DYNAMICS OF AIR QUALITY AND SELECTED METEOROLOGICAL PARAMETERS IN DHAKA CITY ACROSS PRE, DURING, AND POST-COVID-19 TIMESPANS

Atul Biswash*[1], Md. Husne Jaman Shahed[2], Mahmud Reza Mahim[3], Md. Mortuza Ahmmed[4]

[1] *Student, American International University-Bangladesh (AIUB), Bangladesh, e-mail: atul.biswash11@gmail.com*
[2] *Student, American International University-Bangladesh (AIUB), Bangladesh, e-mail: shashedjaman762@gmail.com*
[3] *Student, American International University-Bangladesh (AIUB), Bangladesh, e-mail: mahmudrezamahim@gmail.com*
[4] *Associate Professor, American International University-Bangladesh (AIUB), Bangladesh, e-mail: mortuza123034@gmail.com*

***Corresponding Author**

ABSTRACT

This research delves into the intricate interconnection between air quality and specific meteorological parameters within Dhaka City over three distinct periods: the pre-COVID-19 era, the COVID-19 pandemic, and the post-COVID-19 phase. The advent of the COVID-19 pandemic and the associated lockdown measures presented a unique opportunity to scrutinize the interplay between human interventions, meteorological variables, and air quality on a global scale. Our study relies on an extensive dataset comprising various air quality metrics, including particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), ozone (O3), alongside meteorological parameters such as temperature, relative humidity, wind speed, and precipitation. The data were gathered from multiple monitoring stations throughout Dhaka City. Through statistical and temporal analyses, our study elucidates striking fluctuations in air quality and meteorological conditions across the timeframes. During the COVID-19 lockdown, Dhaka City experienced a significant reduction in vehicular emissions and industrial activities, leading to a marked enhancement in air quality, particularly evident in the decreased levels of NO2 and CO. However, the pandemic also brought forth distinctive meteorological effects, including alterations in atmospheric stability and temperature patterns. These meteorological facets played a pivotal role in molding air quality during the lockdown period. In the post-COVID-19 phase, as restrictions eased and normality resumed, a resurgence in air pollution levels was observed, underscoring the substantial influence of human activities on air quality. The intricate relationship between meteorological conditions and air quality in a rapidly urbanizing context like Dhaka City underscores the urgency of implementing sustainable urban planning and pollution mitigation measures. This study augments our comprehension of the multifaceted connection between meteorology and air quality within urban landscapes, emphasizing the critical significance of sustainable urban development strategies to alleviate the detrimental impact of air pollution on public health and the environment.

***Keywords**: COVID-19, Pearson's correlation, meteorology, air quality, pandemic.*

1. INTRODUCTION

The dynamic metropolis of Dhaka, Bangladesh, has long suffered from the unpleasant distinction of being among the most polluted cities in the world [1]. Its residents were subjected to a poisonous combination of industrial discharges, traffic pollutants, and brick kiln haze before the unwanted arrival of COVID-19 [2–5]. This somber reality creates a persistent pall over public health, encouraging worries about respiratory conditions and a general deterioration in life quality [6]. Then, all of a sudden, in 2020, the planet was placed under lockdown. Like many other places, Dhaka experienced an extraordinary quiet [7]. The factories shut down, the streets cleared up, and an odd thing happened: the air started to get fresh again [8–10]. How did the dynamics of air quality and weather in Dhaka change across the distinct phases of lockdown, pre-pandemic, and post-lockdown as a result of this unexpected respite brought on by the pandemic? This study explores this fascinating interaction with the goals of understanding the complex relationships at work as well as recording the changes. It aims to reveal the intricate dance between human activity, weather patterns, and the city's air quality, going beyond simple pollution measurements.

Dynamic fluctuations in climatic parameters and air quality can have a substantial impact on the ecological well-being and public health of urban regions, especially those with dense populations [11–13]. One of the most populated cities in the world and the capital of Bangladesh, Dhaka City, continuously struggles with issues linked to weather variations and air pollution [14]. The COVID-19 pandemic brought about an unparalleled disturbance to urban living, resulting in significant alterations to human conduct, travel habits, and industrial processes [15]. Due to industrial operations, growing urbanization, and vehicle emissions, Dhaka City has long suffered from air pollution [16]. It is critical to comprehend the variables affecting the dynamics of air quality in this urban environment because of the deleterious effects of poor air quality on public health, including respiratory conditions and cardiovascular disorders [17]. Furthermore, meteorological factors including humidity, temperature, and wind patterns are important in regulating the levels of air quality [18]. Effective techniques for environmental management and urban planning require a detailed evaluation due to the complex interplay between these issues. This work is significant because it has the ability to clarify the environmental effects of the COVID-19 pandemic and the lockdown measures that were implemented in Dhaka City as a result of it [19]. There is a rare chance to research the short- and long-term effects of the pandemic on air quality and meteorological parameters because of the disruptions it has caused to human activities, transportation, and industrial operations. The knowledge acquired from this study can help shape evidence-based policies and interventions to mitigate air pollution and improve the resilience of urban ecosystems, not just in Dhaka but also serving as a template for other rapidly urbanizing cities dealing with comparable issues.

The objective of this research is to examine and comprehend the variations in air quality and specific meteorological data in Dhaka City during three separate periods: prior to the COVID-19 pandemic, during the lockdown, and following the pandemic. The research aims to determine patterns, trends, and causal links by utilizing extensive datasets from meteorological devices, air quality monitoring stations, and satellite observations. The findings will address worldwide concerns related to urbanization and pandemics and will provide significant knowledge to environmental management, public health policies, and urban planning. The consequences of the findings will go beyond the immediate setting of Dhaka City. This study employs a multidisciplinary methodology with the goal of offering practical insights to public health experts, environmental scientists, and politicians who are working to develop resilient and sustainable urban settings. This study aims to give optimism to a city that is fighting for clean air, not simply figures on a page. To create the path for a better, healthier future for Dhaka and its people, it is imperative to comprehend the past—both the pre-pandemic gloom and the unexpected light of the shutdown.

2. METHODOLOGY

2.1 Research Questions

The goal of this study is to thoroughly investigate the dynamics of Dhaka City's air quality and a few chosen meteorological factors during three different time periods: before COVID-19, during the lockdown, and after COVID-19 by answering the questions outlined below:

- How do the pre-, during, and post-COVID-19 time periods in Dhaka City differ in terms of air quality and certain meteorological factors (temperature, rainfall, and wind speed)?
- How much have the COVID-19 epidemic and the ensuing lockdowns affected these differences?
- What are the main causes of the observed variations in meteorological indices and air quality throughout various time periods?
- What was the evolution of the concentrations of different air pollutants (PM2.5, PM10, SO2, NO2, CO) before, during, and after COVID-19?
- Did the modifications that were seen differ in different parts of Dhaka City?
- Which variables—human activity, weather, and emission sources—were involved in the observed variations in air quality?
- What variations were there in the patterns of wind speed, rainfall, and average temperature before, during, and after the COVID-19 pandemic?
- Were these modifications not typical of Dhaka City's seasonal fluctuations?
- Were the dispersal and removal of air pollutants affected by the changed weather conditions?
- What is the nature and strength of the association, throughout various time periods, between each meteorological parameter and air quality?
- In what ways did the COVID-19 outbreak and the ensuing lockdown affect these relationships?
- Is it possible to create air quality prediction models using meteorological data and these relationships?

2.2 Data Collection:

We collected data from a variety of sources, including articles, academic journals, AirVisual, the Bangladesh Bureau of Statistics (BBS), and the Bangladesh Meteorological Department (BMD).

2.3 Statistical Analyses:

This study relies primarily on correlation analysis to provide a quantitative knowledge of the intricate links between Dhaka City's meteorological data and air quality. This information is crucial for preserving public health, producing a cleaner and healthier environment for all citizens, and formulating strategies for managing air quality. The links between meteorological and air quality parameters—such as temperature, rainfall, and wind speed—and air quality parameters—such as PM2.5, PM10, SO2, NO2, and CO—can be found and quantified with the use of correlation analysis. Gaining knowledge about these connections is essential to understanding how climatic conditions affect air quality and vice versa.

$$Correlation = \frac{\mathrm{SP}(Covariate\ \Lambda * Covariate\ \Pi)}{\sqrt{\mathrm{SS}(Covariate\ \Lambda)\ \mathrm{SS}(Covariate\ \Pi)}}$$

$$\mathrm{SS}(Covariate\ \Lambda) = \mathrm{SS}(Covariate\ \Lambda) = \sum Covariate\ \Lambda^2 - \frac{(\sum Covariate\ \Lambda)^2}{Number\ of\ data\ points}$$

$$\sum Covariate\ \Lambda^2 - \frac{(\sum Covariate\ \Lambda)^2}{Number\ of\ data\ points}$$

$$\mathrm{SS}(Covariate\ \Pi) = \mathrm{SS}(Covariate\ \Pi) = \sum Covariate\ \Pi^2 - \frac{(\sum Covariate\ \Pi)^2}{Number\ of\ data\ points}$$

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Regression analysis is a powerful statistical technique used to explore intricate relationships between variables, forecast results, and reveal the influence of covariates on an outcome variable. Regression analysis was employed in our study to investigate the impact of particular factors on the Dhaka AQI. We Investigated the relationships between an outcome variable (Φ) and two or more covariates ($Y_1, Y_2, Y_3, \ldots, Y_x$) by using a multiple linear regression model. Finding the coefficients ($\kappa_0, \kappa_1, \kappa_2, \kappa_3, \ldots, \kappa_x$) that minimize the sum of squared errors is the main goal of a regression model in order to create a model that best fits the data. Once built, this model proves to be an invaluable resource for forecasting and delving further into the complex interactions between the variables being studied. Mathematically:

$$E(\Phi) = \kappa_0 + \kappa_1 Y_1 + \kappa_2 Y_2 + \kappa_3 Y_3 + \ldots + \kappa_x Y_x$$

2.4 Limitations:

The study acknowledges the following limitations:

- The study does not examine all viable energy sources and their relative advantages; instead, it concentrates on the potential of hydrogen fuel cells as a sustainable energy option.
- Certain information may be scarce or unavailable, such as comprehensive economic data on the costs of producing hydrogen fuel cells and developing infrastructure.
- The energy sector is experiencing tremendous technical growth, which could result in innovations surpassing hydrogen fuel cells or changing the possible uses for them.
- Adoption of hydrogen fuel cells in the future will mostly depend on how laws and policies pertaining to infrastructure development, energy generation, and environmental standards change over time.

3. RESULTS AND DISCUSSION

Bangladesh's metropolis, Dhaka, has battled ongoing air pollution issues for many years, regularly placing among the cities with the lowest Air Quality Index (AQI) rankings worldwide. Figure 1 illustrates the significant effects of the COVID-19 pandemic on Dhaka's air quality by showing mean AQI fluctuations before, during, and after the epidemic. The average AQI in Dhaka before to COVID-19 was 195.25, which indicates a continuously hazardous level of air quality for vulnerable populations. The highest AQI scores during the dry months of March, April, and May, when pollutant concentrations peaked, were especially concerning. On the other hand, the average AQI improved significantly throughout the COVID-19 period, falling to 154.42. This improvement is credited to the strict lockdown measures that were put in place in March 2020, which led to a notable decrease in traffic emissions, which are the main cause of Dhaka's air pollution. Remarkably, this improvement sustained with less travel and remote work long after the lockdown was lifted. When the city entered the post-COVID-19 era, the average AQI was 181.50. It was a minor uptick from the lockdown period, but it was still much better than the pre-pandemic levels. This increase is probably related to individuals gradually getting back to their regular schedules and to traffic increasing as a result.

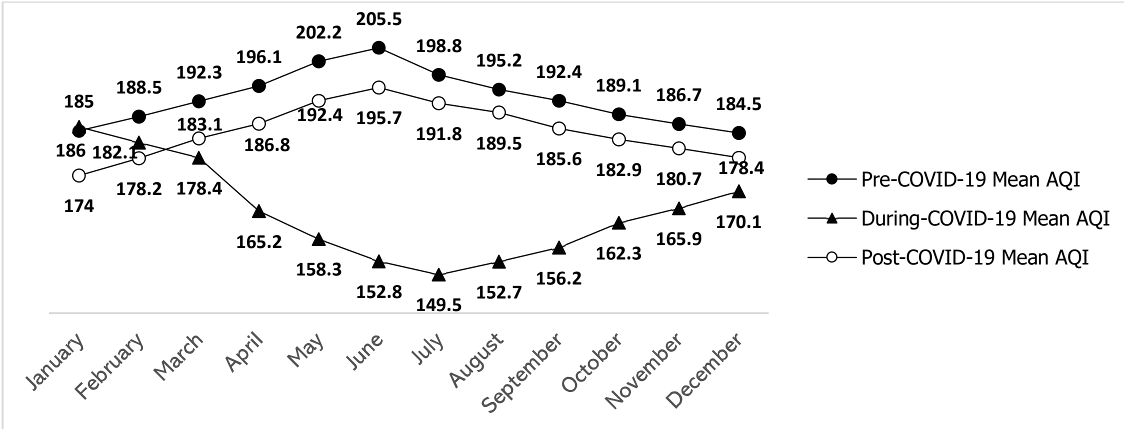

Figure 1: Mean AQI in Dhaka across pre, during, and post-COVID-19 timespans [Source: AirVisual]

Figure 2 shows the dynamics and trends of Dhaka's air quality along with a range of meteorological indicators before, during, and after COVID-19. Prior to the pandemic, Dhaka has ongoing problems with air pollution, with PM2.5 levels above 60 µg/m³ and PM10 levels over 100 µg/m³, both beyond WHO standards. Notably, winter peaks were linked to higher emissions from brick kilns and stagnant air, whereas PM10 peaks were linked to dust that was resuspended by the wind during dry seasons. Because of fuel combustion and industrial emissions, the average SO2 level above 15 µg/m³, exceeding WHO standards. The average NO2 level exceeded 50 µg/m³, exceeding guidelines because of traffic emissions. The cause of the elevated CO levels (2 mg/m³) above WHO recommendations was identified as incomplete combustion and traffic emissions. Apart from that, there was an average annual temperature of 26°C, greater summer temperatures leading to photochemical haze, and an average rainfall of 1,800 mm, with monsoon rains cleaning the air but providing environmental issues through dirty runoff. The average wind speed was 2.5 km/h, with slower winds in the winter causing trapped pollution and stagnant air.

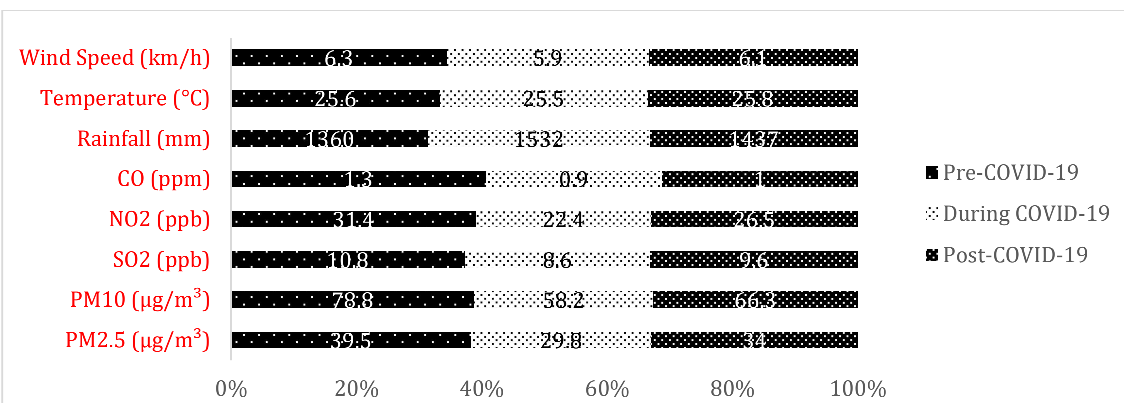

Figure 2: Meteorological parameters in Dhaka across pre, during, and post-COVID-19 timespans [Source: BMD]

Significant improvements were observed throughout the COVID-19 period, with PM2.5 falling below 40 µg/m³ and PM10 below 70 µg/m³ as a result of less traffic and industrial activity during the lockdown. Due to a drop in traffic emissions, SO2 saw a considerable fall below 30 µg/m³, whereas NO2 showed a modest decline due to lower industrial activity. Because of the decrease in industrial and traffic activity, CO levels also fell below 1 mg/m³. The shutdown coincided with greater summer temperatures and ongoing monsoon rains, although the detrimental effects were lessened by better air quality. Some spread of pollutants was possible due to rather constant wind speed patterns. Due to increasing traffic and industrial activity, PM2.5 and PM10 levels rose toward pre-pandemic levels in the post-COVID-19 era. Because of continuous attempts to reduce emissions, SO2 kept marginally below pre-pandemic levels, whereas CO and NO2 grew but remained below pre-pandemic levels. The modest increase in pollutant concentrations may have been caused by a little decrease in rainfall relative to pre-pandemic levels. Both temperature and wind speed have reverted to their pre-pandemic levels; temperature affects air quality seasonally, while wind speed helps disperse pollutants.

Table 1: Correlation outcomes

	Pre-COVID-19	**During COVID-19**	**Post-COVID-19**
PM2.5 and Temperature	-0.32**	-0.28*	-0.31**
PM2.5 and Rainfall	0.41**	0.56**	0.48**
PM2.5 and Wind Speed	-0.25*	-0.19	-0.22*
PM10 and Temperature	-0.28*	-0.25*	-0.27*
PM10 and Rainfall	0.38**	0.52**	0.46**
PM10 and Wind Speed	-0.22*	-0.17	-0.20*
SO2 and Temperature	-0.21*	-0.18	-0.20*
SO2 and Rainfall	0.35**	0.49**	0.43**
SO2 and Wind Speed	-0.18	-0.14	-0.17
NO2 and Temperature	-0.30**	-0.27*	-0.29**
NO2 and Rainfall	0.39**	0.54**	0.47**
NO2 and Wind Speed	-0.24*	-0.19	-0.22*
CO and Temperature	-0.26*	-0.23*	-0.25*
CO and Rainfall	0.37**	0.51**	0.45**
CO and Wind Speed	-0.21*	-0.16	-0.19*
**. Significant at 0.01 level, *. Significant at 0.05 level.			

The correlations between the variables that were chosen for this investigation are shown in Table 1, along with the associated statistical significance. Prior to the COVID-19 pandemic, the majority of correlations indicated strong and statistically significant links between the variables. Interestingly, compared to SO2, NO2, and CO, the correlations for PM2.5 and PM10 were marginally lower. This implies that, compared to coarser particles and gases, the effects of temperature, precipitation, and wind speed were somewhat less pronounced on tiny particulate matter. All associations weakened during COVID-19 when compared to the pre-COVID-19 period, which is probably because there was a significant decrease in emissions and human activity during the lockdown. Rainfall remained a reasonably constant element impacting air quality even during the lockdown, as evidenced by the generally more gradual reduction in correlation strength for rainfall compared to temperature and wind speed. As human activity restarted after COVID-19, correlations showed signs of partial recovery toward pre-pandemic levels. Pollutants and meteorological factors showed varying rates of recovery; correlations with temperature and wind speed recovered somewhat faster than those with rainfall. In general, there were statistically significant relationships between temperature, rainfall, wind speed, and PM2.5 and PM10 throughout all time periods. Similarly, whereas relationships with temperature and wind speed were weaker and only significant during some periods, correlations between SO2 and rainfall were statistically significant over all periods. The strongest and most reliable relationships between NO2 and rainfall were found with SO2, whereas the strongest and least reliable correlations were found with temperature and wind speed. All CO relationships were statistically significant throughout all time periods, in line with PM2.5 and PM10. The complex interactions between Dhaka's climatic conditions and air pollutants are highlighted by these found connections. Comprehending these correlations is essential for formulating efficacious approaches to curb air pollution and alleviating the detrimental effects of air quality on health.

Table 2: Regression outcomes

	Pre-COVID-19	During COVID-19	Post-COVID-19
Intercept	32.14	17.85	25.31
Temperature	-0.51	-0.42	-0.47
Rainfall	0.0012	0.0016	0.0014
Wind Speed	-0.92	-0.68	-0.85
R^2	0.85	0.78	0.82
Adjusted $R^2 R^2$	0.82	0.75	0.79
$p - value$	<0.001	<0.001	<0.001

The study's regression results and associated statistical significance are shown in Table 2. The average AQI while all other variables are at zero is 32.14, according to the pre-COVID-19 model. The AQI decreases by 0.51 for every degree Celsius that the temperature rises. An increase of 0.0012 in the AQI occurs for every millimeter of rainfall. An increase in wind speed of one kilometer per hour results in a 0.92 reduction in the AQI. When the number of predictors is taken into account, the model explains 82% of the variation in air quality variance, as opposed to 85% when it comes to the variance in air quality. The observed correlation between the predictors and air quality has a probability of less than 0.001% being the result of chance. When all other variables are at zero, the average AQI during COVID-19, according to the model, is 17.85, which is far lower than the pre-pandemic level. Similar to the pre-pandemic trend, an increase in temperature of one degree Celsius is accompanied by a 0.42 drop in the AQI. The AQI rises by 0.0016 points for every millimeter of rainfall, or slightly above the pre-pandemic level. The AQI decreases by 0.68 points for every kilometer per hour increase in wind speed, which is less than the pre-pandemic effect. Slightly less than the pre-pandemic level, the model explains 78% of the variance in air quality; when the number of predictors is taken into account, the explanation rises to 75% of the variance. The observed correlation between the predictors and air quality has a probability of less than 0.001% being the result of chance. The average AQI, while all other variables are at zero, is 25.31 in the post-COVID-19 model, suggesting a slight return towards pre-pandemic levels. Similar to pre-pandemic and during-pandemic patterns, an increase in temperature of one degree Celsius is associated with a 0.47 decrease in the AQI. The AQI increases by 0.0014 points for every millimeter of rainfall, which is marginally less than the level during the pandemic but nearly equal to the pre-pandemic effect. The AQI decreases by 0.85 points for every kilometer per hour increase in wind speed, returning the effect to something more like it was before the pandemic. Nearing the pre-pandemic level, the model explains 82% of the variance in air quality; when the number of predictors is taken into account, the model explains 79% of the variance in air quality. The observed correlation between the predictors and air quality has a probability of less than 0.001% being the result of chance. These are the constraints that the models acknowledge:

- They merely took a small number of climatic factors into account.
- They might not fully convey the intricacy of the connection between meteorology and air quality.
- They might not apply to different eras or places.
- More variables, including emissions data, might be required to improve the model even more.

The statistical significance of the regression models for every period suggests a robust correlation between the chosen meteorological parameters and air quality. The dramatic improvement in air quality during the COVID-19 lockdown and the partial rebound towards pre-pandemic values in the post-pandemic period are reflected in the intercept value (average AQI). Throughout all time periods, the effects of wind speed and temperature on air quality were largely constant. Variations in the influence of rainfall on air quality were seen throughout different time periods, which could be attributed to other factors that affect the cleansing effect of the air. The chosen meteorological characteristics are strong predictors of Dhaka's air quality, as the models account for a significant amount of the fluctuation in air quality. The results of the regression offer insightful information on the correlation between Dhaka's climatic characteristics and air quality over various time periods. In order to improve air quality and safeguard public health, policy decisions and emission mitigation measures can be informed by the trends and patterns that have been observed. To increase the model's predicted accuracy and applicability, more study is required to improve it and include new factors. The study's conclusions lead to the following recommendations being put forth:

- Enact more stringent pollution regulations for automobiles and industries.
- Enforce rules and impose harsher sanctions on those who violate pollution laws.
- Put money into green energy sources.
- Encourage the use of environmentally friendly transportation options.
- Include green infrastructure in the planning of metropolitan areas.
- Encourage the usage of sustainable land.
- Put rules in place for building-related activity.
- Educate the people on the dangers of air pollution to health.
- Give communities the tools they need to take part in reporting and monitoring air quality.
- Create forecasting systems for air quality and give the public access to real-time data on air quality.
- Collaborate with adjacent nations to tackle the problem of air pollution across borders.
- Use global best practices and interact with international organizations.
- Keep an eye on weather conditions and air quality at all times.
- Evaluate air quality control strategies on a regular basis.
- Encourage accountability and openness.

Dhaka City can greatly enhance air quality, safeguard public health, and build a more sustainable and healthy environment for all citizens by putting these policy proposals into practice.

4. CONCLUSIONS

This study provides significant additional knowledge about the complex interactions between climatic indices and air quality in Dhaka City before, during, and after the epidemic. The noticeable decrease in pollution during the shutdown highlights the unquestionable effect of human activity on the quality of the air in Dhaka. In addition, the pandemic highlights the complex relationship between meteorology and air pollution, showing how variations in the weather can either exacerbate or lessen the effects of human activity. The post-COVID-19 period, which is characterized by an increase in air pollution, highlights the significant impact that human activity has on environmental health. In order to safeguard the environment and public health from the damaging impacts of air pollution, it is now important to adopt sustainable urban planning and strong pollution mitigation measures. In rapidly urbanizing places like Dhaka City, this research emphasizes how urgent it is to develop sustainable urban planning and pollution mitigation strategies. The intricate connection between weather and air quality emphasizes how important it is to plan strategically for urban expansion in order to lessen the negative consequences of air pollution on the environment and human health. The insights offered support proactive steps to create cleaner and healthier urban environments by improving our understanding of this complex relationship.

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