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ASSESSING THE DYNAMICS OF CLIMATE CHANGE IN KHULNA CITY: A COMPREHENSIVE ANALYSIS OF TEMPERATURE, RAINFALL, AND HUMIDITY TRENDS

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ABSTRACT

The study analyzes the temperature, rainfall, and humidity dynamics of Khulna city from 1981 to 2020. The average rainfall changes are 0.0018 mm, with an increase in daytime temperatures of 0.0223°C each year. Nighttime temperatures also show an increasing trend, with an increase in minimum temperatures of 0.0342°C each year. The overall humidity decreases, indicating less humid weather. The decadal average rainfall ranges from 5.13 mm from 1981 to 2000, with a drop to 4.65 mm between 1991 and 2000. The maximum temperature ranges from 30.94°C to 31.31°C, with a slight increase to 22.17°C between 2011 and 2020. The decadal average humidity ranges from 81.28% from 1991–2000 to 80.72% from 2001–2010. Pre-monsoon average rainfall declines by 5.13 mm, indicating a drier season. The monsoon season has an inclining trend of 0.0239 mm, with a promising increment of rain resulting in a wetter monsoon. Post-monsoon average rainfall increases by 0.0121 mm, resulting in a wetter season each year. The winter season has a slight decline of -0.0043 mm at 6°C. The variability of temperature, rainfall, and humidity patterns in Khulna city reveals a correlation between rainfall and temperature, which indirectly impacts crop yield. Better observational rainfall, humidity, and temperature data are necessary for effective agriculture and crop production. The estimated value for the average temperature (maximum) from 1981 to 2020 is 0.023°C, suggesting that if the year increases by one year, the average maximum temperature increases by 0.023°C

1 Introduction

Climate change is a significant issue that affects the environment and society, with the global mean temperature increasing by 0.70 °C within the last century (Rabbani et al., 2011). Khulna city, one of the largest deltas in the world, is most vulnerable to climate change due to its unpredictable climatic parameters such as temperature, rainfall, and humidity (Karim & Mimura, 2008). A strong hydrometeorology monitoring network is crucial for detecting and attributing present-day hydrological changes, particularly changes in water resources and extreme events like floods, cyclones, droughts, erratic rainfall, storms, and cold spells (Murtaza, 2001). Bangladesh is often cited as one of the most vulnerable countries to climate change due to its disadvantageous geographic location, flat and low-lying topography, high population density, high levels of poverty, reliance on climate-sensitive sectors, particularly agriculture and fisheries, and inefficient institutional aspects (Rahaman & Bari, 2024). The anticipated adverse effects of climate change, such as sea level rise, higher temperatures, enhanced monsoon precipitation, and an increase in cyclone intensity, will aggravate existing stresses that already impede development in Bangladesh, particularly by reducing water and food security and damaging essential infrastructure. These impacts could be extremely detrimental to the economy, environment, national development, and the people of Bangladesh (Shahid, 2010).

Khulna was part of the ancient kingdoms of Vanga and Samatata, became part of the Sena dynasty during the 12th-century reign of Ballala Sena, and formed part of the Bagri division of Bengal (Murtaza, 2001). It was ruled by autonomous Bengali nawabs until 1793 when the British East India Company abolished nizamat (local rule) and took control of the city (Saito, 2008). The city was first declared part of India in 1947, and the Boundary Commission declared it part of East Bengal(Rabbani et al., 2011). Climate change is predicted to lead to a steady increase in temperature and change in rainfall patterns, which may have implications for agriculture, water resources, and public health in Bangladesh. The adverse impacts of climate change are expected to be severe in Bangladesh and may lead to substantial economic losses (Shahid, 2010). Major climate change phenomena, such as extreme rainfall and delayed discharge caused by sea level rise, are chiefly responsible for frequent waterlogging in urban areas of Bangladesh. Khulna City, one of the major coastal cities in Bangladesh, is highly vulnerable to climate change due to the influence of the tides of the Bay of Bengal. The city's inhabitants face frequent waterlogging during the rainy season, and extreme precipitation events make the situation worse. Waterlogging affects over 90% of households in the southern part of KCC, with 38% experiencing short-term waterlogging frequently (Mirza, 2003). The city experiences 1,808.5 mm of annual rainfall, making residents more vulnerable to waterlogging. KCC has spent $20 million over the last five years on the re-excavation of rivers and canals to improve the drainage system. However, the methods for identifying affected areas and prioritizing projects have not been clarified, and spatial modeling of the drainage system has not been studied. Consequently, KCC spends significant government funds on random projects, but the condition of waterlogging remains unchanged (Murphy & Mitchell, 1995).

1.1 Rationale

Khulna, Bangladesh's third-largest city, is in the southwestern part of the country, on the Rupsha and Bhairab Rivers. It covers 59.57 square kilometers and is part of the Ganges Delta, the world's largest river delta. The city has a tropical wet and dry climate, with hot and humid summers and warm winters. The monsoon of South Asia significantly affects Khulna, but it receives less rainfall due to its location and the effects of the Sundarbans south of the city (Murphy & Mitchell, 1995). The city experiences an annual average temperature of 26.3 °C (79.3 °F), with monthly averages ranging from 11.4 °C (52.5 °F) to 34.6 °C (94.3 °F) during April afternoons. Climate change has forced many rural residents to migrate to cities, leading to a sharp rise in the slum population in Dhaka (Rajib et al., 2010). As Bangladesh is less than 20 feet above sea level, there are fears that by the end of the 21st century, over a quarter of the country will be inundated and 15 million people will be displaced. This research aims to analyze the annual, seasonal, and decadal trends of temperature, rainfall, and humidity in Khulna City from 1981 to 2020. The study also seeks to assess the impacts of these climatic elements using linear regression methods (Shahid, 2010). Given the significant discussions around global warming and climate change, this study is pertinent as it explores the potential threats posed by temperature increases and rainfall variability in Khulna, which could inform mitigation strategies. However, the study faces several limitations. Data on temperature, rainfall, and humidity were exclusively collected for the years 1981 to 2020 from the Bangladesh Meteorological Department (BMD) (Swapan et al., 2017). These secondary data sets reflect broader climate change impacts but may not capture the full extent as models like ARIMA, CMIP6, and USE could potentially offer more precise predictions. Additionally, challenges include the lack of local-level data acquisition capabilities in Bangladesh, which restricts the study to available regional data (Shahid, 2010). This limitation, alongside the inherent data heterogeneity and the time constraints imposed on the research, means that while accurate results may not be achievable, the study will provide the best possible estimates of climatic trends and impacts in Khulna City.

2 Literature Review

Bangladesh, being one of the largest deltas in the world, because of its Geological location is highly vulnerable to natural disasters. The country has a flat and low-lying landscape, high population density, lack of institutional setup, etc. The total land area of 147,570 sq. km. consists mostly of floodplains (almost 80%) (Hossain et al., 2023). The adverse effects of climate change on Bangladesh especially:

2.1 High Temperature

The impacts of climate change are increasingly evident in Bangladesh, a country acutely vulnerable to environmental fluctuations. Higher temperatures are linked to more variable precipitation, more extreme weather conditions, and increased humidity—factors that collectively contribute to the intensification of climate-related challenges (Biswas, 2013). These climatic shifts are particularly concerning as they lead to significant sea-level rise, a phenomenon that has far-reaching implications for the region.

2.2 Sea-Level Rise

The mechanism of sea-level rise is primarily attributed to the thermal expansion of seawater and the melting of glaciers, including those in the Himalayas, which is accelerated by the rise in global temperatures (Rajib et al., 2010). Projections indicate that a sea-level rise of just one meter could submerge up to 15% of Bangladesh's land area, resulting in catastrophic losses of coastal agricultural land and widespread human displacement (Swapan et al., 2017). Such a drastic change in land availability is expected to trigger forced migration, placing immense pressure on inland areas to accommodate displaced populations and straining already scarce resources (Botswana Statistics, 2012).

Moreover, the implications of sea-level rise extend beyond the immediate loss of land. The inundation of coastal zones threatens critical habitats, endangers agricultural productivity, and increases the salinity of freshwater sources, further jeopardizing food security and human health (Swapan et al., 2017). These developments underscore the critical need for targeted adaptation strategies that address the specific vulnerabilities of affected communities and the broader socioeconomic impacts of climate change (Botswana Statistics, 2012).

In light of these challenges, policy makers and stakeholders must prioritize climate resilience initiatives and integrate sustainable practices into national development plans. Enhancing the capacity of Bangladesh to respond to environmental changes, safeguarding at-risk populations, and promoting sustainable development are crucial steps in mitigating the adverse effects of climate change and ensuring the long-term welfare of the nation (Fung et al., 2006).

2.3 Cyclones and Strom Surges

The geographic location of Bangladesh by the Bay of Bengal, surrounded by numerous rivers, makes it exceptionally vulnerable to the effects of climate change, notably cyclones and storm surges (Karim & Mimura, 2008). These natural disasters are predicted to become more intense as climate change progresses, leading to more frequent and severe floods, droughts, and storms. This heightened risk is compounded by the country's low elevation and high population density along the coastal areas, which intensifies the impact of such events (Hossain et al., 2023).

2.4 Salinity Intrusion

Salinity intrusion is another critical issue exacerbated by climate change in Bangladesh. During the dry season, low river flows combined with increased evaporation rates reduce the availability of freshwater. Concurrently, sea-level rise contributes to higher sea salinity, which further intrudes into freshwater systems (Fung et al., 2006). This salinity intrusion not only affects the quality of drinking water but also has severe implications for agriculture, as increased soil salinity can drastically reduce crop yields and affect the livelihoods of local communities (Hossain et al., 2023).

Both cyclones with accompanying storm surges and salinity intrusion highlight the broader environmental challenges faced by Bangladesh due to climate change. Addressing these issues requires integrated coastal zone management and robust disaster preparedness strategies that incorporate climate resilience measures to protect vulnerable populations and ensure sustainable development in the face of escalating environmental risks (Fung et al., 2006). The increase in climate change will cause more intense floods, droughts, and storms. As the country is located by the Bay of Bengal and there are many rivers all around the country.

2.5 Threats on biodiversity

The "Sundarbans," recognized as a World Heritage site, stands as the world's largest mangrove forest, covering 57,700 hectares along the Bay of Bengal. It is an ecological treasure, hosting a diverse array of species including the iconic Royal Bengal Tiger. Unfortunately, this vital ecosystem is under threat from climate change, which poses significant risks to the biodiversity and ecological balance of the region. (Huq et al., 2004) highlights that among various ecosystems in Bangladesh, the Sundarbans are expected to be one of the most adversely affected. The increasing frequency and severity of climatic events like cyclones and sea-level rise could lead to salinity intrusion, degradation of mangrove habitats, and loss of biodiversity, which are critical concerns for conservation efforts (Mirza, 2003).

2.6 Heavy Monsoon Downpours

Bangladesh's climate is characterized by heavy monsoon seasons, and the country is traversed by over 150 rivers, many of which approach or exceed danger levels during the monsoon season. Climate change is expected to exacerbate these conditions by increasing the intensity and frequency of rainfall during these periods (Karim et al., 1999). Recent trends have shown an increase in both pre-monsoon and post-monsoon downpours. Such changes in precipitation patterns could lead to more severe and frequent flooding, impacting millions of people, agriculture, and infrastructure (Murtaza, 2001). Additionally, research by Biswas (2013) suggests that a global temperature rise of 2° Celsius could threaten 30% of all land species with a heightened risk of extinction, highlighting the broader ecological stakes of climate change. These observations underscore the urgency of implementing robust climate adaptation and mitigation strategies. Protecting ecosystems like the Sundarbans and preparing for increased monsoon variability is critical to maintaining biodiversity and supporting the livelihoods of communities dependent on these natural resources. Conservation efforts must be coupled with comprehensive policies aimed at climate resilience, particularly in biodiversity-rich areas that are crucial for ecological health and human well-being (Karim & Mimura, 2008)

3 The effects of climate variation on temperature rise of Khulna City

In Khulna City, Bangladesh, an analysis of multi-model climate projections—specifically Regional Climate Models (RCMs) and Global Climate Models (GCMs)—reveals a distinct pattern of temperature variations. According to Rajib et al. (2010), there is an expectation that the winter months may experience more pronounced warming compared to the monsoon and pre-monsoon seasons. Despite these seasonal variations, a consistent upward trend in temperatures is anticipated across all months, reflecting a broader pattern of global warming (Biswas, 2013).

The Intergovernmental Panel on Climate Change (IPCC) has provided projections indicating significant global temperature increases ranging from 1.8°C to 4.0°C by the end of the 21st century (IPCC, 2007). This rise in temperatures is expected to have profound effects on sea levels. The IPCC also forecasts a sea-level rise of 0.18 to 0.59 meters during this period. Furthermore, the U.S. Environmental Protection Agency (EPA) notes that if the melting of polar ice continues at a rate consistent with global temperature increases, sea levels could rise by 0.49 to 0.79 meters by 2100 (EPA, 2014). The ramifications of such changes are particularly severe for Bangladesh. An IPCC briefing suggests that a 45 cm rise in sea levels could submerge nearly 10.9% of Bangladesh's territory, displacing approximately 5.5 million people from coastal regions (ICCCAD, 2014). This potential displacement underscores the critical challenges facing Bangladesh due to climate change, highlighting the urgent need for robust adaptation and mitigation strategies to protect vulnerable communities and sustain national development (Islam, 2009).

Botswana Statistics (2012) conducted a comprehensive study on Dhaka, the capital and only megacity of Bangladesh, highlighting its vulnerability to a myriad of climate-induced hazards. These include temperature variations, excessive and erratic rainfall, waterlogging, flooding, cyclones, as well as heat and cold waves. Such hazards recurrently disrupt city life and livelihoods, and the situation is likely to deteriorate as these climate-related challenges become intertwined with socio-economic and demographic factors.

The research points out that the adverse effects of these climate hazards are compounded by non-climatic stressors such as high population density, widespread poverty, significant rural-urban migration, high rates of illiteracy, unplanned urban development, and insufficient public utilities and services (Swapan et al., 2017). These factors exacerbate the city's resilience to climate change, increasing the vulnerability of its residents, particularly the urban poor, to environmental shocks.

Dhaka, the capital and primary megacity of Bangladesh, is increasingly strained by the compounded effects of climatic and non-climatic factors. According to Alam and Rabbani (2012), the city's infrastructure and public services already stretched to their limits, must adapt to these growing pressures through integrated urban planning and robust climate adaptation strategies. Enhancing the resilience of Dhaka's infrastructure, along with improving educational and social services, is critical to safeguarding the city against the escalating impacts of climate threats. This approach underscores the urgent need for policies that not only address immediate concerns but also anticipate future challenges (Rabbani et al., 2011).

The 2030 Agenda for Sustainable Development, adopted by the General Assembly in September 2015, introduces 17 Sustainable Development Goals (SDGs) aimed at promoting holistic sustainable development globally. This agenda emphasizes an inclusive approach, coined as "leaving no one behind," which seeks to ensure that progress in one area does not lead to setbacks in others (Botswana Statistics, 2012). For cities like Dhaka, this global framework provides a roadmap to address various socio-economic and environmental challenges through sustainable practices and solutions.

Swapan et al. (2017) highlight the specific challenges faced by Khulna, the eleventh-largest megacity globally, with a rapidly growing population now standing at 18.2 million residents within a 1,528 km² area. This urban expansion traces back to the city's development trajectory, which has been significantly shaped by informal urbanization and the impacts of climate change. As Khulna continues to grow, it encounters pressing challenges in providing basic urban services, which are critical to the city's functionality and the well-being of its inhabitants. In Khulna, the need for a reliable transportation network, constant water and energy supplies, effective sanitation, sustainable waste management, and affordable housing are among the top priorities. These issues are exacerbated by the adverse effects of climate change, which further complicate the urban environment and strain existing infrastructure (Alam & Rabbani, 2012). Addressing these challenges requires a concerted effort to implement integrated infrastructure planning and development, which must be coupled with sustainable management practices.

4 Methodology

Khulna City, situated in Bangladesh near the Bay of Bengal, has historically been highly susceptible to the impacts of climate change. As the third-largest city and a key industrial center, it covers an area of 50.61 square kilometers and has a population of 663,342 according to the 2011 census, with a density of 13,107 people per square kilometer. The broader Khulna District, spanning 4,389.11 square kilometers, includes neighboring areas like Jessore, Narail, and Bagerhat. Over the years, the population of the metropolitan area showed variable trends, reaching 950,000 in 2022, a slight increase from previous years. Data for a study on climate change impacts was collected from the Bangladesh Meteorological Department and the Meteorological Department at the University of Dhaka, covering the period from 1981 to 2020. This data, which included temperature, humidity, and rainfall measurements, was analyzed using Microsoft Excel and univariate Regression Analysis to understand the long-term climate trends and their implications for the region. This research aimed to provide insights into how climate change has affected Khulna City, supporting urban planning and policy-making efforts to enhance the area's resilience and sustainability in the face of environmental challenges (Hossain et al., 2015; Karim & Mimura, 2008).

Figure 1: Map showing the Southern region, Khulna District, and Khulna City of Bangladesh

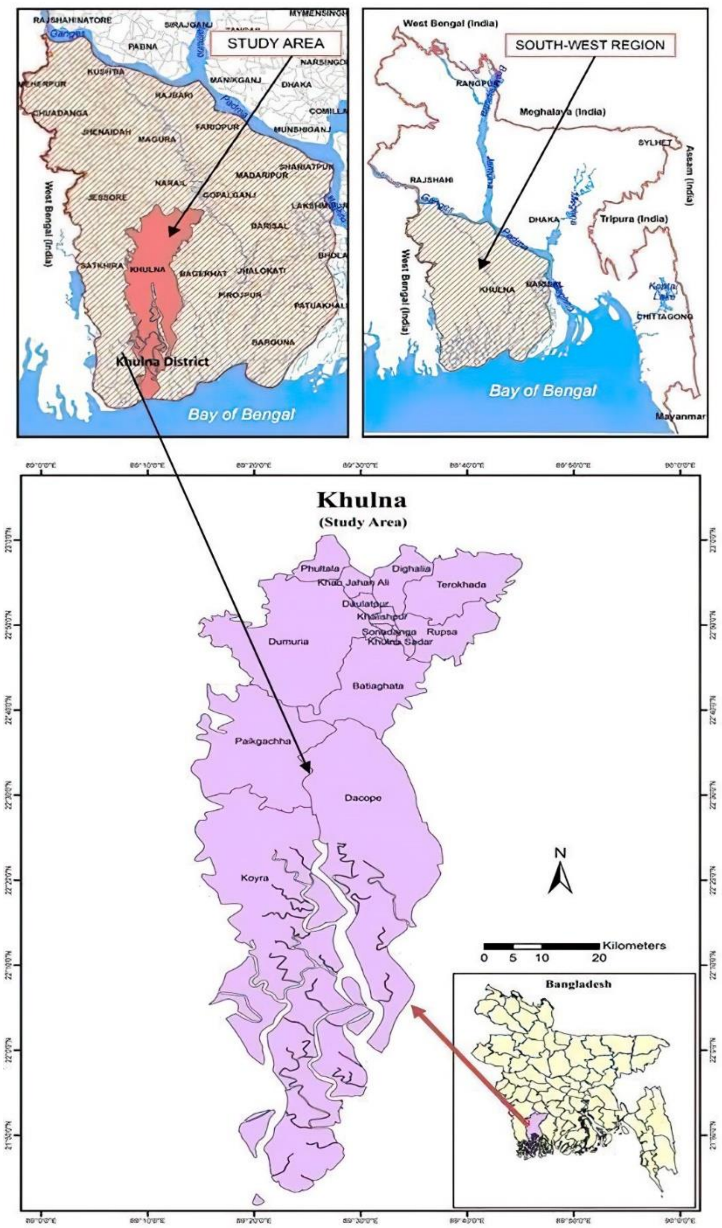
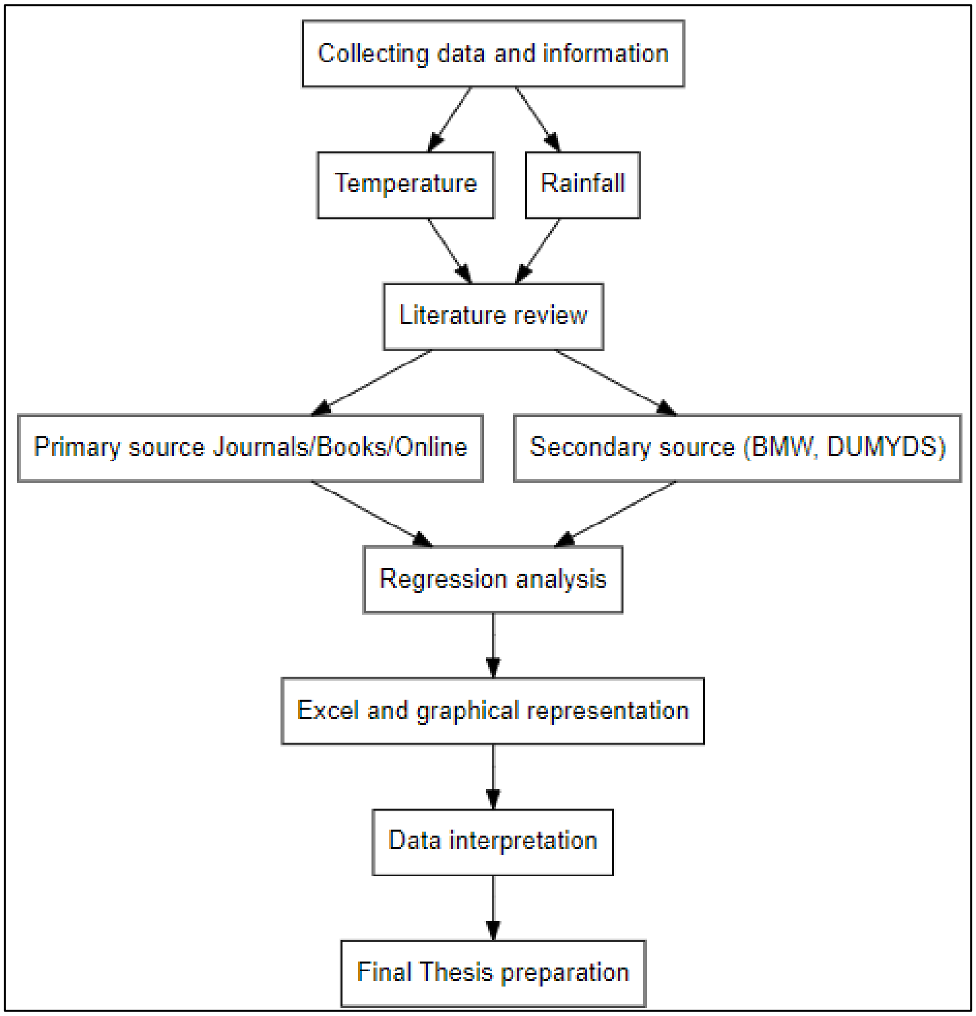


Figure 2: Flowchart of the Research Wor



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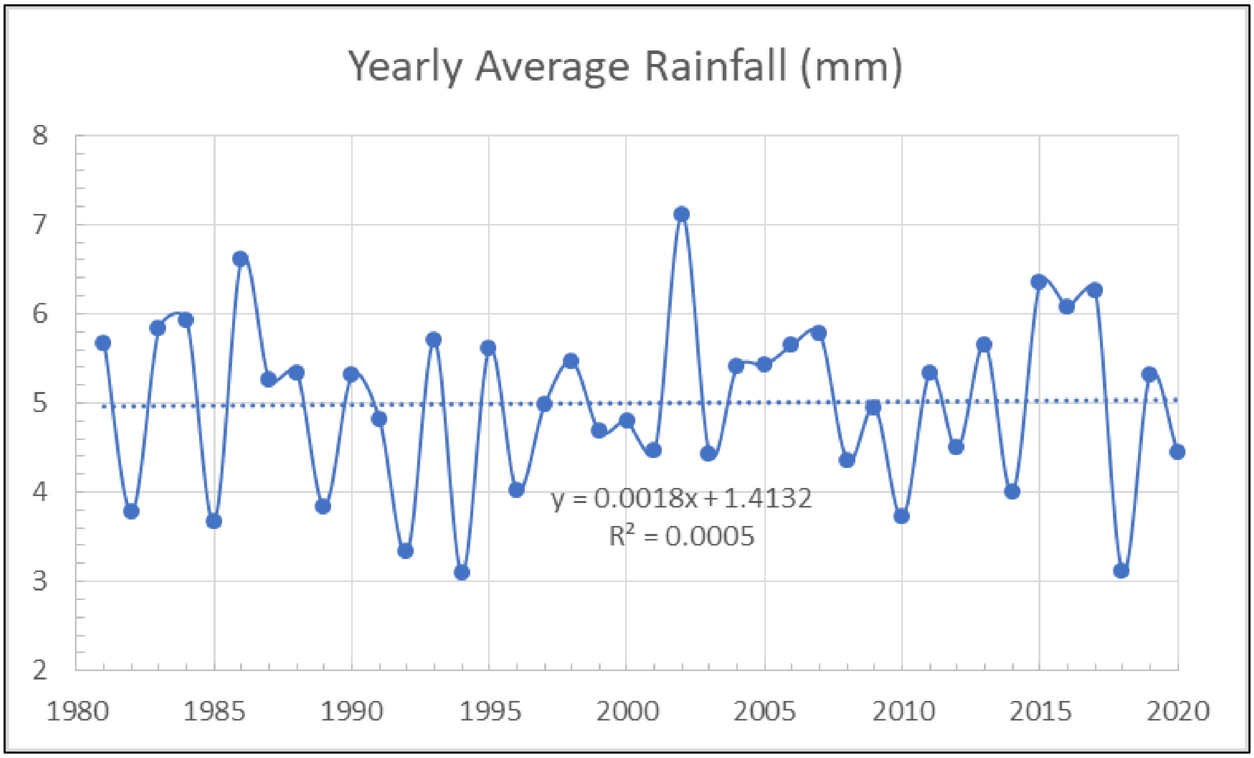
The temperature, Rainfall, and humidity of Khulna city were studied from 1980-2020. The change of average, minimum, and maximum temperature and also decadal temperature were done graphically and statistically. Similar way the data from 1980-2020 for rainfall and humidity were collected.

5 Finding

5.1 Rainfall

Over the period from 1981 to 2020, the average annual rainfall in Khulna City exhibited a decreasing trend, with an annual reduction in rainfall of approximately 0.0018 mm, suggesting a shift toward drier conditions. The peak rainfall recorded during this period was 7.2 mm in 2003, contrasted sharply by the lowest measurements of 3 mm observed in both 1994 and 2014. This significant variability in annual rainfall over the decades highlights the challenges posed by changing precipitation patterns. Such trends are crucial for understanding the long-term climatic changes in Khulna, especially concerning their potential impacts on regional water resources and agricultural activities. This data provides a foundation for further research into adaptive strategies for water management and farming practices to mitigate the effects of these changes.

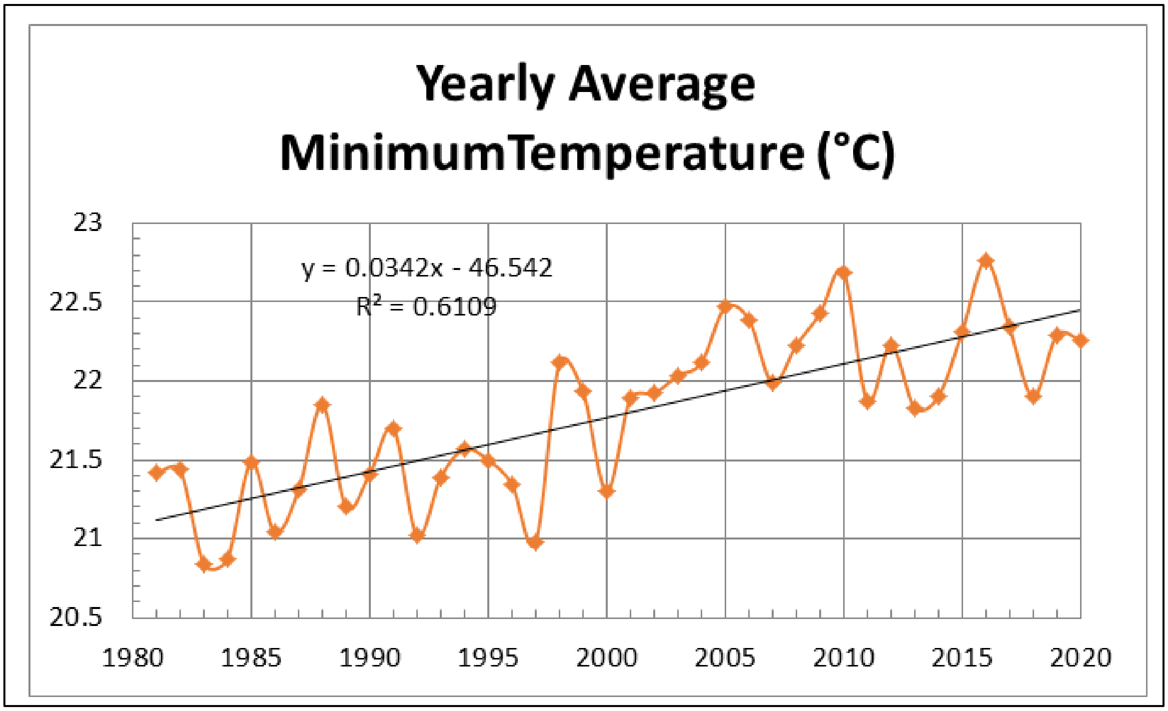
Figure 3: Average rainfall from the years 1981 to 2020



Over the period from 1981 to 2020, significant shifts in temperature dynamics have been observed in Khulna City, specifically in the patterns of average maximum and minimum temperatures. The analysis revealed a consistent rise in daytime temperatures, with an average annual increase of 0.0223°C. This gradual warming trend is further illustrated in the regression model y=0.0223x + 13.375, with an R-squared value of 0.3338, indicating a moderate correlation. This statistical model underscores the ongoing changes in climate conditions, suggesting that daytime temperatures in Khulna are progressively increasing, which could have implications for urban heat management and public health strategies.

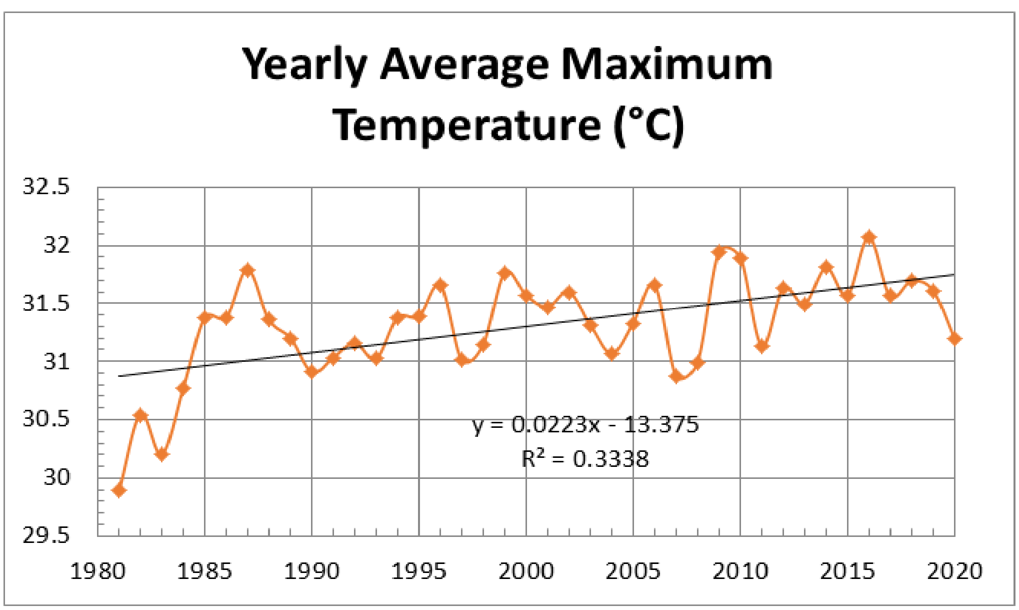
In Khulna City, the study of temperature trends from 1980 to 2020 reveals significant increases in both daytime and nighttime temperatures. While daytime temperatures have shown a gradual increase with an average annual rise of 0.0223°C, as represented in Figure 3 and modeled by the regression equation y=0.0223x + 13.375 (R^2=0.3338), nighttime temperatures have experienced a more pronounced increase. Figure 4 illustrates a sharper ascent in nighttime temperatures, with an average annual increase of 0.0342°C, which is supported by the regression equation y=0.0342x - 46.542, and an R-squared value of 0.6109, indicating a stronger correlation than daytime temperatures. These observations highlight a consistent and significant elevation in temperatures during both parts of the day, Figure

4: Average minimum temperature from the year 1980-2020



.signaling important climatic shifts in Khulna City over the past four decades. The stronger correlation in nighttime temperature increases suggests that these periods may be warming faster than daytime periods, a trend that has broader implications for the urban heat island effect, public health, and energy consumption patterns in the city.

Figure 5: Average Maximum temperature from the year 1980-2020



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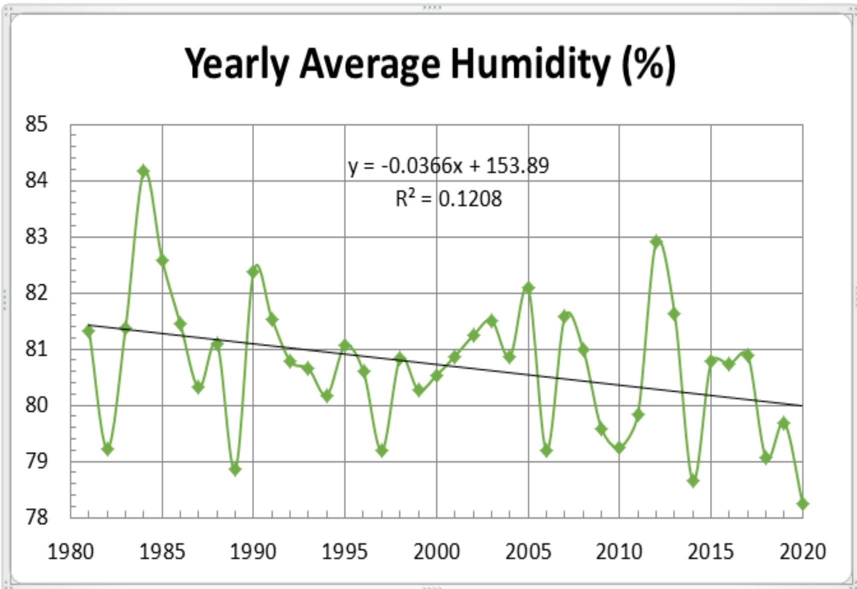
5.2 Humidity (Yearly Average) in Khulna City.

Figure 6: Change of Yearly Average Humidity in the percentage year 1981-2020



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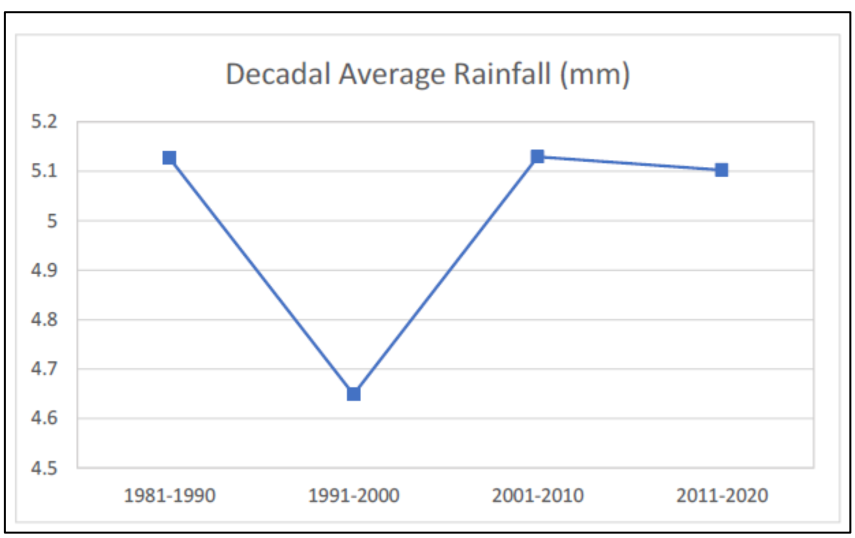
For the years 1981-2020, the yearly change in average humidity for Khulna is -0.0366. Indicating that the overall humidity in Khulna has a decreasing trend and each year it is decreasing by -0.0366. It is indicative of less humid weather throughout the years and the regression equation is y= 0.0366x-153.89; R2=0.1208 (Fig.6).

Figure 7: Decadal Average rainfall from the year 1980-2020 in decadal for



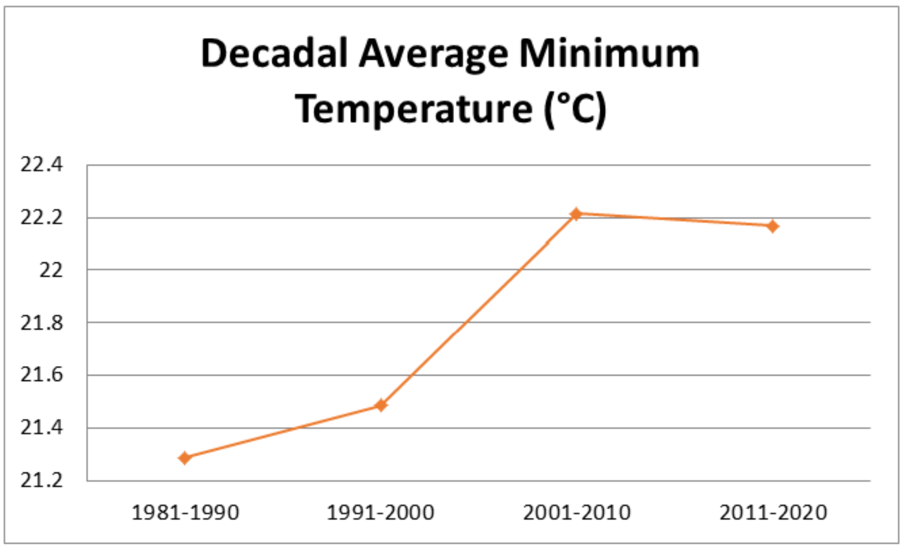
5.3 Decadal Maximum and Minimum Temperature Trends in Khulna (1981-2020):

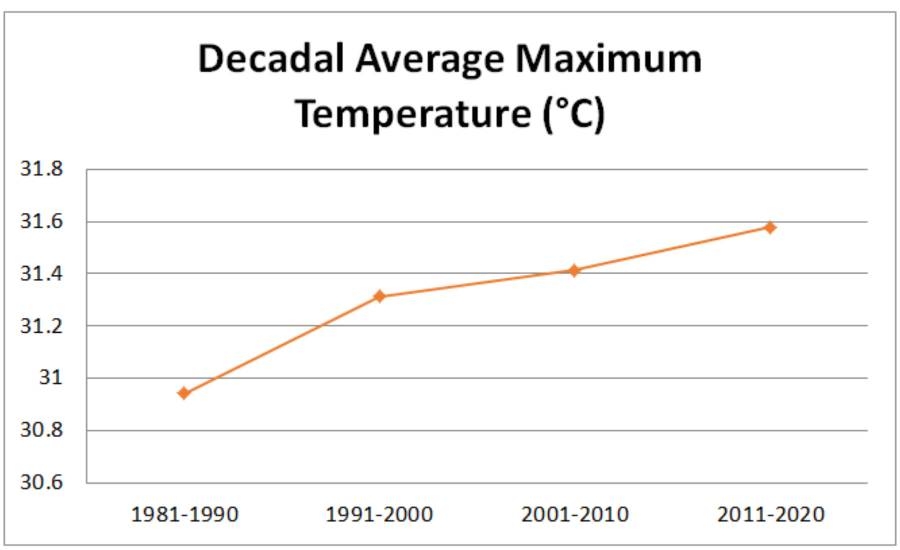
The decadal analysis of Khulna's climate data from 1981 to 2020 reveals a gradual increase in the city's average maximum temperature, as depicted in Figure 7. The average maximum temperature rose from 30.94°C in the 1980s to 31.31°C in the 1990s, followed by a slight uptick to 31.41°C in the 2000s, and reaching 31.58°C in the 2010.

In contrast, the average minimum temperature, shown in Figure 8, displayed a steady climb from

21.29°C in the 1980s to 21.48°C in the 1990s and a significant jump to 22.21°C in the 2000s, before a marginal decline to 22.17°C in the 2010s. This data indicates not only a warming trend but also a complex pattern of temperature changes in Khulna over the last four decades.

Figure 8: Decadal Maximum and Minimum Temperature





5.4 Decadal average Humidity of Khulna City

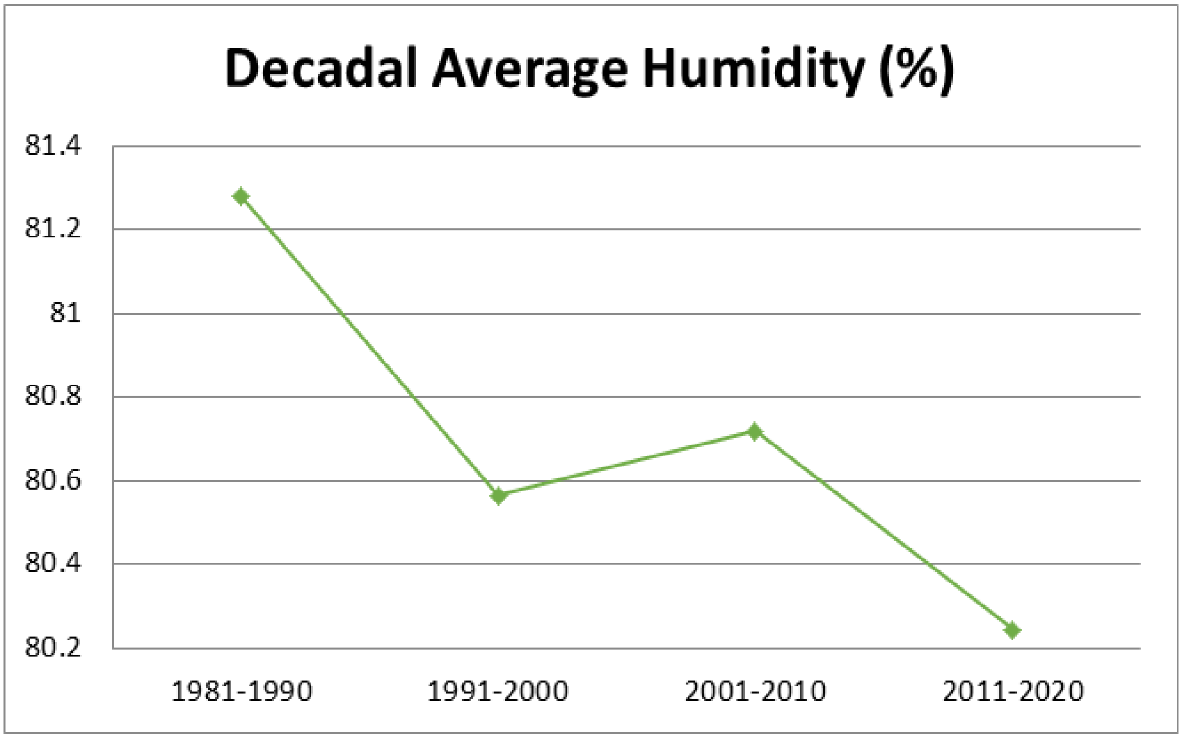


Figure 9: Decadal average humidity (%) from the year 1980-2020

Above is the decadal average humidity (Fig 9) of Khulna from 1981 to 2020. From 1981 to 1990 the average humidity in Khulna was 81.28%. For 1991-2000 that average decreased to 80.56%. From 2001 to 2010 average humidity increased to 80.72%. Then, from 2011 to 2020 average humidity decreased to 80.24%.

6 Regression Analysis

Linear regression analysis of temperature, and rainfall are given below:

Table 1: Linear regression of Temperature of Khulna City from 1980 to 2020

Tmax	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
year	.023	.003	9.07	0	.018	.028	***
Constant	-15.01	5.103	-2.94	.003	-25.012	-5.007	***

Mean dependent var	31.298	SD dependent var	3.689
R-squared	0.005	Number of obs	14916
F-test	82.352	Prob > F	0.000
Akaike crit. (AIC)	81195.962	Bayesian crit. (BIC)	81211.183

*** *p<.01*, ** *p<.05*, * *p<.1*

.The table includes coefficients for variables, standard errors, t-values, p-values, confidence intervals, and significance levels. The variable year has a coefficient of .023 with a standard error of .003. This is statistically significant at the 0.01 level (indicated by ***), meaning there's strong evidence that the variable year has an effect. The Constant has a coefficient of -15.01 with a standard error of 5.103 and is also statistically significant at the 0.01 level. The R-squared value is 0.005, which indicates that the model explains 0.5% of the variability of the dependent variable. The F-test statistic value is 82.352, which is used to assess the significance of the overall regression model.

Table 2: Linear regression of Temperature (Minimum) of Khulna city from 1980 to 2020

tmin	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
year	.029	.004	7.88	0	.022	.037	***
Constant	-37.142	7.483	-4.96	0	-51.809	-22.474	***

Mean dependent var	21.806	SD dependent var	5.410
R-squared	0.004	Number of obs	14928
F-test	62.061	Prob > F	0.000
Akaike crit. (AIC)	92710.758	Bayesian crit. (BIC)	92725.980

*** *p<.01, *** *p<.05, ** *p<.1*

The table is a summary of a regression analysis. It shows that the average minimum temperature in Khulna City has been increasing by 0.029°C each year from 1980 to 2020. This finding is statistically significant with a p-value of less than 0.01, meaning we can be confident in this upward trend. The R-squared value of 0.004 indicates that the year only explains a small portion of the variance in the temperature data. This suggests that other factors not included in the model might also be influencing the temperature changes. The 95% confidence interval for the 'year' coefficient is not shown in the table. This analysis is crucial in understanding the climate change patterns in Khulna City over the past 40 years.

rainfall	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
year	.002	.01	0.21	.833	-.017	.022	
Constant	.774	20.004	0.04	.969	-38.435	39.984	

Mean dependent var	5.002	SD dependent var	14.414
R-squared	0.000	Number of obs	14915
F-test	0.045	Prob > F	0.833
Akaike crit. (AIC)	121922.035	Bayesian crit. (BIC)	121937.255

*** *p<.01, *** *p<.05, ** *p<.1*

Table 3: Linear regression of Rainfall of Khulna city from 1980 to 2020

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The table is a summary of a regression analysis. It shows that the average rainfall in Khulna City has a coefficient of 0.002, which is not statistically significant with a p-value of 0.833. This suggests that the rainfall does not have a significant effect on the dependent variable in the model. The R-squared value of 0.000 indicates that the model explains none of the variance in the dependent variable. This suggests that other factors not included in the model might be influencing the dependent variable. The 95% confidence interval for the 'rainfall' coefficient is between -0.017 and 0.022. This analysis is crucial in understanding the climate change patterns in Khulna City over the past 40 years.

These trends indicate that Khulna City is undergoing a rise in temperatures while rainfall and humidity are showing mixed trends. These changes pose noteworthy challenges for the city's future, particularly in terms of managing floods and supporting the incomes of its population. The city needs to continue implementing climate change adaptation measures to mitigate these impacts.

· **Table 4: Summary of the Trends of climate factors**

Climate Factor	Trend	Details
Temperature	Increasing	The average maximum temperature has been increasing by 0.023°C each year, and the average minimum temperature has been increasing by 0.029°C each year.
Rainfall	Mixed	The average rainfall showed a decreasing trend of -0.0018 mm per year. However, some studies suggest an increasing trend.
Humidity	Mixed	The average humidity demonstrated a decreasing trend of -0.0366 annually. However, some studies suggest an increasing trend.

7 Discussion

The recent climate study on Khulna City reveals significant trends in temperature, rainfall, and humidity that corroborate earlier research findings while also contributing new insights into the region's climatic shifts (Huq et al., 2004). Consistent with global warming projections, both the average maximum and minimum temperatures in Khulna have shown an upward trend over the last four decades. This study's findings that daytime temperatures have risen by an average of 0.023°C each year and nighttime temperatures by 0.029°C each year align with broader patterns observed globally (Fung et al., 2006; Karim et al., 1999). Notably, the increase in nighttime temperatures may suggest an enhanced urban heat island effect, which could exacerbate public health risks and energy consumption in Khulna. These results are in line with those from similar urban studies, which have observed increased thermal retention during the night due to urban expansion and infrastructure density (Huq et al., 2004).

However, the study also highlighted some unique regional characteristics. Unlike the global trend where an increase in global temperatures has led to increased precipitation in many regions, Khulna has experienced a slight but steady decrease in annual rainfall, with an average decline of -0.0018 mm per year (Murtaza, 2001). This reduction could have critical implications for water resources and agricultural practices in the area, which rely heavily on consistent rainfall patterns. This finding contrasts with studies from other parts of the world where increased temperatures have intensified the hydrological cycle, resulting in more pronounced rainy seasons and, in some cases, increased flooding events (Rahaman & Bari, 2024). Furthermore, the observed decrease in humidity by -0.0366 annually contrasts with the global trend where many regions have reported increases in atmospheric moisture, influencing both local climates and weather patterns significantly (Solomon, 2007). These disparities underscore the complex interactions between global climate drivers and localized environmental and geographical factors, highlighting the need for region-specific climate adaptation strategies. Overall, the climatic changes observed in Khulna necessitate ongoing attention to the development of adaptive measures tailored to local conditions. These should include enhancing urban infrastructure to handle higher temperatures and implementing water conservation strategies to mitigate the effects of reduced rainfall and humidity on agriculture and urban water supplies. Such adaptive strategies will be crucial for sustaining the region's economic activities and health as global climate conditions continue to evolve.

8 Conclusion

Due to climate change, the temperature of Khulna city is changing. From 1981 to 2020 the temperature being rising due to global warming. In these forty years there have been changes have been noticed by the Graphical representation of the average minimum, Maximum, and decadal changes of the temperature, rainfall, and humidity and seasonal variation of those parameters of the years from 1981 to 2020. Climate change is the greatest threat of the twenty-first century. In Bangladesh, one of the country's most vulnerable to climate change, impacts are already evident. The extent of damage to Khulna, a city currently lacking proper response mechanisms, remains uncertain in Khulna city, the combination of multiple climatic factors such as temperature variation and erratic rainfall with non-climatic factors such as population density and poverty may affect city life adversely. Socio-economic uncertainties of Dhaka's city dwellers, one-third of whom live in slums, are also expected to produce a multiplier effect resulting in an increase in morbidity and mortality for future generations. Responding to these risks and vulnerabilities requires immediate action from city authorities. Although climate change has become a serious concern of the government, urban adaptation issues still receive limited attention. Government plans and policies should ensure the wise application of available funds – combined with the efforts of NGOs and research institutions to address climate change through a holistic approach in both rural and urban contexts**.**

9 Recommendations

Climate change poses a significant threat to Khulna city, a major urban center in Bangladesh. The city's vulnerability is exacerbated by frequent natural disasters, low economic resilience, high population density, and inadequate infrastructure. Additionally, the high poverty rates and the population's dependence on agriculture and natural resources increase their susceptibility to climatic changes. In response to these challenges, Bangladesh has initiated several national policy measures aimed at adapting to climate change, particularly concerning Khulna. These initiatives include the National Adaptation Program of Action (NAPA) established in 2005, and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) formulated in 2009. Other significant measures include the submission of National Communications to international bodies, the robust implementation of the Sustainable Development Goals (SDGs), and the creation of dedicated Climate Funds. Furthermore, integrated forest management practices and a series of sectoral policies focusing on water, agriculture, food security, energy, and health are also crucial. Additionally, efforts to generate funds through mechanisms like COP 27 are essential to support these initiatives, ensuring that Khulna and other parts of Bangladesh can adapt effectively to the ongoing and future impacts of climate change.

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