# Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh

**A Thesis Submitted to the Department of Environmental Science, Faculty of Science and Technology, Bangladesh University of Professionals for Partial Fulfillment of the Requirements for the Degree of BSc in Environmental Science**

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# DEDICATION

**To my parents**

# ACKNOWLEDGMENTS

I would like to thank my distinguished supervisor, **Prof. Dr. Md. Younus Mia**, Pro-Vice-Chancellor, Stamford University Bangladesh for his cordial supervision, support, and guidance throughout this study. My thanks go to the Faculties of Bangladesh university of professionals for providing support for my studies at the Department of environmental science. Additionally, I would like to express my appreciation to Feroz Kabir for his invaluable contribution to the collection of air quality data. My heartfelt gratitude also goes to my family for their continuous support.

# DECLARATION

I hereby declare that the research work entitled **"Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh."** has been carried out under the Department of Environmental science, Faculty of Science and Technology, Bangladesh University of Professionals in fulfillment of the requirement for the Degree of BSc in Environmental Science. I have composed this thesis based on original research findings from "Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh" acquired by me along with references from published literature. This has not been submitted in part or full for any other institution for any other degree. I also certify that there is no plagiarized content in this thesis (Maximum 25%).

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# CERTIFICATE OF THE SUPERVISOR

This is to certify that **Atia Zannat Dia** carried out her thesis under my guidelines and supervision, and hence prepared the thesis entitled **“Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh”.** So far as I am aware, the researcher duly acknowledged the other researchers’ materials and sources used in this work. Further, the thesis was not submitted to any other Universities or institutions for any other degree or diplomas.

It is thus recommended that the thesis be submitted to the Department of Environmental Science, Faculty of Science and Technology, Bangladesh University of Professionals, in fulfillment of the requirements for the award of the degree of BSc in Environmental Science. I also certify that there is no plagiarized content in this thesis (Maximum 25%).

22/12/2023

Prof. Dr. Md. Younus Mia

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# Abstract

The comparative study was conducted to assess and compare the air pollutant concentration variations of the selected areas of Uttara and Mirpur in Dhaka, Bangladesh, focusing on buildings with and without rooftop gardens. This study analyzed various air quality parameters, including $O_2$, NO, $NO_2$, $SO_2$, $O_3$, $CH_4$, CO, $CO_2$, and particulate matter ($PM_1$, $PM_{2.5}$, TSP), in buildings with and without rooftop gardens. Samples were collected over two months, August and September, 2023. Newly constructed buildings without rooftop gardens exhibited elevated pollutant levels compared to established structures without such rooftop gardens. Conversely, buildings with rooftop gardens displayed significantly lower particulate matter concentrations ($PM_1$, $PM_{2.5}$, TSP). ANOVA tests consistently underscored the substantial impact of rooftop gardens on air quality. CO concentrations within buildings featuring rooftop gardens remained below the Bangladesh standard. However, in buildings without gardens, the average CO concentration exceeded the WHO standard for the 8-hour averaging period. Notably, both scenarios did not breach the 1-hour and 8-hour EPA standards for CO. Moreover, $NO_2$ concentrations within buildings with rooftop gardens notably fell below the Bangladesh standard for the 24-hour averaging period. Conversely, in buildings without gardens, $NO_2$ concentrations approached this standard. Similarly, while $PM_{2.5}$ average concentration exceeded WHO standards for both scenarios, they were notably lower in buildings with rooftop gardens compared to those without. The study strongly suggests that the absence of rooftop gardens corresponds to heightened pollutant concentrations, particularly evident in NO2, $PM_{2.5}$, $O_3$, and $SO_2$. These disparities underscore the vital role of rooftop garden in mitigating air pollutants, emphasizing the critical importance of integrating rooftop gardens in urban settings to enhance air quality. The statistical analyses consistently highlighted the substantial impact of rooftop gardens on air quality and emphasized the necessity of immediate remedial measures to mitigate health risks associated with poor air quality in buildings without rooftop gardens. The findings of this study highlight the pivotal role of rooftop gardens in residential buildings as a significant contributor to improving urban air quality.

***Keywords:*** *Rooftop gardens, NO, SO, Uttara, Mirpur, PM, TSP, Ozone, Pollutants, Bangladesh standard, WHO, US EPA, ANOVA.*

# List of Abbreviation and Acronyms

| **Abbreviation and Acronyms** | **Expressions** |
|---|---|
| AQI | Air Quality Index |
| $PM_1$ | Particulate Matter with a diameter of 1 micrometer or less |
| $PM_{2.5}$ | Particulate Matter with a diameter of 2.5 micrometers or less |
| TSP | Total Suspended Particulates |
| NO | Nitric Oxide |
| $NO_2$ | Nitrogen Dioxide |
| $SO_2$ | Sulfur Dioxide |
| $O_3$ | Ozone |
| $\mu g/m^3$ | Micrograms per cubic meter |
| ppm | Parts Per Million |
| ANOVA | Analysis of Variance |
| EPA | Environmental Protection Agency |
| WHO | World Health Organization |

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# Chapter One

# Introduction

# Chapter 1: Introduction

## 1.1 Background of the Study

Dhaka, the capital of Bangladesh, is one of the biggest and fastest-growing cities in the world. It covers an area of 306.4 square kilometers and has around 23.21 million people (*Dhaka, Bangladesh Metro Area Population 1950-2023*, n.d.). Unfortunately, the city's unplanned growth has caused some serious environmental issues. Dhaka has 21.57% of open space, with parks making up 0.89%, forestry making up 0.02%, gardens making up 0.90%, and agriculture making up 12.12% (M et al., 2015). The amount of green space has been decreasing over time, while the number of buildings has been growing without taking into account environmental protection. The Chief Town Planner for Dhaka City (2003) said that an ideal city would have 20% of the area covered by trees, but the city only has 8% of vegetation. Unfortunately, the air quality in Dhaka has been getting worse over the past few years, although some measures have been taken to improve it. As urbanization continues to reshape city landscapes, the impact of building structures on environmental factors, including air quality, becomes a critical area of investigation.

As a way to improve urban sustainability by restoring ecosystem services, green roofs have become more and more popular over the last 20 years. Among the many objectives are lowering the urban heat island, extending the roof membrane, intercepting stormwater runoff, removing particulate matter from the air, improving energy efficiency, and supplying city people with locally grown food (Tong et al., 2016). Using the UFORE model, Currie and Bass calculated that, green roofs in Toronto removed 7870 kg of pollutants annually (Currie & Bass, 2008). Studies are required to assess the air quality on building roofs and explore the potential of green roofs in enhancing air quality in residential areas and buildings. The air quality predicament in Dhaka is complex and severe, originating from various sources that collectively contribute to a pervasive cloud of pollutants shrouding the city. The consequences of Dhaka's air pollution are far-reaching, affecting both public health and the environment. Fine particulate matter, noxious gases, and volatile organic compounds released into the atmosphere pose significant threats to the well-being of Dhaka's residents (Dibya et al., 2023). And trees can improve air quality through a number of means, including by (1) reducing air temperature thus altering pollution concentrations, (2) reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power sources, and most notably, (3) directly removing pollutants from the air (*Air Pollution Removal by Urban Forests (U.S. National Park Service)*, n.d.).

Rooftop gardening, often referred to as rooftop farming or green roofs, involves the transformation of previously unused rooftop spaces into thriving gardens. These green havens offer a breath of fresh air, both metaphorically and literally, as they provide a sanctuary for a diverse array of plants, including vegetables, herbs, flowers, and trees. These spaces not only showcase human ingenuity but also hold the potential to ameliorate the city's air quality crisis. The plants on rooftop gardens not only help photosynthesize and reduce the pollutants in the air, but they also deposit them into the growing space, reducing the amount of dust and smog in the air (Li & Babcock, 2014). This, in turn, reduces the amount of greenhouse gases released into the atmosphere. Of course, a single rooftop green roof in an urban area won't make a huge difference, but a large number of rooftop green roofs could make a big difference (Li & Babcock, 2014). The Department of Environment (DoE) said that the levels of Air Pollutants (SOx), NOx and $CO_2$ in the city of Dhaka are about 4-5 times the prescribed levels of AQS in Bangladesh. These pollutants are left and remain in the air due to the lack of tree cover. Trees are able to remove pollution by trapping airborne particles (Nowak et al., 2006). According to the Bangladesh Pollution Action Plan (BAPA) (2002), air pollution causes headaches, burning of eyes, throat pain and bronchitis. It also causes breathing difficulties, heart diseases, anemia, mental disorders, kidney diseases and even cancer. This research embarks on a mission to explore and compare the air quality within the residential confines of Dhaka City, with a specific focus on the presence or absence of rooftop gardens. Its aim is to uncover invaluable insights into the potential benefits of rooftop gardening as a means to bolster air quality in densely populated urban environments. Through a rigorous comparative analysis, the research seeks to evaluate the true effectiveness of rooftop gardening in reducing air pollutants and, consequently, in creating healthier living spaces for the city's residents. The urgency of this study is underscored by the pressing need to address the pervasive issue of air pollution in Dhaka City, necessitating the identification of sustainable and innovative solutions.

## 1.2 Problem Statement

The air quality in residential buildings in Dhaka City is a pressing concern due to high levels of air pollution resulting from urbanization and industrial activities (M. S. Islam, 2016). The problem addressed by this research is the lack of a comprehensive understanding and empirical evidence regarding the impact of rooftop gardening on air quality in residential buildings in Dhaka City, Bangladesh. Despite the growing interest in green interventions for mitigating air pollution, there is a dearth of research specifically focused on the comparative air quality in residential buildings with and without rooftop gardens in this urban context. This knowledge gap hinders informed decision-making for urban planning, sustainable development, and public health initiatives aimed at improving air quality in Dhaka City.

The problem of air quality within residential buildings in Dhaka City is a critical concern driven by the high levels of air pollution resulting from the city's rapid urbanization and burgeoning industrial activities (M. S. Islam, 2016). The central issue addressed by this research is the substantial gap in comprehensive understanding and comparative analysis regarding the influence of rooftop gardening on air quality in residential buildings in Dhaka City, Bangladesh. The escalating problem of air pollution has reached a pivotal juncture, necessitating an effective solution. Dhaka's rapid urbanization and expanding industrial activities have systematically eroded the air quality in these residential neighborhoods over time. With each passing day, residents face increasing exposure to hazardous air pollutants. Consequently, there is an immediate imperative to explore potential measures to ameliorate this problem and enhance living conditions in these densely populated areas.

## 1.3 Research Questions/ Hypothesis

### 1.3.1 Research Questions

- Do buildings with rooftop gardens exhibit lower levels of air pollutants compared to buildings lacking rooftop gardens in these specific urban regions?

### 1.3.2 Hypothesis

Buildings with rooftop gardens will demonstrate significantly lower levels of air pollutants compared to buildings without such green installations.

## 1.4 Research Objectives

- To assess and compare the air quality and pollutant concentrations including particulate matter (PM), nitrogen dioxide ($NO_2$), carbon dioxide ($CO_2$), nitrogen dioxide ($NO_2$), and ozone ($O_3$), total suspended solid (TSP), sulfur dioxide ($SO_2$), carbon monoxide (CO), methane ($CH_4$) in residential buildings with and without rooftop gardens in selected areas of Dhaka City.

- To investigate the impact of rooftop gardening on the air quality of the selected residential buildings.

## 1.5 Limitations of the Study

- This research is primarily centered on the urban settings of Uttara and Mirpur in Dhaka City, Bangladesh, making it challenging to directly apply the findings to other areas, whether urban or rural.
- Variations in weather conditions and seasons can influence air quality and the practice of rooftop gardening, potentially introducing fluctuations in the study's results.
- While the research aims to isolate the impact of rooftop gardens on air quality, it does not encompass external variables such as vehicular emissions, industrial activities, or broader citywide initiatives aimed at improving air quality.

## 1.6 Rationale of the Study

The air quality in densely populated urban areas, such as Dhaka City, Bangladesh, has become a pressing concern. Air pollution has been linked to adverse health effects, making its mitigation a top priority for sustainable urban development. The study aims to quantitatively analyze pollutant levels, including CO, $CO_2$, CH4, $O_3$, NO, $NO_2$, $SO_2$, TSP, $PM_{2.5}$, and $PM_1$ in residential buildings with and without rooftop gardens. However, the availability of open land for traditional tree plantations is severely limited due to rapid urbanization and high population density. This study seeks to assess and compare the impact of rooftop gardens on air quality. The primary rationale behind this research is to explore the effectiveness of rooftop gardens in reducing air pollution in urban environments where conventional green spaces are scarce due to limited land resources.

## 1.7 Outline of the Thesis

This study contains five chapters. The thesis is organized in the following way-

**Chapter 1:** This chapter includes the introductory part of this study. It consists the Problem Statement, Rationale for the Study, Research Gap, Objectives, and Scope of the Study.

**Chapter 2:** This chapter describes a literature review that will delve into the significance of urban air quality, the role of rooftop gardens in mitigating air pollution, past studies in residential air quality, and the importance of comparative studies.

**Chapter 3:** This chapter presents will detail the Methodology employed, encompassing descriptions of the selected residential areas in Dhaka, criteria for selecting buildings with and without rooftop gardens, the methodology for data collection (including sampling and measurements), and the analytical techniques utilized (such as statistical (ANOVA) analysis).

**Chapter 4:** This chapter will focus on the Analysis and Results, presenting the collected data on pollutant concentrations, conducting a comparative analysis between buildings with and without rooftop gardens, and highlighting the statistical findings. The Discussion will involve interpreting the findings, discussing the impact of rooftop gardens on air quality, exploring factors influencing air quality differences, and relating the outcomes to prior research and theoretical frameworks.

**Chapter 5:** This final chapter summarizes the major conclusions from the present study. It also presents recommendations for future study relating air quality in residential areas.

# Chapter Two

# Literature Revie

# Chapter 2: Literature Review

Air quality in Dhaka, the capital of Bangladesh and one of the world's most densely populated megacities, has reached critical levels of concern (Rana et al. 2019). The city's rapid urbanization, burgeoning industrialization, and the ever-increasing number of vehicles on its streets have culminated in a dire air quality situation. High concentrations of air pollutants, including particulate matter, nitrogen dioxide, sulfur dioxide, and ozone, pose severe health risks to its residents (World Health Organization: WHO, 2019). These alarming trends necessitate innovative and sustainable solutions to alleviate the adverse effects of air pollution on the well-being of urban dwellers. In response to the growing challenges of air pollution, rooftop gardening has emerged as an appealing and practical mitigation strategy. Rooftop gardens have garnered attention for their potential to combat urban air pollution and improve overall urban living conditions (“Benefits of Rooftop Gardens,” n.d). These green spaces, cultivated on the rooftops of residential buildings, have demonstrated a range of benefits, including air quality enhancement, mitigation of the urban heat island effect, stormwater

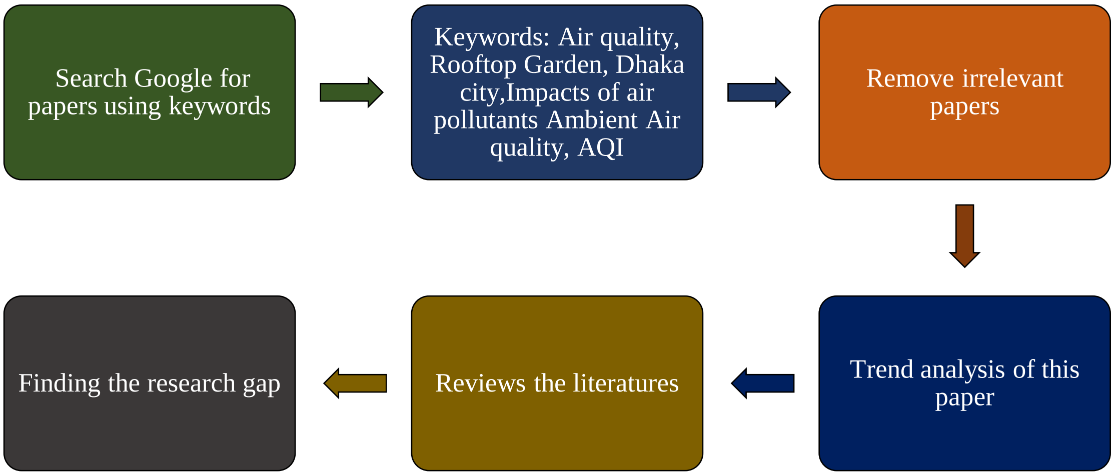

Figure 1. The process of doing literature review

## 2.1 Research Trend Analysis

In the pursuit of research trend analysis, an online version of the core collection in "ScienceDirect" was employed for the search, using the pertinent study title, "Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh." The results of the search indicated that only 9 papers had been published in various journals, featuring most of the words from the provided title as keywords in the keyword list or the abstract. Searches were also conducted across various sources, including different articles, relevant books, newspaper reports, publications and many paper in person in library. However, for the purpose of this study, only articles published between 2000 and 2023 were chosen for conducting the research trend analysis. Additionally, a search was performed to identify articles related to the "impact of rooftop gardens on the air quality of residential buildings," yielding 766 articles published from 2000 to 2023. Similarly, a search was conducted for "Ambient air quality standards in Dhaka, Bangladesh," which produced 624 results or articles incorporating most of the words from the given title as keywords in the keyword list or the abstract. Moreover, a search was carried out to explore the "concentration of air pollutants in residential areas," resulting in the discovery of 28,674 articles. Furthermore, a search for 'impact of rooftop garden to improve air quality' identified 1,177 articles, while the search for 'ambient air quality' and 'air quality index (AQI)' yielded 1,606 articles, all featuring most of the words from the provided title as keywords in the keyword list or the abstract. These additional searches have expanded the pool of relevant literature for comprehensive research trend analysis.

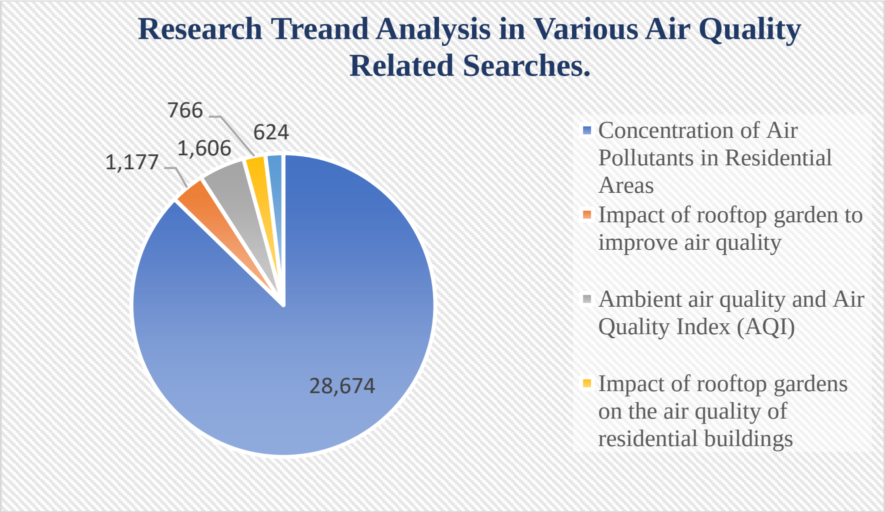

Figure 2. Research Trend Analysis in Various Air Quality Related Searches.

**Table 1.** Selected articles for conducting a systematic literature review

| SI NO. | Title of the paper | Author | Journal | Year |
|---|---|---|---|---|
| 01 | A Case Study of Air Quality Above an Urban Roof Top Vegetable Farm | Zheming Tong, Thomas Whitlow, Andrew Landers, Benjamin Flanner | Environmental Pollution Published by Elsevier BV | 2015 |
| 02 | Ambient Air Quality Scenario In And Around Dhaka City Of Bangladesh | Hafiz Ashraful Haque, Nurul Huda, Ferdouse Zaman Tanu, Nahida Sultana | Barisal University Journal Part 1 | 2017 |
| 03 | Estimation Of Urban AQI Based on Interpretable Machine Learning | Siyuan Wang, Ying Ren, Bisheng Xia | Environmental Science and Pollution Research | 2023 |
| 04 | Ambient Air Quality in Dhaka Bangladesh over | Bilkis A. Begum, Philip K. Hopke | Aerosol and Air Quality Research | 2017 |

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|---|---|---|---|---|
|  | Two Decades: Impacts of Policy on Air Quality |  |  |  |
| 05 | Assessment of Ambient Air Quality in Major cities of Bangladesh | Mehedi Hassan Masum, Sayed Mohammad Rahat Rahman, and Sudip Kumar Pal | Parana Journal of Science and Education (PJSE) | 2020 |
| 06 | Variation of Ambient air Quality Scenario in Chittagong City: A Case Study of Air Pollution | M. Arif Hossen, Asiful Hoque | Journal of Civil Construction and Environmental Engineering | 2018 |
| 07 | Investigating the effect of trees on urban quality in Dublin by combining air monitoring with i-Tree Eco model | Emily Riondato, Francesco Pilla, Arunima Sarkar Basu, Bidroha Basu | Sustainable Cities and Society | 2020 |
| 08 | Spatiotemporal analysis and forecasting of air quality in the greater Dhaka region and assessment of a novel particulate matter filtration unit | R-Rafiul Rahman, Alamgir Kabir | Environmental Monitoring and Assessment | 2023 |
| 09 | Air pollution by fine particulate matter in Bangladesh | Bilkis A. Begum, Philip K. Hopke, Andreas Markwitz | Atmospheric Pollution Research | 2013 |

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|---|---|---|---|---|
| 10 | Assessment of temporal shifting of PM 2.5, lockdown effect, and influences of seasonal meteorological factors over the fastest-growing megacity, Dhaka | Abdullah-Al-Faisal, Abdulla - Al Kafy, Md. Abdul Fattah, Dewan Md. Amir Jahir, Abdullah Al Rakib, Zullyadini A. Rahaman | Spatial Information Research | 2022 |
| 11 | Annual and Seasonal Variations in Air Quality Index of the National Capital Region, India | Surinder Deswal<br>Vineet Verma | World Academy of Science, Engineering and Technology | 2020 |
| 12 | The best trees to reduce air pollution | Vittoria Traverso | Future Planet | 2022 |
| 13 | How trees affect urban air quality: It depends on the source | Tom Grylls, Maarten van Reeuwijk | Atmospheric Environment | 2022 |
| 14 | Tree and forest effects on air quality and human health in the United States | David J. Nowak, Satoshi Hirabayashi, Allison Bodine, Eric Greenfield | Urban Forestry & Urban Greening | 2014 |
| 15 | How Trees Clean The Air | Meaghan Weeden | ONETREEPLANTED | 2023 |

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|---|---|---|---|---|
| 16 | Seasonal Variations of Particulate Matter Capture and the Air Pollution Tolerance Index of Five Roadside Plant Species | Huong-Thi Bui ,Na-Ra Jeong and Bong-Ju Park | Feature Papers in Air Quality | 2023 |
| 17 | How New York City’s Trees and Shrubs Help Clear Its Air | Winston Choi-Schagrin | The New York Times | 2023 |
| 18 | Improving local air quality in cities: To tree or not to tree? | Peter E.J. Vos*, Bino Maiheu, Jean Vankerkom, Stijn Janssen | Environmental Pollution | 2012 |
| 19 | Green roofs as a means of pollution abatement | D. Bradley Rowe | Environmental Pollution | 2011 |
| 20 | Are green roofs the path to clean air and low carbon cities? | S. Rafael, L.P. Correia, A. Ascenso, B. Augusto, D. Lopes, A.I. Miranda | Science of The Total Environment | 2021 |

## 2.2 Major Findings

The major findings from the critical reviews of the previously tabulated articles, encompassing both a Bangladesh-specific and global perspective, offer valuable insights into the impact of rooftop gardens on air pollution control in residential areas. This comparative analysis sheds light on the significance of rooftop gardens and their substantial impact on improving air quality. Hence, the major findings of the systematic literature review are summarized below:

**Tong et al. (2015)** conducted a study that examined air quality above an urban rooftop vegetable farm. Their investigation revealed several noteworthy findings that are particularly relevant to the research at hand. In their 2015 article, "A Case Study of Air Quality Above an Urban Rooftop Vegetable Farm," Zheming Tong, Thomas H. Whitlow, Andrew Landers, and Benjamin Flanner conducted a comprehensive investigation that yielded several significant findings regarding air quality in the context of urban rooftop agriculture. The study emphasized the critical role of elevation, particularly the presence of rooftop gardens, in shaping air quality dynamics. The research revealed that these elevated urban green spaces had a substantial positive impact on air quality, notably in reducing PM2.5 concentrations. A notable observation from the study was the stark contrast between air quality near street level and that experienced on the rooftop. The measurements at street level displayed frequent and unpredictable spikes in PM2.5 concentration, often exceeding background levels. In contrast, air quality on the rooftop was found to be considerably more stable, with fewer spikes. This finding underscores the potential benefits of incorporating rooftop gardens within urban settings, as it appears to offer residents a more consistent and improved air quality experience. Furthermore, the research identified a key relationship between the vertical extinction rate of PM2.5 and atmospheric stability. It was found that less stable atmospheric conditions, coupled with greater wind shear, led to more pronounced PM2.5 extinction due to damped vertical air motion. This insight can be particularly valuable in understanding how atmospheric conditions and aerodynamics influence air quality, shedding light on the complexities of air quality in urban environments. Overall, the findings of this study contribute significantly to the understanding of the positive impact of rooftop gardens on urban air quality, emphasizing the potential advantages of elevated green spaces and the role of atmospheric stability in shaping air quality patterns (Tong et al., 2015).

**Weeden (2023)** delves into the pivotal role trees play in enhancing air quality, both directly and indirectly. The study emphasizes that trees significantly contribute to air quality improvement by actively removing air pollutants and absorbing greenhouse gases. Urban trees in the contiguous United States alone are estimated to eliminate approximately 711,000 metric tons of air pollution annually. The research underscores the importance of understanding the impact of trees on air quality, particularly in the context of the numerous health hazards associated with poor air quality, such as respiratory issues, cardiovascular problems, and increased mortality. The study sheds light on how specific air pollutants, including PM2.5, SO2, NO2, CO, and ground-level ozone, adversely affect human health. It emphasizes the relevance of addressing air pollution issues that plague communities globally. Weeden (2023) then explores how trees play a vital role in reducing air pollution through various mechanisms. These include altering pollutant concentrations by moderating air temperatures, reducing energy consumption in buildings (thereby decreasing reliance on polluting energy sources), and directly removing pollutants from the air. The author categorizes pollutants into gaseous air pollution and particulate matter, explaining how trees, through their leaves' stomata and vegetative surfaces, respectively, absorb and break down pollutants. Furthermore, the research investigates the significant contribution of trees to carbon dioxide absorption, highlighting that trees not only remove pollutants but also play a crucial role in mitigating climate change. On average, a tree is estimated to absorb around 10 kilograms (22 pounds) of carbon dioxide per year during the initial 20 years of growth.

**Bui et al.'s (2023)** research investigates the seasonal variations in particulate matter (PM) capture and the Air Pollution Tolerance Index (APTI) of five roadside plant species in Korea. The study focuses on the crucial role of plants as biofilters in mitigating the impact of PM, a dangerous air pollutant harmful to human health. By evaluating the APTI and four leaves traits of various plant species during spring, summer, and autumn, the research identifies the most effective plants for PM removal in roadside areas. The findings reveal a direct correlation between environmental PM levels and the accumulation of PM in plants, with higher concentrations during periods of increased roadside environmental PM. Euonymus japonicus and Euonymus alatus emerge as the most effective species, accumulating the highest amounts of PM and demonstrating elevated tolerance levels to air pollution. The study recommends the utilization of these species in areas with high PM concentrations to enhance air quality. Moreover, the research underscores the effectiveness of shrubs over trees in PM accumulation, suggesting the combined use of both for increased PM removal in urban areas. The study's significance lies in its contribution to understanding how different plant species, particularly shrubs and trees, respond to PM accumulation across seasons. By analyzing the APTI and leaf traits impacted by air pollution, the research aids in the identification of plants that can serve as long-term, efficient biofilters in high-pollution areas. This knowledge is crucial for urban planning, especially in regions experiencing rapid urbanization and increased air pollution from sources like road traffic. Additionally, the research emphasizes the importance of considering environmental factors, such as rain and wind, which can influence the PM accumulation on plant leaves. Bui et al.'s (2023) work provides valuable insights into selecting plant species for roadside green areas to effectively reduce PM concentration levels and improve air quality. The emphasis on the seasonal variations in PM accumulation and the differential responses of plant species contribute significantly to the understanding of how green infrastructure can be optimized for air pollution control. This research serves as a foundation for future studies exploring the impact of heavy metals released from traffic on plant health and air quality improvement strategies in urbanized regions.

**Riondato et al. (2020)** investigated the impact of urban trees on air quality in Dublin, employing a combination of air quality monitoring and the i-Tree Eco model. The study focused on the effectiveness of trees, particularly in the removal of fine particulate matter ($PM_{2.5}$), a prevalent air pollutant in Dublin originating from sources such as diesel exhaust, brake dust, and rubber tire particles from vehicles. During rush hours, the study revealed that the presence of trees in a designated tree alley led to significantly lower $PM_{2.5}$ concentrations compared to a treeless street section. The i-Tree Eco model, used to estimate air pollution removal, calculated that the tree alley could potentially remove approximately 3 kg of $PM_{2.5}$ annually. However, an intriguing finding emerged when comparing the model's predictions with empirical data obtained from air quality monitoring. While the i-Tree Eco model projected a maximum air quality improvement of 126%, the observed improvement during monitoring exceeded this prediction. Possible factors contributing to this difference include variations in wind currents and potential inaccuracies in the air quality data used by the model. These findings offer valuable insights for the "Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh." In the Dhaka City study, the specificities of tree species and their characteristics, as highlighted by Riondato et al., become paramount. The knowledge that certain trees, based on their canopy size and leaf characteristics, can significantly reduce air pollution provides a foundation for the selection of vegetation in rooftop gardens. Moreover, the emphasis on considering local context, including wind patterns and traffic sources, aligns with the Dhaka City study's objectives. It underscores the importance of strategic urban planning and informed decisions regarding tree species and placement to optimize the air-purifying potential of green infrastructure in residential areas.

**Grylls et al. (2022)** employed large-eddy simulations to comprehensively investigate the impact of trees on urban air quality, emphasizing the importance of thermal effects such as convection, shading, and transpiration. The study highlighted the intricate balance between the deposition and dispersion effects of trees, showing that their influence on local air quality depends on factors like the dominance of background concentrations or local emissions. The research revealed that under conditions where pollutants are predominantly emitted locally, such as nitrogen oxides (NOx) on busy roads, the dispersion effects of trees can counteract the benefits of deposition, potentially leading to elevated concentrations near emission sources. However, in scenarios dominated by background levels, akin to $PM_{2.5}$ in less trafficked areas, the presence of trees consistently improved local air quality by enhancing deposition. The study introduced an integral model that effectively predicted whether air quality would improve, considering the competing effects of deposition and altered pollutant exchange. Importantly, the model aligned well with simulation predictions, offering a valuable tool for urban design purposes. These findings contribute significantly to the "Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh." By elucidating the complexities of tree-induced impacts on air quality, the research by Grylls et al. provides a nuanced understanding of the factors influencing the effectiveness of green infrastructure. Understanding the interplay between deposition and dispersion effects is crucial for selecting appropriate vegetation in rooftop gardens. For the Dhaka City study, this knowledge becomes instrumental in optimizing the design of green spaces to mitigate air pollution. The research underscores the need to consider local conditions, emission sources, and atmospheric dynamics when assessing the potential of green infrastructure. Incorporating insights from Grylls et al., the Dhaka study can leverage this understanding to strategically implement rooftop gardens, ensuring that the chosen green elements effectively enhance air quality while avoiding potential pitfalls associated with local emissions. Overall, Grylls et al.'s research serves as a guiding framework for informed decision-making in the context of urban planning and green infrastructure deployment in Dhaka City.

**Nowak et al. (2014)** conducted a comprehensive study on the impact of trees and forests on air quality and human health in the United States. Their research revealed that trees play a crucial role in removing air pollution through the interception of particulate matter and absorption of gaseous pollutants. In 2010, trees and forests in the conterminous United States removed a significant amount of air pollution, totaling 17.4 million tons, with associated human health effects valued at 6.8 billion U.S. dollars. The majority of pollution removal occurred in rural areas, while the health impacts and values were concentrated in urban areas. Notably, the health benefits included the avoidance of over 850 cases of human mortality and 670,000 cases of acute respiratory symptoms. These findings have direct implications for the "Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh." By demonstrating the substantial impact of trees on air quality and human health, Nowak et al.'s research offers valuable insights for the Dhaka study. Understanding the mechanisms through which trees remove air pollutants and contribute to health improvements is crucial for evaluating the potential benefits of rooftop gardens in residential buildings. The study underscores the importance of incorporating green infrastructure, such as rooftop gardens, in urban planning to enhance air quality and promote human well-being. The documented health benefits, including the avoidance of mortality and respiratory symptoms, emphasize the potential positive outcomes of integrating green spaces into the urban environment of Dhaka City. Therefore, the research by Nowak et al. serves as a foundational reference, guiding the investigation into the effectiveness of rooftop gardens in mitigating air pollution and improving air quality in residential areas of Dhaka City.

**Rana & Biswas, (2019)** conducted a study in which several significant findings shed light on the state of ambient air quality in Bangladesh. The research unveiled notable seasonal variations, with dry seasons (November to April) demonstrating heightened levels of particulate matter pollution, while wet seasons (May to October) offered improved air quality due to frequent rainfall. It was observed that gaseous pollutants, including $SO_2$, CO, NOx, and $O_3$, generally conformed to government standards in urban areas, although a few exceptions were noted, especially regarding $NO_2$ and $O_3$ concentrations. Additionally, fine particles ($PM_{2.5}$) were found to dominate particulate matter concentrations during the dry season throughout the day, with a shift to coarse particles ($PM_{10} – PM_{2.5}$) becoming more prominent in the evening hours. Regional disparities in pollution were evident, with Narayanganj identified as the most polluted city in Bangladesh, characterized by elevated PM concentrations, while Sylhet was deemed the least polluted among the cities under monitoring. Encouragingly, a decline in annual $PM_{10}$ and $PM_{2.5}$ concentrations was noted in Dhaka, which may be attributed to ongoing reforms in the brick kiln sector, signifying the efficacy of such interventions. Furthermore, the study emphasized the importance of understanding seasonal wind patterns, as most regions of the country experienced westerly and northerly winds in the dry season, while the northeast region, particularly Sylhet, received winds from the northeast and southeast directions. These findings collectively underscore the dynamic nature of urban air quality in Bangladesh, with seasonal influences, source apportionment, and policy measures playing pivotal roles in shaping the air quality landscape. Relevance to this research is demonstrated by the information. The importance of understanding seasonal variations in air quality and the factors influencing pollution levels is highlighted in the context of this investigation. Variations throughout the year, presenting diverse challenges and opportunities for maintaining air quality in urban areas, are suggested by the findings. The observation of regional disparities in pollution levels emphasizes the necessity of selecting diverse locations within Dhaka City for the study, enabling the capture of a representative range of air quality conditions. Furthermore, insights into potential interventions and policies that could be explored in the context of rooftop gardens and their effects on air quality are provided by the observed impact of ongoing reforms in reducing particulate matter concentrations. Finally, the interpretation of airflow dynamics in Dhaka City and their potential influence on air quality within residential buildings is facilitated by the recognition of the importance of seasonal wind patterns. The design and interpretation of the research are guided by these insights, contributing to the existing body of knowledge in the field.

The report for the month of **August 2018,** authored by the Clean Air and Sustainable Environment Project (CASE project), revealed significant insights into the air quality situation in Bangladesh. Real-time measurements of ambient air pollutants were conducted in eight major cities, including Dhaka, Narayangonj, Gazipur, Chittagong, Rajshahi, Khulna, Barisal, and Sylhet. The data collected aimed to define the nature and severity of pollution in these urban centers, identify pollution trends, and establish air quality models and emission inventories. The monitoring program focused on criteria pollutants, including carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, $PM_{10}$, and $PM_{2.5}$, to assess compliance with national ambient air quality standards and track air pollution trends. The primary objective of the report was to present, analyze, and make this data accessible to the general public, stakeholders, researchers, and policymakers for the development of effective air pollution mitigation strategies. Data quality was ensured through the operation of the sampling and monitoring network under the Department of Environment (DoE). The findings indicated that $PM_{10}$ and $PM_{2.5}$ were the most critical pollutants during the monitoring month, with slightly higher 24-hour average concentrations compared to the previous month. $PM_{2.5}$ concentrations ranged from 6.46 to 77.41 $\mu g/m^3$, while $PM_{10}$ concentrations varied from 17.59 to 246.66 $\mu g/m^3$. However, gaseous pollutants remained within the limit values of the Bangladesh Ambient Air Quality Standard (BNAAQS). The report also noted a slight increase in pollution levels due to reduced precipitation during August 2018, despite consistent average wind speeds. Furthermore, the calculated Air Quality Index (AQI) values for the month indicated that air quality in most cases fell within the "Good" to "Caution" categories, with a few exceptions of "Unhealthy" levels, primarily attributed to $PM_{2.5}$ pollution (CASE project, August 2018). The findings from the CASE project's report in August 2018 shed valuable light on the air quality situation in Bangladesh, particularly in urban areas, which holds significant relevance to the current study. Through real-time measurements of ambient air pollutants in major cities, including Dhaka, the report aimed to characterize the nature and severity of pollution, assess pollution trends, and establish air quality models and emission inventories. The monitoring program specifically focused on criteria pollutants such as carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, $PM_{10}$, and $PM_{2.5}$, enabling an evaluation of compliance with national ambient air quality standards and tracking air pollution trends. Notably, the report emphasized the paramount importance of $PM_{10}$ and $PM_{2.5}$ as the most critical pollutants during the monitoring period, with their 24-hour average concentrations showing a slight increase compared to the previous month. $PM_{2.5}$ concentrations ranged from 6.46 to 77.41 $\mu g/m^3$, while $PM_{10}$ concentrations varied from 17.59 to 246.66 $\mu g/m^3$. These findings provide a valuable context for assessing the potential impact of air quality improvement measures, such as rooftop gardens, within the urban environment, a core focus of the present study on residential buildings in Dhaka City.

**Vos et al. (2012)** conducted a comprehensive study to explore the effectiveness of urban vegetation, particularly trees, in mitigating air quality issues in cities. Contrary to common assumptions, their research revealed that the impact of roadside urban vegetation on air quality is more intricate than previously believed. Using computer models and real-life examples, the study demonstrated that, in certain scenarios, urban vegetation, instead of improving air quality, led to increased pollutant concentrations locally. The study highlighted that the aerodynamic effects of trees and vegetation, which reduce ventilation responsible for diluting traffic-emitted pollutants, outweigh their pollutant removal capacity. The research challenged the widespread notion that trees universally contribute to air quality improvement, indicating that their impact may vary based on factors like building geometry, wind conditions, and vegetation type. The findings of this study are crucial for policymakers and urban planners who, faced with local air pollution hotspots, often turn to trees intuitively. By emphasizing the potential drawbacks of urban vegetation under specific circumstances, the research prompts a reevaluation of the conventional wisdom surrounding the use of trees for air quality enhancement. The sensitivity analysis and case studies conducted in the research provide valuable insights into the limitations and potential negative consequences of relying solely on urban vegetation to alleviate local air pollution. This nuanced understanding is essential for developing more effective and context-specific strategies to improve air quality in urban areas.

**Islam et al. (2019)** conducted a study on the status of rooftop gardening in selected residential areas of Dhaka City, Bangladesh. Their findings hold significance for my research on the comparative study of air quality in residential buildings with and without rooftop gardens in Dhaka City. The study by Islam et al. revealed that a substantial portion of buildings in the selected areas of Dhaka City had rooftop gardens, with percentages ranging from 22.2% to 59.2% across different locations. This indicates a prevalent interest in rooftop gardening among urban residents. The presence of rooftop gardens was found to depend on individuals' aesthetic preferences and moral values, emphasizing the role of personal choices in urban agriculture. These findings are related to the research as the urban population's willingness to engage in rooftop gardening is highlighted. The understanding of the factors influencing rooftop gardening adoption is crucial in the study, aligning with the objective of investigating how rooftop gardens impact air quality in residential buildings. The presence of rooftop gardens may have implications for air quality through plant-related processes and the potential reduction of air pollutants. Furthermore, the need for long-term policy measures to promote and sustain rooftop gardening is emphasized by the study conducted by Islam et al. This underscores the importance of exploring the potential benefits of rooftop gardens and their alignment with urban sustainability goals. In the research, the aim is to contribute to the knowledge of how rooftop gardens can enhance air quality, making the case for their adoption as a sustainable urban practice. In summary, Islam et al.'s findings provide insights into the prevalence and factors influencing rooftop gardening in Dhaka City. These findings directly relate to the research questions regarding the impact of rooftop gardens on air quality in residential buildings. They contribute to the existing body of knowledge in the field by highlighting the potential role of rooftop gardens in promoting urban sustainability and improving air quality passively.

**Begum et al. (2018)** conducted a comprehensive study on ambient air quality in Dhaka, Bangladesh, spanning two decades from December 1996 to September 2015. The research aimed to assess the impacts of various policies on air quality in Dhaka, a city facing significant urbanization and increasing economic activity. The study collected data on fine and coarse fractions of airborne particulate matter (PM) in a semi-residential area of Dhaka, known for relatively low traffic activity. The findings from Begum et al.'s study indicate that despite the implementation of several policies, including bans on leaded-gasoline and two-stroke engines and efforts to promote green technology for brick burning, the air quality in Dhaka remained stable over the past decade. This stability is notable, considering the city's expanding economic activities and the growing number of pollution sources, such as passenger cars and brick kilns. These findings are pertinent to my research on the comparative study of air quality in residential buildings with and without rooftop gardens in Dhaka City, Bangladesh. Understanding the long-term trends in air quality and the effects of policy interventions is essential for contextualizing the air quality conditions in the selected areas of Dhaka. It provides valuable insights into how air quality can be influenced by policies and urban development over time. The stability in air quality, as observed by Begum et al., can serve as a reference point for evaluating whether the presence of rooftop gardens has any discernible impact on air quality within residential buildings. It is crucial to examine whether such gardens can contribute to maintaining or further improving air quality in a dynamic urban environment like Dhaka. By incorporating the knowledge from this study into my research, I can better understand how rooftop gardens fit into the broader context of urban air quality management. In summary, Begum et al.'s findings, regarding the stability of air quality amidst policy changes and urban growth in Dhaka, provide essential background information for my research on rooftop gardens and their potential effects on air quality in residential buildings. These findings help establish a foundation for evaluating the impact of rooftop gardens on air quality in Dhaka City, contributing to the existing body of knowledge on urban air quality and sustainability.

**Traverso's, 2020** examination of the role of tree species in mitigating urban air pollution contributes valuable insights to the understanding of effective green infrastructure. The study specifically emphasizes that the effectiveness of trees in reducing air pollution is not universal; rather, it depends on factors such as species selection and local context. Conifers, identified as particularly efficient in trapping pollutants, highlight the importance of considering specific tree characteristics. Applying these findings to the research on the "Comparative study of Air Quality in Residential Buildings with and Without Rooftop Garden in Some Selected Area of Dhaka City, Bangladesh," it becomes evident that the choice of tree species for rooftop gardens and urban areas in Dhaka City should be strategic. Factors such as the density of the canopy and the surface characteristics of leaves emerge as critical considerations in maximizing the air-purifying potential of vegetation. Furthermore, Traverso's (2020) insights extend to the broader understanding that effective air quality improvement involves a nuanced approach. The research paper should, therefore, delve into the intricacies of local ecosystems and environmental conditions, ensuring that the selected tree species are well-suited for the specific context of Dhaka City. This approach aligns with Traverso's emphasis on the importance of understanding local and environmental nuances for successful urban tree-planting initiatives.

**Rahman et al.'s (2023)** study presented critical findings regarding air quality in the greater Dhaka region, Bangladesh, highlighting significant relevance for this comparative study of air quality in residential buildings with and without rooftop gardens in Dhaka City. The findings delved into the dire state of air quality in Dhaka, one of the most polluted nations globally, observing distinct spatiotemporal variation in air quality indicators. The highest concentrations were recorded during the dry season, while cleaner air prevailed during the monsoon season, aligning with the research goal. Factors influencing air quality, particularly the rise in emissions from brick kilns and the use of high-sulfur diesel, were emphasized, pertinent to the exploration of various factors, including rooftop gardens, influencing air quality within selected residential buildings. The recognition of these sources and trends is crucial for framing the context of the research. Moreover, the utilization of a seasonal autoregressive integrated moving average (ARIMA) model to forecast weekly Air Quality Index (AQI) values was employed, highlighting the importance of accurate AQI forecasts for urban residents. The consistently unhealthy air quality levels underscored the need for sustainable solutions, such as rooftop gardens, in the research. Additionally, an innovative particulate matter filtration unit was introduced, demonstrating substantial particulate matter removal from the atmosphere through experimental simulations. These findings serve as valuable references for the development of air pollution mitigation strategies in the Dhaka region, aligning with the research on rooftop gardens as a potential solution for urban sustainability and contributing to the broader body of knowledge regarding air quality and pollution control measures in Dhaka City.

In **Begum et al. (2013)**, it was observed that in Dhaka, Bangladesh, particular matter (PM), specifically fine particles with an aerodynamic diameter less than 2.2 µm, constitutes the most harmful air pollutant to public health and the environment when compared to other measured criteria pollutants. These fine particles are primarily of anthropogenic origin, with transport-related sources, particularly from motor vehicles, playing a significant role. The study indicated that despite government efforts to control PM emissions, PM concentrations in Dhaka frequently exceeded the Bangladesh National Ambient Air Quality Standard (BNAAQS), with meteorological conditions and long-range transport contributing to these high levels. Additionally, the study highlighted the role of black carbon (BC) as a significant component of fine PM before the implementation of control policies. Importantly, the research suggested that BC's contribution had not increased proportionally with the growth in the number of combustion sources, indicating the effectiveness of government policy interventions. This study's findings are relevant to this research. Understanding the sources and composition of air pollutants, particularly fine PM, is crucial for assessing the potential impact of rooftop gardens on air quality. The prevalence of fine PM in Dhaka, predominantly from transportation sources, underscores the pressing need to explore sustainable solutions like rooftop gardens to mitigate air pollution. Additionally, the observation that BC, a component of fine PM, decreased with government interventions aligns with the paper's focus on evaluating the influence of urban vegetation on air quality. These findings contribute to the existing body of knowledge in the field of air quality and urban sustainability, providing valuable insights into the context of the research.

**Choi-Schagrin (2023)** conducted research, led by forest ecologist Dr. Andrew Reinmann and colleagues at the City University of New York, revealing the significant impact of New York City's greenery on its carbon footprint. The study, published in Environmental Research Letters, demonstrated that the combined tree canopies, shrubs, and lawns, covering nearly 35 percent of the city, absorb up to 40 percent of the human-caused carbon emissions during the growing season in spring and summer. Unexpectedly high numbers challenged previous assumptions about urban environments being largely inhospitable to significant carbon absorption. Using radar images at a finer resolution, the researchers identified tiny patches of vegetation, such as backyard grasses and shrubs, overlooked by previous surveys. Dr. Roisin Commane, an atmospheric chemist and co-author, emphasized the underestimated productivity of lawns as ecosystems, highlighting their role in carbon sequestration. The implications of this research extend beyond environmental awareness. The findings are instrumental for city officials in understanding the efficacy of emission reduction policies, such as congestion pricing and retrofitting buildings. By recognizing the substantial role of urban greenery in absorbing carbon, policymakers can make informed decisions about strategies to mitigate climate change effectively. Moreover, the study aligns with ongoing initiatives, such as the City Council's goal to increase New York City's tree canopy cover by 50 percent before 2035. Council Member Shekar Krishnan frames these plans not only as climate policy but also as a matter of racial justice, emphasizing the importance of trees in cooling neighborhoods, especially in low-income areas vulnerable to heat-related illnesses. Dr. Commane notes that while the primary benefits of trees are related to cooling and providing shade, the additional bonus of carbon uptake further underscores the value of urban greenery in addressing climate challenges.

**Faisal et al. (2022)** investigated air quality in Dhaka, Bangladesh, from 2019 to 2021. The study found that Dhaka consistently experiences high levels of air pollution, particularly in terms of $PM_{2.5}$ concentrations, which significantly exceeded international and national standards. Daily average $PM_{2.5}$ concentrations were observed to be about four times higher than the WHO limit and twice as high as the Bangladesh standard. This finding underscores the severity of air pollution in Dhaka. The diurnal variations in $PM_{2.5}$ levels, as indicated by Faisal et al. (2022), can be highly relevant to your research on the Comparative Study of Air Quality in Residential Buildings with and Without Rooftop Gardens in Some Selected Areas of Dhaka City, Bangladesh. Understanding the temporal patterns of $PM_{2.5}$ concentrations can help you assess the effectiveness of rooftop gardens in mitigating air pollution at different times of the day. This knowledge can inform the design and usage of rooftop gardens in residential buildings to maximize their air quality benefits. Furthermore, it is noteworthy that Green Roof Technologies have been shown to significantly reduce the risk of $PM_{2.5}$. These technologies are highly suitable and sustainable concerning the economic, socio-economic, and housing properties of Dhaka City. This finding implies that incorporating green roofs in your comparative study may offer a valuable air pollution mitigation strategy. Green roofs can potentially play a crucial role in reducing $PM_{2.5}$ levels and improving air quality in residential buildings, aligning with your research objectives. In summary, the findings from this paper provide essential context and data related to air quality in Dhaka, which can contribute to your comparative study on air quality in residential buildings with and without rooftop gardens in selected areas of Dhaka City. These findings offer insights into the challenges posed by air pollution and highlight the potential of green roof technologies in reducing $PM_{2.5}$ and enhancing air quality, making them a valuable component of your research.

**Hossen (2018)** conducted an in-depth analysis of Chittagong's air quality, with a particular focus on the Air Quality Index (AQI). Their study uncovered a noteworthy seasonal disparity in AQI levels, wherein the concentration of particulate matter (PM), specifically $PM_{2.5}$, demonstrated substantial fluctuations. During the monsoon season, AQI levels largely remained within acceptable limits, while in the non-monsoon period, they escalated significantly. This surge in AQI levels, particularly during January 2013 and December 2015, was largely attributed to heightened $PM_{2.5}$ concentrations. The findings indicated that this fine particulate matter emerged as a primary contributor to deteriorating air quality in Chittagong. The study's assessment of the yearly increase in AQI values emphasized the growing air pollution concerns in the city, underscoring the urgency of addressing this issue. These insights into the AQI trends and the influence of $PM_{2.5}$ on air quality fluctuations align with research on the impact of rooftop gardens on AQI in densely populated urban environments. Understanding the dynamics of AQI in Chittagong, as explored by Hossen and Hoque, can provide valuable context for this investigation**.**

## 2.3 Criteria Air Pollutants (CAP)

Criteria air pollutants are air pollutants for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. The Clean Air Act requires EPA to establish National Ambient Air Quality Standards (NAAQS) for six common air pollutants (also known as “criteria air pollutants”). The U.S. Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards for six common air pollutants (known as criteria air pollutants) that contribute to smog, acid rain, and other environmental problems and pose risks to people's health based on science and health under the federal Clean Air Act:

- Ground-Level Ozone
- Particle Pollution
- Carbon Monoxide
- Lead
- Sulfur Dioxide
- Nitrogen Dioxide

The Government of Bangladesh (GoB) has established guidelines for every CAP to regulate their airborne presence. All of the CAPs in the air of the nation's major cities are monitored by the DoE's CASE project, with the exception of lead (Rana et al., 2019). Following the phase-out of lead additives in gasoline in mid-1999, lead concentrations in ambient air were significantly reduced (Begum and Biswas 2008). An introductory note on the characteristics, sources and health impact potential of each of the CAP is given below,

### 2.3.1 Sulfur Dioxide ($SO_2$)

Colorless and possessing a strong odor, sulfur dioxide dissolves better in cold water than in hot. The burning of fossil fuels in power plants and other industrial facilities, such as brick kilns, is the main source of $SO_2$ emissions. High $SO_2$ concentrations are typically caused by emissions that also result in the formation of other sulfur oxides, of which $SO_3$ is a significant one. The atmosphere contains much smaller concentrations of other gaseous SOx than $SO_2$, such as $SO_3$. The gas sulfur dioxide is extremely irritating and corrosive. Some people are very sensitive to the effects of sulfur dioxide, particularly children, the elderly, and people with asthma. High concentrations of gaseous SOx can damage foliage and stunt growth, which can be harmful to trees and plants. Additionally caused by $SO_2$, acid rain degrades buildings and historical monuments while also having an adverse effect on the ecosystem. After $SO_2$ is oxidized by OH- in the atmosphere, it reacts with water and oxygen to produce sulfuric acids, which combine with other substances and water before collapsing to the earth. Acid rain is a problem for everyone, not just those who live close to these sources, as winds have the ability to carry $SO_2$ over great distances and across international borders. (*Sulfur Dioxide Basics | US EPA*, 2023)

### 2.3.2 Nitrogen Oxides (NOx)

The air's nitrogen oxides (NOx) are made up of mostly composed of nitrogen dioxide and nitric oxide (NO). These two types of nitrogen oxides in gaseous form are important atmospheric pollutants. In the point of anthropogenic source discharge, additional greater than 90% of NOx is made available as NO, a toneless and gas with no taste; the remainder is mostly $NO_2$ NO is easily transformed into the far more dangerous $NO_2$ through chemical interaction with the atmosphere's ozone. $NO_2$ is a reddish-brown to yellowish-orange gas that has a strong oxidant with a strong, grating smell. The combustion of coal, oil, diesel fuel, and natural gas, particularly in electric power plants, releases nitrogen oxides into the atmosphere. Motor vehicle exhaust is another source of nitrogen oxide emissions. Moreover, they are released during industrial procedures like electroplating and welding. Nitric oxide and nitrogen dioxide exposure can result in collapse, rapid burning and swelling of the throat and upper respiratory tract tissues, breathing difficulties, spasms in the throat, and accumulation of fluid in the lungs

(Görgüner & Akgün, 2010). It may disrupt the blood's capacity to carry oxygen throughout the body, resulting in fatigue, headaches, dizziness, and a blue tint to the lips and skin. As an air pollutant and transient climate pollutant, ozone is formed from nitrogen oxide precursors. Long-term exposure to the two main components of photochemical smog, NOx and $O_3$, can cause major respiratory issues, including lung tissue damage and reduced lung function.

### 2.3.3 Ozone ($O_3$)

While ozone molecules are harmless to all living things on Earth when they are found in the stratosphere, they are harmful when they are found in the troposphere. Ground-level ozone molecules are both greenhouse gases and air pollutants in the troposphere. Ozone, in contrast to the majority of other air pollutants, is created when sunlight—especially ultraviolet light—interacts with nitrogen oxides and hydrocarbons, which are released from smokestacks and car exhaust. Ozonated air can harm lung tissue when breathed in. Every kind of cell is negatively impacted by ozone. For those who have asthma, it may result in more frequent attacks, eye irritation, headaches, nausea, coughing, and chest congestion. Emphysema, bronchitis, and heart disease can all get worse from it. Photochemical smog primarily consists of tropospheric ozone. Individuals with lung or cardiovascular conditions, older adults, and children are especially vulnerable to negative health outcomes. Ozone causes significant drops in crop yields and has negative effects on plants and trees as well. Plants' capacity to absorb $CO_2$ is diminished by $O_3$, which modifies plant growth and variety. Food security is threatened because it undermines the health and productivity of crops, as well as the structures and functions of ecosystems (*Ground-level Ozone Basics | US EPA*, 2023).

### 2.3.4 Carbon Monoxide (CO)

This gas has no taste, smell, or color and is called carbon monoxide. In addition to being highly toxic to humans and other oxygen-breathing creatures, it is also flammable. The blood protein called hemoglobin, which transports oxygen from the lungs to all of the body's cells, is more than 200 times more likely to bind with carbon monoxide than it is with oxygen. This implies that excessive CO inhalation can cause hemoglobin to become saturated, which prevents the blood from carrying oxygen to the body's cells

(*Carbon Monoxide Poisoning - Symptoms and Causes - Mayo Clinic*, 2023). The oxidation of volatile hydrocarbons, burning of biomass, and the combustion of fossil fuels all produce carbon monoxide (CO), which is found in the troposphere. Often, incomplete combustion results in the production of carbon monoxide (CO) rather than carbon dioxide ($CO_2$) when something burns because there may be too little oxygen or too much carbon present. Typical urban areas have atmospheric carbon monoxide concentrations of 10 ppm, or parts per million, which is approximately 100 times higher than the planet's overall atmosphere.

CO levels can increase to as much as 50 parts per million in places with high traffic. In the troposphere, carbon monoxide indirectly contributes to the accumulation of certain greenhouse gases (Manisalidis et al., 2020). Methane and ozone concentrations in the atmosphere are raised as a result of its reaction with some chemicals that would otherwise destroy them.

### 2.3.5 Particulate Matters

A mixture of liquid or solid particles suspended in air is known as particulate matter (PM). Particles of all kinds, including dust, pollen, soot, smoke, and liquid droplets, are part of this complex mixture. Depending on their size (aerodynamic diameter), airborne particles are classified into two groups based on their diverse origins, sizes, and compositions. Large, primarily mechanically produced airborne particles are known as coarse particles. Dust, pollen, spores, fly ash, and plant and insect parts are examples of coarse particles. The aerodynamic diameter of coarse particles ($PM_{10}$-$_{2.5}$) ranges from 2.5 to 10µm. Smaller than coarse particles, fine particles are carried in the air. Their aerodynamic diameter ($PM_{2.5}$) is 2.5 µm or less.

The portion of particles that are the most harmful to human health in the air are the fine particles. The majority of the particulate matter's acidity (hydrogen ion) and mutagenic potential are found in the fine fraction. Fine particles that have been chemically enriched have the ability to deeply enter the respiratory system and seriously harm it. According to recent studies, there is a connection between fine and ultrafine particles and deadly illnesses like cancer, diabetes, heart attacks, etc. (*How Does PM Affect Human Health? | Air Quality Planning Unit | New England | US EPA*, n.d.).

## 2.4 Role of Rooftop Garden in Reducing Air Pollution

Rooftop gardens play a pivotal role in mitigating urban air pollution and fostering a healthier environment. These elevated green spaces serve as effective filters, capturing particulate matter suspended in the air and reducing its presence (Száraz, 2014). Additionally, the lush vegetation on rooftops acts as a natural absorber of various gaseous pollutants like nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), and carbon monoxide (CO) (Evan, 2017). By absorbing these pollutants through their leaves, rooftop gardens significantly contribute to purifying the surrounding air. Moreover, rooftop gardens participate in the crucial process of carbon sequestration, absorbing carbon dioxide ($CO_2$) from the atmosphere and mitigating greenhouse gas levels, thus supporting efforts against climate change (Seyedabadi et al., 2021). The choice of rooftop garden type significantly influences its capacity to mitigate air pollution and its overall ecological impact (Wong et al., 2017). Beyond their pollution-reducing capabilities, these gardens also assist in regulating building temperatures, offering insulation, and reducing the urban heat island effect. Their presence not only contributes to improved air quality but also creates habitats for urban biodiversity, fostering ecological balance (Unep, n.d.). Ultimately, rooftop gardens provide not only environmental benefits but also aesthetic appeal and spaces for community engagement, positively impacting the well-being of urban residents. Their multifaceted contributions make rooftop gardens a valuable asset in combating urban air pollution and enhancing the overall quality of urban life.

## 2.5 Oxygen Release and Air Humidity

In addition to their air purification abilities, rooftop gardens offer additional contributions to urban air quality enhancement. These green spaces act as oxygen generators, releasing fresh oxygen into the atmosphere (Akher, 2022). This release of oxygen not only aids in decreasing pollutant concentrations but also fosters a healthier urban atmosphere for residents. Moreover, rooftop gardens have the capacity to increase air humidity (Sultana et al., 2021). This aspect is instrumental in mitigating the adverse effects of dry and polluted urban air, rendering it more breathable and conducive to public health (Getter & Rowe, 2006).

By serving as natural filters, oxygen generators, and humidity regulators, rooftop gardens present a multifaceted approach to improving air quality in urban areas (Ahmed et al., 2020). Their role in the reduction of air pollutants and the enhancement of overall urban well-being is substantiated by various research findings, demonstrating their significance as a potential solution to urban air quality issues.

## 2.6 Research Gap

It has been observed that despite considerable research on air pollution and air quality utilizing computer models and exploring seasonal variation, along with numerous studies on the role of rooftop gardens in addressing food scarcity, there is a very limited study on the significance of rooftop gardens and their impact on air quality in residential buildings. In this study, the significance is sought to be determined by comparing the air quality of buildings with and without rooftops to understand how rooftop gardens can genuinely contribute to improving the air quality in Dhaka.

# Chapter Three

# Methodology

# Chapter 3: Methodology

This research employs a mixed-methods approach, encompassing quantitative experiments, content analysis, and a review of secondary literature from various sources such as books, journal articles, websites, and newspaper articles. The primary aim is to investigate and understand the impact of rooftop gardens on the air quality of residential buildings. The chosen methodology facilitates a comprehensive exploration of air pollutant concentrations, integrating precise quantitative measurements with qualitative insights obtained through literature analysis. Additionally, statistical analysis will be applied to elucidate patterns and relationships within the collected data, providing a robust foundation for the study's findings. This chapter outlines the procedural steps of the study, details the sources of data, specifies the areas where data collection occurred, describes the sample selection, and highlights the instruments used in the research process.

## 3.1 Research Design

This study adopts a mixed-methods research design to investigate the impact of rooftop gardens on the air quality of residential buildings. The quantitative component involves conducting experiments to measure air pollutant concentrations within buildings with and without rooftop gardens, utilizing state-of-the-art monitoring instruments. Concurrently, a qualitative analysis of relevant literature is undertaken to provide context and insights into influencing factors. A purposive sampling technique is employed to select residential buildings based on specific criteria. The collected data undergoes statistical analysis for quantitative findings and content analysis for qualitative insights. This comprehensive research design aims to yield a holistic understanding of how rooftop gardens influence air quality.

## 3.2 Study Area

The study is conducted in two distinct areas within Dhaka city, namely Dakshin Khan at Uttara and Mirpur-13 in Dhaka, Bangladesh. The selection of Uttara and Mirpur as the study areas is underpinned by their recognition for affordability and popularity as residential locales in Dhaka, meeting the demand for budget-friendly housing (The Financial Express, n.d.).

Uttara, situated in the northern part of the city, is known for its planned residential communities and commercial spaces (BTI Brokerage, n.d.). Mirpur, located to the west, exhibits a mix of residential and industrial zones (Beg, 2015). These areas were chosen due to their distinctiveness in urban development and the presence of various types of buildings. Uttara represents a relatively planned and organized urban landscape, while Mirpur offers a contrasting mix of residential and industrial structures. The study aims to capture a comprehensive understanding of the impact of rooftop gardens on air quality in diverse urban settings.

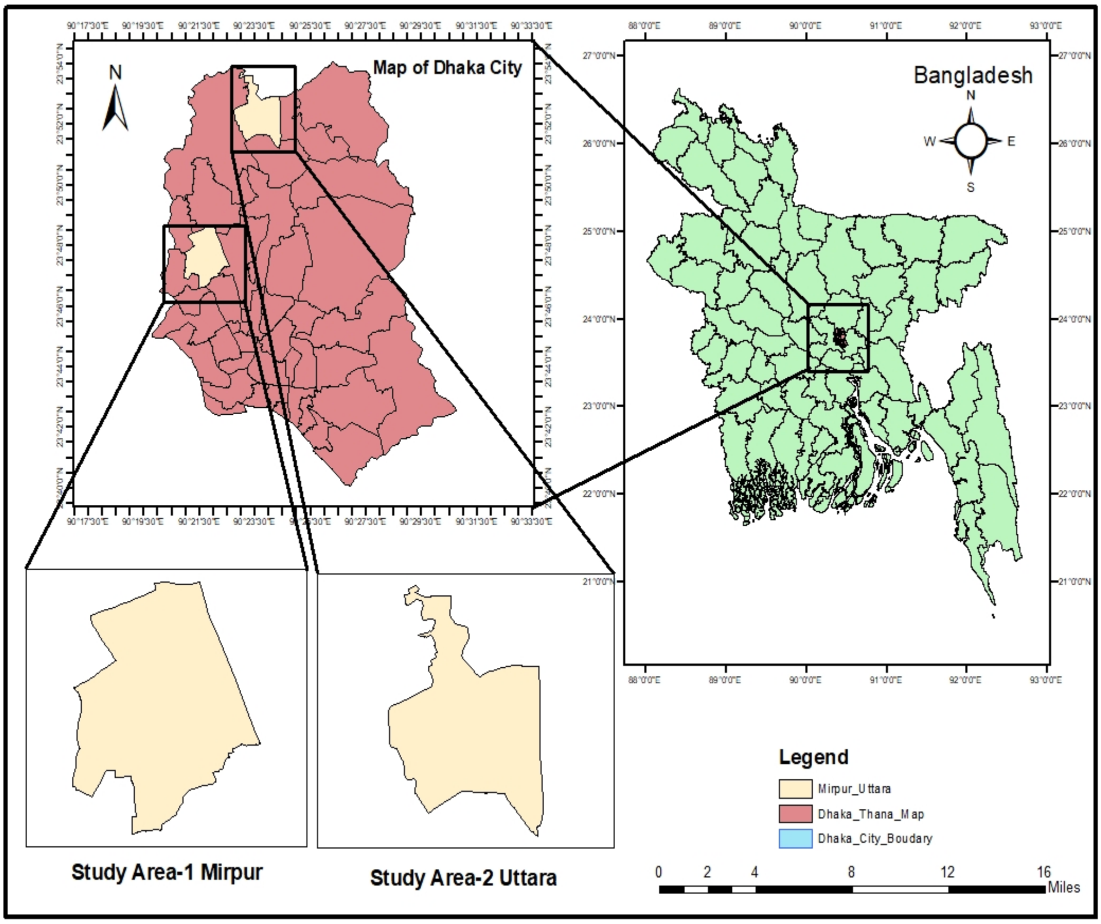

Figure 3. Map showing the study areas in Dhaka

## 3.3 Data Collection Sources

To gather comprehensive insights into the impact of rooftop gardens on air quality, a multi-faceted approach is employed, drawing on both primary and secondary data sources.

### 3.3.1 Secondary Data Source

The study draws on a literature review encompassing academic publications on rooftop gardens, air quality, and urban environmental studies. Additionally, air quality standards, including those from the US EPA, DOE for Bangladesh, and WHO, are consulted to provide a theoretical framework and reference points for interpreting the primary data. These standards guide the assessment of pollutant levels and contribute to a comprehensive understanding of the impact of rooftop gardens on air quality in the selected residential buildings.

### 3.3.2 Primary Data Sources

High-precision air quality monitoring is conducted using a specialized instrument known as the Haz Scanner. This instrument is strategically placed within selected buildings to measure concentrations of various air pollutants, ensuring a detailed assessment of the air quality. The collected quantitative data includes parameters such as oxygen (O2), carbon monoxide (CO), carbon dioxide (CO2), nitrogen monoxide (NO), nitrogen dioxide (NO2), sulfur dioxide (SO2), total suspended particulates (TSP), fine particulate matter (PM2.5), ultrafine particulate matter (PM1), and methane (CH4).

## 3.4 Sampling Technique

This study was conducted during the months of August and September to assess the air quality parameters within residential buildings located at Dakshin Khan, Uttara and Mirpur-10. A systematic sampling technique was employed to collect data from a total of 20 buildings, divided equally between the two locations. Stratified and cluster sampling methods were utilized to ensure a representative selection of buildings with and without rooftop gardens in each area. At Uttara and Mirpur, 10 buildings each were chosen, focusing on five buildings with rooftop gardens and five without in both locations. This deliberate selection aimed to capture a diverse representation of residential settings to analyze the impact of rooftop gardens on air pollutant concentrations. The collected data encompassed measurements of various air pollutants using high-precision air quality monitoring instruments placed within the selected buildings. These measurements were taken during the daytime from 9 am to 3 pm over a two-month period, providing a comprehensive assessment of pollutant levels during this timeframe. Additionally, buildings with more than 60% rooftop garden coverage were specifically chosen for the "with rooftop garden" category, considering criteria such as the presence of shrubs and trees to further refine the selection process.

## 3.5 Instrument

The study utilizes the **Haz-Scanner™** model HIM-6000 air quality monitoring station, a versatile instrument designed for precise measurement and documentation of trace-level criteria air pollutants ("HIM 6000-2," n.d.). This portable and expandable system offers simultaneous measurement of PM 2.5 and PM 10, crucial for assessing fine particulate matter concentrations. Moreover, the HIM-6000 features the capacity for up to 12 sensors, enabling comprehensive monitoring of toxic gases, sound, radiation, and various meteorological air parameters. The instrument's flexibility and advanced capabilities make it an ideal choice for capturing a comprehensive dataset to evaluate the impact of rooftop gardens on air quality in the selected residential buildings.

## 3.6 General Phenomenon of Sample Collection

In the process of sample collection for this research, a structured approach was employed to gather data on air pollutant concentrations within residential buildings in Uttara and Mirpur. The selection of samples involved a systematic method to ensure representation from buildings with and without rooftop gardens in both locations. Through stratified and cluster sampling techniques, a deliberate effort was made to capture a diverse range of environments and building types. The collection of data involved high-precision air quality monitoring instruments placed within selected buildings, enabling the measurement and documentation of various air pollutants. This systematic approach aimed to provide a comprehensive understanding of how the presence of rooftop gardens influences air quality within the selected residential areas, facilitating an insightful comparison between buildings with and without such green infrastructure.

## 3.7 Methods for Analysis

The concentrations of air parameters assessed by the Haz Scanner include $O_2$, CO, $CO_2$, $CH_4$, NO, $NO_2$, $O_3$, $PM_{2.5}$, $PM_1$, TSP, and $SO_2$. The data obtained from the Haz Scanner will undergo a comprehensive analysis employing both descriptive and statistical methods. Descriptive statistical techniques, encompassing mean, median, and standard deviation calculations, will provide an initial overview of pollutant concentrations. Inferential methods such as ANOVA will enable comparisons between buildings with and without rooftop gardens, revealing significant variations in air quality. This multifaceted analytical approach aims to establish a robust understanding of the impact of rooftop gardens on air quality within the selected residential areas.

## 3.8 Statistical Analysis

### 3.8.1 Analysis of Variance (ANOVA)

In this study, the one-way Analysis of Variance (ANOVA) test was chosen as the statistical method to analyze the data. ANOVA is selected for its efficiency in simultaneously comparing means across multiple groups (buildings with and without rooftop gardens in different locations) and controlling for Type I errors. The primary objective of conducting an ANOVA test is to investigate whether there are significant differences in the means of three or more groups, contributing to a deeper understanding of the factors influencing observed variations.

The ANOVA test was conducted in Microsoft Excel, examining each pollutant individually. The analysis focused on the mean concentrations of pollutants within buildings with and without rooftop gardens, pooling data from both Uttara and Mirpur locations. This consolidated approach was chosen to underscore the primary emphasis on discerning differences attributable to the presence or absence of rooftop gardens, rather than variations based on location.

In the context of conducting an Analysis of Variance (ANOVA) test, several crucial components are integral to the interpretation of results:

### 3.8.2 Between-Groups Variation (or Between-Conditions Variation)

This represents the variability in the means of different groups (conditions or categories) being compared. In the context of your study, it would indicate how much the pollutant concentrations vary between buildings with rooftop gardens and those without.

### 3.8.3 Within-Groups Variation (or Within-Conditions Variation)

This represents the variability within each group. In your study, it indicates how much the pollutant concentrations vary within the buildings with rooftop gardens and within the buildings without rooftop gardens.

### 3.8.4 F-Statistic

The F-statistic is the ratio of the Between-Groups Variation to the Within-Groups Variation. It is calculated using the formula:

$$\mathbf{F} = \frac{\textbf{Between}-\textbf{Groups Variation}}{\textbf{Within}-\textbf{Groups Variation}}$$

A higher F-value suggests a larger difference between group means compared to within-group variability.

### 3.8.5 Degrees of Freedom (Between and Within)

**Degrees of Freedom Between ($df_{Between}$):** This represents the number of groups minus 1. In your study, it would be the number of categories (e.g., buildings with and without rooftop gardens) minus 1.

**Degrees of Freedom Within ($df_{Within}$):** This represents the total number of observations minus the number of groups. In your study, it would be the total number of buildings minus the number of categories.

### 3.8.6 p-Value

The p-value is the probability that the observed F-statistic occurred by chance. A p-value less than 0.05 is often considered statistically significant.

## 3.9 Workflow Diagram

The whole process of the research study is shown in the following follow chart:

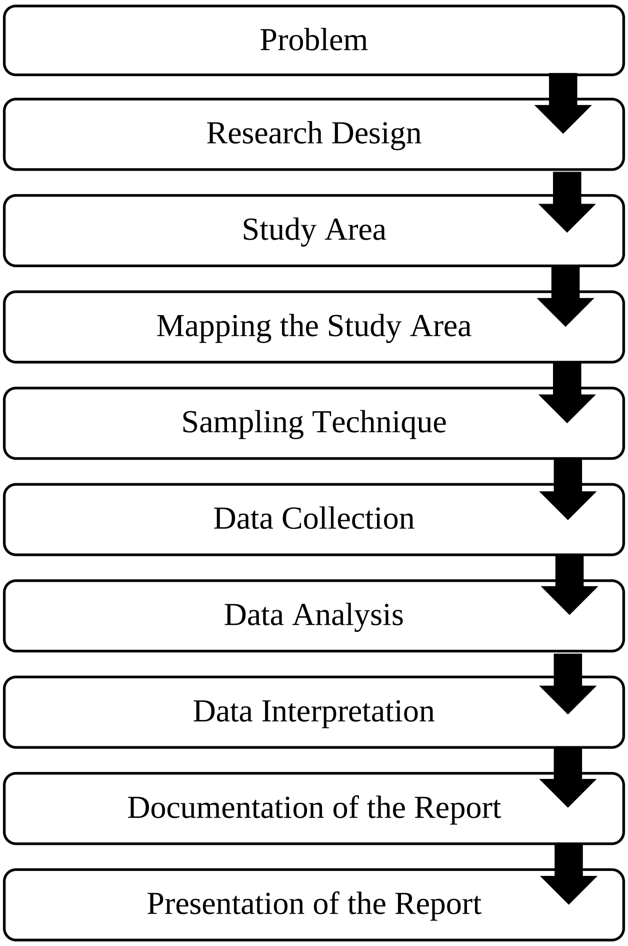

Figure 4. Methodological Flow Chart overall of the study

# Chapter Four

# Result and Discussion

# Chapter 4: Result and Discussion

The study was conducted during August and September 2023 in residential areas of Uttara and Mirpur to assess air quality parameters. The study focused on analyzing various air pollutants within these locations, aiming to understand the impact of rooftop gardens on pollutant concentrations. A comprehensive comparison was made between buildings with and without rooftop gardens in the two areas. The findings and detailed analysis derived from this investigation are presented below-

## 4.1 Air Quality Parameters

### 4.1.1 Oxygen ($O_2$) Concentrations

During the months of August and September, the oxygen concentrations (%) were measured in buildings located in Uttara. With Rooftop Gardens (Uttara): Oxygen concentration measurements were meticulously recorded across several buildings during the evaluation period. The mean oxygen concentrations, accompanied by their respective standard deviations (SD), were observed as follows: 59.26% ± 3.54%, 49.12% ± 0.47%, 56.24% ± 0.07%, 58.22% ± 3.47%, and 52.34% ± 1.56%. Without rooftop gardens, the mean oxygen concentrations were 51.54% ± 0.70%, 43.05% ± 0.54%, 49.11% ± 1.06%, 46.63% ± 0.13%, and 47.23% ± 1.26%. These observations were collected from various buildings in Uttara, revealing the variation in oxygen concentration levels, both with and without rooftop gardens, during the assessment period.

Buildings equipped with rooftop gardens displayed mean oxygen concentrations ranging approximately from 49.12% to 59.26%, with standard deviations varying from 0.07% to 3.54%. Conversely, buildings lacking rooftop gardens exhibited mean oxygen concentrations ranging from approximately 43.05% to 51.54%, with standard deviations fluctuating from 0.13% to 1.26%. These measurements indicate substantial differences in oxygen concentration levels between the evaluated buildings in Uttara. Buildings with rooftop gardens generally maintained higher mean oxygen concentrations compared to those without green spaces atop their structures. The standard deviations suggest varying levels of consistency in oxygen concentration among the buildings within each category.

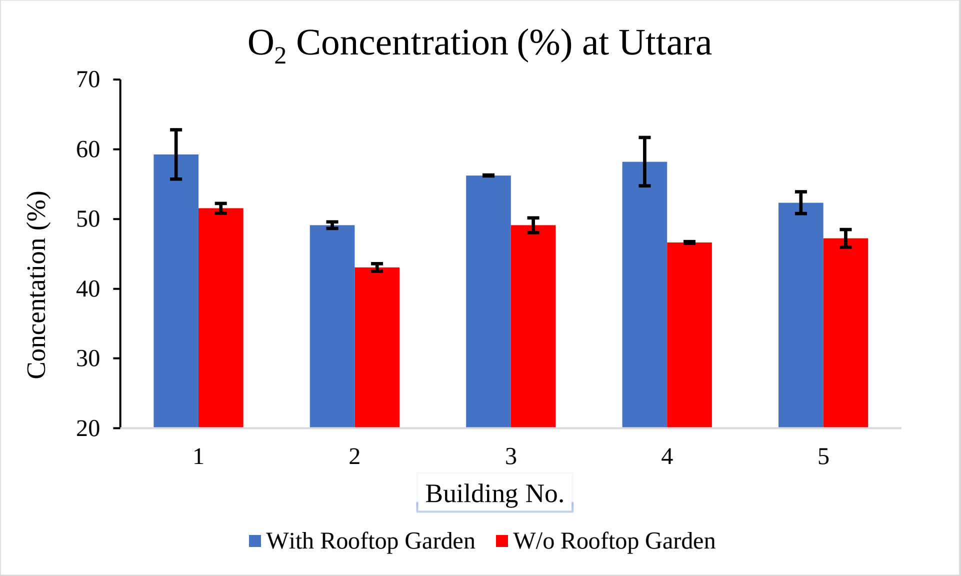

Figure 5. Comparison of $O_2$ Concentration (%) (Mean ± SD) at Uttara: With and Without Rooftop Gardens

The mean oxygen concentrations in the selected buildings equipped with rooftop gardens at Mirpur were 53.73% ± 0.70%, 49.05% ± 4.54%, 59.11% ± 1.64%, 49.63% ± 2.13%, and 53.23% ± 5.26%. Similarly, the mean oxygen concentrations in selected buildings without rooftop gardens were 49.24% ± 0.70%, 45.05% ± 3.54%, 52.10% ± 1.06%, 43.69% ± 0.10%, and 48.22% ± 1.26%. These observations offer insights into the diverse oxygen concentration levels among buildings, both with and without rooftop gardens, at Mirpur.

The measured oxygen concentration levels in buildings at Mirpur present discernible variations, showcasing differences between buildings equipped with rooftop gardens and those without such green spaces. For buildings with rooftop gardens, the mean oxygen concentrations varied between approximately 49.05% and 59.11%, with corresponding standard deviations ranging from 1.64% to 5.26%. Conversely, buildings without rooftop gardens displayed mean oxygen concentrations ranging from around 43.69% to 52.10%, with standard deviations fluctuating from 0.10% to 3.54%. These observations highlight significant differences in oxygen concentration levels between the evaluated buildings at Mirpur. The findings suggest that buildings with rooftop gardens generally maintained higher mean oxygen concentrations compared to those without such installations. The wider range of standard deviations within the without-rooftop-garden category indicates varying levels of consistency in oxygen concentration among these buildings.

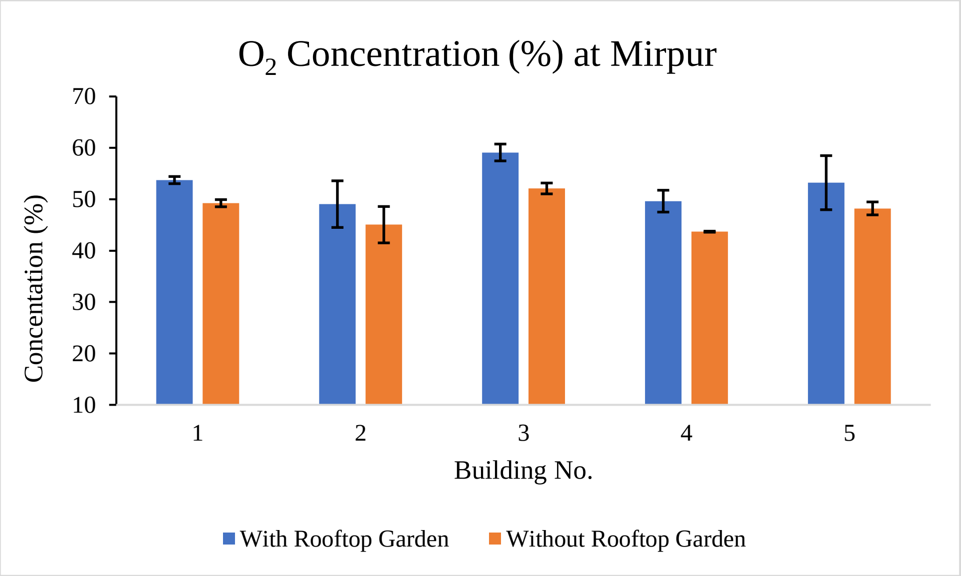

Figure 6. Comparison of $O_2$ Concentration (%) (Mean ± SD) at Mirpur: With and Without Rooftop Gardens

### 4.1.2 Carbon Monoxide (CO) Concentration *(ppm)*

The average CO (Carbon Monoxide) concentrations for buildings with rooftop gardens in Uttara were as follows: 2.10 ± 0.97 ppm, 2.35 ± 1.02 ppm, 2.00 ± 0.94 ppm, 1.87 ± 0.89 ppm, and 2.25 ± 0.63 ppm in the selected buildings. On the other hand, CO concentrations in buildings without rooftop gardens were observed as 3.50 ± 0.71 ppm, 4.00 ± 0.50 ppm, 3.13 ± 0.71 ppm, 2.87 ± 0.43 ppm, and 3.36 ± 0.33 ppm. These observations offer insights into the diverse CO concentration levels among buildings in Uttara, both with and without rooftop gardens, from the selected buildings.

Buildings equipped with rooftop gardens displayed mean CO concentrations ranging between 1.87 ppm and 2.35 ppm, accompanied by standard deviations spanning from ± 0.63 ppm to ± 0.97 ppm. These measurements denote a relatively narrower range of CO concentrations and variability within this category. In contrast, buildings lacking rooftop gardens exhibited higher mean CO concentrations, ranging from 2.87 ppm to 4.00 ppm, with standard deviations varying between ± 0.33 ppm and ± 0.71 ppm. These values highlight higher average CO levels and a broader spectrum of variability compared to buildings with rooftop gardens. The discernible trend indicates that buildings with rooftop gardens tend to maintain lower average CO concentrations and showcase less variability in CO levels compared to buildings without such green installations. This observation strongly suggests a potential advantage associated with rooftop gardens in managing indoor air quality concerning CO content within buildings at Uttara. The lower average CO concentrations in buildings with rooftop gardens suggest a positive influence of these green spaces on indoor air quality, particularly in mitigating CO levels. This trend underscores the potential for rooftop gardens to contribute positively to reducing indoor CO levels, thereby fostering improved air quality within buildings at Uttara in comparison to buildings without.

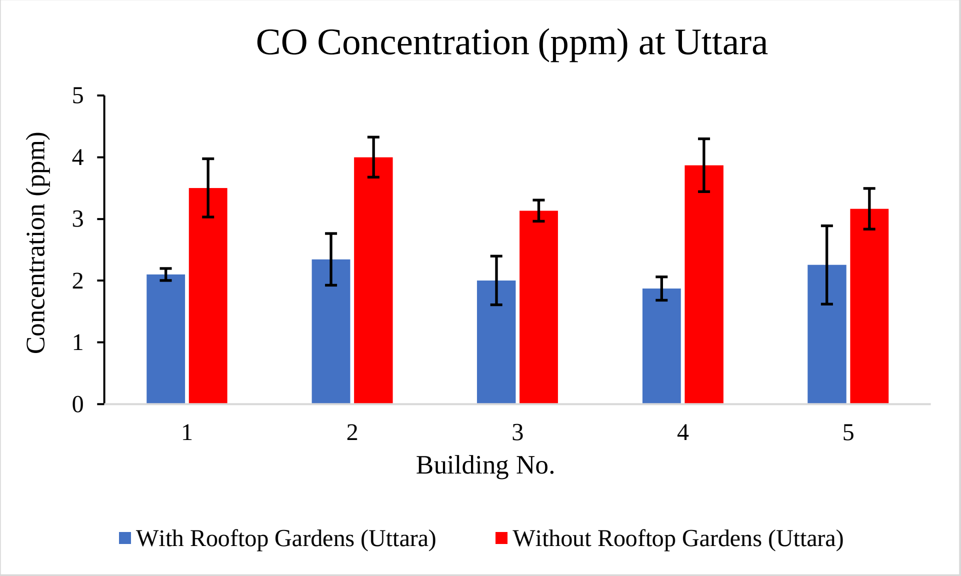

Figure 7. Comparison of CO Concentration (ppm) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens

The mean CO concentrations in parts per million (ppm) for buildings with rooftop gardens at Mirpur were as follows: 3.50 ± 0.07, 2.10 ± 0.35, 1.98 ± 0.36, 2.38 ± 0.09, and 2.87 ± 0.33 in those selected buildings. Conversely, CO concentrations were measured in buildings without rooftop gardens. The mean CO concentrations observed were: 4.50 ± 0.07, 3.78 ± 0.05, 3.06 ± 0.13, 4.89 ± 0.28, and 3.12 ± 0.30 in those selected buildings. These results highlight the variations in CO concentration levels between buildings in Mirpur, with and without rooftop gardens.

The recorded CO concentrations in Mirpur's buildings, both with and without rooftop gardens, exhibit noticeable variations, indicating distinct differences in air quality between the two categories. In buildings with rooftop gardens, CO concentration levels ranged between the highest recorded value of 3.50 ppm (± 0.07) and the lowest at 1.98 ppm (± 0.36). This range reflects a diversity in air quality within this group, spanning approximately 1.52 ppm, showcasing fluctuations in indoor CO levels despite the presence of rooftop green spaces. Conversely, buildings lacking rooftop gardens displayed a higher range of CO concentrations. The highest recorded value in this category peaked at 4.89 ppm (± 0.28), while the lowest observed concentration was 3.06 ppm (± 0.13). This broader spectrum between the highest and lowest values encompasses a range of approximately 1.83 ppm, indicating a significant variance in CO levels among buildings without rooftop gardens.

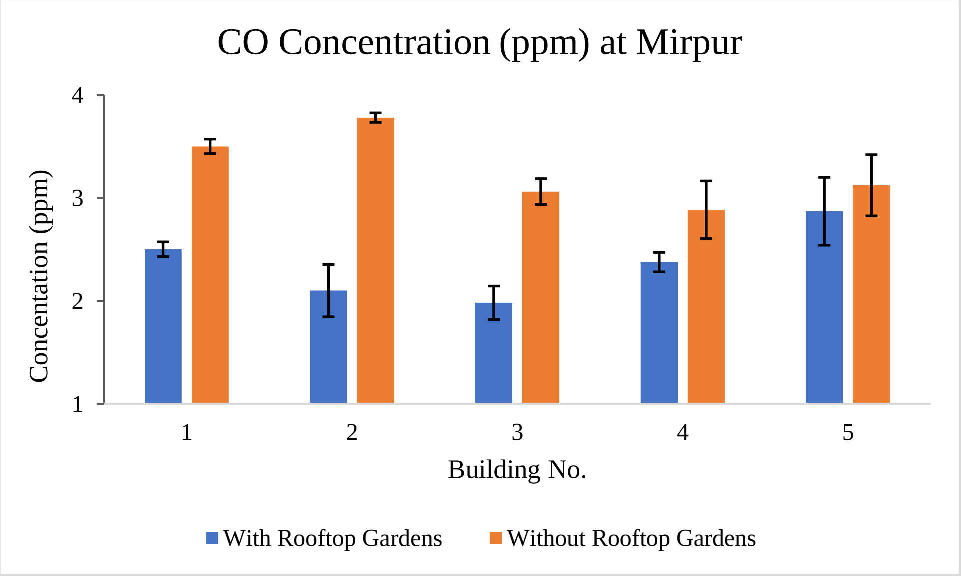

Figure 8. Comparison of CO Concentration (ppm) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens

### 4.1.3 Carbon Dioxide ($CO_2$) Concentration (ppm):

At Uttara, the mean $CO_2$ concentrations (in parts per million - ppm) were measured for both buildings with and without rooftop gardens. For buildings with rooftop gardens, the mean $CO_2$ concentrations were observed as follows: 431.65 ± 11.59, 597.06 ± 54.94, 439.42 ± 34.56, 470.33 ± 53.26, and 535.77 ± 26.53 across the five selected buildings. Conversely, in buildings without rooftop gardens at Uttara, the mean $CO_2$ concentrations were recorded as 545.43 ± 7.01, 611.52 ± 17.02, 562.87 ± 9.13, 557.22 ± 13.41, and 567.92 ± 11.00. These findings illustrate notable variations in $CO_2$ concentration levels between buildings in Uttara, emphasizing the influence of rooftop gardens on the observed variances from the selected buildings.

Therefore, in buildings with rooftop gardens, the mean $CO_2$ concentrations ranged approximately from 431.65 ppm to 597.06 ppm across the five selected buildings. On the other hand, buildings without rooftop gardens showed higher mean $CO_2$ concentrations, ranging from around 545.43 ppm to 611.52 ppm. The findings underline noticeable disparities in $CO_2$ concentration levels between buildings in Uttara, indicating the potential impact of rooftop gardens on these variations. Buildings without rooftop gardens consistently exhibited higher $CO_2$ concentrations compared to those with green spaces atop their structures.

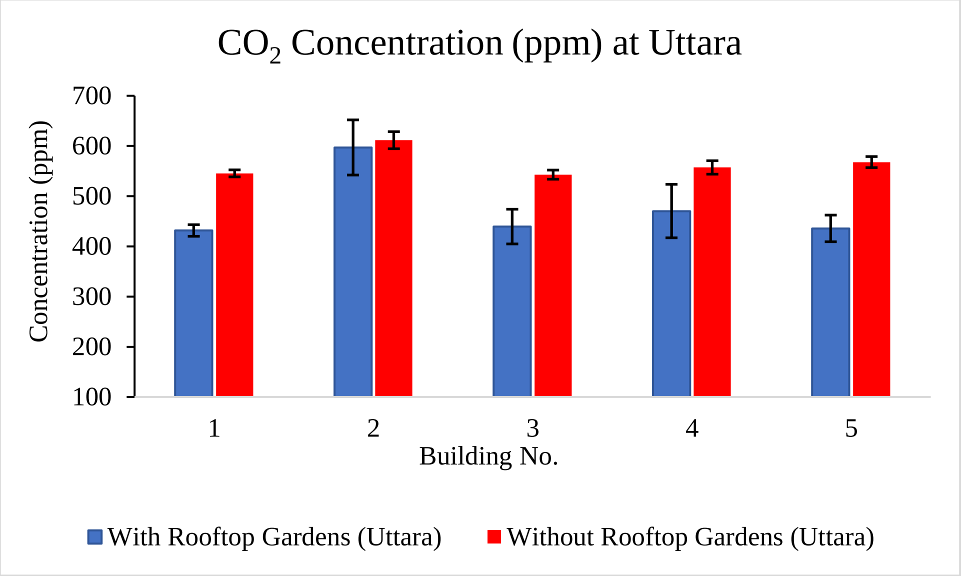

Figure 9. Comparison of $CO_2$ Concentration (ppm) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens

The average $CO_2$ concentrations (in parts per million - ppm) were assessed in Mirpur for buildings both with and without rooftop gardens. In buildings with rooftop gardens, the recorded mean $CO_2$ concentrations were as follows: 429.22 ± 13.04, 523.68 ± 7.02, 472.37 ± 11.13, 521.79 ± 15.41, and 470.33 ± 21.00. Conversely, in buildings without rooftop gardens, the mean CO2 concentrations were 495.43 ± 13.01, 575.52 ± 21.59, 521.89 ± 34.94, 537.22 ± 31.59, and 527.92 ± 26.94. These figures delineate the range of $CO_2$ levels within the selected buildings in Mirpur, accentuating the potential impact of rooftop gardens on $CO_2$ concentration variance.

In buildings with rooftop gardens, the mean $CO_2$ concentrations ranged from approximately 429.22 ppm to 523.68 ppm. On the other hand, buildings without rooftop gardens showed higher mean $CO_2$ concentrations, ranging from around 495.43 ppm to

575.52 ppm. The comparison underscores the potential impact of rooftop gardens on $CO_2$ concentration variance. Buildings with rooftop gardens generally demonstrate lower $CO_2$ levels compared to those without. This discrepancy suggests that the presence of rooftop gardens might contribute to a more controlled indoor environment regarding $CO_2$ concentrations. The range of values indicates that buildings without rooftop gardens consistently displayed higher $CO_2$ concentrations across the recorded samples, emphasizing a potential advantage associated with the presence of rooftop gardens in mitigating $CO_2$ levels within buildings.

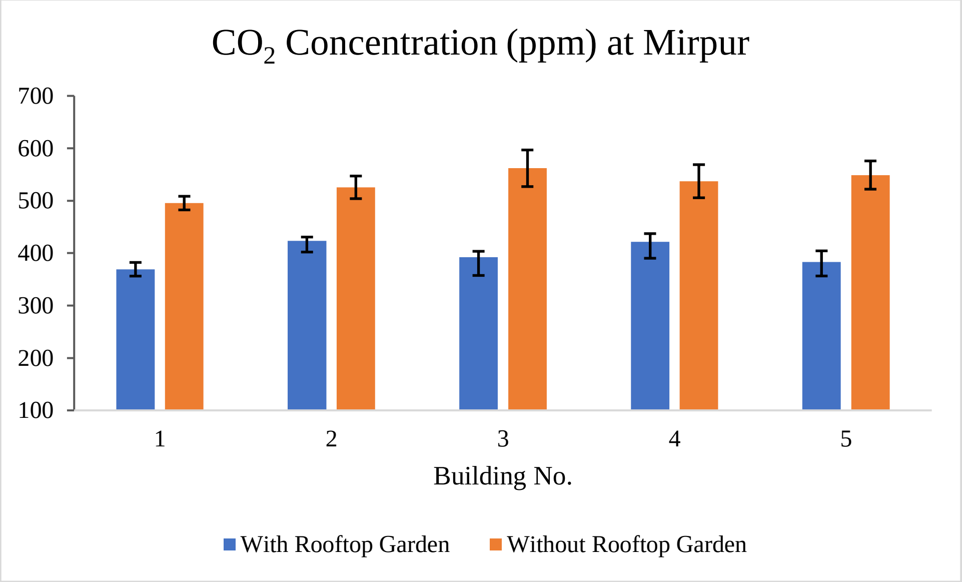

Figure 10. Comparison of $CO_2$ Concentration (ppm) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens

### 4.1.4 $CH_4$ Concentrations (ppm)

The methane ($CH_4$) concentrations in parts per million (ppm) in buildings with rooftop gardens at Uttara were measured as follows: 1.17 ppm ± 0.40, 1.08 ppm ± 0.01, 1.11 ppm ± 0.03, 1.00 ppm ± 0.53, and 1.26 ppm ± 0.03. In buildings without rooftop gardens, the methane concentrations were observed as follows: 1.91 ppm ± 0.13, 2.18 ppm ± 0.13, 3.37 ppm ± 0.03, 1.32 ppm ± 0.10, and 1.26 ppm ± 0.13. These measurements demonstrate the variation in methane concentration levels between buildings at Uttara, with and without rooftop gardens, during the assessment. In buildings with rooftop gardens, the mean $CH_4$ concentrations ranged approximately from 1.00 ppm to 1.26 ppm across the five selected buildings. On the contrary, buildings lacking rooftop gardens demonstrated higher mean $CH_4$ concentrations, ranging from about 1.91 ppm to 3.37 ppm.

The findings vividly highlight considerable differences in methane concentration levels between these buildings in Uttara, signifying the potential influence of rooftop gardens on these variations. Buildings without rooftop gardens consistently displayed higher methane concentrations compared to those with green spaces atop their structures.

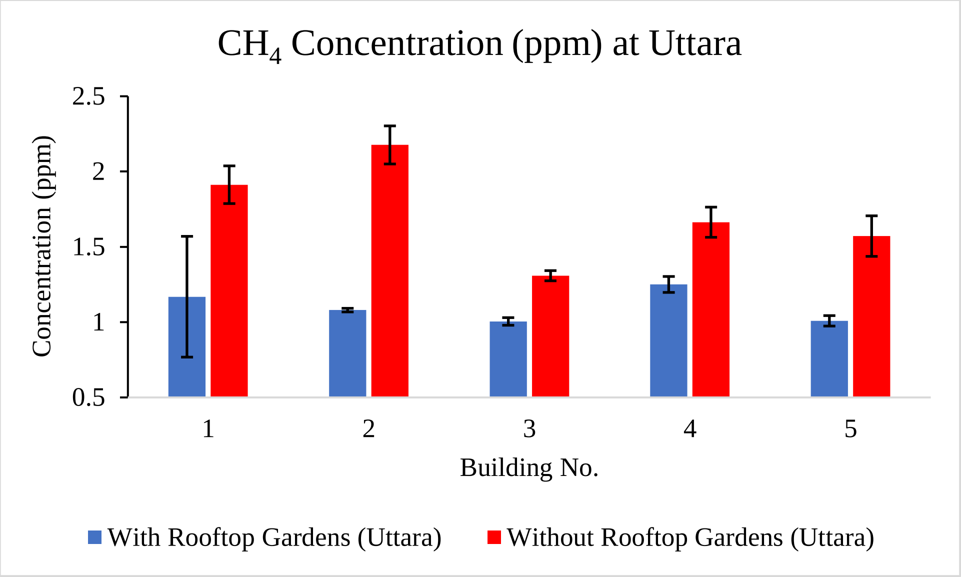

Figure 11. Comparison of $CH_4$ Concentration (ppm) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens

The methane ($CH_4$) concentrations measured in parts per million (ppm) for buildings with and without rooftop gardens in Mirpur were as follows: With Rooftop Gardens (Mirpur): 1.37 ppm ± 0.02, 1.47 ppm ± 0.10, 1.08 ppm ± 0.04, 1.11 ppm ± 0.10, and 1.00 ppm ± 0.03. Without Rooftop Gardens (Mirpur): 1.99 ppm ± 0.14, 2.79 ppm ± 0.04, 3.89 ppm ± 0.01, 2.36 ppm ± 0.20, and 1.89 ppm ± 0.01.

The recorded methane ($CH_4$) concentrations in Mirpur's buildings, categorized by the presence or absence of rooftop gardens, depict distinct trends emphasizing potential differences in indoor air quality: Buildings featuring rooftop gardens exhibited methane concentrations ranging from 1.00 ppm to 1.47 ppm, with relatively minor fluctuations indicated by standard deviations between ± 0.02 ppm and ± 0.10 ppm. These measurements suggest a more consistent range of methane levels within this group.

Conversely, buildings lacking rooftop gardens displayed noticeably higher methane concentrations, spanning from 1.89 ppm to 3.89 ppm, with larger standard deviations ranging between ± 0.01 ppm and ± 0.20 ppm. These values imply significantly higher variability and overall higher methane levels compared to buildings with rooftop gardens.

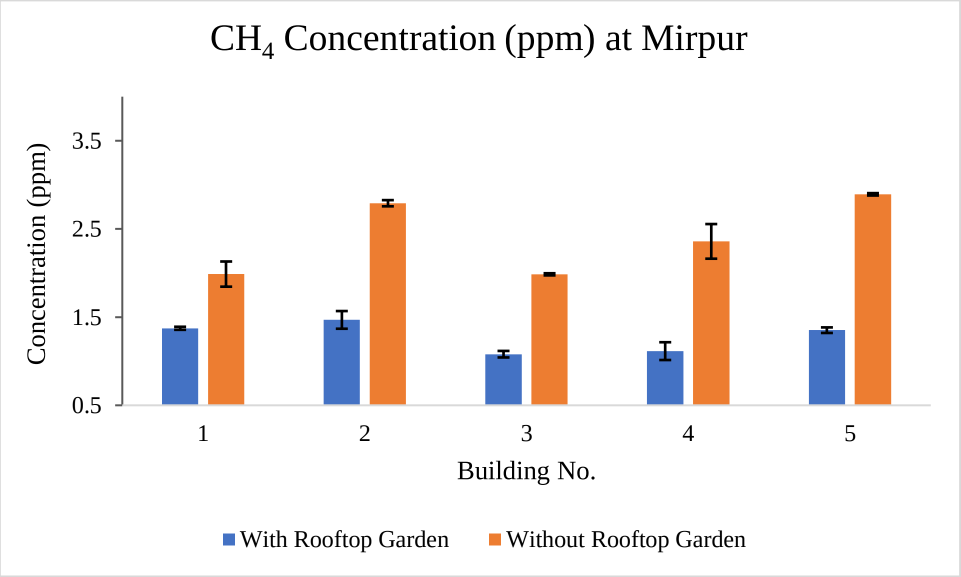

Figure 12. Comparison of $CH_4$ Concentration (ppm) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens

### 4.1.5 NO Concentrations (ppm):

The nitric oxide (NO) concentrations measured in parts per million (ppm) for buildings at Uttara with rooftop gardens and without rooftop gardens were as follows: The recorded NO concentrations in buildings with and without rooftop gardens in Uttara highlight distinct variations in rooftop air quality. Buildings featuring rooftop gardens display diverse NO concentrations on their rooftops, with mean values ranging from approximately 0.0047 ppm to 0.0468 ppm. The corresponding standard deviations vary between approximately ± 0.0016 and ± 0.0038. These values signify fluctuations in NO levels specifically on the rooftops of buildings with green installations. On the other hand, buildings without rooftop gardens exhibit NO concentrations on their rooftops with mean values ranging from around 0.0320 ppm to 0.0577 ppm. The associated standard deviations range between approximately ± 0.0001 and ± 0.0003. This data suggests higher average NO concentrations on the rooftops of buildings lacking rooftop gardens, with relatively lower variability in NO levels compared to those with green installations. The observed differences in rooftop NO concentrations between buildings with and without rooftop gardens suggest potential advantages associated with rooftop gardens in maintaining lower NO levels. These findings hint at a possible role of rooftop gardens in contributing to improved rooftop air quality concerning NO content within buildings in Uttara.

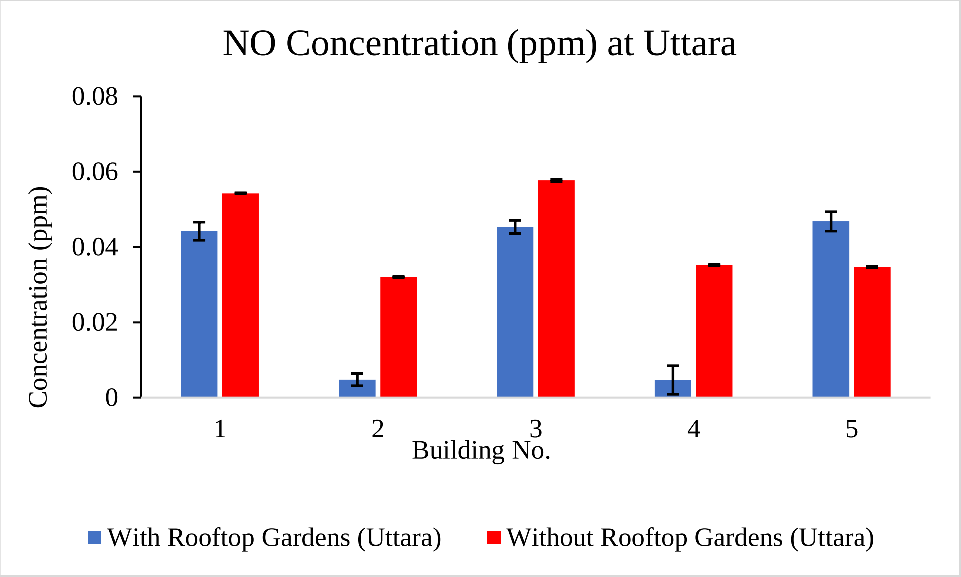

Figure 13. Comparison of NO Concentration (ppm) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens

For buildings at Mirpur, with and without rooftop gardens, the nitric oxide (NO) concentrations in parts per million (ppm) were as follows: With Rooftop Gardens (Mirpur): 0.03 ppm ± 0.01, 0.05 ppm ± 0.00, 0.01 ppm ± 0.00, 0.04 ppm ± 0.00, and 0.00 ppm ± 0.00. Without Rooftop Gardens (Mirpur): 0.04 ppm ± 0.00, 0.06 ppm ± 0.00, 0.04 ppm ± 0.00, 0.05 ppm ± 0.00, and 0.04 ppm ± 0.00. These observations were taken from specific buildings in Mirpur. The recorded Nitric Oxide (NO) concentrations present an evident disparity between buildings with and without rooftop gardens in Uttara. Structures equipped with rooftop gardens consistently displayed lower NO concentrations compared to those lacking green spaces. The average NO concentrations within buildings featuring rooftop gardens ranged from 0.0047 ppm to 0.0468 ppm, exhibiting smaller standard deviations, indicative of more stable readings. Conversely, in buildings without rooftop gardens, the NO concentrations ranged from 0.0320 ppm to 0.0577 ppm, showcasing relatively higher average values with slightly larger standard deviations.

This clear contrast emphasizes the impactful role of rooftop gardens in reducing NO concentrations, contributing to improved air quality within urban settings. The findings underline the significance of integrating green spaces, like rooftop gardens, as a viable strategy to mitigate pollutant levels, specifically highlighting their potential to alleviate Nitric Oxide concentration in indoor environments.

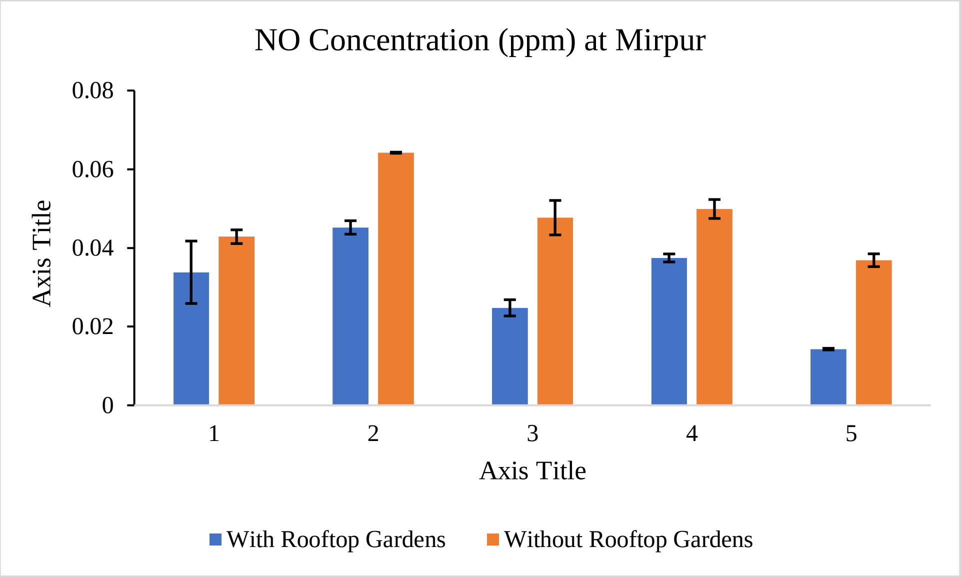

Figure 14. Comparison of NO Concentration (ppm) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens

### 4.1.6 $NO_2$ Concentration (ppm):

At buildings at Uttara, both with and without rooftop gardens, the nitrogen dioxide ($NO_2$) concentrations in parts per million (ppm) were recorded: In buildings with rooftop gardens at Uttara, the concentrations were measured as follows: 0.02 ppm ± 0.00, 0.03 ppm ± 0.00, 0.03 ppm ± 0.00, 0.02 ppm ± 0.00, and 0.03 ppm ± 0.00. In buildings without rooftop gardens, the concentrations were observed as follows: 0.03 ppm ± 0.00, 0.05 ppm ± 0.02, 0.05 ppm ± 0.01, 0.03 ppm ± 0.01, and 0.02 ppm ± 0.00.

The comparison of nitrogen dioxide ($NO_2$) concentrations in buildings with and without rooftop gardens in Uttara reveals a noticeable difference. Buildings equipped with rooftop gardens consistently exhibited lower $NO_2$ concentrations, with readings ranging between 0.02 ppm and 0.03 ppm, displaying minimal variance. In contrast, structures lacking rooftop gardens displayed higher average $NO_2$ concentrations, ranging from 0.03 ppm to 0.05 ppm, showcasing slightly more variability in readings.

These findings underscore the potential impact of rooftop gardens in reducing nitrogen dioxide levels within indoor environments. The recorded lower $NO_2$ concentrations in buildings with rooftop gardens emphasize the positive contribution of green spaces to mitigating air pollutants. This highlights the relevance of incorporating rooftop gardens as a viable strategy to maintain improved indoor air quality and mitigate nitrogen dioxide concentrations in urban settings.

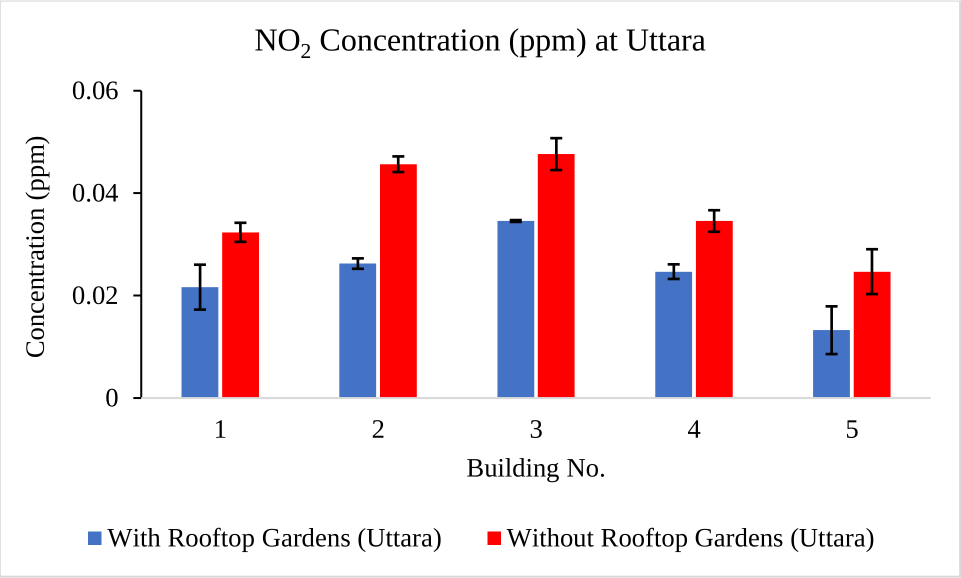

Figure 15. Comparison of $NO_2$ Concentration (ppm) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens

The mean $NO_2$ concentrations in parts per million (ppm) for buildings with rooftop gardens at Mirpur were observed as follows: 0.013 ppm ± 0.001, 0.026 ppm ± 0.001, 0.035 ppm ± 0.000, 0.025 ppm ± 0.001, and 0.033 ppm ± 0.005. For buildings without rooftop gardens at Mirpur, the mean NO2 concentrations were observed as follows: 0.028 ppm ± 0.002, 0.045 ppm ± 0.015, 0.048 ppm ± 0.011, 0.035 ppm ± 0.010, and 0.025 ppm ± 0.004. The comparison of nitrogen dioxide ($NO_2$) concentrations between buildings with and without rooftop gardens in Mirpur showcases a distinct difference. Buildings equipped with rooftop gardens consistently displayed lower mean $NO_2$ concentrations, ranging from 0.013 ppm to 0.035 ppm, with relatively minor fluctuations. Conversely, structures without rooftop gardens exhibited higher average $NO_2$ concentrations, varying from 0.028 ppm to 0.048 ppm, showing a slightly wider range of values.

These findings emphasize the potential role of rooftop gardens in reducing indoor nitrogen dioxide levels. The consistently lower $NO_2$ concentrations in buildings with rooftop gardens highlight the positive impact of green spaces in mitigating this air pollutant. It underscores the relevance of integrating rooftop gardens as an effective measure to maintain better indoor air quality and alleviate nitrogen dioxide concentrations within urban environments.

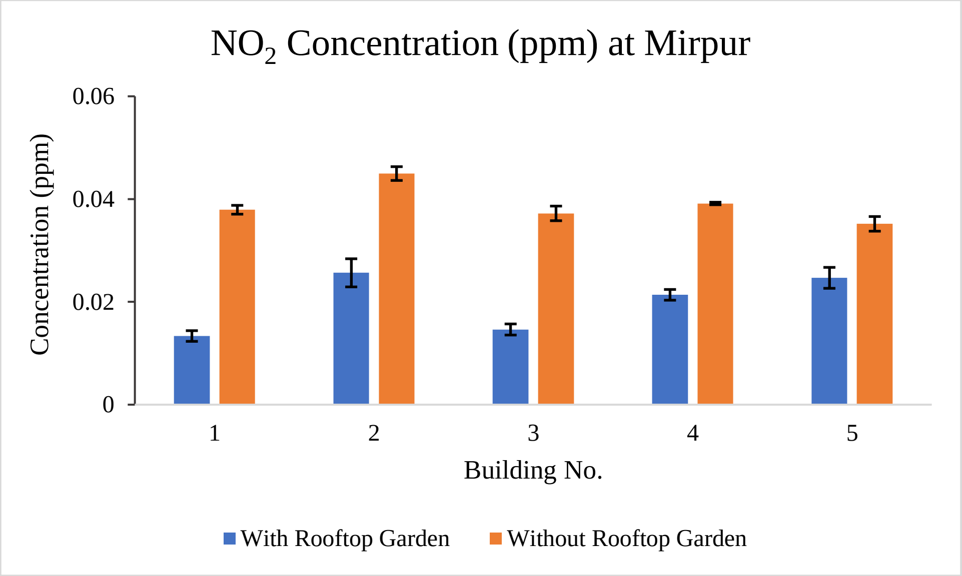

Figure 16. Comparison of $NO_2$ Concentration (ppm) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens

### 4.1.7 $O_3$ Concentration (ppm):

The mean $O_3$ concentrations in parts per million (ppm) for buildings with rooftop gardens at Uttara were: 0.020 ppm ± 0.015 ppm, 0.046 ppm ± 0.008 ppm, 0.047 ppm ± 0.004 ppm, 0.034 ppm ± 0.003 ppm, and 0.029 ppm ± 0.002 ppm. For buildings without rooftop gardens at Uttara, the mean $O_3$ concentrations were: 0.070 ppm ± 0.003 ppm, 0.054 ppm ± 0.016 ppm, 0.066 ppm ± 0.016 ppm, 0.047 ppm ± 0.001 ppm, and 0.034 ppm ± 0.002 ppm.

The presented ozone ($O_3$) concentration data for buildings in Uttara, categorized by the presence or absence of rooftop gardens, indicates notable distinctions in air quality. In buildings with rooftop gardens, $O_3$ concentrations range between 0.020 ppm and 0.047 ppm, with corresponding standard deviations fluctuating from ± 0.002 ppm to ± 0.015 ppm. This data showcases variations in $O_3$ levels within this group. Conversely, buildings without rooftop gardens exhibit $O_3$ concentrations spanning from 0.034 ppm to 0.070 ppm, accompanied by standard deviations ranging between ± 0.001 ppm and ± 0.016 ppm. These values suggest higher average $O_3$ concentrations and a wider variability range compared to buildings with rooftop gardens. The discerned differences in $O_3$ concentrations between buildings with and without rooftop gardens suggest a potential advantage associated with rooftop gardens in potentially mitigating and maintaining lower $O_3$ levels. While further investigation is warranted, these findings imply a possible role of rooftop gardens in contributing to improved air quality concerning O3 content within buildings in Uttara.

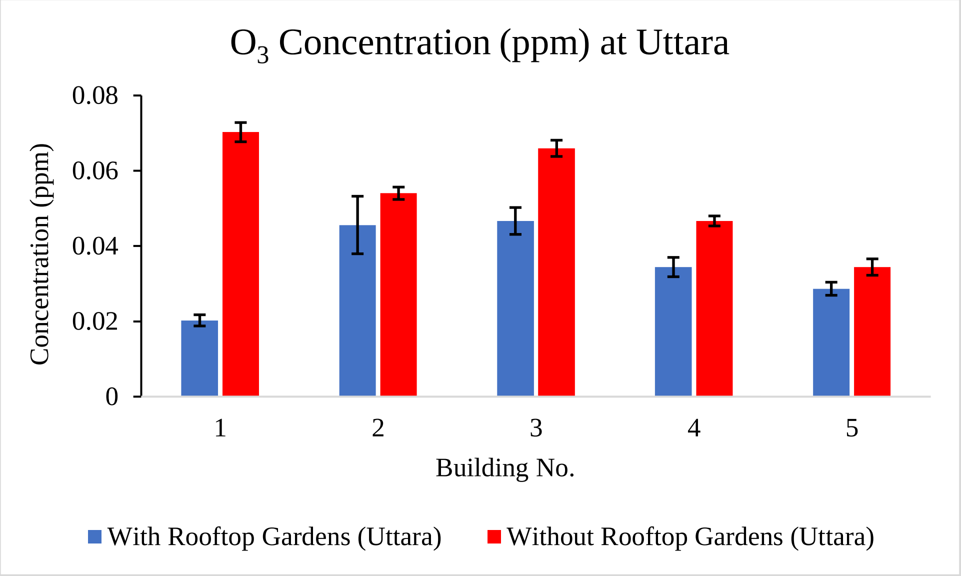

Figure 17. Comparison of $O_3$ Concentration (ppm) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens

At Mirpur, the mean $O_3$ concentrations in parts per million (ppm) for buildings with rooftop gardens were: 0.034 ppm ± 0.002, 0.032 ppm ± 0.002, 0.025 ppm ± 0.002, 0.037 ppm ± 0.001, and 0.031 ppm ± 0.005. For buildings without rooftop gardens at Mirpur, the mean $O_3$ concentrations were: 0.060 ppm ± 0.001, 0.051 ppm ± 0.005, 0.050 ppm ± 0.003, 0.057 ppm ± 0.001, and 0.040 ppm ± 0.001. The provided ozone ($O_3$) concentration data for buildings in Mirpur, distinguished by the presence or absence of rooftop gardens, highlights substantial differences in air quality. In buildings with rooftop gardens at Mirpur, $O_3$ concentrations range between 0.025 ppm and 0.037 ppm, with corresponding standard deviations varying from ± 0.001 ppm to ± 0.005 ppm. These values denote variations in $O_3$ levels within this group of buildings.

Contrarily, buildings without rooftop gardens display $O_3$ concentrations spanning from 0.040 ppm to 0.060 ppm, accompanied by standard deviations ranging between ± 0.001 ppm and ± 0.005 ppm. This data indicates higher average $O_3$ concentrations and a wider variability range compared to buildings with rooftop gardens. The observed disparity in $O_3$ concentrations between buildings with and without rooftop gardens suggest a potential advantage associated with rooftop gardens in maintaining lower $O_3$ levels. These findings hint at a possible role of rooftop gardens in contributing to improved air quality concerning $O_3$ content within buildings in Mirpur.

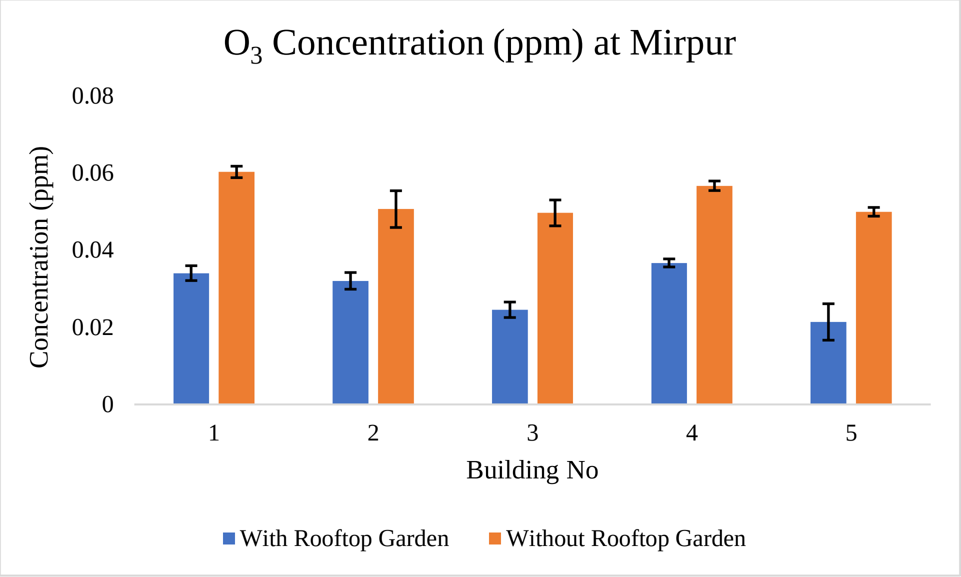

Figure 18. Comparison of $O_3$ Concentration (ppm) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens.

### 4.1.8 $PM_{2.5}$ Concentrations (μg/m³):

The $PM_{2.5}$ concentrations (μg/m³) were meticulously measured in buildings located at Uttara, considering both structures with and without rooftop gardens. In buildings equipped with rooftop gardens, the mean $PM_{2.5}$ concentrations were observed as follows: 32.72 ± 5.07 μg/m³, 64.66 ± 3.02 μg/m³, 39.75 ± 6.56 μg/m³, 30.78 ± 7.33 μg/m³, and 38.35 ± 5.43 μg/m³. Meanwhile, for buildings without rooftop gardens, the mean $PM_{2.5}$ concentrations were determined as: 49.66 ± 5.07 μg/m³, 87.23 ± 6.16 μg/m³, 55.26 ± 2.25 μg/m³, 42.75 ± 4.16 μg/m³, and 49.78 ± 3.12 μg/m³. These readings provide insights into the variation of $PM_{2.5}$ levels among buildings at Uttara, illustrating distinctions between those with and without rooftop gardens. This data indicates higher average $PM_{2.5}$ concentrations and a broader variability range compared to buildings with rooftop gardens.

The detailed assessment of $PM_{2.5}$ concentrations in buildings at Uttara, categorized by the presence or absence of rooftop gardens, underscores discernible distinctions in air quality. The findings disparity in $PM_{2.5}$ concentrations between buildings with and without rooftop gardens suggests a potential advantage associated with rooftop gardens in maintaining lower $PM_{2.5}$ levels. These findings hint at a plausible role of rooftop gardens in contributing to improved air quality concerning $PM_{2.5}$ content within buildings at Uttara.

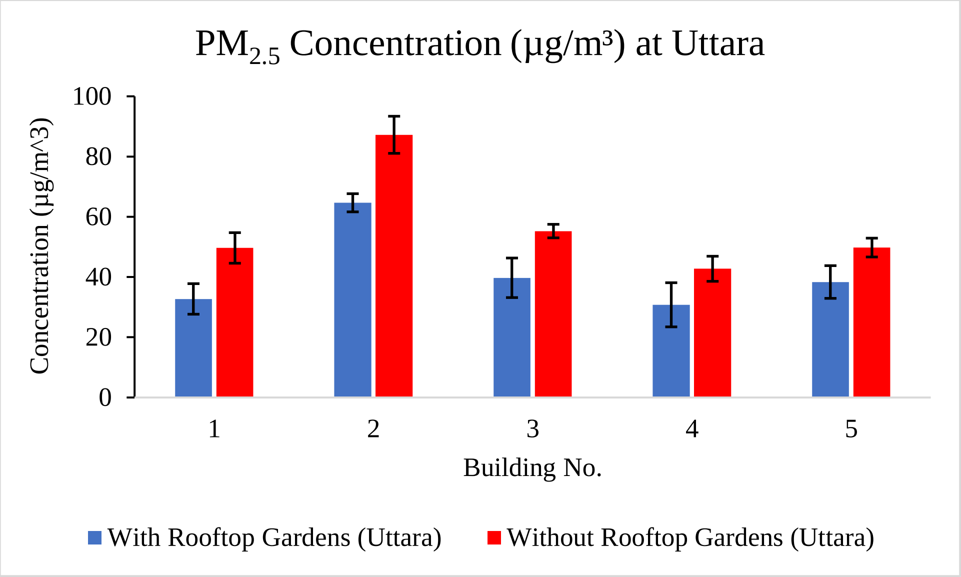

Figure 19. Comparison of $PM_{2.5}$ Concentration (µg/m³) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens.

In buildings equipped with rooftop gardens at Mirpur, the mean $PM_{2.5}$ concentrations were observed as follows: 37.66 ± 9.07 µg/m³, 42.72 ± 11.15 µg/m³, 32.66 ± 5.25 µg/m³, 39.75 ± 6.16 µg/m³, and 30.72 ± 9.12 µg/m³. Conversely, for buildings without rooftop gardens, the mean PM2.5 concentrations were determined as: 59.66 ± 3.07 µg/m³, 72.23 ± 4.02 µg/m³, 65.26 ± 1.50 µg/m³, 72.75 ± 7.00 µg/m³, and 49.78 ± 3.42 µg/m³. This data suggests higher average PM2.5 concentrations and a broader variability range compared to buildings with rooftop gardens. Buildings equipped with rooftop gardens exhibit mean $PM_{2.5}$ concentrations ranging from 30.72 µg/m³ to 42.72 µg/m³, accompanied by standard deviations varying between ± 5.25 µg/m³ and ± 11.15 µg/m³. These measurements indicate fluctuations in $PM_{2.5}$ levels within this group. In contrast, buildings without rooftop gardens display higher mean $PM_{2.5}$ concentrations, spanning from 49.78 µg/m³ to 72.75 µg/m³, with standard deviations ranging between ± 1.50 µg/m³ and ± 7.00 µg/m³.

The notable difference in $PM_{2.5}$ concentrations between buildings with and without rooftop gardens underscores a potential advantage associated with rooftop gardens in maintaining lower $PM_{2.5}$ levels. These findings suggest a possible role of rooftop gardens in contributing to improved air quality concerning $PM_{2.5}$ content within buildings in Mirpur. These readings provide insights into the variation of $PM_{2.5}$ levels among buildings at Mirpur, illustrating distinctions between those with and without rooftop gardens. Buildings without rooftop gardens generally exhibited higher mean $PM_{2.5}$ concentrations compared to those with rooftop gardens, suggesting a potential advantage associated with rooftop gardens in mitigating $PM_{2.5}$ levels within indoor environments at Mirpur.

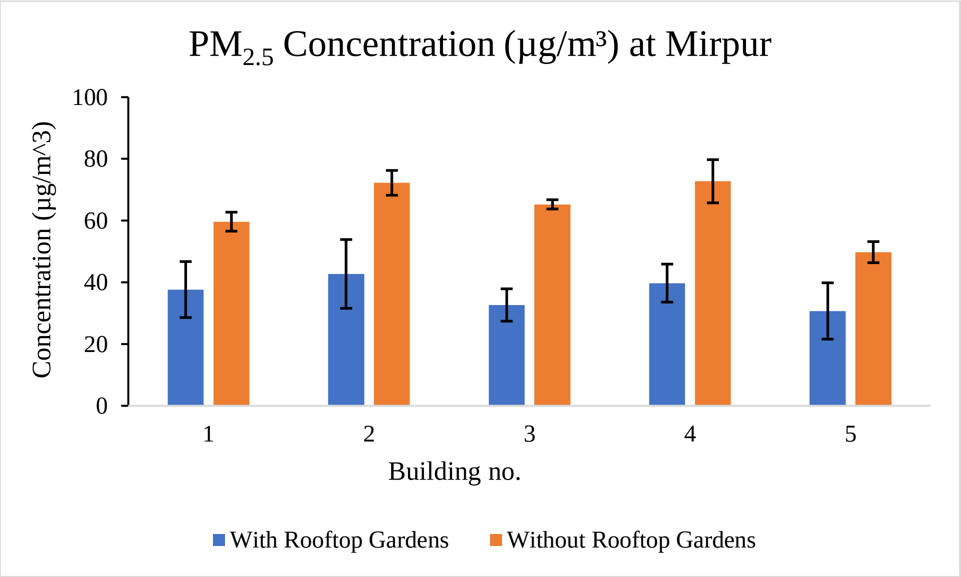

Figure 20. Comparison of $PM_{2.5}$ Concentration (µg/m³) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens.

### 4.1.9 $PM_1$ Concentrations (µg/m³):

At Uttara, the mean $PM_1$ concentrations in buildings with rooftop gardens were observed as follows: 5.68 ± 1.37 µg/m³, 33.88 ± 7.46 µg/m³, 7.53 ± 2.44 µg/m³, 9.43 ± 2.36 µg/m³, 11.64 ± 7.43 µg/m³. For buildings without rooftop gardens at Uttara, the mean PM1 concentrations were: 39.47 ± 5.26 µg/m³, 43.34 ± 9.32 µg/m³, 21.12 ± 6.77

µg/m³, 35.14 ± 3.14 µg/m³, 23.32 ± 6.32 µg/m³. The provided $PM_1$ concentration data for buildings in Uttara, distinguished by the presence or absence of rooftop gardens, highlights substantial differences that emphasize the potential significance of rooftop gardens in influencing air quality.

Buildings equipped with rooftop gardens depict mean $PM_1$ concentrations ranging from 5.68 µg/m³ to 33.88 µg/m³, with corresponding standard deviations varying between ± 1.37 µg/m³ and ± 7.46 µg/m³. These measurements illustrate variations in $PM_1$ levels within this group. Conversely, buildings without rooftop gardens display higher mean $PM_1$ concentrations, ranging from 21.12 µg/m³ to 43.34 µg/m³, accompanied by standard deviations between ± 3.14 µg/m³ and ± 9.32 µg/m³. This data suggests higher average $PM_1$ concentrations and a wider variability range compared to buildings with rooftop gardens.

The evident disparity in $PM_1$ concentrations between buildings with and without rooftop gardens suggests a potential advantage associated with rooftop gardens in maintaining lower $PM_1$ levels. These findings underscore the possible role of rooftop gardens in contributing to improved air quality concerning $PM_1$ content within buildings in Uttara.

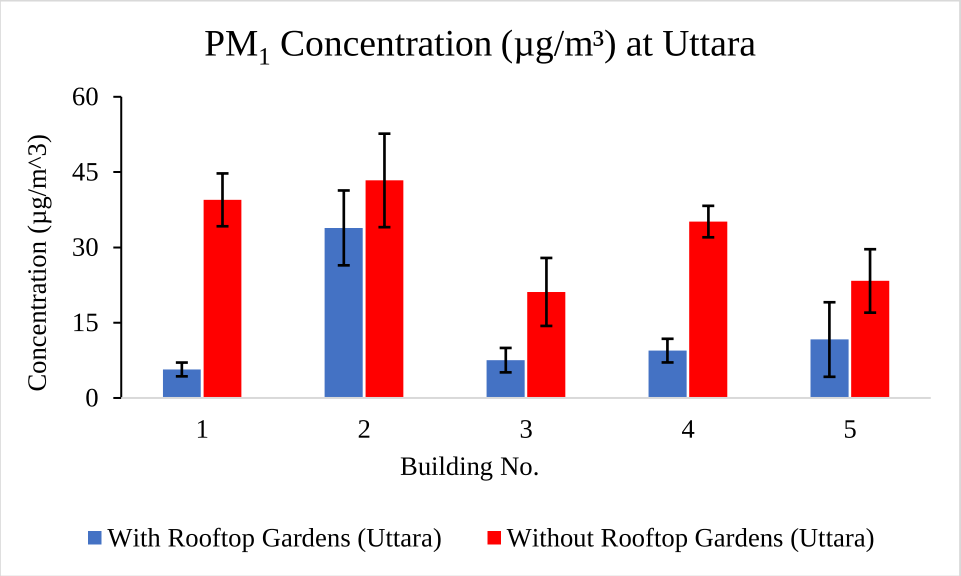

Figure 21. Comparison of $PM_1$ Concentration (µg/m³) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens.

At Mirpur, the mean $PM_1$ concentrations in buildings with rooftop gardens were observed as follows: 9.43 ± 1.25 µg/m³, 7.13 ± 2.32 µg/m³, 16.81 ± 3.08 µg/m³, 9.13 ±

1.14 μg/m$^3$, 6.93 ± 1.30 μg/m$^3$. For buildings without rooftop gardens at Mirpur, the mean PM1 concentrations were: 21.47 ± 2.74 μg/m$^3$, 33.34 ± 3.41 μg/m$^3$, 23.12 ± 3.44 μg/m$^3$, 35.14 ± 1.51 μg/m$^3$, 19.78 ± 1.90 μg/m$^3$. At Mirpur, the measured PM$_1$ concentrations in buildings, categorized by the presence or absence of rooftop gardens, signify substantial variations in air quality. Buildings equipped with rooftop gardens display mean PM$_1$ concentrations ranging from 6.93 μg/m$^3$ to 16.81 μg/m$^3$, with associated standard deviations varying between ± 1.14 μg/m$^3$ and ± 3.08 μg/m$^3$. These measurements depict fluctuations in PM$_1$ levels within this group of buildings. Conversely, buildings without rooftop gardens exhibit higher mean PM$_1$ concentrations, ranging from 19.78 μg/m$^3$ to 35.14 μg/m$^3$, accompanied by standard deviations between ± 1.51 μg/m$^3$ and ± 3.44 μg/m$^3$. This data suggests higher average PM$_1$ concentrations and a broader variability range compared to buildings with rooftop gardens. The observed disparity in PM$_1$ concentrations between buildings with and without rooftop gardens underscores a potential advantage associated with rooftop gardens in maintaining lower PM$_1$ levels. These findings hint at a possible role of rooftop gardens in contributing to improved air quality concerning PM$_1$ content within buildings in Mirpur.

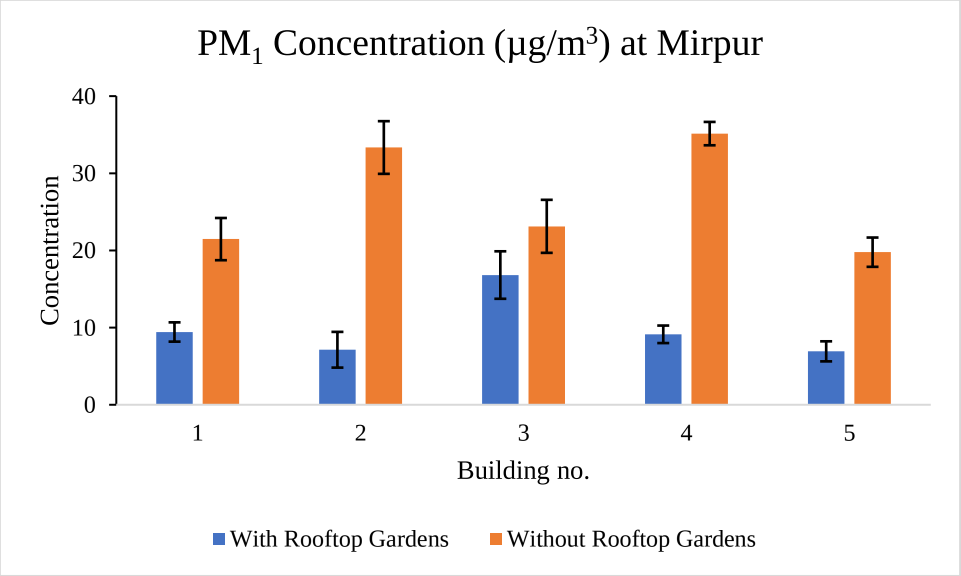

Figure 22. Comparative Analysis of PM$_1$ Concentration (μg/m$^3$) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens.

### 4.1.10 T.S.P Concentration (µg/m³):

At Uttara, the mean T.S.P (Total Suspended Particulate) concentrations in buildings with rooftop gardens were observed as follows: 38.41 ± 8.44 µg/m³, 62.54 ± 12.95 µg/m³, 46.14 ± 9.54 µg/m³, 38.49 ± 11.46 µg/m³, 37.36 ± 9.35 µg/m³. For buildings without rooftop gardens, the mean T.S.P concentrations were: 43.13 ± 5.51 µg/m³, 66.92 ± 12.44 µg/m³, 59.54 ± 9.95 µg/m³, 54.36 ± 13.03 µg/m³, 47.14 ± 11.17 µg/m³. The recorded Total Suspended Particulate (T.S.P) concentrations in buildings, categorized by the presence or absence of rooftop gardens, reveal distinctive variations in airborne particle levels. Buildings equipped with rooftop gardens depict mean T.S.P concentrations ranging from 37.36 µg/m³ to 62.54 µg/m³, accompanied by standard deviations varying between ± 8.44 µg/m³ and ± 12.95 µg/m³. These measurements showcase fluctuations in T.S.P levels within this group of buildings.

Conversely, buildings without rooftop gardens exhibit higher mean T.S.P concentrations, ranging from 43.13 µg/m³ to 66.92 µg/m³, with associated standard deviations between ± 5.51 µg/m³ and ± 13.03 µg/m³. This data suggests higher average T.S.P concentrations and a broader variability range compared to buildings with rooftop gardens. The observed differences in T.S.P concentrations between buildings with and without rooftop gardens suggest a potential advantage associated with rooftop gardens in maintaining lower T.S.P levels. These findings hint at a possible role of rooftop gardens in contributing to improved air quality concerning Total Suspended Particulate content within buildings in Uttara.

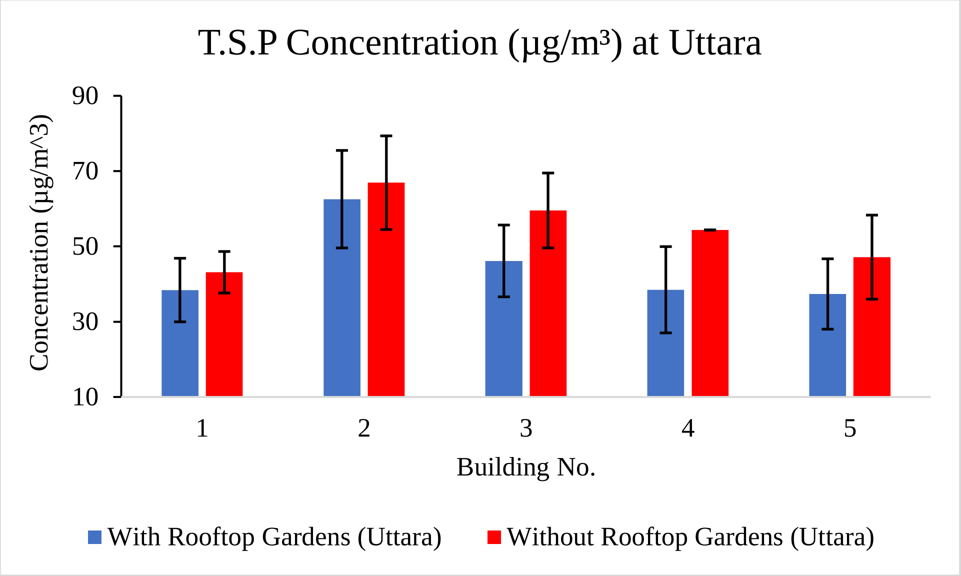

Figure 23. Comparison of T.S.P Concentration (µg/m³) (Mean ± SD) in Buildings at Uttara: With and Without Rooftop Gardens.

At Mirpur, the recorded Total Suspended Particulate (T.S.P) concentrations in buildings, differentiated by the presence or absence of rooftop gardens, exhibit significant variations that highlight the potential impact of rooftop gardens on air quality. Buildings equipped with rooftop gardens depict mean T.S.P concentrations ranging from 29.16 µg/m³ to 42.51 µg/m³, with associated standard deviations varying between ± 2.92 µg/m³ and ± 11.03 µg/m³. These measurements showcase fluctuations in T.S.P levels within this group of buildings. Conversely, buildings without rooftop gardens display higher mean T.S.P concentrations, ranging from 43.14 µg/m³ to 69.36 µg/m³, accompanied by standard deviations between ± 3.35 µg/m³ and ± 10.44 µg/m³. This data suggests higher average T.S.P concentrations and a broader variability range compared to buildings with rooftop gardens.

The noticeable disparity in T.S.P concentrations between buildings with and without rooftop gardens implies a potential advantage associated with rooftop gardens in maintaining lower T.S.P levels. These findings hint at a possible role of rooftop gardens in contributing to improved air quality concerning Total Suspended Particulate content within buildings in Mirpur.

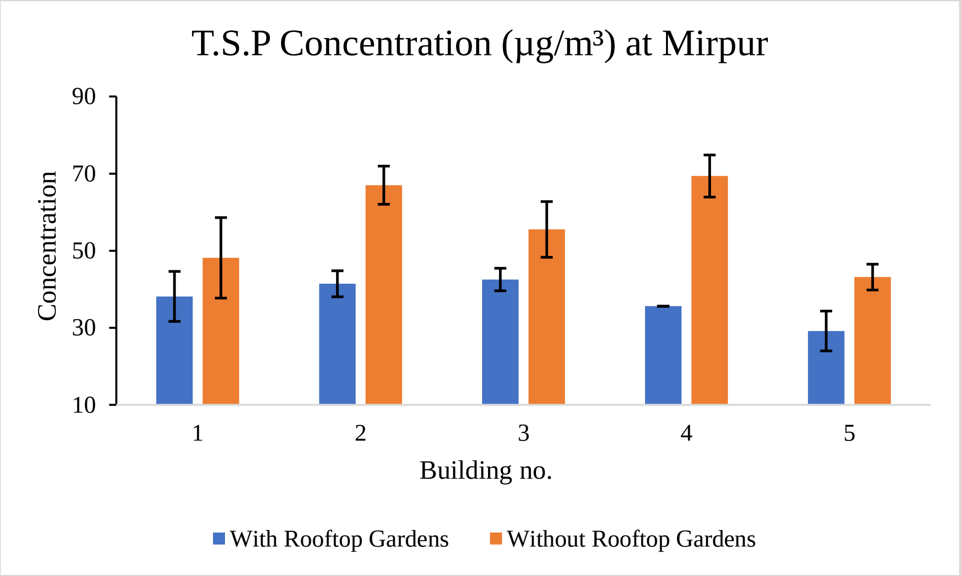

Figure 24. Comparison of T.S.P Concentration (µg/m³) (Mean ± SD) in Buildings at Mirpur: With and Without Rooftop Gardens.

### 4.1.11 $SO_2$ Concentrations (ppm):

At Uttara, the mean $SO_2$ concentrations in buildings with rooftop gardens were observed as follows: 0.054 ± 0.010 ppm, 0.048 ± 0.004 ppm, 0.061 ± 0.003 ppm, 0.052 ± 0.013 ppm, and 0.043 ± 0.001 ppm. For buildings without rooftop gardens, the mean SO2 concentrations were: 0.063 ± 0.002 ppm, 0.072 ± 0.001 ppm, 0.101 ± 0.003 ppm, 0.062 ± 0.003 ppm, and 0.072 ± 0.001ppm.
At Uttara, the examination of sulfur dioxide (SO2) concentrations in buildings, both with and without rooftop gardens, showcases a notable trend suggesting a favorable impact of rooftop gardens on indoor air quality concerning SO2 levels. Buildings featuring rooftop gardens displayed mean SO2 concentrations ranging between 0.043 ppm and 0.061 ppm, with corresponding standard deviations varying from ± 0.001 ppm to ± 0.013 ppm. These measurements denote comparatively lower average SO2 levels and a narrower spectrum of fluctuation within this group. In contrast, buildings without rooftop gardens exhibited mean SO2 concentrations ranging from 0.062 ppm to 0.101 ppm, with standard deviations ranging between ± 0.001 ppm and ± 0.003 ppm. These values indicate higher average SO2 concentrations and a wider variability range compared to buildings with rooftop gardens. The discernible pattern suggests that

buildings equipped with rooftop gardens tend to maintain lower average SO2 concentrations and showcase less variability in SO2 levels compared to buildings lacking such green installations. This pattern strongly implies a potential advantage associated with rooftop gardens in mitigating indoor SO2 levels within buildings at Uttara.

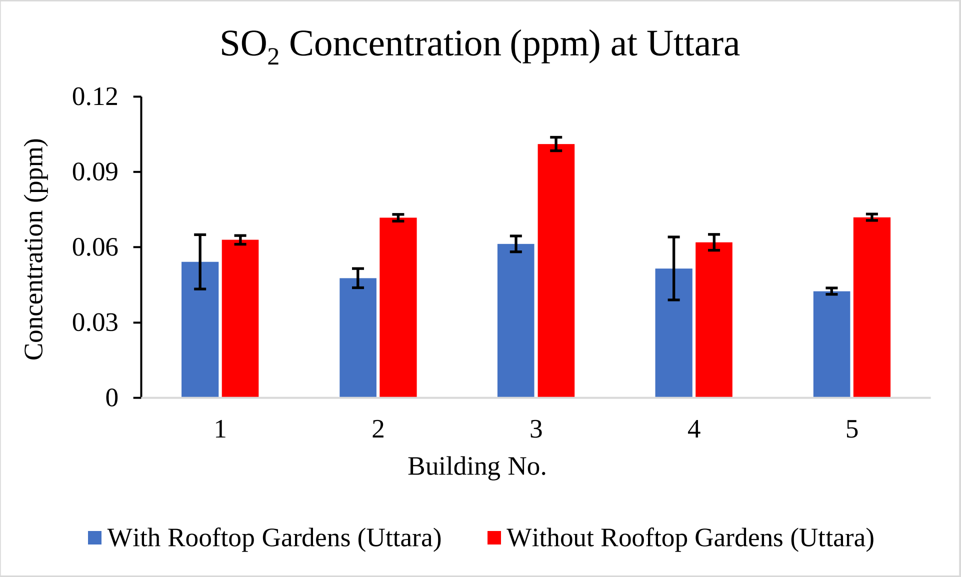

Figure 25. Comparative $SO_2$ Concentration (Mean ± SD) in Buildings at Uttara.

At Mirpur, the mean $SO_2$ concentrations in buildings with rooftop gardens were observed as follows: 0.041 ± 0.002 ppm, 0.048 ± 0.001 ppm, 0.067 ± 0.003 ppm, 0.043 ± 0.003 ppm, and 0.052 ± 0.001 ppm. For buildings without rooftop gardens, the mean SO2 concentrations were: 0.053 ± 0.001 ppm, 0.072 ± 0.002 ppm, 0.077 ± 0.003 ppm, 0.062 ± 0.002 ppm, and 0.072 ± 0.001 ppm. The comparison of sulfur dioxide ($SO_2$) concentrations between buildings with and without rooftop gardens at Mirpur reveals noteworthy differences. Buildings equipped with rooftop gardens displayed lower mean $SO_2$ concentrations, ranging from 0.041 ppm to 0.067 ppm, with relatively consistent values and a minor range of fluctuation. In contrast, structures without rooftop gardens exhibited higher average $SO_2$ concentrations, varying from 0.053 ppm to 0.077 ppm, indicating a slightly wider range of values and consistently higher levels compared to buildings with green spaces.

These findings highlight the potential role of rooftop gardens in reducing indoor sulfur dioxide levels. The consistently lower $SO_2$ concentrations in buildings with rooftop gardens emphasize the positive impact of these green spaces in mitigating this particular air pollutant. This underscores the relevance of incorporating rooftop gardens as a feasible measure to help maintain better indoor air quality and alleviate sulfur dioxide concentrations within urban settings.

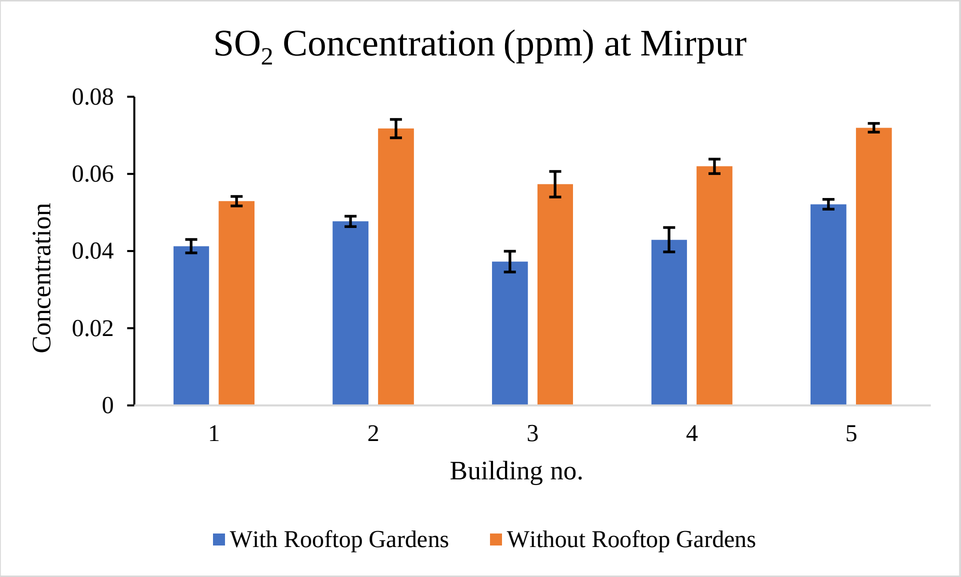

Figure 26. Mean $SO_2$ Concentration (Mean ± SD) in Buildings at Mirpur.

So, from these data illustrates varying air quality parameters, showcasing different concentrations of gases (such as NO, $NO_2$, $SO_2$, $O_3$) and particulate matter ($PM_1$, $PM_{2.5}$, TSP) in buildings with and without rooftop gardens. Buildings with rooftop gardens generally exhibit lower pollutant concentrations, suggesting a potential positive impact on air quality. This suggests that implementing green spaces like rooftop gardens could play a role in reducing pollution levels within urban environments.

## 4.2 Statistical Analysis: Interpretation of One-Way ANOVA Results

- A p-value less than 0.05 suggests that the observed differences in pollutant concentrations between buildings with and without rooftop gardens are unlikely to have occurred by random chance alone.

It provides statistical evidence to support the hypothesis, that there is a significant difference in pollutant concentrations among the groups being compared.

**Table 2.** ANOVA - Comparison of Pollutant Concentrations in Buildings with and without Rooftop Gardens

| Pollutant Name | Between-Groups variation (SS) | Within-Groups Variation (SS) | F-Statistic (F) | Degrees of Freedom (df) Between | Degrees of Freedom (df) Within | p-Value | Conclusion |
|---|---|---|---|---|---|---|---|
| CO | 8.2183937 | 6.207827 | 68.4929 | 1 | 18 | 0.00012 | Significant |
| $CO_2$ | 18687.093 | 35851.09 | 9.382357 | 1 | 18 | 0.0066988 | Significant |
| $CH_4$ | 6.3675613 | 6.599814 | 17.36657 | 1 | 18 | 0.0005788 | Significant |
| NO | 0.0015033 | 0.004615 | 5.863814 | 1 | 18 | 0.0262395 | Significant |
| $NO_2$ | 0.0007135 | 0.000968 | 13.27386 | 1 | 18 | 0.001859 | Significant |
| $O_3$ | 0.0018859 | 0.001723 | 19.70638 | 1 | 18 | 0.0003168 | Significant |
| $PM_{2.5}$ | 2196.2173 | 2622.376 | 15.07485 | 1 | 18 | 0.0010908 | Significant |
| $PM_1$ | 1577.8195 | 1309.838 | 21.68265 | 1 | 18 | 0.0001963 | Significant |
| T.S.P | 373.85377 | 1079.78 | 6.232167 | 1 | 18 | 0.0224741 | Significant |
| $SO_2$ | 0.0019419 | 0.002141 | 16.32594 | 1 | 18 | 0.0007673 | Significant |

*** A p-value <0.05 indicates statistical significance.

The ANOVA results exhibit substantial significance across all assessed air pollutants, as demonstrated by the calculated F-statistics and associated p-values. The Between-Groups variation (SS) signifies differences in pollutant concentrations attributed to the presence or absence of rooftop gardens, while the Within-Groups Variation (SS) reflects variations within the buildings themselves.

- The p-value for CO is 0.00012, significantly lower than 0.05, indicating a substantial difference in pollutant concentrations between buildings with and without rooftop gardens, confirming the significance of this disparity.
- Similarly, for $CO_2$, $CH_4$, NO, $NO_2$, $O_3$, $PM_{2.5}$, $PM_1$, T.S.P, and $SO_2$, the calculated p-values of 0.0066988, 0.0005788, 0.0262395, 0.001859, 0.0003168, 0.0010908, 0.0001963, 0.0224741, and 0.0007673, respectively, all fall below the critical threshold of 0.05. These values indicate significant differences in pollutant concentrations among buildings with and without rooftop gardens for each respective pollutant.

- The consistent pattern of p-values less than 0.05 across all assessed pollutants underscores the robust statistical significance, affirming that rooftop gardens play a significant role in reducing concentrations of these air pollutants within the studied buildings.

The notably high F-statistics and corresponding p-values less than 0.05 for all pollutants underscore the statistical significance of the differences in concentrations between buildings with and without rooftop gardens. These outcomes strongly support the assertion that the presence of rooftop gardens significantly influences and reduces air pollutant concentrations within the studied buildings. This comprehensive statistical analysis reinforces the consistent and substantial impact of rooftop gardens in mitigating air pollutant levels across various pollutants, affirming their potential as effective mechanisms for enhancing air quality within residential environments. The findings accentuate that buildings with rooftop gardens consistently exhibit lower pollutant levels, highlighting the potential environmental advantages associated with the integration of green infrastructure in residential settings.

**Table 3.** Bangladesh National Ambient Air Quality Standards (2022) vs. WHO Guideline Values and US EPA Standards

| **Pollutant** | **Averaging period** | **Bangladesh Standards (μg/m$^3$)** | **WHO Guideline Values (μg/m$^3$)** | **US EPA Standards (μg/m$^3$)** |
|---|---|---|---|---|
| CO | 8 hours | 5,000 | 4,000 | 10,310 |
| | 1 hour | 20,000 | 30,000 | 40,096 |
| $NO_2$ | 24 hours | 80 | 25 | - |
| | Annual | 40 | 10 | 100 |
| $PM_{2.5}$ | 24 hours | 65 | 15 | 35 |
| | Annual | 35 | 5 | 12 |
| $O_3$ | 8 hours | 100 | 100 | 137 |
| | 1 hour | 180 | - | - |
| $SO_2$ | 24 hours | 80 | 40 | 365 |
| | 1 hour | 250 | - | 197 |

***(“Air-Pollution-Control-Rules-2022,” 2022) (*World Health Organization (WHO) Air Quality Guidelines (AQGs) and Estimated Reference Levels (RLs)*, n.d.) (*NAAQS Table | US EPA*, 2023)

The established air quality standards provide critical thresholds for various pollutants, reflecting safe and healthy levels of exposure. The set standards by Bangladesh, WHO, and the US EPA for Carbon Monoxide (CO) exhibit variations in the updated 2022 standards. Bangladesh's CO standards stand at 5,000 µg/m³ for an 8-hour average and 20,000 µg/m³ for a 1-hour average. The US Environmental Protection Agency (EPA) establishes air quality standards to regulate various pollutants. For Carbon Monoxide (CO), the EPA sets a standard of 4,000 µg/m³ for an 8-hour average and 30,000 µg/m³ for a 1-hour average. Whereas, the World Health Organization (WHO) standards for various pollutants are established at different concentrations to maintain air quality and safeguard public health. For Carbon Monoxide (CO), WHO specifies a limit of 4,000 µg/m³ for a 1-hour average but doesn't provide an explicit value for an 8-hour average. Nitrogen Dioxide ($NO_2$) standards in Bangladesh are notably revised to 80 µg/m³ (24-hour) and 40 µg/m³ annually, closer to WHO benchmarks but higher in annual terms. WHO specifies Nitrogen Dioxide ($NO_2$) standard at 25 µg/m³ for a 24-hour average and 10 µg/m³ annually. For Particulate Matter ($PM_{2.5}$), in Bangladesh, the standards stand at 65 µg/m³ for a 24-hour average and 35 µg/m³ annually. Regarding Particulate Matter ($PM_{2.5}$), the EPA defines standards of 35 µg/m³ for a 24-hour average and 12 µg/m³ annually. WHO's guidelines for Particulate Matter ($PM_{2.5}$) include 15 µg/m³ for a 24-hour average and 5 µg/m³ annually. Ozone ($O_3$) standards remain consistent with WHO guidelines. Regarding Ozone ($O_3$), WHO maintains a standard of 100 µg/m³ for an 8-hour average without specifying a value for a 1-hour average. Notably, Sulfur Dioxide ($SO_2$) limits have been decreased to 80 µg/m³ for a 24-hour average and 250 µg/m³ for a 1-hour average. For Sulfur Dioxide ($SO_2$), WHO prescribes a limit of 40 µg/m³ for a 24-hour average but doesn't provide a specific value for a 1-hour average For Ozone ($O_3$), the EPA sets a standard of 100 µg/m³ for an 8-hour average and 137 µg/m³ for a 1-hour average. Sulfur Dioxide ($SO_2$) standards established by the EPA are 365 µg/m³ for a 24-hour average and 197 µg/m³ for a 1-hour average. These EPA standards serve as regulatory measures to control pollution levels, ensuring the protection of public health and the environment. These standards serve as crucial references to ensure air quality remains within safe limits, reducing potential health risks associated with exposure to these pollutants. The averaging period refers to the duration over which measurements of air pollutants are averaged to assess compliance with air quality standards. For certain pollutants like Carbon Monoxide (CO) and Ozone ($O_3$), the averaging periods are set at 8 hours and 1 hour. This shorter timeframe reflects the rapid fluctuations in these pollutants' concentrations over shorter periods, especially due to traffic and atmospheric variations. On the other hand, pollutants like Nitrogen Dioxide ($NO_2$), Sulfur Dioxide ($SO_2$), and Particulate Matter ($PM_{2.5}$) have longer averaging periods of 24 hours and annually. This choice acknowledges their persistence in the atmosphere over extended periods, reflecting their cumulative effects and potential health risks over time.

The varying averaging periods cater to the different behaviors of these pollutants in the atmosphere. For instance, pollutants like CO and $O_3$ can fluctuate more rapidly due to traffic patterns or specific weather conditions, hence the shorter timeframes. Meanwhile, pollutants such as $NO_2$, $SO_2$, and $PM_{2.5}$ tend to exhibit more sustained impacts, hence the longer assessment periods. These distinctions help in assessing both immediate and prolonged exposure risks associated with these pollutants.

Exceeding established air quality standards can have severe health and environmental implications. When pollutant levels surpass defined limits, adverse health effects become more prevalent. For instance, high concentrations of Carbon Monoxide (CO) can lead to headaches, dizziness, and in extreme cases, even death by depriving the body of oxygen (Rose et al., 2017). Elevated Nitrogen Dioxide (NO2) levels are associated with respiratory issues, aggravation of asthma, and increased susceptibility to respiratory infections (*Basic Information About NO2 | US EPA*, 2023).

Particulate Matter ($PM_{2.5}$) exceeding prescribed levels can lead to respiratory problems, heart diseases, and aggravate existing conditions like asthma or bronchitis (Xing et al., 2016). Ozone ($O_3$) exposure above standard levels can cause throat irritation, coughing, chest pain, and worsen existing respiratory conditions. Sulfur Dioxide ($SO_2$) inhalation beyond permissible levels can irritate the respiratory system, causing coughing and shortness of breath, particularly in vulnerable populations like children and the elderly (Tj et al., 1985).

Environmentally, these pollutants contribute to smog formation, acid rain, and damage to vegetation and ecosystems (Manisalidis et al., 2020). Exceeding these standards not only impacts human health but also disrupts the delicate balance of ecosystems, affecting biodiversity and agricultural productivity.

**Table 4.** Comparison of the criteria air pollutants against Bangladesh National Ambient Air Quality Standards, WHO Guideline Values and US EPA Standards

| **Pollutant** | **Averaging period** | **Bangladesh Standard (µg/m³)** | **WHO Guideline Values (µg/m³)** | **US EPA Standards (µg/m³)** | **With Rooftop Garden Average Value (µg/m³)** | **Without Rooftop Garden Average Value (µg/m³)** |
|---|---|---|---|---|---|---|
| **CO** | 8 hours | 5,000 | 4,000 | 10,310 | 2,682 | 4,151 |
| | 1 hour | 20,000 | 30,000 | 40,096 | | |
| **$NO_2$** | 24 hours | 80 | 25 | - | 49.08 | 71.56 |
| | Annual | 40 | 10 | 100 | | |
| **$PM_{2.5}$** | 24 hours | 65 | 15 | 35 | 40.97727 | 61.93541 |
| | Annual | 35 | 5 | 12 | | |
| **$O_3$** | 8 hours | 100 | 100 | 137 | 65.592 | 103.702 |
| | 1 hour | 180 | - | - | | |
| **$SO_2$** | 24 hours | 80 | 40 | 365 | 133.27 | 184.91 |
| | 1 hour | 250 | - | 197 | | |

In buildings with rooftop gardens, the average concentrations of pollutants such as Carbon Monoxide (CO), Nitrogen Dioxide ($NO_2$), Particulate Matter ($PM_{2.5}$), Ozone ($O_3$), and Sulfur Dioxide ($SO_2$) consistently portray lower levels compared to buildings lacking these green spaces. The comparison of air pollutant levels against established standards reveals significant variations.

For Carbon Monoxide (CO), the concentrations within buildings featuring rooftop gardens were 2,682 µg/m$^3$ in average, that remained below the Bangladesh standard. However, in structures lacking rooftop gardens, the average value was 4,151 µg/m$^3$ and which surpassed the WHO standard for the 8-hour averaging period. Remarkably, both with and without rooftop garden values did not exceed the 1-hour averaging time WHO standard. Notably, the CO value within buildings with rooftop gardens was notably lower, nearly half the concentration observed in structures without rooftop gardens. Additionally, both types did not breach the 1-hour and 8-hours EPA standard for CO.

Nitrogen Dioxide ($NO_2$) concentrations within buildings featuring rooftop gardens were 49.08 µg/$m^3$ in average, notably below the Bangladesh standard for the 24-hour averaging time. Conversely, in structures without a rooftop garden, the $NO_2$ concentration, 71.56 µg/$m^3$, approached the Bangladesh standard for this duration. Although both building types surpassed the WHO standard, the concentration within structures lacking rooftop gardens was notably higher. Despite both types showing average values for $NO_2$ lower than the USEPA standard, the concentration observed in structures without a rooftop garden nearly reached the EPA standard, signifying its proximity to the specified threshold. The average $PM_{2.5}$ value in buildings with rooftop gardens remained notably lower than the Bangladesh standards for both the 24-hour and annual averaging period. Even though both scenarios exceeded the WHO standards for this period, the average $PM_{2.5}$ value in buildings with rooftop gardens was significantly lower than those without. In both cases, the average values surpassed the daily EPA standards, yet the without rooftop garden values were notably higher, almost reaching the standard limit. Furthermore, while both with and without rooftop gardens exceeded the annual EPA standard, the values without gardens were substantially higher. These findings underline the importance of implementing measures to reduce $PM_{2.5}$ concentrations, particularly in buildings lacking rooftop gardens, to align with international air quality guidelines and standards.

The average concentration of Ozone ($O_3$) in buildings with rooftop gardens fell below the Bangladesh, WHO, and US EPA standards set for the 8-hour averaging period. However, the average value without rooftop gardens surpassed both the Bangladesh and WHO standards for the 8-hour averaging period and approached the EPA standard for the same duration. Although both with and without rooftop garden values were below the 1-hour averaging period standard of Bangladesh, the value without a rooftop garden was closer to the prescribed standard. This significant difference between the average values of buildings with and without rooftop gardens emphasizes their varying impact on Ozone ($O_{3)}$ concentration level.

The average value of Sulfur Dioxide ($SO_2$) with a Rooftop Garden was 133.27 µg/m³, while the value without one stood notably higher at 184.91 µg/m³. In terms of the Bangladesh and WHO standards for the 24-hour averaging period, both values surpassed the set limits of 80 and 40 µg/m³, indicating that both with and without rooftop values exceeded these standards. However, the concentration without a rooftop garden significantly exceeded these limits compared to the value with a garden. Moreover, for the EPA standard of 365 µg/m³ over 24 hours, neither value surpassed it, but the concentration without a garden was closer to this standard. When considering the 1-hour averaging period standards of $SO_2$, which are 250 µg/m³ for Bangladesh and 197 µg/m³ for the EPA, the concentration without a rooftop garden was much closer to these standards compared to the value with a garden. This clear difference between the values of buildings with and without rooftop gardens emphasizes their distinct impact on $SO_2$ concentration levels across different averaging periods. The findings strongly suggest that the absence of rooftop gardens corresponds to heightened pollutant concentrations, particularly evident in $NO_2$, $PM_{2.5}$, $O_3$, and $SO_2$. These disparities highlight the pivotal role of green spaces in mitigating air pollutants. Introducing and enhancing green infrastructure in urban settings can substantially improve indoor air quality, ultimately fostering healthier living environments.

The comprehensive analysis reveals a clear trend: buildings with rooftop gardens consistently maintain lower concentrations of various air pollutants compared to those without green spaces. Even though both scenarios occasionally exceed established air quality standards, the values within buildings featuring rooftop gardens remain notably lower across all pollutants, showcasing the substantial impact of rooftop gardens in mitigating air pollutants. The findings affirm that in areas where overall air pollution concentrations are high, both scenarios—buildings with and without rooftop gardens—may surpass standard values. However, the concentrations in buildings with rooftop gardens consistently remain significantly lower. This indicates the considerable influence of rooftop gardens in reducing air pollutant levels. This underscores the crucial role of implementing rooftop gardens extensively across urban settings. While rooftop gardens alone might not entirely solve the pollution challenge, they notably contribute to lowering pollutant concentrations. The results emphasize the necessity for multifaceted measures to control and reduce overall pollution levels. Introducing rooftop gardens alongside other strategies holds promise in enhancing urban air quality and fostering healthier living environments.

# Chapter Five

# Conclusion and Recommendation

# Chapter 5: Conclusion and Recommendations

The comparative study conducted in Dhaka, Bangladesh, analyzed air quality variations across Uttara and Mirpur, analyzing buildings with and without rooftop gardens. Air quality parameters, including $O_2$, NO, $NO_2$, $SO_2$, $O_3$, $CH_4$, CO, $CO_2$, and particulate matter ($PM_1$, $PM_{2.5}$, TSP), were meticulously examined over two months (August and September 2023). The severe contrast revealed significantly higher air pollutant concentrations in buildings lacking rooftop gardens, notably exemplified by elevated $O_2$ levels in structures without green spaces. Notably, newly constructed buildings devoid of rooftop gardens exhibited even higher pollutant levels compared to established structures without such green installations. Conversely, buildings equipped with rooftop gardens showcased significantly lower particulate matter concentrations ($PM_1$, $PM_{2.5}$, TSP). Moreover, the highest values recorded were $PM_{2.5}$ at 87.23 µg/m³ at Mirpur, TSP at 66.92 µg/m³ at Uttara, $NO_2$ at 0.077 ppm at Mirpur, $O_3$ at 0.070 ppm at Uttara, and NO at 0.067 ppm at Mirpur. Conversely, the lowest concentrations were found in $PM_1$ at 7.53 µg/m³ at Uttara, TSP at 35.59 µg/m³ at Mirpur, $SO_2$ at 0.0425 ppm at Uttara, $O_3$ at 0.025 ppm at Mirpur, and NO at 0.04251 ppm at Uttara. The values for pollutants in buildings with rooftop gardens exhibit generally lower concentrations compared to those without rooftop gardens. Carbon Monoxide (CO) concentrations within buildings featuring rooftop gardens remained below the Bangladesh standard. However, in buildings without gardens, the average CO concentration exceeded the WHO standard for the 8-hour averaging period. Despite this, both scenarios, with rooftop gardens buildings and without, did not breach the 1-hour and 8-hour EPA standards for CO. Nitrogen Dioxide ($NO_2$) concentrations within buildings with rooftop gardens notably fell below the Bangladesh standard for the 24-hour averaging period. Conversely, in buildings without gardens, $NO_2$ concentrations approached this standard. Particulate Matter ($PM_{2.5}$) concentrations, though exceeding WHO standards for both scenarios, were notably lower in buildings with rooftop gardens compared to those without. The latter nearly reached the standard limit. Ozone ($O_3$) concentrations within buildings with rooftop gardens were below the Bangladesh, WHO, and US EPA standards for the 8-hour averaging period. In contrast, buildings lacking gardens surpassed Bangladesh and WHO standards and approached the EPA standard for the same duration. Sulfur Dioxide ($SO_2$) concentrations within both scenarios surpassed Bangladesh and WHO standards for the 24-hour averaging period. However, concentrations without rooftop gardens significantly exceeded these limits compared to those with gardens. The findings strongly suggest that the absence of rooftop gardens corresponds to heightened pollutant concentrations, particularly evident in $NO_2$, $PM_{2.5}$, $O_3$, and $SO_2$. These disparities highlight the pivotal role of green spaces in mitigating air pollutants. Introducing and enhancing green infrastructure in urban settings can substantially improve indoor air quality, ultimately fostering healthier living environments. The statistical analyses, ANOVA test, consistently underscored the substantial impact of rooftop gardens on air quality. These findings illuminate concerning levels of air pollutants in buildings without rooftop gardens, surpassing standard thresholds set by Bangladesh Standards, WHO, and EPA. These elevated levels necessitate immediate remedial measures to mitigate health risks associated with poor air quality. These findings emphasize the critical importance of rooftop gardens in mitigating air pollution and underline the necessity of integrating green spaces in urban planning and policy-making. The findings presented in this study support the implementation of green infrastructure to enhance air quality, promoting healthier living environments in densely populated urban areas.

The research suggested that the following appropriate actions should be implemented to address air quality concerns:

- Encouraging the incorporation of rooftop gardens or green spaces in building designs across urban areas to actively mitigate air pollutants.
- Implementing urban planning policies that prioritize and incentivize the creation of green infrastructure to counteract rising pollution levels.
- Establishing stringent regulatory standards to enforce the inclusion of green spaces in new construction projects, promoting sustainable urban development.
- Instituting regular monitoring systems to track air quality in various urban zones and assess the impact of rooftop gardens on pollution reduction.

For a more comprehensive understanding of the dynamics between rooftop gardens and air quality improvement, further research is essential.

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