TEMPERATURE TREND IN KHULNA DISTRICT OF BANGLADESH

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ABSTRACT

This study examines the trends in monthly maximum, minimum, and average temperatures over a 20-year period (2003-2022) in Khulna district, Bangladesh. The temperature data were sourced from the Regional Inspection Center (R.I.C) of the Bangladesh Meteorological Department, Gollamary, Khulna. The aim was to assess temperature deviations in the district over time. Using linear trend analysis, long-term temperature changes were evaluated. The annual mean maximum, minimum, and average temperatures showed increasing trends when plotted against the years, though the year-to-year variability was not statistically significant. The regression equations obtained for maximum, minimum, and average temperatures were: ($y = 0.0251x - 19.006$, $R^2 = 0.1525$), ($y = 0.0177x - 8.789$, $R^2 = 0.1492$), and ($y = 0.0098x + 2.5477$, $R^2 = 0.0476$), respectively. A bimodal dispersion pattern was observed across all three temperature aspects throughout the months during 2003-2022. Monthly temperatures (maximum, minimum, and average) did not follow a consistent pattern, as shown by the linear regression analysis, with both increasing and decreasing trends identified over the two decades. May was found to be the warmest month, while January was the coldest when considering mean monthly maximum and average temperatures. Furthermore, the highest upsurge in mean monthly average temperature was recorded in July (0.0539^{0}C), while the bulk reduction was detected in February (0.0367^{0}C). Principal component analysis indicated that the first two components accounted for 93% of the total variation. The study recommends further temperature monitoring methods due to observed instability in temperature.

KEYWORDS

Bangladesh, Khulna District, Temperature, Trend

1. INTRODUCTION

Climate change has emerged as one of the greatest challenges to sustainable development, with its effects- such as rising sea levels, melting polar ice caps, wildfires, and extreme droughts- being felt across various regions of the world (Dioha and Kumar, 2020; Ali et al., 2013). Temperature and rainfall are two key climatic parameters used to assess the impact of climate change in any given area (Cannarozzo et al., 2006; Machiwal et al., 2016). Understanding changes in temperature patterns and trends from different spatial perspectives has become crucial in global climatological, hydrological, and meteorological research (Kumar et al., 2010; Jain and Kumar, 2012; Saboohi et al., 2012; Jain et al., 2013; Deka et al., 2013; Goyal, 2014; Rao et al., 2014; Talaee, 2014; Xia et al., 2015; Chatterjee et al., 2016; Tian et al., 2017; Yang et al., 2017). Bangladesh, a South Asian country, ranks among the most climate-vulnerable nations due to its unique geographic position, flat riverine topography, widespread floodplains, low elevation, high population density, and heavy reliance on agriculture. The 2021 Global Climate Risk Index by Germanwatch ranks Bangladesh 7th among countries most at risk from climate disasters (Chowdhury, 2023).

Bangladesh experiences a humid, warm climate with significant periodic variations in precipitation, high temperatures, and humidity. The country primarily has three distinct seasons: i) a hot and humid summer from March to June, ii) a hot and rainy season from June to November, and iii) a cool, dry winter from December to February (Bosu et al., 2020). Average temperatures in Bangladesh range from 23.9°C to 31.1°C in summer and from 7.2°C to 12.8°C in winter (Shahid, 2010). Summer temperatures can reach between 38°C and 41°C, with April being the hottest month, while January is the coldest month. During winter, the average daytime temperature is between 16°C and 20°C, dropping to around 10°C at night (Agrawala et al., 2003).

Over the past century, Bangladesh has experienced a temperature increase of 0.5°C (Ahmad et al., 1996), while a separate study found a rise of 0.3°C in the mean annual temperature between 1895 and 1980 (Parthasarathy et al., 1987; Mehrotra and Mehrotra, 1995). Both summer and winter temperatures have shown an upward trend (Islam and Neelim, 2010). By 2050 and 2100, the mean annual maximum temperature in Bangladesh is projected to rise by 0.4°C and 0.73°C, respectively (Karmakar and Shrestha, 2000).

The variability of mean annual temperatures in Bangladesh closely follows that of the Northern Hemisphere, with warming observed from 1910 to 1940, a slight cooling until the mid-1970s, and a resumption of warming thereafter (Folland et al., 1990; 1992). Between 1979 and 1991, 12 of 13 years were warmer than the reference period. Recent research indicates that both yearly mean maximum and minimum temperatures are on the rise, placing Bangladesh at significant risk due to its disaster-prone nature and low-lying topography (Basak et al., 2013; Elahi and Khan, 2015).

Agriculture plays a crucial role in Bangladesh's economy and the livelihoods of its people. The sector contributes 12.91% to the nation's GDP, supports poverty reduction, and ensures food security. Approximately 42.7% of the population is employed in agriculture, with around 60% relying on it for their livelihoods (Chowdhury, 2023). The productivity of agriculture in Bangladesh is heavily influenced by climate, as the sector is largely dependent on natural conditions. Projected climate change impacts, such as rising temperatures, shifts in precipitation patterns, and extreme weather events like droughts and floods, are

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expected to directly affect crop yields (Abrol and Ingram, 1996; Adams et al., 1998; Mendelsohn, 2008; Mendelsohn and Reinsborough, 2007; Mendelsohn et al., 1994).

Khulna district, located in the southwest coastal region of Bangladesh, is characterized by low-lying areas surrounded by man-made polders and is highly vulnerable to climate change-induced hazards. The region encounters significant socio-economic challenges and is susceptible to to natural disasters such as high temperatures, heavy rainfall, flooding, cyclones, salinity intrusion, and drought (Bhuiyan et al., 2018). To address the impacts of climate change, Bangladesh requires effective policy responses that focus on adaptation. Empowering local people and utilizing local resources are indispensable for sustainable adaptation to climate change impacts. Monitoring climate variability and its effects at the local level, while empowering communities to develop their own adaptation strategies, is the most operative way to build resilience.

Although many studies have scrutinized climate change at the national and international levels, few have focused on local impacts (Alam et al., 2010; Rakib, 2018; Rashid et al., 2014; Shahid, 2010; Shirin et al., 2022; Khattak and Ali, 2015; Lacerda et al., 2015; Kruger and Nxumalo, 2017; Byakatonda et al., 2018; Cattani et al., 2018; Abaje and Oladipo, 2019). Some researcher explored climate change and its effects on natural calamities and the southwest monsoon in Bangladesh, revealing an increase in the decadal average yearly temperature, particularly after 1961-1970 (Karmakar and Nessa, 1997). A study found that the Dhaka division (Dhaka, Faridpur, and Mymensingh stations) showed a stronger positive temperature trend compared to the Khulna division (Mondal et al., 2018).

This study aims to analyze how climate change manifests at the local level in the Khulna district of Bangladesh. Specifically, it seeks to assess the temporal variability and trends in temperature over the past two decades to better comprehend local climate changes. Understanding these temperature trends at the local level will deliver valuable intuitions for anticipating the effects of climate change and developing appropriate coping strategies for the local inhabitants.

2. Research Gap

Atmospheric temperature is one of the most critical weather elements, influencing the environmental conditions of a region and impacting crop production. Statistical and trend analyses of temperature play a key role in accepting climate change. Numerous studies worldwide have assessed temperature variability and trends to gauge climate change effects. However, limited research has focused on climate variability in southern Bangladesh, particularly in Khulna district. The primary goal of this study was to examine temperature variability in Khulna district using regression analysis. Additionally, we analyzed trends in monthly minimum, maximum, and average temperatures by applying both regression analysis and Principal Component Analysis (PCA).

3. Methodology

3.1 Study Area

Khulna district is located between 21°41' and 23°00' N latitudes and 89°14' to 89°45' E longitudes, at an elevation of 8.17 m above sea level (Figure 1) (Banglapedia, 2023). The region experiences a tropical savanna climate, characterized by generally flat plains. With an average daily maximum temperature exceeding 30°C, Khulna ranks among the warmer districts in Bangladesh. The average annual temperature is 25°C, peaking at 35.5°C in June and dropping to a low of 12.5°C in January (Wikipedia, 2024; Weather and Climate, 2024).

3.2 Data Collection and Tabulation

This study relied on secondary data, with temperature records sourced by the researchers from the Regional Inspection Center (R.I.C) of the Bangladesh Meteorological Department (BMD) in Gallamary, Khulna. Monthly data on maximum, minimum, and average temperatures (in degrees Celsius) were collected for the period 2003-2022. The data was carefully compiled and rigorously analyzed after collection. A master sheet was then prepared to organize the data, consolidating all individual variables into a unified dataset.

3.3 Data Analyses

A trend refers to the overall direction of a data sequence over an extended period or the long-term change in a dependent variable over time (Webber and Hawkins, 1980). In this study, trends were identified by analyzing the relationship between temperature and time. Regression analysis was used to explore the functional relationship between the years and the mean maximum, minimum, and average temperatures. Additionally, the mean, standard deviation, and coefficient of variation for monthly maximum, minimum and average temperatures were calculated using MS Excel software. Principal Component Analysis (PCA) was also applied to assess the contribution of these three temperature variables to total variability.

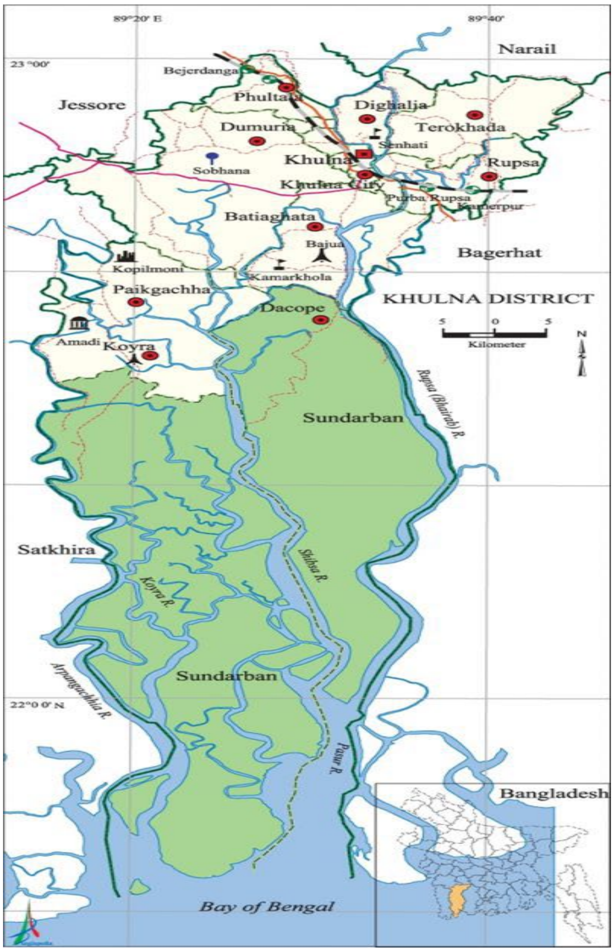


Figure 1: Map of the study area (Khulna district of Bangladesh). (Source: Banglapedia, 2023).

4. Results and Discussion

4.1 Variability in Mean Annual Temperatures

Table 1 presents the variability in the mean yearly maximum, minimum, and average temperatures in Khulna from 2003 to 2022. The data shows that the distribution pattern of yearly mean temperatures (°C) for maximum, minimum, and average values are quite similar over this period. The mean maximum temperature ranged between 30.99°C and 32.07°C, with an overall average of 31.47°C. The highest maximum temperature was recorded in 2016 (32.07°C), followed closely by 2009 (31.93°C), 2010 (31.88°C), and 2014 (31.81°C). The lowest maximum temperature was observed in 2007 (30.46°C). The years with mean maximum temperatures below the average included 2003 (31.27°C), 2004 (30.99°C), 2005 (31.32°C), 2007 (30.46°C), 2008 (31.00°C), 2011 (31.12°C), and 2020 (31.25°C). In contrast, the years with above-average maximum temperatures were 2006 (31.67°C), 2009 (31.93°C), 2010 (31.88°C), 2012 (31.65°C), 2013 (31.50°C), 2014 (31.81°C), 2015 (31.56°C), 2016 (32.08°C), 2017 (31.55°C), 2018 (31.66°C), 2019 (31.61°C), 2021 (31.67°C), and 2022 (31.49°C).

The yearly average minimum temperature fluctuated between 21.81°C and 22.76°C, with an average of 22.25°C (Table 1). The highest minimum temperature was observed in 2016 (22.76°C), followed closely by 2010 (22.57°C), 2021 (22.57°C), and 2022 (22.47°C). The lowest minimum temperature was noted in 2013 (21.81°C). The years with below-average minimum temperatures included 2003 (22.03°C), 2004 (22.08°C), 2007 (22.22°C), 2008 (22.17°C), 2011 (21.84°C), 2012 (22.24°C), 2013 (21.81°C), 2014 (21.87°C), and 2018 (21.87°C). Conversely, the years with above-average minimum temperatures were 2005 (22.40°C), 2006 (22.39°C), 2009 (22.42°C), 2010 (22.57°C), 2015 (22.29°C), 2016 (22.76°C), 2017 (22.32°C), 2019 (22.32°C), 2020 (22.34°C), 2021 (22.57°C), and 2022 (22.47°C) (Table 1).

Table 1: Mean maximum, minimum and average temperature (°C) in Khulna over years

Year	Average maximum temperature (°C)	Average minimum temperature (°C)	Average mean temperature (°C)
2003	31.27	22.03	26.64
2004	30.99	22.08	26.54
2005	31.32	22.40	26.86
2006	31.67	22.39	27.03
2007	30.46	22.22	26.34
2008	31.00	22.17	26.59
2009	31.93	22.42	27.18
2010	31.88	22.57	27.23
2011	31.12	21.84	26.48
2012	31.65	22.24	26.94
2013	31.50	21.81	26.65
2014	31.81	21.87	26.83
2015	31.56	22.29	26.92
2016	32.07	22.76	27.41
2017	31.55	22.32	26.93
2018	31.66	21.87	26.77
2019	31.61	22.32	26.96
2020	31.25	22.34	26.77
2021	31.67	22.57	27.15
2022	31.49	22.47	27.00
Mean	31.47	22.25	26.86

The mean annual average temperature in Khulna from 2003 to 2022 fluctuated between 26.34°C and 27.41°C, with an overall average of 26.86°C (Table 1). Bosu et al. (2020) reported that average yearly temperature of Bangladesh was 25.96°C. The highest annual average temperature was recorded in 2016 (27.41°C), closely followed by 2009 (27.18°C), 2010 (27.23°C), and 2021 (27.15°C). The lowest value was observed in 2007 (26.34°C). The years with average annual temperatures below the mean included 2003 (26.64°C), 2004 (26.54°C), 2007 (26.34°C), 2008 (26.59°C), 2011 (26.48°C), 2012 (22.24°C), 2018 (26.77°C), and 2020 (26.77°C). In contrast, the years with above-average temperatures were 2005 (26.86°C), 2006 (27.03°C), 2009 (27.18°C), 2010 (27.23°C), 2012 (26.94°C), 2015 (26.92°C), 2016 (27.41°C), 2017 (26.93°C), 2019 (26.96°C), 2021 (27.15°C), and 2022 (27.00°C) (Table 1).

The data in Table 1 indicates a similar pattern between annual maximum and annual average temperatures over the period from 2003 to 2022 in the Khulna district. Overall, the results suggest that temperature, as a climatic variable, did not show significant variation during the study period. This aligns with the findings of who noted that tropical regions generally experience minor fluctuations in average temperatures compared to other climatic zones (Akintola et al., 2005).

4.2 Relationship between Years and Maximum, Minimum, and Average Temperatures

The relationships between different years and the yearly mean maximum, minimum, and average temperatures are illustrated in Figure 2. The data indicate an upward trend in annual mean maximum, minimum, and average temperatures, though this increase was not statistically significant. The annual average maximum temperature showed a yearly rise of 0.0251°C, suggesting that Khulna has seen a 0.502°C increase in maximum temperature over the past 20 years. A group researcher reported that the annual maximum temperature in Khulna increased by 0.008°C per year from 1960 to 2015 (Mondal et al., 2017). Similarly, documented a rise in Bangladesh's yearly temperature at a rate of 0.02°C per year between 1981 and 2019 (Bosu et al., 2020). Sarkar and Chakraborty also identified a growing trend in mean maximum annual temperature from 1988 to 2017 in South 24 Parganas District, West Bengal, India (Sarkar and Chakraborty, 2022). Our findings align with those of who noted a 0.4558°C rise in annual mean maximum temperature over 43 years at the Labhandi Observatory in Raipur, Chhattisgarh, India (Khavse et al., 2015).

In a similar trend, the mean annual minimum temperature increased by 0.0098°C per year (as shown in Figure 2), indicating that Khulna experienced a 0.196°C rise in minimum temperature over the last two decades. This result aligns with who reported an increase of 0.002°C per year in mean annual minimum temperature in Khulna district between 1960 and 2015 (Mondal et al., 2017). Additionally, a group researcher analyzed precipitation and temperature trends from 1980-2014 in six stations of the Kashmir valley, India, using the Mann-Kendall test (Ul Shafiq et al., 2018). Their findings showed that mean maximum temperatures in plains were rising faster than in mountainous areas, while mean minimum temperatures increased more rapidly in mountainous regions.

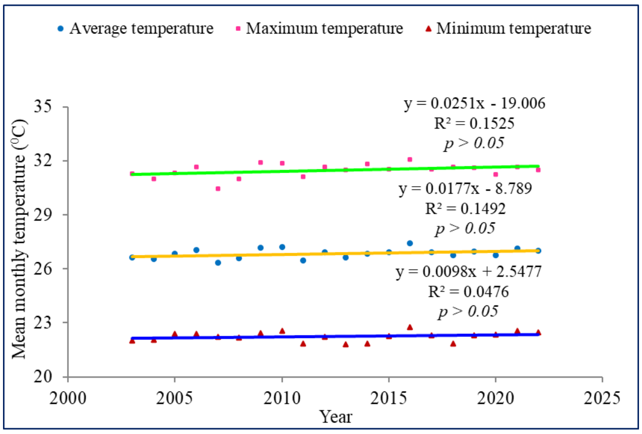


Figure 2: Functional relationship between year and temperature (°C) in Khulna district.

Furthermore, Khulna's mean annual average temperature displayed a yearly increase of 0.0177°C between 2003 and 2022 (as illustrated in Figure 2), signifying a total rise of 0.354°C over the past 20 years. These findings are consistent with those of who noted a 0.005°C per year increase in mean annual average temperature in Khulna between 1960 and 2015 (Mondal et al., 2017). Some researcher also observed a similar upward trend in mean maximum annual temperature in South 24 Parganas District, West Bengal, India, from 1988 to 2017 (Sarkar and Chakraborty, 2022). A studied rainfall (1871–2008) and temperature (1901–2003) trends in northeast India, finding no significant trends in rainfall but a clear rise in temperature (Jain et al., 2013).

4.3 Variation in Monthly Maximum Temperature

Over time, the analysis of monthly maximum temperature data has provided valuable insights into the temperature distribution in Khulna (Table 2). The highest mean monthly maximum temperature occurs in May (35.29°C), while the lowest is recorded in January (24.95°C). These findings well agreed to who documented that the warmest month in the Haryana state of India is May with mean monthly maximum temperature above 40°C and the coolest month is January bearing average monthly maximum temperature around 20°C (Singh et al., 2018). Table 2 also shows that April (35.19°C) and May (35.29°C) exhibit closely similar high temperatures. Additionally, December (26.15°C), January (24.95°C), and February (28.95°C) - show average monthly maximum temperatures below 30°C (Table 2). A group researcher who observed similar monthly maximum temperature in Bangladesh (Bosu et al., 2020).

Table 2: Mean monthly maximum temperature (°C) in Khulna over years (2003-2022)

Month	Mean temperature (°C)	Standard deviation (°C)	CV (%)
January	24.95	0.95	3.81
February	28.95	1.27	4.39
March	32.88	1.07	3.27
April	35.19	0.98	2.78
May	35.29	0.90	2.56
June	33.85	0.76	2.24
July	32.45	0.74	2.29
August	32.70	0.50	1.53
September	32.94	0.70	2.13
October	32.19	0.92	2.87
November	30.11	0.58	1.94
December	26.15	0.78	2.98

The standard deviation (SD) and coefficient of variation (CV) for the mean monthly maximum temperature in Khulna district were highest in February (1.27°C and 4.39%), and lowest in August (0.50°C and 1.53%), indicating greater temperature stability in August and more variability in February. These findings align with who noted unusual fluctuations in mean monthly maximum temperature before 2015, with an SD and CV of 0.47°C and 1.50%, respectively, for Khulna district (Mondal et al., 2017). Similarly, a group researcher reported a CV between 2.18-6.09% for mean monthly maximum temperatures in Raipur district, India (Khavse et al., 2015). Ogbonna and Urhibo on the other hand reported SD and CV of 0.32⁰C and 0.01%, respectively for mean maximum temperature from 1995-2014 in Southeast Nigeria (Ogbonna and Urhibo, 2022). The seasonal trends in Khulna's mean monthly maximum temperatures from 2003 to 2022 showed a bimodal distribution pattern, with the highest peak in May (36.70°C) and a nearly identical second peak in April (36.60°C) (Figure 3). Some other but relatively smaller peaks were also observed for the months of April, July, September and October.

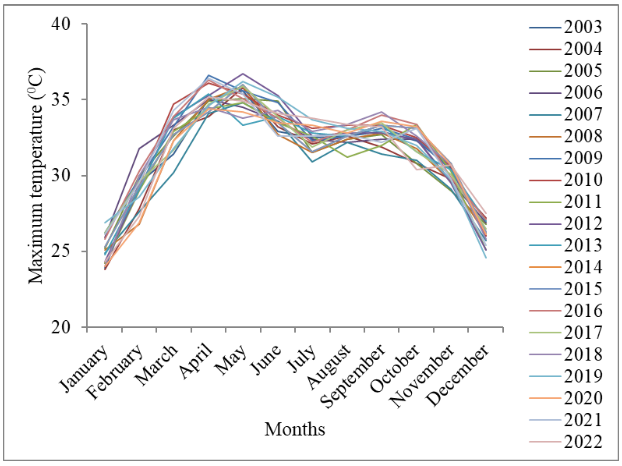


Figure 3: Monthly trends in monthly average maximum temperature (⁰C) in Khulna district during 2003-2022.

Table 3: Mean monthly minimum temperature (⁰C) in Khulna over years (2003-2022)			
Month	**Mean temperature (⁰C)**	**Standard deviation (⁰C)**	**CV (%)**
January	13.03	1.13	7.66
February	16.32	1.25	7.68
March	21.29	1.06	4.97
April	24.93	0.97	3.91
May	25.84	0.52	2.03
June	26.73	0.43	1.62
July	26.65	0.36	1.34
August	26.66	0.31	1.15
September	26.37	0.29	1.10
October	24.52	0.64	2.21
November	19.51	0.78	3.98
December	15.11	0.87	5.79

Table 3 presents the mean monthly minimum temperatures in Khulna over the years. The highest mean minimum temperature was recorded in June (26.73°C), while the lowest occurred in January (13.03°C). These findings are consistent with the results of documented that the month of July is the warmest having average minimum temperature around 27°C and the coldest month is January having average minimum temperature around 6°C (Singh et al., 2018). The data also shows that the mean minimum temperatures were closely grouped in June (26.73°C), July (26.65°C), August (26.66°C), and September (26.37°C). In contrast, lower temperatures were observed in December (15.11°C), January (13.03°C), and February (16.32°C). These findings are consistent with who reported similar patterns of monthly minimum temperatures in Bangladesh (Bosu et al., 2020). The SD and CV for Khulna's mean monthly minimum temperature peaked in February (1.25°C and 7.68%) and were lowest in September (0.29°C and 1.10%), indicating greater stability in September and more variability in February. These results align with who noted abnormal fluctuations in mean monthly minimum temperature before 2015, with an SD and CV of 0.48°C and 2.20%, respectively, for Khulna district (Mondal et al., 2017). Contrarily, Ogbonna and Urhibo got SD and CV of 0.64⁰C and 0.03%, respectively for mean minimum temperature from 1995-2014 in Southeast Nigeria (Ogbonna and Urhibo, 2022). The trends in Khulna's mean monthly minimum temperature from 2003 to 2022 followed a bimodal pattern, with the first peak in June (27.70°C) and a nearly identical second peak in July (27.50°C) (Figure 4).

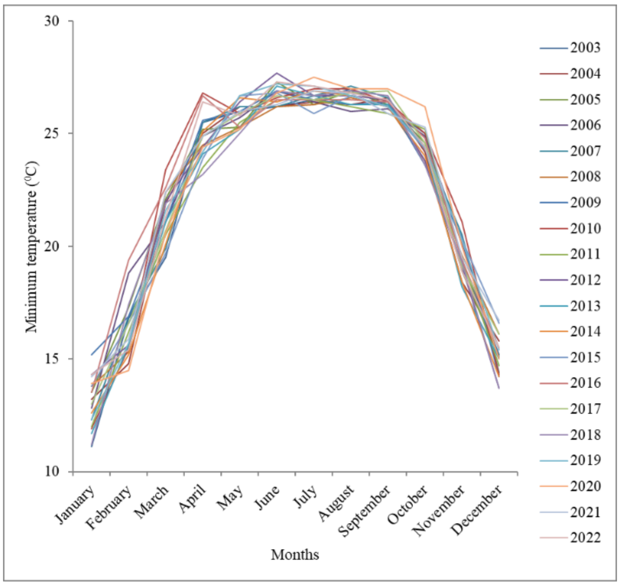


Figure 4: Monthly trends in average monthly minimum temperature (⁰C) in Khulna district over years (2003-2022).

Table 4: Mean monthly average temperature (⁰C) in Khulna over years (2003-2022)			
Month	**Mean temperature (⁰C)**	**Standard deviation (⁰C)**	**CV (%)**
January	18.99	0.85	4.48
February	22.63	1.19	5.23
March	27.09	0.97	3.60
April	30.06	0.83	2.78
May	30.57	0.67	2.20
June	30.30	0.57	1.87
July	29.56	0.52	1.77
August	29.68	0.35	1.18
September	29.65	0.41	1.38
October	28.36	0.64	2.25
November	24.81	0.47	1.91
December	20.88	1.18	3.22

Table 4 presents the mean monthly average temperatures in Khulna from 2003 to 2022. The highest average temperature was observed in May (30.57°C), while the lowest was recorded in January (18.99°C). The data also reveals that mean monthly average temperatures were relatively high in April (30.06°C), May (30.57°C), and June (30.30°C), with values close to each other. In contrast, the temperatures were lower in December (20.88°C), January (18.99°C), and February (22.63°C). As expected, the standard deviation (SD) and coefficient of variation (CV) for mean monthly average temperature were highest in February (1.19°C and 5.23%) and lowest in August (0.35°C and 1.18%), indicating more average temperature stability in August and greater variability in February.

These findings are consistent with who found that before 2015, the mean monthly average temperature fluctuated irregularly, with an SD and CV of 0.406°C and 1.53%, respectively, in Khulna district (Mondal et al., 2017). Ogbonna and Urhibo demonstrated that the SD and CV of 0.43⁰C and 0.02%, respectively for mean average temperature from 1995-2014 in Southeast Nigeria (Ogbonna and Urhibo, 2022). The periodic trends in Khulna's mean monthly average temperature over the 20-year period revealed a trimodal pattern. The first peak occurred in May 2014 (31.55°C) while, the second and third, with nearly identical peaks of 31.40°C and 31.50⁰C, was recorded in April 2016 and June 2012, respectively (Figure 5).

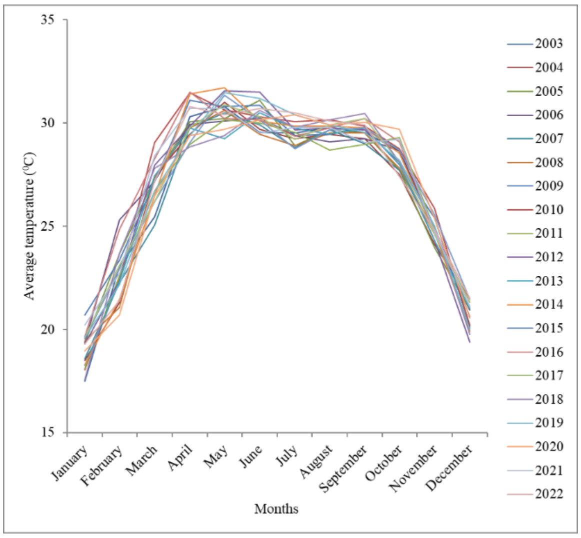


Figure 5: Monthly trends in mean monthly average temperature (^{0}C) in Khulna district over 20 years.

4.4 Trend Analysis of Mean Monthly Maximum Temperature

The trends in monthly mean maximum temperatures over the years were analyzed using simple linear regression. The regression equations and coefficients of determination for each month, from January to December, are shown in Figures 6a and 6b and summarized in Table 5. As indicated in these figures, the monthly mean maximum temperatures displayed no consistent pattern over time, with both increasing and decreasing trends observed. The mean monthly maximum temperature increased in all months except for February, May, and December, where a decline was noted. Additionally, variations in mean monthly maximum temperatures over the years were generally insignificant, except for July ($p < 0.05$) and September ($p < 0.10$) (Table 5). It can also be apprehended from the analysis that for July about 32% of the variation in mean monthly maximum temperature was due to different years. However, for September it was found that the advancement of years defined around 25% of the variation in mean monthly maximum temperature. These findings are consistent with those of who also reported insignificant variation in average maximum temperatures over time for the Khulna district (Mondal et al., 2017).

Similar results were found by who observed both significant and insignificant variations in mean monthly maximum temperatures in Labhandi Observatory in Raipur district, Chhattisgarh, India (Khavse et al., 2015). In Khulna, the largest increase in mean monthly maximum temperature occurred in July, with a rise of 0.0717°C per annum that accounted a cumulative increase of 1.434°C over the past 20 years. Conversely, the greatest decrease was in February, with a decline of 0.756°C during the same period. These results align with findings, where the largest increase in average monthly maximum temperature at Labandi Raipur Station, Chhattisgarh, India, was recorded in December, with a rise of 1.1008°C during the 1971-2013 periods (Khavse et al., 2015).

Table 5: Linear regression equations for all the months of (2003-2022) of maximum temperature (^{0}C) in Khulna district.

Month	Regression equation	R^2	p value
January	y = 0.0333x - 42.078	0.0429	0.580
February	y = -0.0378x + 105.07	0.0310	0.308
March	y = 0.0438x - 55.332	0.0581	0.517
April	y = 0.0239x - 12.928	0.0209	0.869
May	y = -0.0153x + 66.158	0.0101	0.371
June	y = 0.0157x + 2.23	0.0150	0.971
July	y = 0.0717x - 111.75	0.3255	0.033**
August	y = 0.0434x - 64.614	0.2624	0.131
September	y = 0.0591x - 85.994	0.2485	0.095*
October	y = 0.0435x - 55.417	0.0778	0.446
November	y = 0.04x - 50.39	0.1648	0.253
December	y = -0.02x + 66.4	0.0231	0.296

*Significant at 10% level, **Significant at 5% level

Table 6: Linear regression equations for all the months of (2003-2022) of average minimum temperature (^{0}C) in Khulna district.

Month	Regression equation	R^2	p value
January	y = 0.0412x - 69.891	0.0466	0.439
February	y = -0.0398x + 96.517	0.0354	0.341
March	y = 0.0175x - 13.962	0.0100	0.870
April	y = -0.0223x + 69.876	0.0184	0.379
May	y = -0.0017x + 29.325	0.0004	0.495
June	y = 0.0214x - 16.39	0.0852	0.629
July	y = 0.0335x - 40.681	0.3064	0.107
August	y = 0.012x + 2.6058	0.0532	0.914
September	y = 0.0095x + 7.1579	0.0380	0.757
October	y = 0.0189x - 13.455	0.0304	0.793
November	y = -0.0032x + 26.022	0.0006	0.681
December	y = 0.0281x - 41.482	0.0361	0.555

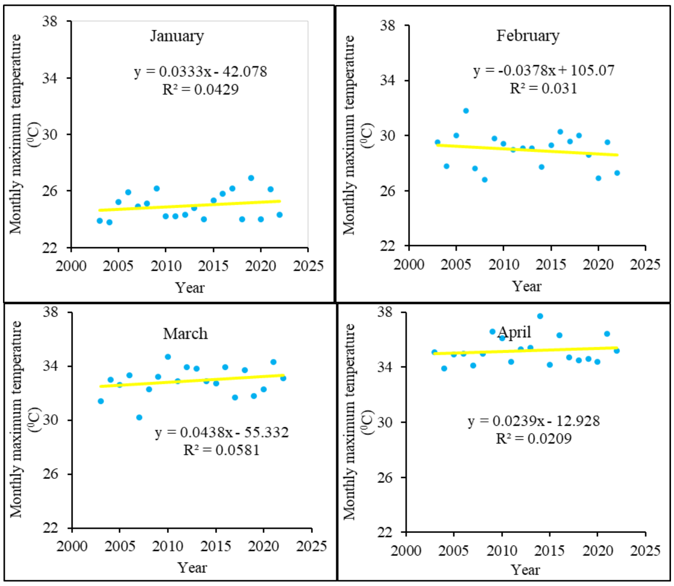
4.5 Trend Analysis of Mean Monthly Minimum Temperature

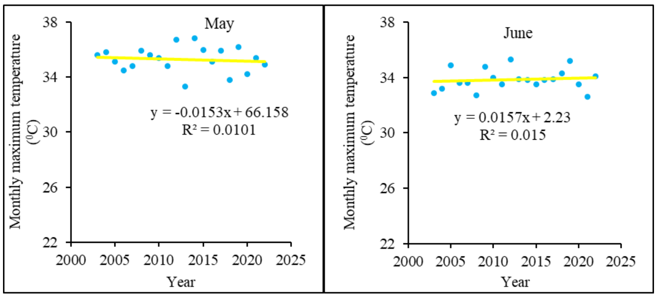
The trends in monthly mean minimum temperatures for the period 2003-2022 were analyzed using linear regression. The regression equations, along with the coefficients of determination for each month, are presented in Figures 7a and 7b, and summarized in Table 6. As shown in these figures, the monthly mean minimum temperatures exhibited an irregular pattern, with both increasing and decreasing trends. While the mean monthly minimum temperature increased for most months, a decline was observed in February, May, and December. Additionally, no significant variation ($p > 0.05$) in mean monthly minimum temperatures over the years was found for any month. These results align with the findings of who also reported insignificant variations in average minimum temperatures over time for the Khulna district (Mondal et al., 2017).

A group researcher investigated temperature trends from 1980-2014 in six stations of the Kashmir valley, India, by the Mann-Kendall test (Ul Shafiq et al., 2018). Their findings showed that mean maximum temperatures in plain lands were growing faster than in hilly areas, while mean minimum temperatures increased more rapidly in mountainous regions than in smooth areas. In Khulna, the largest increase in mean monthly minimum temperature occurred in January, with a rise of 0.824°C over the past 20 years. On the other hand, the greatest decrease in mean monthly minimum temperature was observed in February, with a decline of 0.796°C during the same period.

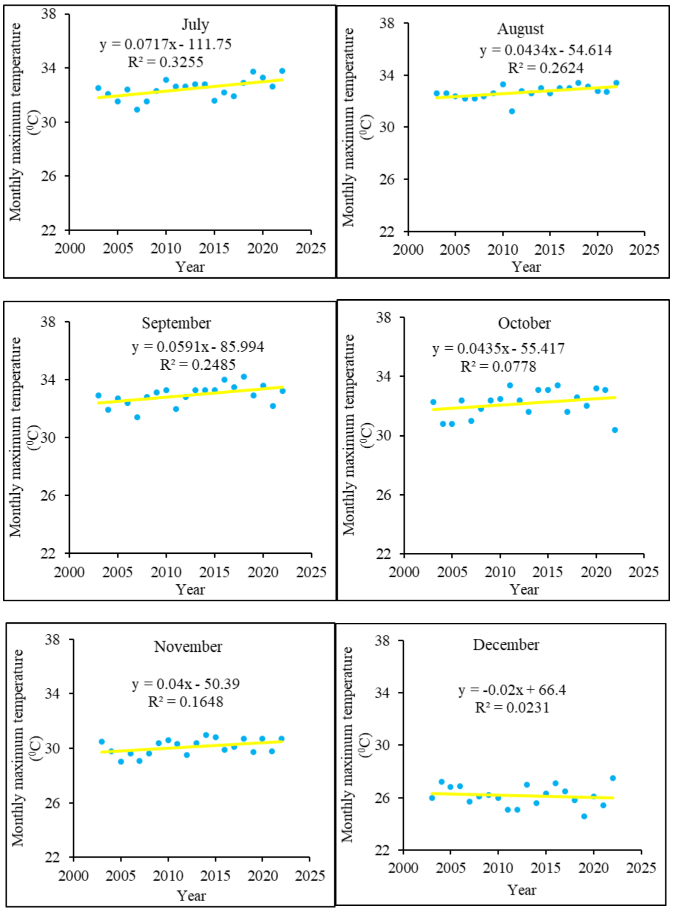
4.6 Trend Analysis of Mean Monthly Average Temperature

The trends of monthly mean monthly average temperature over the period 2003-2022 were obtained using linear regression analysis. The trends with their regression equations and coefficient of determination for all the months of a year are represented in Figure 8a and Figure 8b and summarized in Table 7. It is evident from Figure 8a and Figure 8b that mean monthly average temperature showed an irregular pattern with both increasing and decreasing trends.



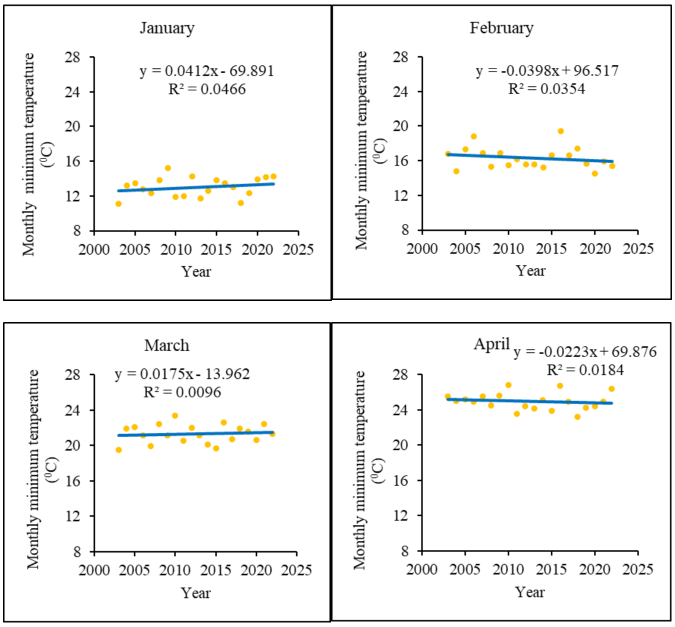


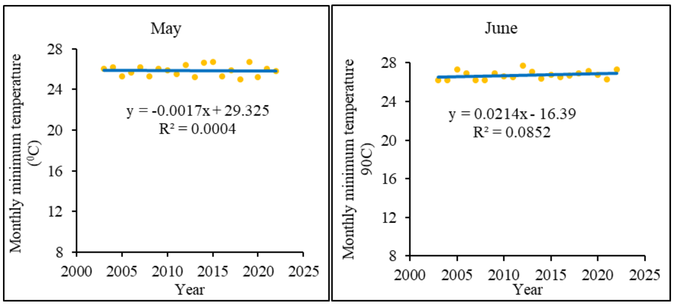
(a)



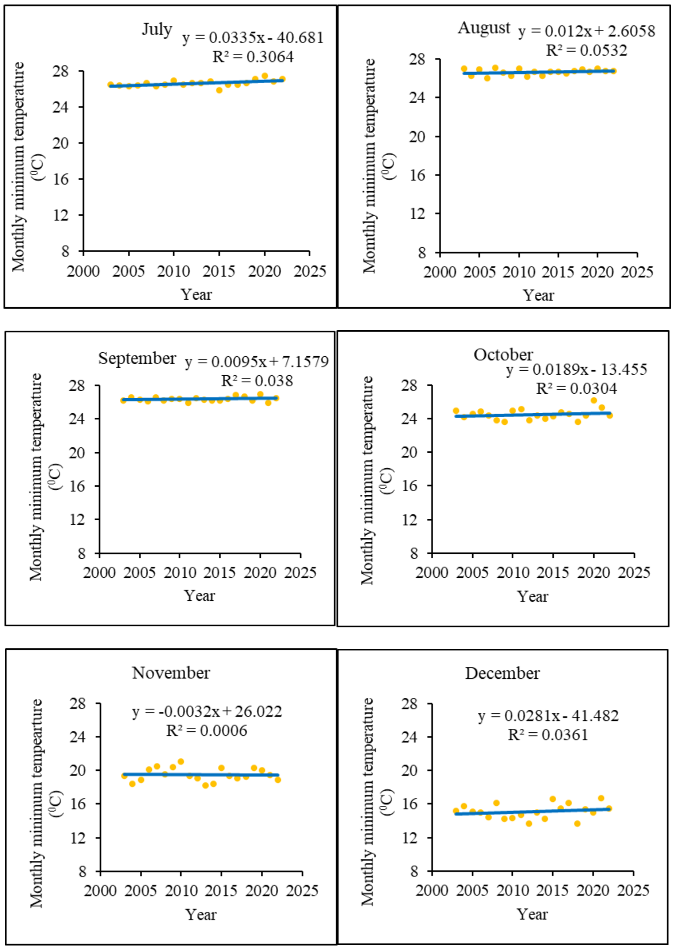
(b)

Figures 6: (a) and (b) Trend analyses of monthly maximum temperatures (⁰C) in Khulna over years.



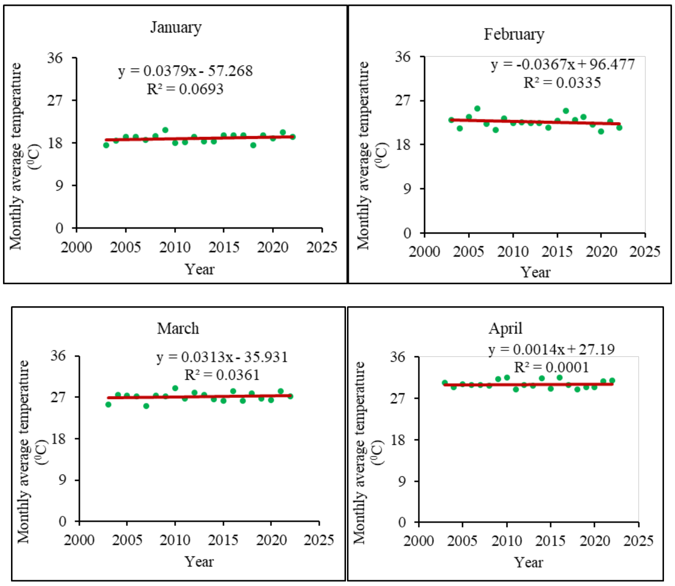


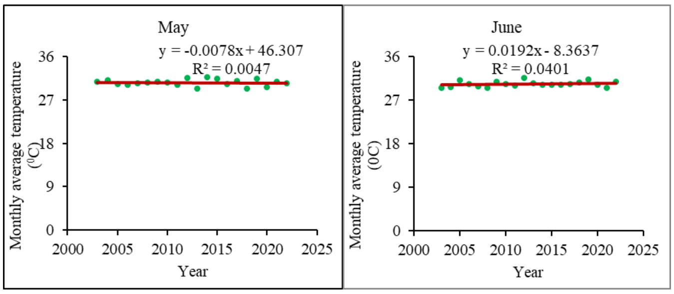
(a)



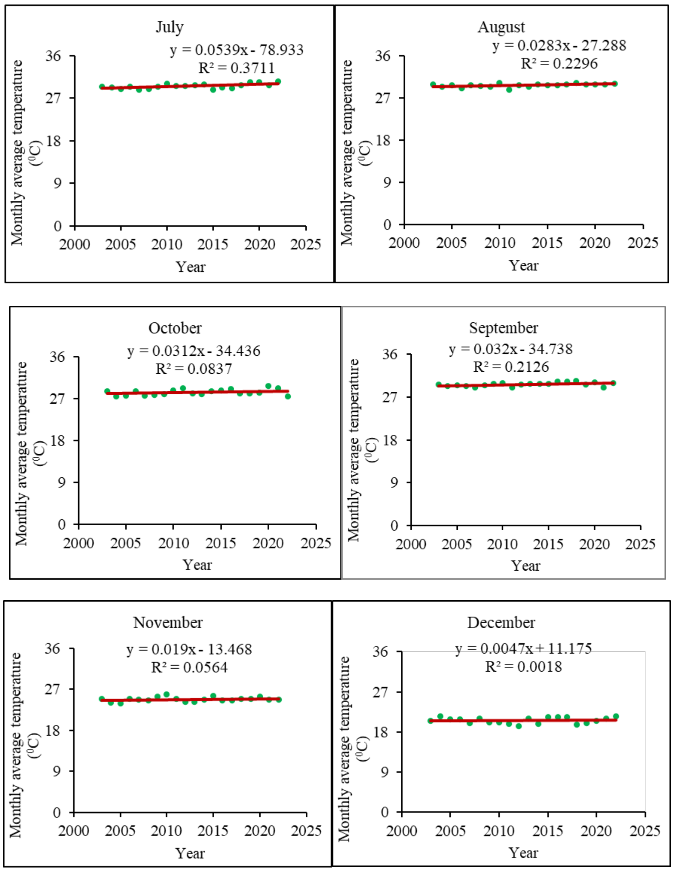
(b)

Figure 7: (a) and 7 (b) Trend analyses of minimum monthly temperatures (⁰C) in Khulna over time.





(a)



(b)

Figure 8: (a) and 8 (b) Trend analyses of average monthly temperatures (^{0}C) in Khulna over 2003-2022.

Table 7: Linear regression equations for all the months of (2007-2022) of average temperature (^{0}C) in Khulna district.			
Month	**Regression equation**	**R^2**	**p value**
January	y = 0.0379x - 57.268	0.0693	0.396
February	y = -0.0367x + 96.477	0.0335	0.316
March	y = 0.0313x - 35.931	0.0361	0.645
April	y = 0.0014x + 27.19	0.0001	0.689
May	y = -0.0078x + 46.307	0.0047	0.401
June	y = 0.0192x - 8.3637	0.0401	0.853
July	y = 0.0539x - 78.933	0.3711	0.029**
August	y = 0.0283x - 27.288	0.2296	0.212
September	y = 0.032x - 34. 738	0.2126	0.250
October	y = 0.0312x - 34.436	0.0837	0.491
November	y = 0.019x - 13.468	0.0564	0.719
December	y = 0.0047x + 11.175	0.0018	0.836

**Significant at 5% level

The mean monthly minimum temperature increased for all the months except for February and May, for which a decline in mean maximum average temperature was noticed. Additionally, insignificant variation (*$p > 0.05$*) in mean monthly minimum average temperatures over years was identified except for the month of July (*$p < 0.05$*), where 37% variation in mean monthly average temperature might be explained by years. A group researcher reported insignificant variation in average monthly minimum temperature against years for Khulna district (Mondal et al., 2017).

It is well to note that in Khulna, the maximum increase in mean monthly average temperature was found in July, with an increase of 0.758^{0}C over the past 20 years. Conversely, the highest decrease in mean monthly average temperature was occurred in February, with a decline of 0.734^{0}C during the same period. After analyzing temperature trends of northeastern part of Bangladesh for the period 1980-2016, concluded that average temperature increased in the Srimangal station, Sylhet, Bangladesh for all the months except April, which exhibited a negative trend (Mondal et al., 2020). They further added that the average temperature values dominate significantly only in July and September to November according to the Sen's slope estimates.

4.7 Principal Component Analysis

Principal component analysis (PCA) was conducted to extract the principal components that account for up to 95% of the cumulative variance from the mean maximum, minimum, and average temperatures in the Khulna district. The first three eigenvalues (C1, C2, C3) were selected for further analysis, as they collectively contributed to 100% of the cumulative variance (as shown in Table 8 and Figure 9). The years having higher PC1 scores were clustered on the right of the PC1 axis; the years with lower scores were placed on the left. A group researcher described similar arrangement of treatments during studying sorghum germination under salt stress through PCA (Chen et al., 2021). The findings of this study align with those of who found that the first three components explained up to 97% of the total variance for maximum and minimum temperatures in Haryana, India, following PCA (Singh et al., 2018).

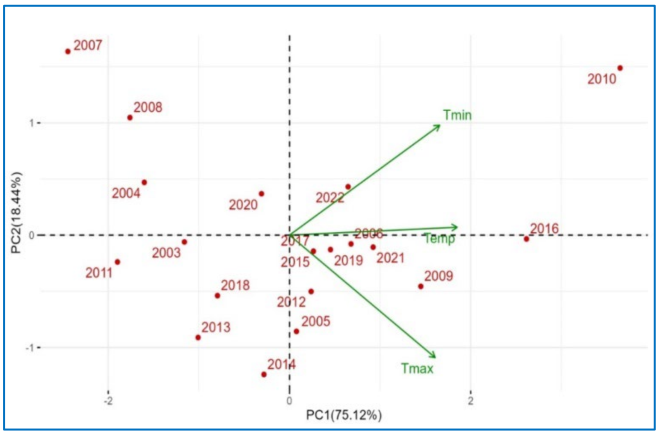


Figure 9: Principal Component analysis of average, maximum and minimum temperatures of Khulna district for the years of 2003-2022.

Table 8: Proportion of variables after PCA			
Importance of components	**PC1**	**PC2**	**PC3**
Eigen values	2.253	0.553	0.193
Proportion of Variance (%)	75.12	18.44	6.44
Cumulative Proportion (%)	75.12	93.56	100.00
Standard deviation	1.501	0.744	0.439

5. Conclusion

This study aimed to analyze temperature variability in the Khulna district using historical data from 2003 to 2022. The findings reveal that the mean maximum, minimum, and average temperatures remained closely aligned over the years. The hottest year recorded in the study was 2026, with peak values across all three temperature categories, while 2007 was identified as the coolest year based on mean monthly maximum and average temperatures. An overall increasing trend was observed for monthly maximum, minimum, and average temperatures, though the rates of increase varied among the three measures. Between 2003 and 2022, the monthly maximum, minimum, and average temperatures increased by 0.50°C, 0.19°C, and 0.35°C, respectively.

Seasonal trends in the mean monthly maximum, minimum, and average temperatures showed a bimodal distribution, with the second peak being slightly smaller. The monthly mean maximum, minimum, and average temperatures did not follow a consistent pattern over the years, displaying both upward and downward trends. A significant increase in mean monthly maximum temperature was noted in July ($p < 0.05$) and September ($p < 0.10$), and the mean monthly average maximum temperature also rose significantly in July ($p < 0.05$). However, the variation in average monthly maximum and mean monthly average temperatures across the remaining months was not statistically significant, and the distribution of average monthly minimum temperature across different months showed no significant variation either. Principal component analysis (PCA) revealed that the first two components accounted for about 95% of the total variation.

The study provides valuable insights for policymakers and planners, offering guidance for proactive measures to address climate change. The findings are also useful for developing climate-resilient strategies for various regions of Bangladesh, as well as for advancing climatology studies and assessing the impact of climate change nationwide. Most climate change research in Bangladesh focuses on the national level, with few studies examining local temperature trends. This study helps fill that gap and serves as a crucial resource for crafting local-level climate change adaptation strategies. In light of the study's outcomes, it is essential to emphasize that rising temperatures in Bangladesh pose a significant threat in the context of global warming.

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