DETERMINATION OF INDOOR AIR QUALITY AND POSSIBLE HEALTH RISKS AT KINDERGARTEN SCHOOLS IN DHAKA CITY, BANGLADESH

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DEDICATION

I dedicate this thesis to my loving parents whose unwavering support and encouragement fueled this academic journey and to my cherished little sister, a constant source of inspiration and joy.

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Finally, I would like to acknowledge my parents and my little sister for their sacrifices, belief in my potential, and enduring encouragement.

DECLARATION

I hereby declare that the research work "Determination of Indoor Air Quality and Possible Health Risks at Kindergarten Schools in 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 the original research findings from "Determination of Indoor Air Quality and Possible Health Risks at Kindergarten Schools in Dhaka City, Bangladesh" acquired by me along with the references from published literature. This work has not been submitted in part or full to any other institution for any other degree or diploma. I also certify that plagiarized content in this thesis is not more than 20%.

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CERTIFICATE OF THE SUPERVISOR

This is to certify that Suchana Biswas carried out her thesis under my guidelines and supervision, and hence prepared the thesis entitled "Determination of Indoor Air Quality and Possible Health Risks at Kindergarten Schools in 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 fulfilment of the requirements for the award of the degree of BSc. in Environmental Science. I also certify that plagiarized content in this thesis is not more than 20%.

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ABSTRACT

Air quality refers to the state of the air in our environment concerning the presence of pollutants and the overall composition of gases. In urban environments, the quality of air has become a pressing concern, impacting the health and well-being of inhabitants. This study sought to evaluate indoor air quality (IAQ) and identify possible health risks for children under 6 in Dhaka City's kindergarten schools. It specifically focused on comparing schools located near roadways and in residential areas. Primary Data were collected from six kindergarten schools, comprising three located along roadsides and three situated in residential areas using Haz-Scanner (Model HIM-6000). For Dhaka city the mean concentrations of the measured parameters including CO_2, CO, NO_2, SO_2, O_3, $PM_{2.5}$ and PM_{10} were found to be 904.709 ± 125.89 ppm, 1488.091 ± 292.05 ppb, 95.793 ± 33.304 ppb, 29.931 ± 6.89 ppb, 99.882 ± 29.91 ppb, 65.694 ± 11.68 ug/m^3 and 120.673 ± 22.97 $\mu g/m^3$ respectively. The obtained data were compared against World Health Organization (WHO) guidelines, revealing that PM_{10}, $PM_{2.5}$, SO_2, NO_2, and O_3 levels exceeded recommended limits. The average concentrations of the parameters for roadside kindergartens were CO_2 (1028.523 ± 9.37) ppm, CO (1573.922 ± 268.24) ppb, NO_2 (128.584 ± 3.50) ppb, SO_2 (30.156 ± 7.17) ppb, O_3 (128.979 ± 5.13) ppb, $PM_{2.5}$ (74.433 ± 3.34) ug/m^3, PM_{10} (138.959 ± 15.21) ug/m^3 and for residential kindergartens were CO_2 (780.895 ± 26.42) ppm, CO (1402.261 ± 291.70) ppb, NO_2 (63.001 ± 6.15) ppb, SO_2 (29.705 ± 6.65) ppb, O_3 (70.786 ± 7.50) ppb, $PM_{2.5}$ (56.955 ± 10.43) ug/m^3, PM_{10} (102.387 ± 12.37) ug/m^3. A t-test was employed to ascertain significant differences between roadside and residential schools. With roadside values consistently higher, notably, SO_2 was the only pollutant exhibiting non-significant variations. A semi structured questionnaire survey was used among the guardians, teachers and staff to collect the perception of IAQ along with possible health risks related to air quality. The findings emphasize increased vulnerabilities, especially respiratory problems, among students in kindergarten schools along with environmental concerns. They underscore the urgent need for targeted interventions to improve Indoor Air Quality (IAQ), with a particular focus on the well-being of the most vulnerable group, children under six, acknowledging that they are the future generation.

Keywords: *Air pollution, particulate matter, respiratory problems , vulnerable group*

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List of Acronyms and Abbreviations

IAQ	Indoor Air Quality
PM_{10}	Particulate Matter with a diameter of 10 micrometers or less
$PM_{2.5}$	Particulate Matter with a diameter of 2.5 micrometers or less
SO_2	Sulfur Dioxide
NO_2	Nitrogen Dioxide
O_3	Ozone
CO_2	Carbon Dioxide
CO	Carbon Monoxide
WHO	World Health Organization
ppm	Parts Per Million
$\mu g/m^3$	Micrograms per Cubic Meter of Air

CHAPTER ONE

INTRODUCTION

1.0. Introduction

1.1. Background of the Study

Air pollution is presently a typical word that we have acclimated with. Nonetheless, it's a major global concern (Mizen et al., 2020). One way to describe air pollution is as changes in the chemical composition of the atmosphere brought about by the introduction of chemicals, particles, or organic materials into the atmosphere. Although these substances are already in the air, air pollution results when their concentration exceeds a natural limit (Mizen et al., 2020). The adverse effects of exposure to air pollution are a global public health concern in both developing and developed nations (Zhang et al., 2018). Children and young people are particularly vulnerable to the effects of air pollution because of its impact on physical and mental development which can cause health implications across the lifespan (Mizen et al., 2020). Detrimental impacts from exposure to air pollution have been reported for early life health outcomes such as pregnancy outcomes, lung development and function, the central nervous system, life expectancy at birth, and infant mortality (Currie et al., 2013). Furthermore, air pollution has also been reported to have adverse effects on mental development, language development, attention and sensory perception (Mizen et al., 2020).

The term "Indoor Air Quality" (IAQ) describes the quality of the air inside and surrounding buildings and other structures, with a focus on how it affects the comfort and health of building inhabitants (US EPA, 2019). IAQ is a component of indoor environmental quality (IEQ), which also covers other elements of the physical and psychological aspects of living indoors, like acoustics, lighting, and thermal comfort. Comfortable humidity and temperature, a sufficient supply of fresh outdoor air, and the management of contaminants both indoor and outdoor are all essential components of a healthy indoor air quality (Bruce et al., 2000). The developed countries have been working with indoor air quality (IAQ) for many years. They identified the indoor air pollutants and investigated their impacts on health. After research on possible way outs, they have found the solution for improving the indoor environment. They have worked with school students and school buildings to ensure a healthy and comfortable environment for students and teachers during the classes (US EPA, 2017). Indoor air quality (IAQ) has become a major public health concern, especially in developing countries like Bangladesh, where crowded urban conditions exacerbate poor IAQ (Zaman et al., 2021). Children are especially vulnerable to the adverse health effects of poor indoor air quality as their respiratory systems are still developing (Zaman et al., 2021). Exposure to indoor air pollutants like particulate matter, carbon monoxide, and volatile organic compounds have been linked to increased risks of respiratory illnesses like asthma, allergies, and airway irritation in children (Zaman et al., 2021).

For people's overall health, especially that of vulnerable populations like children, clean indoor air is crucial (Rosbach et al., 2013). Children are more vulnerable to air pollution than adults because the volume of air they breathe in relation to their body weight is developing their tissues and organs. Children typically spend a significant amount of time in school facilities (Stabile, 2017). Children's health may be impacted by the indoor air quality in schools, which could also have an indirect impact on their ability to study. Maintaining indoor environmental quality (IEQ) is necessary for the school to offer a comfortable and healthy learning environment. IEQ elements, such as indoor air pollution, have a significant impact on students' health, performance, presence, and comfort (Stabile et al., 2017).

Over 70% of a pupil’s school life is spent inside a classroom, and indoor air quality has a significant impact on students’ attendance and learning potential. Therefore, the indoor air quality in kindergarten school buildings is highly important (Peng et al., 2017). Bangladesh, a developing country, is one of the most densely populated countries in the world. As the country is developing, pollution is on the rise. Particularly activities such as industrial production, transportation, construction etc., pollution is increasing with increase of different types of pollutants in the air. Deforestation is also affecting the overall situation. The resulting increase in outdoor air pollutants in Bangladesh also affects indoor air. Dhaka, the densely populated capital of Bangladesh with over 18 million residents, faces serious indoor and outdoor air pollution problems from rapid urbanization, uncontrolled industrialization, heavy traffic congestion, and weak environmental regulations. While the World Bank has studied indoor air quality of poor families with particular attention on household cooking, there has been no research on indoor air quality in schools. Our country has studied indoor air quality of school and health of students but on a limited basis. However, few studies have specifically examined IAQ and associated health risks in kindergarten schools in Dhaka which enroll children under age 6 who are even more vulnerable.

1.2. Problem Statement

Poor indoor air quality is a significant public health threat, especially for young children in developing countries like Bangladesh. Rapid urbanization and uncontrolled growth have led to serious indoor and outdoor air pollution problems in the densely populated capital Dhaka. The majority of people are aware that air pollution from the outside can have an adverse effect on their health, but indoor air pollution can also be seriously hazardous (Tran et. al.,2020). According to EPA studies, Indoor air pollution levels can often be 100 times higher than outdoor levels, ranging from two to five times higher. The level of indoor air quality can significantly affect a student's capacity to succeed in the classroom (Peng et al.,2017). Additionally, recent studies have revealed that poor indoor air quality may directly impact children's capacity to study, in addition to contributing to illnesses that keep them from attending school (Zaman et al., 2021). Consistent data suggests that indoor air pollution raises children's risk of acute respiratory infections and chronic obstructive pulmonary disease, which is the leading cause of death for children under five in developing nations (Pozzer et al., 2022). Hence, determining the indoor air quality of kindergarten schools in Dhaka city is necessary.

1.3. Research Gap

Numerous researches have been carried out to assess the indoor air quality at schools in different countries like India, China, Portugal etc. (Chithra et al., 2012; Peng et al., 2017; Paixão et al., 2016;). Also in Bangladesh many studies have focused on assessing Indoor Air Quality and also the health impacts on students in schools of Dhaka city (Ahmad et al., 2017; Roy et al., 2023). However, there is little or no studies that specifically examine IAQ and associated health risks in kindergarten schools in Dhaka which enroll children under age 6 who are even more vulnerable. As a result, data from this study would be essential for assessing the effects of Indoor Air Quality for children that are most vulnerable.

1.4. Rationale of the Study

The investigation into the indoor air quality (IAQ) at kindergarten schools in Dhaka City, Bangladesh, holds paramount significance due to the potential impact on the health and well-being of young children. Children spend a substantial amount of their time indoors, particularly within the confines of educational institutions, making the quality of indoor air a critical factor in their overall health. Dhaka City, characterized by rapid urbanization and industrialization, is confronted with escalating levels of air pollution, which may significantly contribute to indoor air pollutants. This study aims to comprehensively evaluate the indoor air quality in kindergarten schools, considering particulate matter, CO_2, CO, SO_2, NO_2 and O_3. By identifying and quantifying these pollutants, the research intends to estimate the associated health risks faced by children, providing valuable insights for policymakers, educators, and parents to enhance the environmental conditions within educational settings. The findings of this study are anticipated to contribute not only to the scientific understanding of indoor air quality but also to inform targeted interventions that can safeguard the health and well-being of the youngest members of the community in Dhaka City.

1.5. Research Hypothesis

a. Kindergarten schools located near roadways will have higher levels of indoor air pollutants compared to those in residential areas.

b. Identified indoor air pollutants will be associated with potential health risks for children.

1.6. Research Question

i) What are the levels of indoor air pollutants in kindergarten schools compared to established air quality standards?

ii) Is there a significant difference in indoor air quality between roadside and residential kindergarten schools?

iii) What are the potential health risks associated with the identified indoor air pollutants?

1.7. Research Objectives

1.7.1. Broad Objective

The broad objective of the study is to comprehensively assess the indoor air quality in kindergarten schools within Dhaka City, Bangladesh, with a specific focus on estimating potential health risks. Additionally, the study aims to investigate and compare air quality disparities between kindergartens located in roadside and residential settings.

1.7.2. Specific Objectives

i) To determine the concentration of PM_{10}, $PM_{2.5}$, CO_2, CO, SO_2, NO_2 and O_3 in different kindergarten schools

ii) Examine the variation in indoor air quality between kindergarten schools located in roadside and residential areas of Dhaka City

iii) Investigate potential health risks associated with identified air pollutants among kindergarten students

1.8. Definitions of Terms Used in Thesis

Indoor Air Quality (IAQ): Refers to the condition of air within buildings and structures, particularly as it relates to the health and comfort of occupants.

Particulate Matter (PM_{10} and $PM_{2.5}$): Refers to tiny particles suspended in the air, with diameters of 10 micrometers or less (PM_{10}) and 2.5 micrometers or less ($PM_{2.5}$). They can include various pollutants and pose health risks when inhaled.

Sulfur Dioxide (SO_2): A colorless gas with a pungent odor, primarily produced by burning fossil fuels containing sulfur. It can contribute to respiratory issues and other health problems.

Nitrogen Dioxide (NO_2): A reddish-brown gas produced by combustion processes, particularly in vehicles and industrial facilities. Prolonged exposure can lead to respiratory and cardiovascular problems.

Ozone (O_3): A gas composed of three oxygen atoms. While beneficial in the upper atmosphere, ground-level ozone is a pollutant that can cause respiratory issues.

Carbon Dioxide (CO_2): A colorless, odorless gas naturally present in the air. Elevated levels can indicate inadequate ventilation and may contribute to discomfort and health issues.

Carbon Monoxide (CO): A colorless, odorless gas produced by incomplete combustion of carbon-containing fuels. It can be toxic when inhaled, interfering with the body's ability to transport oxygen.

World Health Organization (WHO) Guidelines: Standards and recommendations established by the World Health Organization to guide public health policies and practices, including those related to air quality.

T-test: A statistical test used to determine if there is a significant difference between the means of two groups.

Respiratory Issues: Health problems affecting the respiratory system, such as asthma, bronchitis, or other conditions related to breathing.

Air Pollution: The presence of harmful substances in the air, often resulting from human activities, that can have adverse effects on human health and the environment.

1.9. Outline of the Thesis

1) **Chapter one** provides a brief introduction on the background, problem statement, research gap, rationale of the study, research hypothesis, research questions and objectives of the study.

2) **Chapter two** discusses related works of literature

3) **Chapter three** discusses the research methodology of the study that includes data collection, research design, instruments and data analysis.

4) **Chapter four** discusses the results of the study and its explanations.

5) **Chapter five** summarizes the study as a concluding remark and provides recommendations for future prospects.

The references are attached at the end.

CHAPTER TWO

LITERATURE REVIEW

2.0. Literature Review

2.1. Indoor Air Quality

Indoor air quality (IAQ) is a critical aspect of environmental health, as individuals spend a significant portion of their lives indoors. IAQ research is receiving more and more attention because of its significant effects on productivity and human well-being. Numerous elements, such as building materials, ventilation systems, and human activities, affect the quality of indoor air (Kumar et al., 2023). The existence of indoor pollutants, such as biological contaminants, particulate matter, and volatile organic compounds (VOCs), which may all be harmful to respiratory and general health, has been the subject of several studies. The use of ventilation techniques, such as mechanical and natural ventilation, is essential for reducing indoor pollution (Mata et al., 2022). Additionally, cutting-edge methods for continuously monitoring and enhancing IAQ have been made possible by the rise of smart technology. Even with great progress, there are still issues with comprehending the intricate relationships between different indoor contaminants and their long-term consequences (Marzouk & Atef, 2022). It will need more multidisciplinary study to create all-encompassing plans for preserving ideal IAQ and fostering a healthy indoor environment. Current research on indoor air quality has a strong emphasis on the variety of contaminants and their sources that might harm the air in confined environments. A complex blend of indoor and outdoor pollutants, building materials and furniture, and home cleaning products all contribute to airborne toxins. Research elucidates the health consequences of extended exposure to these contaminants, associating subpar indoor air quality with allergies, respiratory disorders, and other deleterious health consequences (Mizen et al., 2020). The need to address indoor air quality concerns immediately is highlighted by the sensitivity of some populations, including children, the elderly, and those with pre-existing health disorders. Recent research has focused on the potential of indoor plants as natural air purifiers, examining how well they can eliminate certain contaminants and improve the general quality of indoor air (Tran et al., 2020). This environmentally friendly strategy fits in with the expanding trend of green building designs that put occupant health and environmental sustainability first.

2.2. Sources and Exposure of Indoor Air Pollutants

Indoor air pollution is a significant environmental concern that can have profound implications for human health. Various sources contribute to the degradation of indoor air quality, leading to an array of potential respiratory and cardiovascular problems (Raju et al., 2020). Combustion processes, such as those associated with cooking and heating, are primary culprits. Inefficient stoves and the use of solid fuels release pollutants like carbon monoxide, particulate matter, and volatile organic compounds into the air (Bennett et al., 2019). Additionally, tobacco smoke is a major indoor air pollutant, containing numerous harmful chemicals that can linger in enclosed spaces (Bennett et al., 2019). Building materials and furnishings can also emit pollutants, as volatile organic compounds are released from paints, adhesives, and certain types of flooring (Pozzer et al., 2022). Furthermore, inadequate ventilation exacerbates indoor air pollution by allowing pollutants to accumulate without sufficient fresh air exchange. Household cleaning products, pesticides, and personal care items contribute to the chemical cocktail present in indoor air. Understanding the diverse sources of indoor air pollution is crucial for developing effective strategies to mitigate its adverse effects on human health and well-being (Raju et al., 2020).

CO_2 is an odourless and colourless gas that is created by human respiration, combustion, and a variety of indoor activities. It has drawn attention recently because of possible health risks associated with increased concentrations of CO_2 in confined areas. The researches on CO_2 exposure and how it affects indoor air quality emphasizes how important it is to keep ventilation rates at their ideal levels in order to stop the gas from building up (Sadrizadeh et al., 2022). Elevated carbon dioxide levels, which are frequently a sign of insufficient ventilation, have been linked to several unfavorable health consequences, such as headaches, lightheadedness, and a reduction in mental capacity (Sadrizadeh et al., 2022). For comfort and indoor air quality, the WHO advises keeping indoor CO_2 levels below 1000 parts per million (ppm). Over 1000 parts per million of CO_2 can be uncomfortable and stuffy, and it may also be a sign of poor ventilation. There are no current health hazards linked with this CO_2 concentration, though. When CO_2 levels are above 1000 parts per million, people may feel increased pain, although this is not regarded as a direct health risk.

Indoor air pollution is a significant concern, with carbon monoxide (CO) emerging as a prominent source of contamination. When fossil fuels like gas, oil, and wood are not completely burned, a colorless, odorless gas known as CO is created. Stoves with inadequate ventilation, heating systems, and broken gas appliances are common indoor sources (Sadrizadeh et al., 2022). Because CO competes with oxygen for hemoglobin binding, exposure to high amounts of CO can have detrimental effects on health by reducing the amount of oxygen delivered to essential organs. The ubiquity of CO in indoor spaces and the health hazards connected with it have been the subject of several research (Bennett et al., 2019). High-risk groups are more susceptible to the negative consequences of CO exposure, including small children, the elderly, and people with pre-existing medical issues.

Sulfur dioxide (SO_2) is a prominent indoor air pollutant with diverse sources, contributing to the degradation of indoor air quality and posing potential health risks. The primary sources of indoor SO_2 include combustion processes involving fossil fuels, such as coal and oil, and the use of certain heating systems and appliances. In addition to these anthropogenic sources, indoor SO_2 levels can also be influenced by natural sources, such as volcanic emissions and outdoor air pollution infiltration (Pierina Ielpo et al., 2019). The combustion of coal and oil for heating purposes, especially in confined spaces, releases significant amounts of SO_2 into indoor environments. Additionally, household activities like cooking with certain fuels or using gas appliances can contribute to elevated SO_2 concentrations (Pierina Ielpo et al., 2019).

One of the main causes of indoor air pollution is NO_2, which is mostly released during combustion processes using fossil fuels such those found in heating systems, cooking equipment, and tobacco smoke (Wang et al., 2020). When these fuels burn, NO_2 is released as a byproduct that builds up in enclosed areas. Moreover, wood-burning stoves, kerosene heaters, and gas stoves are examples of indoor sources of NO_2. These fuels burn incompletely, releasing other pollutants in addition to NO_2, which worsens the quality of indoor air (Wang et al., 2020).

With a variety of sources and exposure routes, ozone (O_3) is a major indoor air pollutant that adds to the intricate web of indoor air quality. Elevated ozone levels are caused by a variety of indoor sources, such as electrical gadgets, air purifiers, and specific home goods (Huang et al., 2019). The issue of indoor ozone exposure is extremely important in schools since the students, in particular, are a vulnerable group. Children may be particularly vulnerable to the respiratory effects of ozone since they often breathe more quickly than adults do. Additionally, schools frequently have distinct indoor environments with particular ventilation patterns, pollutant sources, and occupancy characteristics. Ozone is released during the operation of electronic equipment like printers and photocopiers, and it can also be produced as a byproduct of air purifiers that use ionization technology. Furthermore, volatile organic compounds (VOCs) released by some cleaning and personal care products have the ability to react with indoor air to generate ozone (Tran et al., 2020).

Particulate matter (PM) pollution has been recognized by several schools as a significant contributor to indoor air pollution (Becerra et al., 2020). Particulate matter comes from a variety of interior sources, which adds to its heterogeneous makeup and possible negative health effects. Combustion operations, such as using solid fuels for cooking, tobacco smoke, and certain heating systems, are common sources (Becerra et al., 2020). Numerous studies have identified common sources of particulate matter in schools, including but not limited to, dust mites, mold, pollen, and combustion byproducts from cooking activities and heating systems. However, Oliveira et al. demonstrated that outside air is the main cause of PM pollution in schools. Additionally, particles from the outside world infiltrate schools through ventilation, particularly in urban areas where vehicle exhausts are the main source. Tobacco smoke is another well-known indoor air contaminant that releases dangerous chemicals and tiny particles that can remain in small places. The kind of heating system used, particularly those that burn wood or other solid fuels, can increase PM levels indoors even more (Tran et al., 2020). Particulate matter emissions are also caused by human activity and construction materials; tasks like dusting and sweeping up accumulated particles can resuscitate them. Numerous factors, such as the length and severity of pollution sources, ventilation rates, and building attributes, affect an individual's exposure to indoor particulate matter. Because solid fuels and traditional cooking methods are so widely used, residents of underdeveloped nations are frequently more vulnerable (Tran et al., 2020). The issue is made worse by inadequate ventilation, which permits PM to build up indoors.

2.3. Health Effects on Children

According to current studies, schoolchildren's exposure to indoor air pollution, especially carbon dioxide (CO_2), might have negative health impacts. Poor ventilation can lead to elevated CO_2 levels, which have been linked to a number of negative health effects. In a research by Zhang et al., indoor air quality in elementary schools was examined. The results showed that in a considerable proportion of classrooms, CO_2 concentrations were higher than indicated. According to the study, there is a direct link between school-age children's respiratory complaints and their heightened CO_2 levels. In particular, the study found that in classrooms with greater CO_2 concentrations, coughing, wheezing, and shortness of breath were more common. Furthermore, the study discovered that poorer test scores and shorter attention spans among kids were linked to greater CO_2 levels and a decline in cognitive function. This implies that indoor surroundings with high CO_2 have health impacts on schoolchildren that go beyond respiratory problems and affect their general well-being and academic performance. According to Zhang et al. (2018), these results highlight the critical need for efficient ventilation techniques and policies to reduce the health concerns connected to high CO_2 levels in schools.

Using a cross-sectional survey, Madureira et al. (2015) investigated the relationship between children's respiratory complaints and indoor air quality (IAQ) in schools. The concentrations of bacteria, fungus, aldehydes, $PM_{2.5}$, PM_{10}, carbon dioxide, and volatile organic compounds (VOC) were tested in 73 classrooms across 20 public primary schools in Porto, Portugal. Madureira et al. (2015) found that indoor air quality in schools, elevated levels of CO_2 were associated with an increased prevalence of respiratory symptoms among students. The researchers found a statistically significant correlation between higher CO_2 concentrations and the occurrence of coughing, wheezing, and other respiratory issues

Numerous studies have investigated the health effects of indoor air pollutants, with a specific focus on carbon monoxide (CO), on school children. According to a study conducted by Sadrizadeh et al., exposure to elevated levels of CO in indoor environments, such as schools, can have significant health implications for children. The research found that increased CO concentrations were associated with adverse respiatory effects, including exacerbation of asthma symptoms and respiratory infections among school children (Sadrizadeh et al., 2022). Furthermore, a comprehensive meta-analysis by De Gennaro et al. (2014) reinforced these findings, reporting a clear correlation between elevated indoor CO levels and a higher incidence of respiratory issues in children. The study indicated that even low to moderate exposure to CO in indoor settings could lead to a measurable increase in the risk of respiratory problems among school-aged children.

Indoor air pollutants, particularly nitrogen dioxide (NO_2), have been recognized as significant contributors to health concerns, particularly among school children who spend a substantial portion of their time in educational environments. Nitrogen dioxide, a common indoor air pollutant originating from combustion processes, such as vehicular emissions and gas appliances, has been associated with various adverse health effects. Studies have consistently demonstrated a correlation between elevated levels of indoor NO_2 and respiratory issues in school children. For instance, a study conducted by Sadrizadeh et al in urban schools found that increased exposure to indoor NO_2 was positively associated with a higher prevalence of respiratory symptoms among students. The study utilized air quality monitoring data to assess NO_2 levels and health surveys to gather information on respiratory symptoms. The findings indicated a statistically significant relationship between elevated NO_2 concentrations and an increased incidence of respiratory problems, including coughing, wheezing, and shortness of breath.

A comprehensive study conducted by (Kim et al., 2021) in school environments found a significant positive association between indoor SO_2 concentrations and the prevalence of respiratory symptoms among school children. The study, which included air quality monitoring and health assessments, revealed that higher SO_2 levels were consistently linked to increased reports of respiratory discomfort among students. Moreover, (Tian et al., 2019) conducted a study investigating the health impact of SO_2 exposure on a cohort of school children over several years. The findings indicated a clear correlation between elevated SO_2 levels and an increased incidence of new-onset asthma cases within the studied population.

Research studies have consistently demonstrated the adverse effects of ozone exposure on respiratory health in school children. A study by Becerra et al., (2020) found that short-term exposure to elevated ozone levels was associated with increased respiratory symptoms and decreased lung function in a cohort of school children. The research, conducted in urban environments, emphasized the need for effective air quality management strategies in schools to protect children from ozone-related health risks.

The health effects of PM_{10} and $PM_{2.5}$ on school children are well-documented. Long-term exposure to elevated PM concentrations has been associated with respiratory issues, including asthma, bronchitis, and decreased lung function (Sadrizadeh et al., 2022). Notably, a study by Tian et al. investigated the impact of indoor PM exposure on the academic performance of school children. The findings indicated a negative correlation between increased PM levels and cognitive functions, suggesting a potential link between indoor air quality and academic outcomes. Furthermore, a meta-analysis by Xing et al. synthesized data from multiple studies and highlighted the heightened vulnerability of children to PM-induced health effects due to their developing respiratory and immune systems. The study emphasized the need for stringent measures to reduce indoor PM concentrations in educational settings, calling for improved ventilation and targeted interventions to mitigate health risks.

CHAPTER THREE

METHODOLOGY

3.0. Methodology

3.1. Study Area

Kindergarten schools were selected from diverse locations in Mirpur, Uttara, and Dhanmondi, ensuring representation from both roadside and residential areas. The locations were selected to roughly cover the whole Dhaka city area.

Concentration of indoor air parameters were taken from six kindergarten schools where two kindergartens were selected from each location. One of the two kindergartens was situated along a road, and the other one was situated in a residential area.

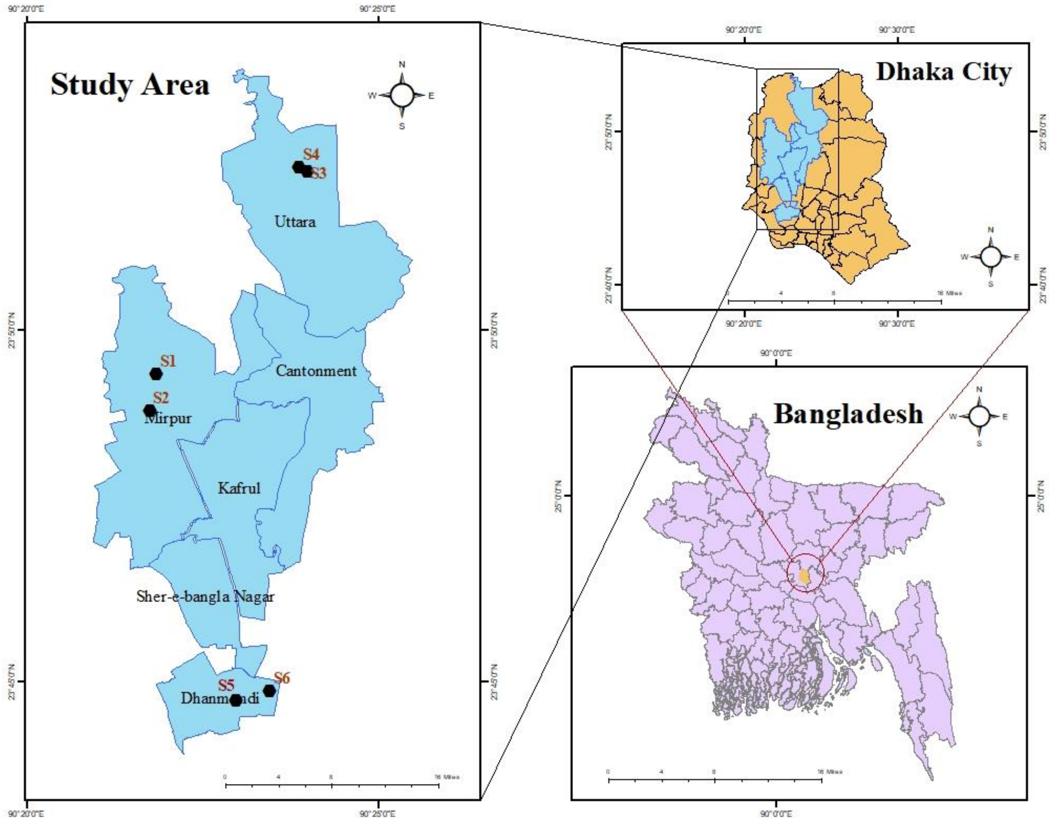

Figure 3.1: Study Area Map

3.2. Research Design

The main point of the research has been the research question and the research gap found by literature reviews. A part of the research has been collecting primary data of the concentrations of indoor air quality parameters and comparing them with existing international WHO standards. Another part of data collection has been conducting a questionnaire survey among the guardians, teachers and staff of the kindergarten schools for possible health risks related to air quality. The data analyzing part also includes a comparison between roadside areas and residential areas schools.

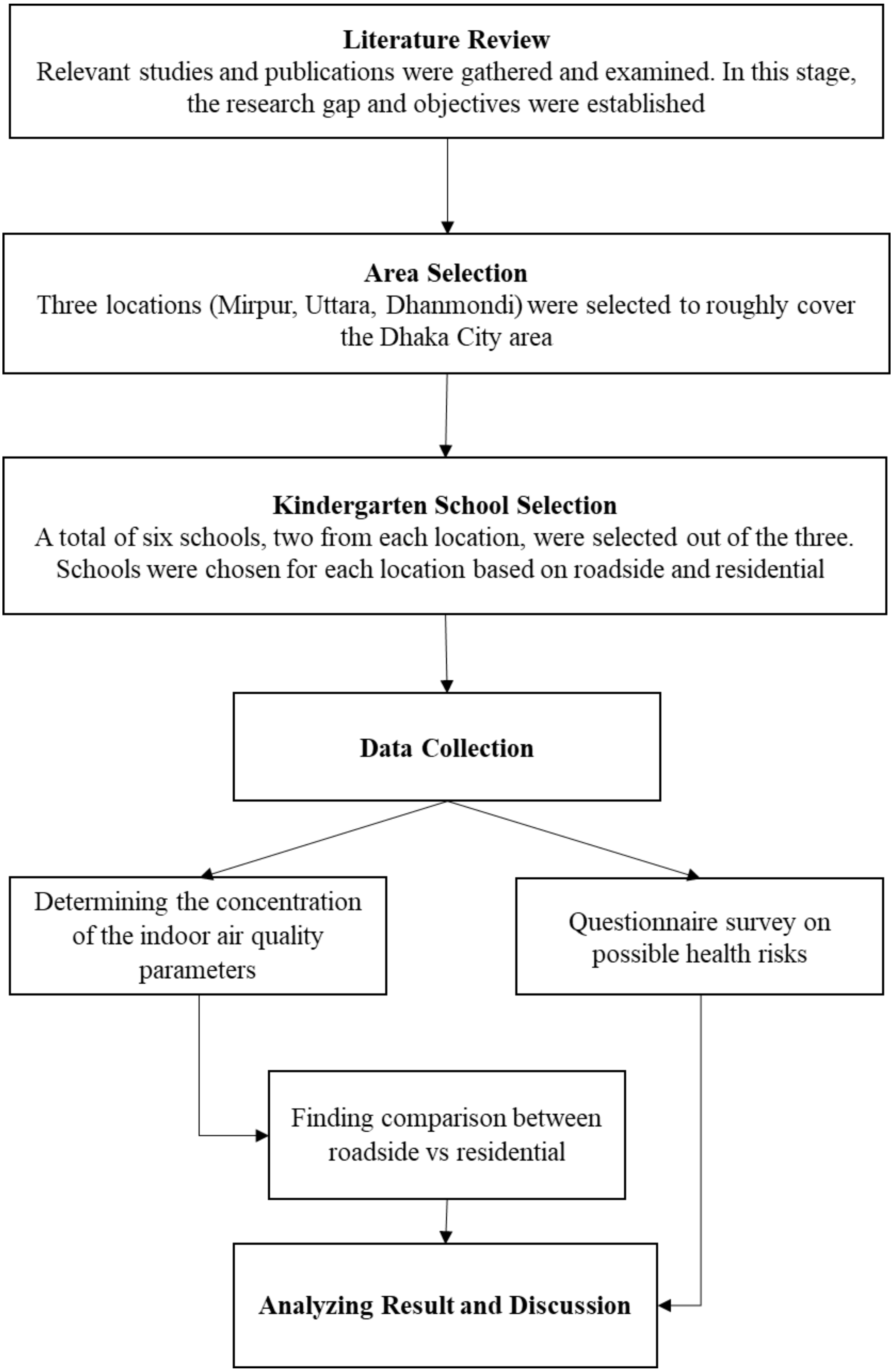

Figure 3.2: Research design of the study

3.3. Data Collection:

This study used instrumental methods to determine concentrations of PM_{10}, $PM_{2.5}$, CO_2, CO, SO_2, NO_2 and O_3 in classrooms of different kindergarten schools. The parameter concentrations were measured using the haz-scanner. For every school, data was collected on several working days. On the same days, data from the same site were measured. The 9 a.m. to 12 p.m. data collection window was selected with kindergarten regular school hours in mind. A questionnaire survey on basic information about potential health hazards, facility conditions, environmental factors etc. was also given to the staff, teachers, and guardians. The students were unable to participate in the survey since they were under the age of six. Out of the 60 respondents surveyed across various kindergarten schools in both roadside and residential areas, a diverse representation of guardians, teachers, and staff participated in sharing their insights.

3.4. Instrument

3.4.1. Required Machine

- Haz-Scanner (Model HIM-6000): A comprehensive, readily transportable, and deployable ambient air quality monitor, the Haz-Scanner (Model HIM-6000) is made to measure and record vital hazardous air parameters for air quality investigations, emergency preparedness, and regulatory compliance. Haz-Scanner has the ability to log data and offers direct readings in real-time. Up to 12 simultaneous crucial air measurements may be provided by Haz-Scanner in a single, conveniently portable, battery-operated device.

3.5. Statistical Analysis

Using Microsoft Excel, statistical analysis was performed to determine the mean, maximum, minimum and standard deviation of the primary data and plot in the graphs. Moreover, two sample t-test was conducted among the roadside and residential values to discover any significant difference.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0. Result and Discussions

4.1. Results

4.1.1. Indoor Air Quality Assessment

The Indoor Air Quality (IAQ) assessment conducted in kindergarten schools yielded comprehensive data, providing valuable insights into the environmental conditions within the educational facilities. Primary data collection involved the measurement of key pollutants, including PM_{10}, $PM_{2.5}$, CO_2, CO, SO_2, NO_2 and O_3. The results present a snapshot of the indoor air composition and their concentrations in different kindergarten schools along with comparison between roadside and residential kindergarten schools.

4.1.1.1 CO_2 Concentration

The overall concentration average for CO_2 in Dhaka city was found to be 904.709 $\pm$ 125.89 ppm. Notably, this level is in close proximity to the standard guideline of 1000 ppm set for indoor air quality. The data demonstrated a consistent trend across different schools within Dhaka, emphasizing the potential concern for elevated CO_2 levels in these educational settings. The average CO_2 concentration in roadside kindergarten schools was found to be 1028.523 ppm which exceeds the standard value, while the average in residential kindergarten schools was 780.895 ppm. The standard deviation for roadside schools was 9.37, and for residential schools, it was 26.42 (figure 4.1). A t-test has been conducted among the values to find any significance difference. A statistically significant result ($p < 0.001$) has been found between roadside and residential kindergarten which is shown in the **supplementary table A1**. Several factors contribute to the observed disparity in CO_2 levels between roadside and residential kindergarten schools. The observed CO_2 levels in kindergarten schools in Dhaka city, nearing the 1000 ppm threshold, raise important questions about indoor air quality and its potential implications for the health and well-being of both students and educators. Though WHO does not consider CO_2 as a direct hazard regarding indoor air pollution, both WHO and ASHRAE guidelines recommend CO_2 levels to be kept under 1000 ppm. Over 1,000 parts per million of CO_2 can be uncomfortable and stuffy, and it may also be a sign of poor ventilation. There are no current health hazards linked with this CO_2 concentration, though (WHO, 2010). When CO_2 levels are above 1,000 parts per million, people may feel increased pain, although this is not regarded as a direct health risk.

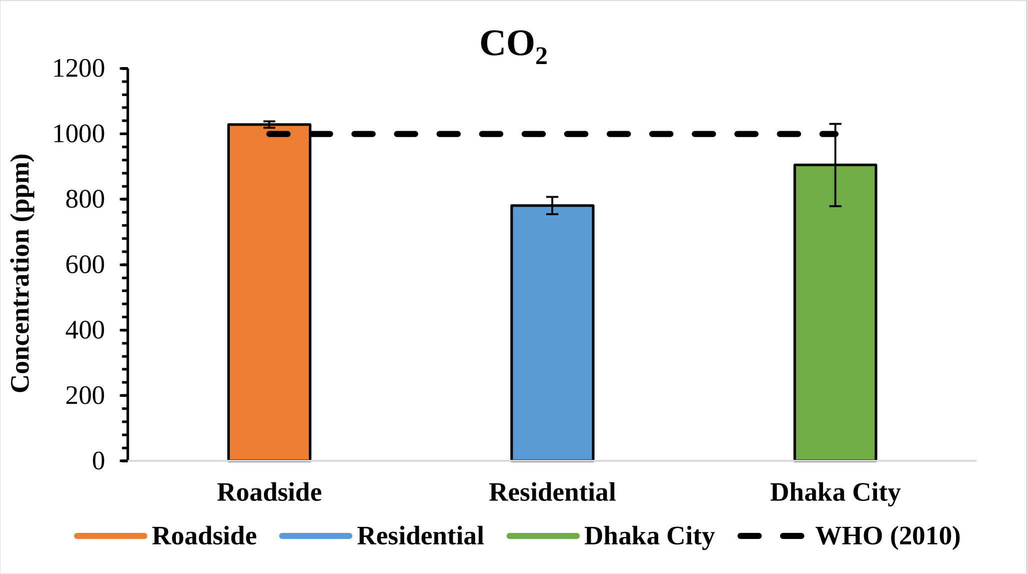

Figure 4.1: Mean concentration of CO_2 in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical lines indicate standard deviation.

4.1.1.2. CO Concentration

The overall concentration average for CO in Dhaka city was found to be 1488.091 ± 292.05 ppb (figure 4.2). The investigation into carbon monoxide (CO) levels within indoor kindergarten schools in Dhaka City yielded results indicating that the concentrations did not exceed the World Health Organization (WHO) standard of 9000 parts per billion (ppb). This is a positive finding, as it reflects a commitment to maintaining indoor air quality within the recommended safety limits. The average CO concentration in roadside kindergarten schools was found to be 1573.922 ppb, while the average in residential kindergarten schools was 1402.261 ppb. The standard deviation for roadside schools was 268.24, and for residential schools, it was 291.70 (figure 4.2). A t-test has been conducted among the values to find any significance difference. A statistically significant result ($p = 0.001$) has been found between roadside and residential kindergarten which is shown in the **supplementary table A1**.

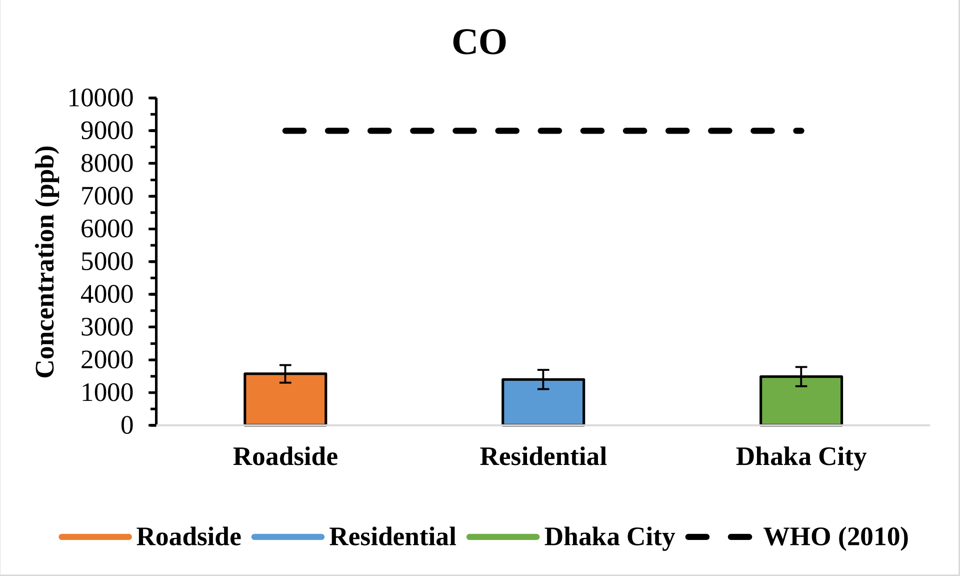

Figure 4.2: Mean concentration of CO in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical lines indicate standard deviation.

The data suggests that, while CO levels in kindergarten schools remain within acceptable limits, there is a discernible difference between roadside and residential areas. The elevated CO levels near roadways can be attributed to vehicular emissions.

4.1.1.3. NO_2 Concentration

The overall concentration average for NO2 in Dhaka city was found to be 95.793 ± 33.304 ppb. This concentration significantly surpasses the World Health Organization (WHO) standards, which are set at 50 ppb and 20 ppb, respectively (figure 4.3). The average NO_2 concentration in roadside kindergarten schools was found to be 128.584 ppb, while the average in residential kindergarten schools was 63.001 ppb. The standard deviation for roadside schools was 3.50, and for residential schools, it was 6.15. A t-test has been conducted among the values to find any significance difference. A statistically significant result ($p < 0.001$) has been found between roadside and residential kindergarten which is shown in the **supplementary table A1**.

The results indicated that both settings exhibited NO_2 concentrations exceeding the World Health Organization (WHO). Notably, the NO_2 levels along roadways were found to be significantly higher than those in residential areas.

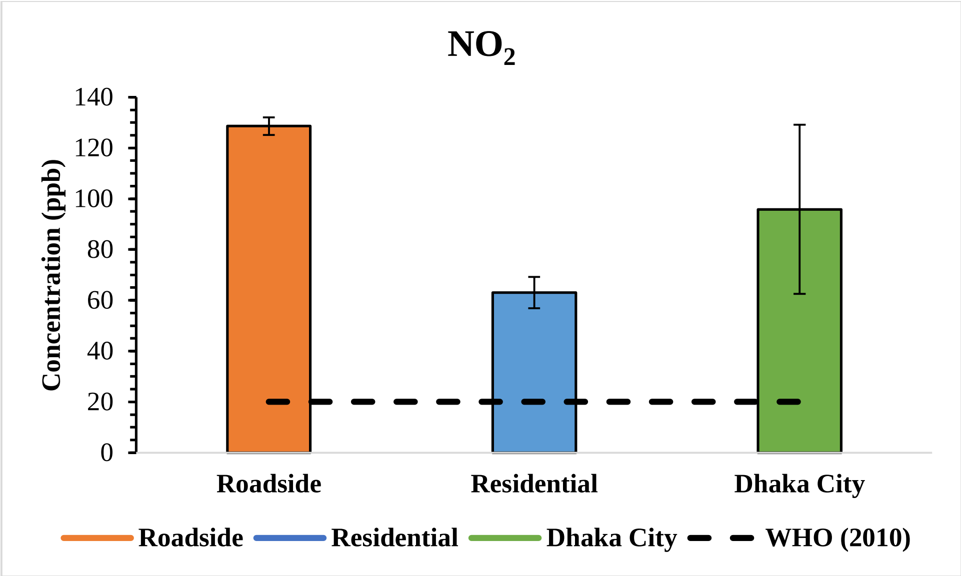

Figure 4.3: Mean concentration of NO_2 in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical lines indicate standard deviation.

4.1.1.4. SO_2 Concentration

The mean total concentration for SO2 in Dhaka city was found to be 29.931 $\pm$ 6.89 ppb. The data is higher than the indoor air quality recommended limit of around 8 ppb by the World Health Organization (WHO). The average SO2 concentration in roadside kindergarten schools was found to be 30.156 $\pm$ 7.17 ppb, while the average in residential kindergarten schools was 29.705 $\pm$ 6.65 ppb shown in figure 4.4. A t-test has been conducted among the values to find if there is any significant difference. The p value has been found to be p= 0.721 that shows no significant difference between roadside and residential kindergarten which is shown in the **supplementary table A1**. This finding offers a nuanced perspective on the air quality scenario in Dhaka, suggesting that SO_2 levels in kindergarten schools do pose a potential risk to the health of the children (Wang et al., 2020) when compared to more stringent international guidelines.

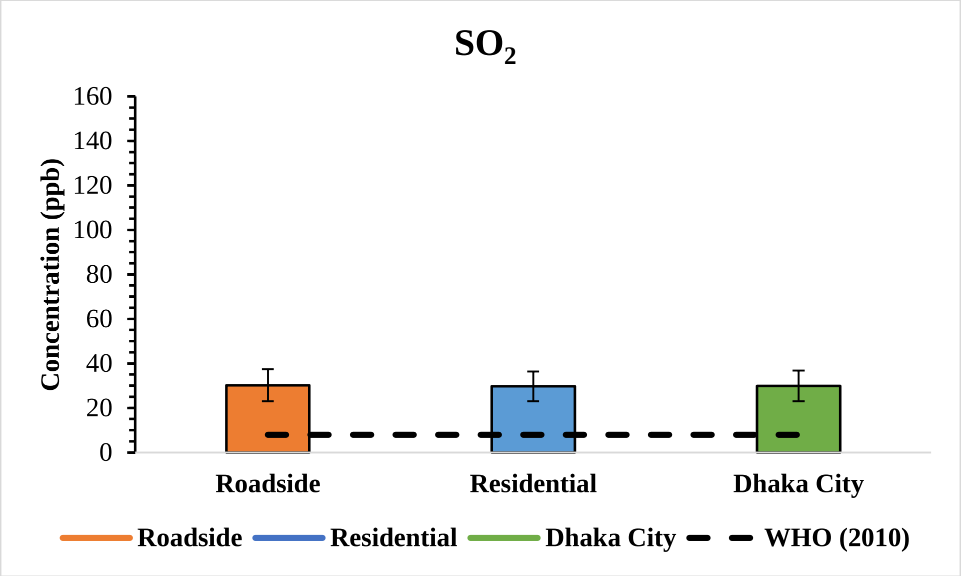

Figure 4.4: Mean concentration of SO_2 in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical lines indicate standard deviation.

4.1.1.5. O_3 Concentration

The mean total concentration for O_3 in Dhaka city was found to be 99.882 ± 29.91 ppb. This exceeds the value of WHO which is 50 ppb. The mean value for roadside kindergartens is 128.979 ± 5.13 ppb and for roadside kindergartens the mean is 70.786 ± 7.50 ppb. All the concentrations exceed the WHO standard value (figure 4.5). A t-test has been conducted among the values to find if there is any significant difference. A statistically significant result ($p < 0.001$) has been found between roadside and residential kindergarten which is shown in the **supplementary table A1**.

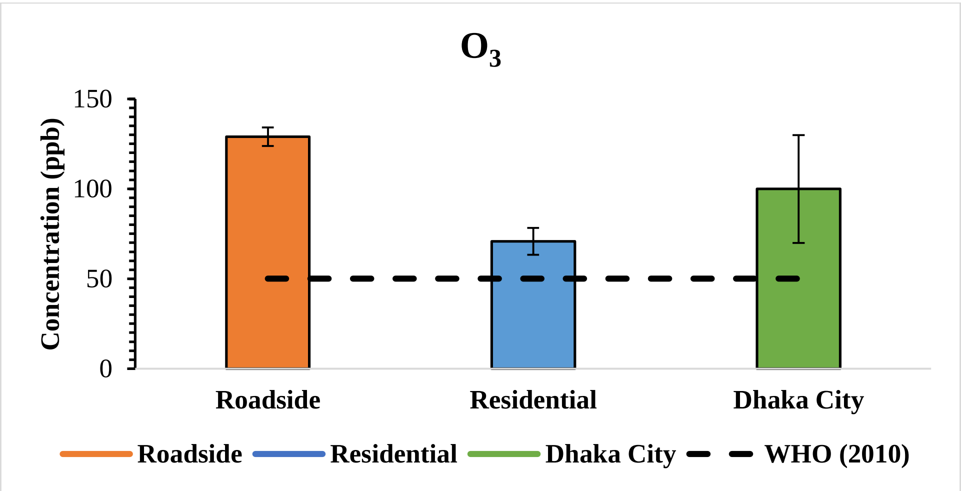

Figure 4.5: Mean concentration of O_3 in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical lines indicate standard deviation.

4.1.1.6. $PM_{2.5}$ Concentration

The mean total concentration for PM 2.5 in Dhaka city was found to be 65.694 ± 11.68 ug/m^3. This exceeds the value of WHO standard. The mean value for roadside kindergartens is 74.433 ± 3.34 ug/m^3 and for roadside kindergartens the mean is 56.955 ± 10.43 ug/m^3. All the concentrations exceed the WHO standard value. A t-test has been conducted among the values to find if there is any significant difference. A statistically significant result ($p < 0.001$) has been found between roadside and residential kindergarten which is shown in the **supplementary table A1**.

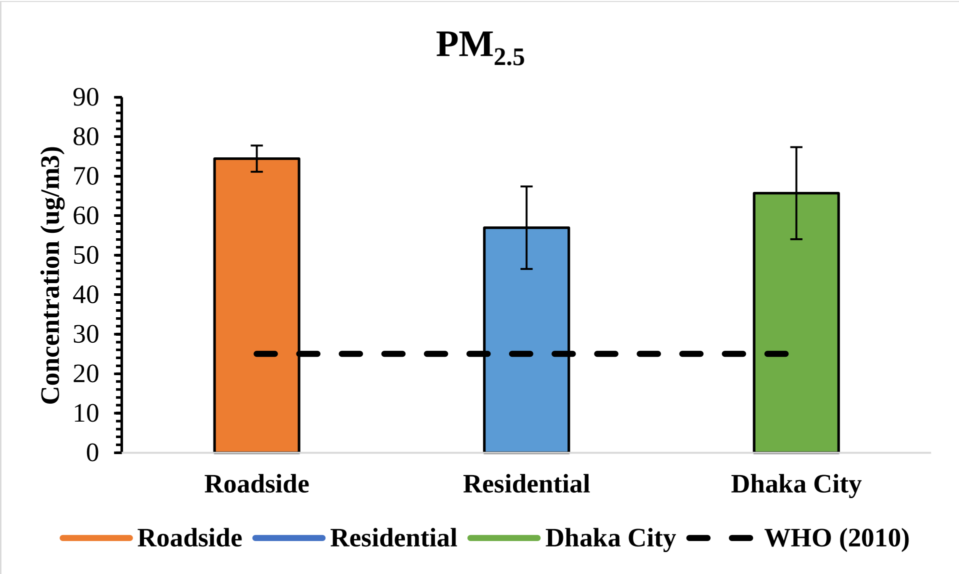

Figure 4.6: Mean concentration of $PM_{2.5}$ in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical lines indicate standard deviation.

The assessed $PM_{2.5}$ concentrations of kindergarten schools shows that the levels of Dhaka city, roadside and residential areas exceed the WHO standard. The WHO standard for indoor $PM_{2.5}$ is 25 ug/m^3.

4.1.1.7. PM_{10} Concentration

The calculated mean total concentration of PM_{10} in Dhaka city is 120.673 ± 22.97 µg/m^3, exceeding the WHO thresholds. The mean concentration for roadside kindergartens is 138.95 ± 15.21 µg/m³, while for residential kindergartens, it is 102.387 ± 12.37 µg/m³. All these concentrations surpass the WHO standard. A t-test has been employed to assess the significance of the differences between roadside and residential kindergarten values, revealing a statistically significant result ($p < 0.001$), as detailed in the **supplementary table A1**.

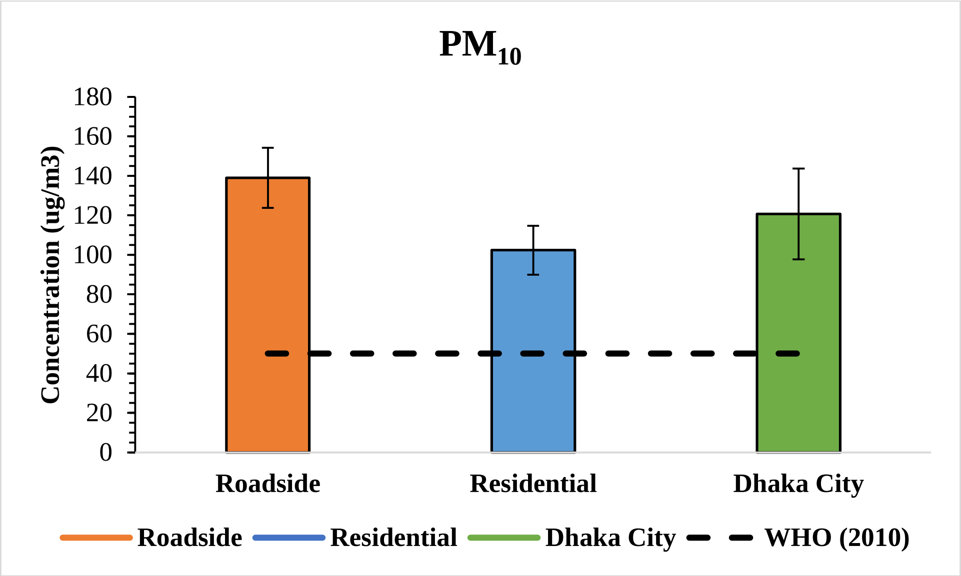

Figure 4.7: Mean concentration of PM_{10} in indoor air of kindergarten schools in roadside, residential and overall Dhaka city along with the recommended values. The vertical bars indicate standard deviation.

The evaluation of PM_{10} concentrations in kindergarten schools indicates that the levels in Dhaka city, both along roadsides and in residential areas, surpass the established WHO standard. The WHO standard for indoor PM_{10} is 50 µg/m.

4.1.2. Perception of Possible Health Risks

4.1.2.1. Concerns about Indoor Air Quality:

The survey reveals a notable level of concern about indoor air quality in kindergarten schools, with 45% of respondents expressing a high degree of worry. Additionally, 40% indicate a moderate level of concern, emphasizing a pervasive awareness of the issue. However, 15% report being unconcerned, suggesting a subset of respondents who may not perceive indoor air quality as a significant worry in the context of kindergarten school environments.

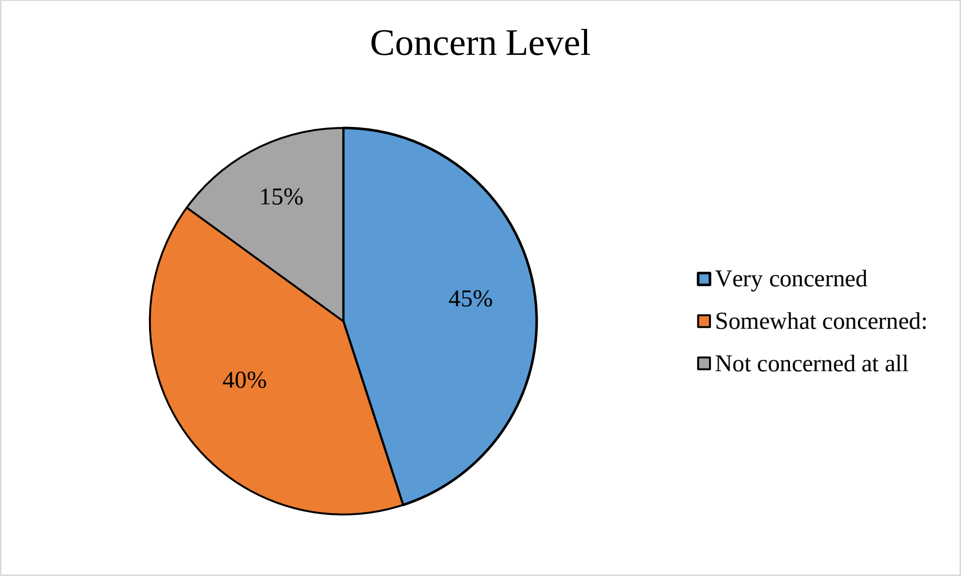

Figure 4.8: Percentage of respondents concerned about indoor air quality in kindergarten schools

4.1.2.2. Health Experiences:

Approximately 30% of respondents or their children reported experiencing asthma-like symptoms, indicating a noteworthy prevalence of respiratory concerns within kindergarten schools. This percentage underscores the potential impact of indoor air quality on respiratory health, emphasizing the need for targeted interventions to create healthier environments.

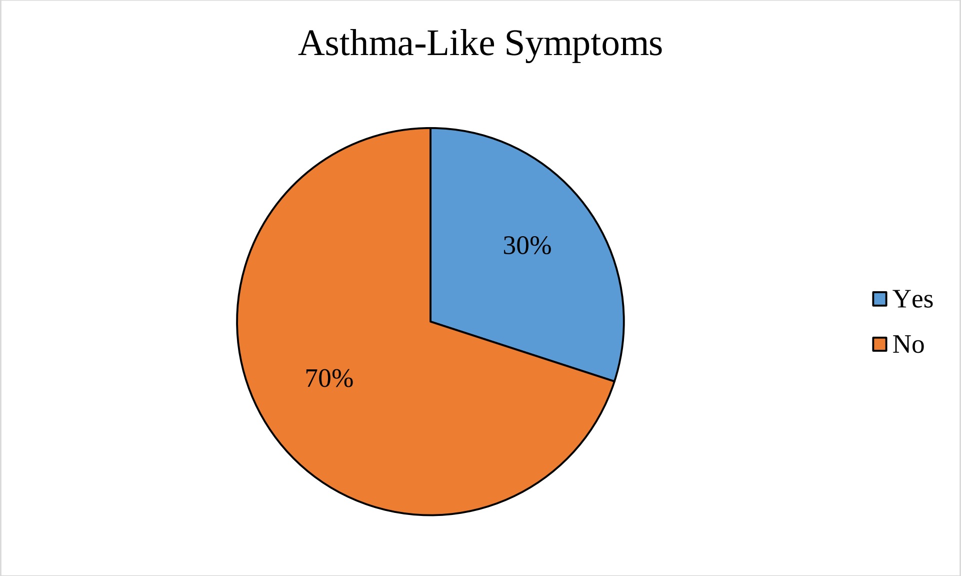

Figure 4.9: Percentage of respondents who reported experiencing asthma-like wheezing in themselves or their children

A significant portion of respondents (50%) reported no health issues related to poor indoor air quality in kindergarten schools. However, among those who did, the most commonly mentioned concerns were allergies (30%) and coughing (25%), indicating a notable impact on respiratory health. Additionally, headaches (20%) and skin irritations (15%) were reported, highlighting the diverse health effects associated with suboptimal indoor air quality. The variety of health issues emphasizes the multifaceted nature of the challenges faced by children in these environments.

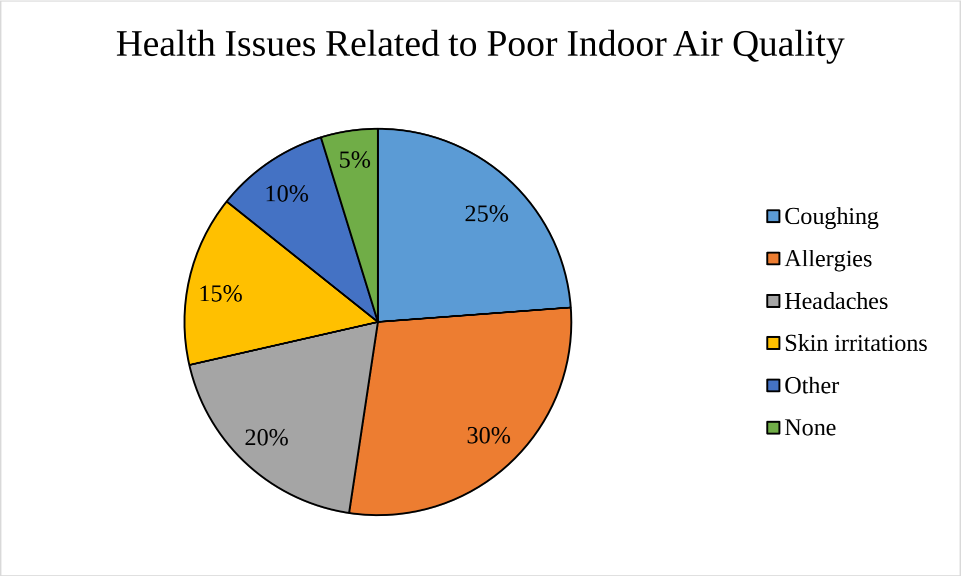

Figure 4.10: Percentage of respondents reporting health issues believed to be linked to poor indoor air quality at kindergarten school.

4.1.2.3. Household Smoking Habits:

20% of respondents acknowledge household smoking habits, indicating a notable minority with smoking members in their homes. This finding underscores a potential source of indoor air pollution, as tobacco smoke is a known contributor to compromised air quality. The majority (80%) reporting no household smoking emphasizes the prevalence of smoke-free environments among the surveyed participants, yet the identified minority signals a need for targeted interventions to address this specific contributor to indoor air pollutants.

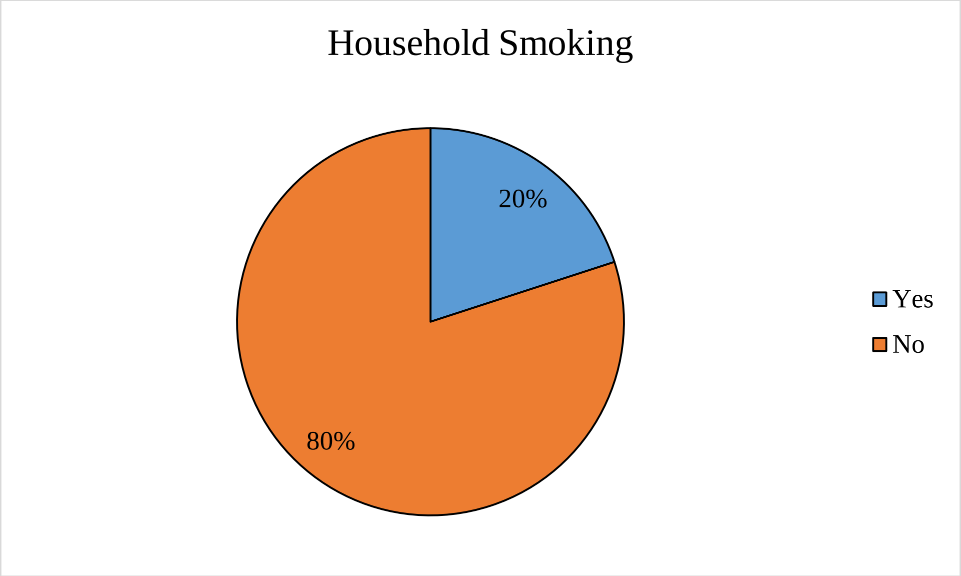

Figure 4.11: Distribution of smoking habits among survey respondents' households showcasing the percentage of those with at least one household member who smokes.

Indoor smoking practices were reported by 10% of respondents, indicating a noteworthy but limited prevalence. This highlights a potential source of indoor air pollution, emphasizing the importance of strategies to address smoking-related concerns within kindergarten school environments.

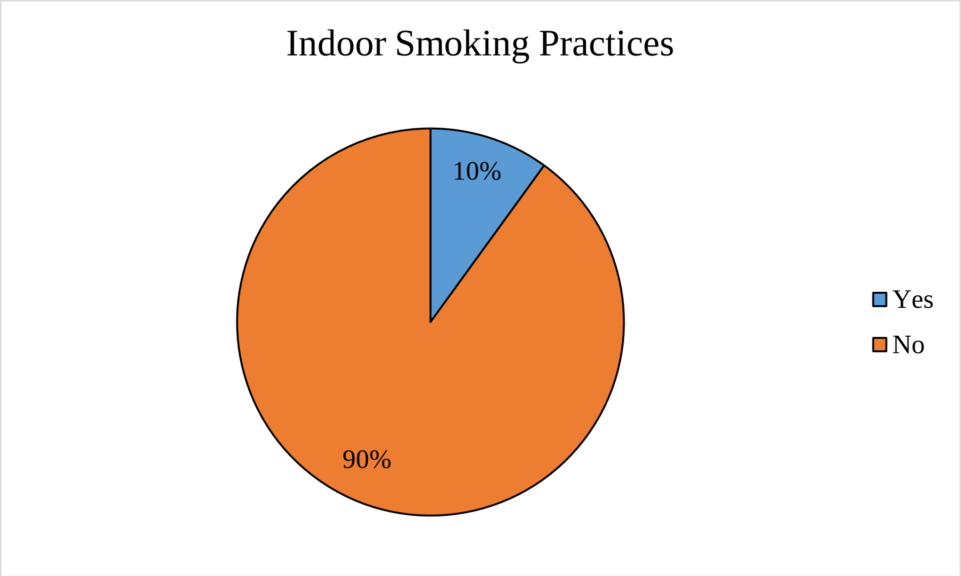

Figure 4.12: Percentage of respondents indicating indoor smoking within households where at least one member is a smoker.

4.1.2.4. Facility Conditions:

70% of respondents have observed ventilation systems in kindergarten schools, indicating a prevalent awareness and provision for airflow. This positive response suggests a proactive approach by the schools in addressing indoor air quality concerns. However, the 30% who haven't noticed ventilation systems highlight a potential area for improvement in communication or infrastructure visibility within these educational settings.

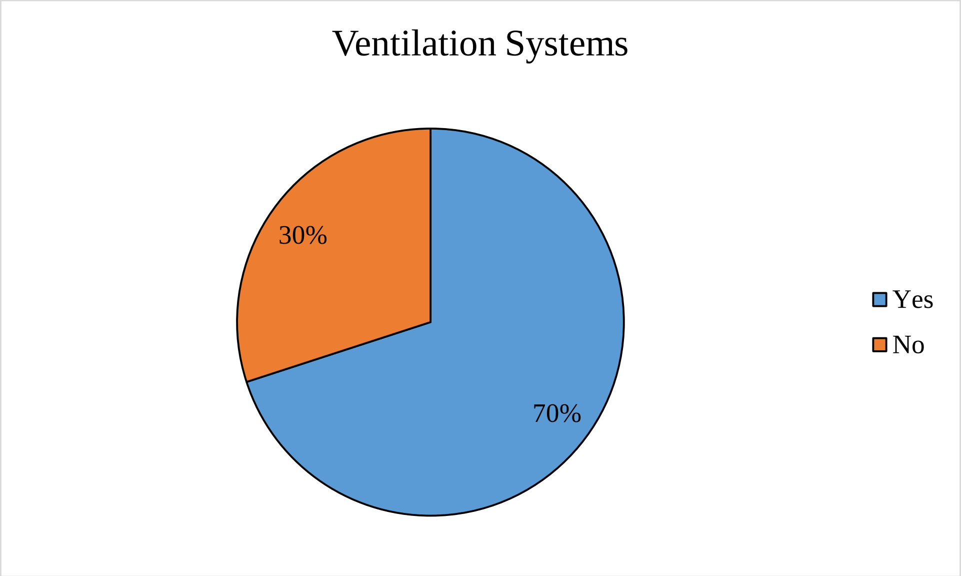

Figure 4.13: Percentage of respondents indicating awareness of ventilation systems within kindergarten schools.

With a notable 65% expressing satisfaction with cleanliness standards in kindergarten schools, it is evident that a substantial majority approves of the hygiene conditions, including play areas, restrooms, and shared facilities. However, the remaining 35% highlighting dissatisfaction suggests there is room for improvement, emphasizing the importance of maintaining a consistently high standard to meet the expectations of all.

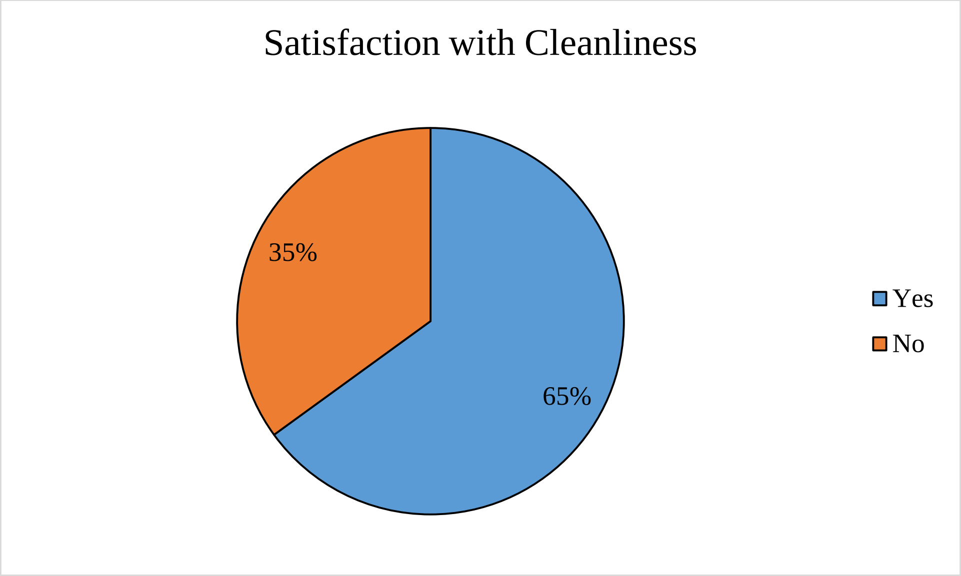

Figure 4.14: Percentage of respondents expressing satisfaction with school cleanliness and hygiene standards, encompassing play areas, restrooms, and shared facilities

4.1.2.5. Environmental Factors:

The survey indicates diverse levels of vegetation within kindergarten school areas, with 40% reporting a significant presence, 30% noting a few, and 30% indicating a lack of vegetation. This variability underscores the need for targeted interventions, potentially emphasizing greenery initiatives to enhance indoor air quality in schools with limited vegetation

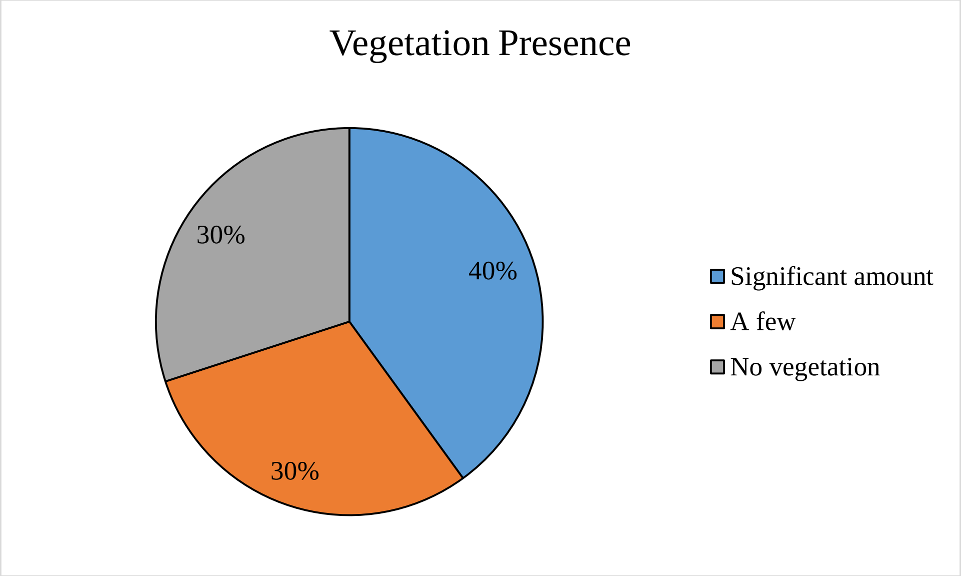

Figure 4.15: Percentage of respondents indicating the presence of vegetation within the kindergarten school area.

While a 25% of surveyed kindergarten schools exhibit a significant amount of indoor plants, representing a positive embrace of green elements, a notable 40% lack any indoor plants. This discrepancy suggests a need for greater emphasis on incorporating greenery in school environments to potentially enhance indoor air quality and overall well-being.

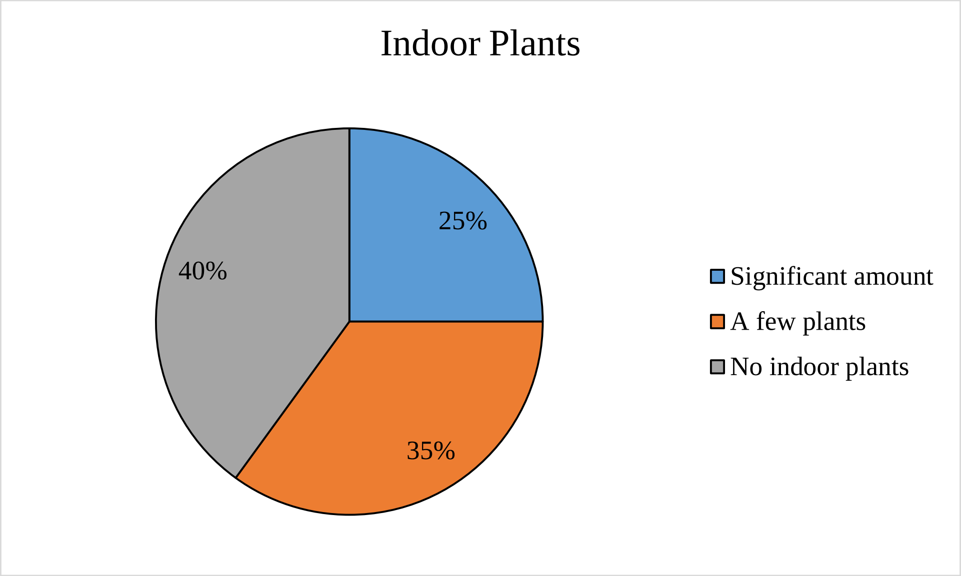

Figure 4.16: Percentage distribution of respondents indicating the presence of indoor plants in kindergarten schools.

4.1.2.6. School Initiatives and Awareness:

In assessing school initiatives and awareness about air quality, 15% of respondents rated the efforts as "Excellent," while 35% deemed them "Good," indicating a combined 50% positive perception. Those giving positive responses likely appreciate visible measures such as efficient ventilation systems, educational programs, and green initiatives. The 30% who rated efforts as "Fair" might feel that while there are initiatives, there is room for improvement. The 10% who perceived efforts as "Poor" and another 10% who reported "No efforts made" express dissatisfaction or a lack of awareness, possibly indicating a need for more transparent communication or enhanced initiatives.

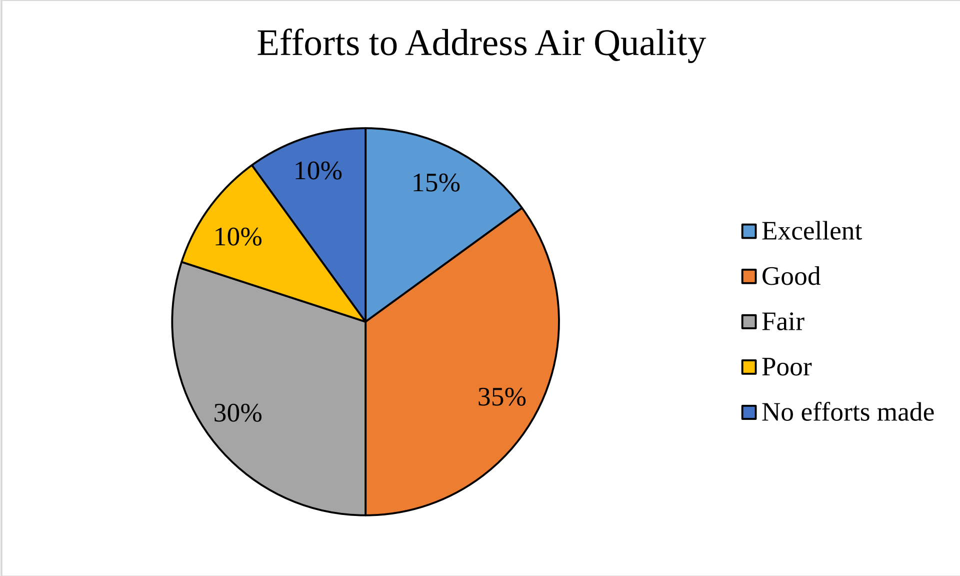

Figure 4.17: Percentage distribution of respondents' ratings on the kindergarten school's efforts in addressing air quality concerns

20% of respondents are aware that kindergarten schools regularly conduct monitoring measures for indoor air quality, demonstrating a proactive approach in ensuring a healthy environment. Another 30% are aware of occasional monitoring efforts, indicating a varying degree of engagement. However, a significant 50% of respondents are unaware of any monitoring measures, suggesting a potential gap in communication or transparency regarding air quality assessments within these kindergarten schools.

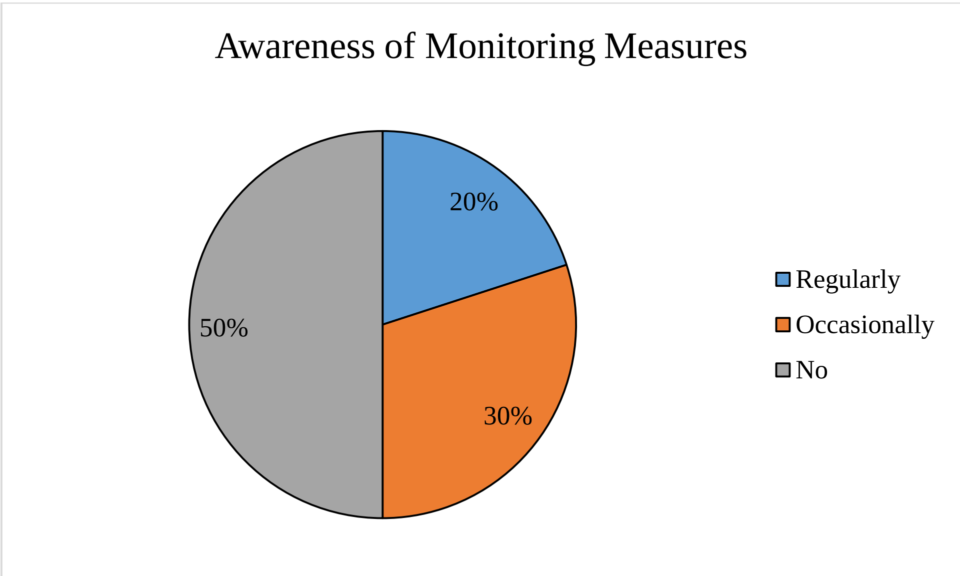

Figure 4.18: Percentage of respondents aware of indoor air quality monitoring or assessment measures implemented by kindergarten schools.

4.1.2.7. Recommendations and Additional Comments:

The respondents' recommendations highlight a consensus on key strategies to improve indoor air quality in kindergarten schools. With 35% advocating for increased ventilation and fresh air intake, 25% endorsing the use of air purifiers or filtration systems, and 20% emphasizing a reduction in the use of chemicals or pollutants, there is a clear call for practical measures. Additionally, 15% suggest incorporating more vegetation and indoor plants, underscoring the recognition of natural elements as integral to creating healthier learning environments. The diverse perspectives captured in the "Other" category (5%) further emphasize the importance of tailoring strategies to the specific needs of each school.

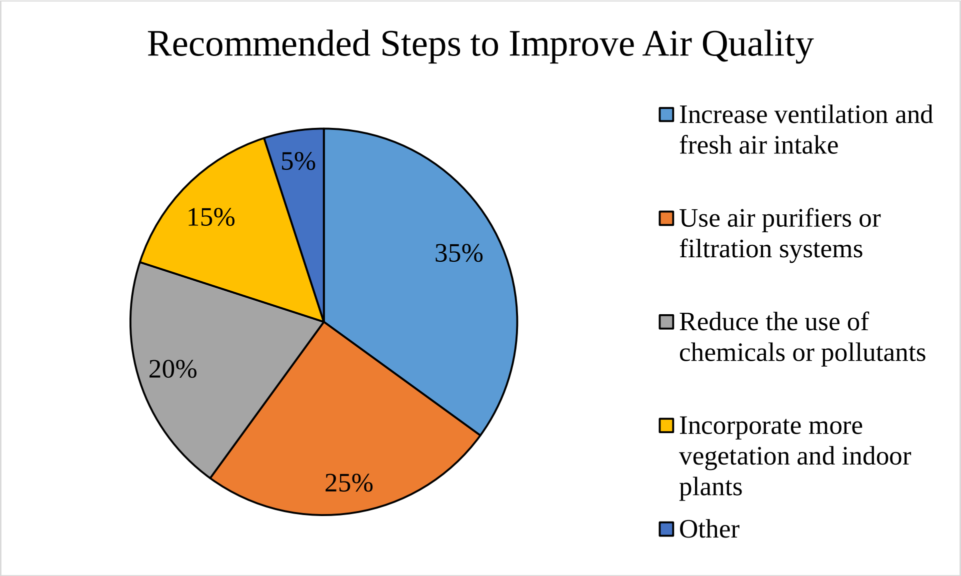

Figure 4.19: Percentage distribution of respondents' opinions on recommended steps for kindergarten schools to enhance air quality.

The additional comments and concerns provided by parents underscore a collective call for heightened attention to the health and safety of their children within kindergarten school environments. The urgent appeal for schools to prioritize air quality management reflects a deep-seated parental concern for the well-being of their young learners. Parents recognize the critical role of indoor air quality in influencing the overall health of their children, and their impassioned plea emphasizes the need for proactive measures by educational institutions.

4.2. Discussions

4.2.1. Overall Indoor Air Quality

The overall indoor air quality (IAQ) is a critical point of discussion in this thesis, encompassing a comprehensive evaluation of various pollutants within kindergarten schools in Dhaka City.

Roadside kindergarten schools consistently show higher levels of CO_2 compared to residential counterparts due to factors like increased vehicular traffic and limited pollutant dispersion. The proximity to busy roads contributes to elevated carbon dioxide emissions from vehicles, leading to indoor accumulation (Sadrizadeh et al., 2022). Inadequate ventilation systems in these schools may hinder pollutant removal, exacerbating CO_2 levels. Addressing ventilation systems is crucial for mitigating high CO_2 concentrations (Stabile, 2017). The health implications for students and staff include impaired cognitive function and respiratory issues (Tran et al., 2020). Measures like upgrading ventilation or relocating schools away from high-traffic areas are necessary for creating a healthier learning environment for young children.

The study highlights that the primary source of carbon monoxide (CO) in indoor kindergarten schools in Dhaka City is attributed to the combustion of fossil fuels, particularly through cooking appliances, heating systems, and occasionally, electrical generators (Zhang & Srinivasan, 2020). This is particularly prevalent in densely populated urban areas like Dhaka, where traditional cooking methods and heating appliances are common (Tran et al., 2020). While the overall CO levels remain below the WHO standard of 9000 ppb, it's crucial to understand and mitigate these indoor sources of combustion for the safety and health of children and staff (Roy et al., 2023). The study emphasizes the importance of regular appliance maintenance, proper ventilation systems, and the promotion of cleaner energy sources. Furthermore, the proximity of schools to roads exposes them to higher concentrations of CO due to factors such as increased traffic density and inefficient combustion of fuel. The findings underscore the significance of considering geographical location when designing educational facilities and implementing strategies to mitigate the impact of vehicular emissions on school environments (Marzouk & Atef, 2022). Public awareness campaigns are also recommended to empower communities to advocate for measures improving air quality around educational institutions. Despite differences between roadside and residential areas, the study concludes that overall CO levels within kindergarten schools are within standard limits, emphasizing the need for continued monitoring and proactive measures to maintain a safe and healthy environment for students and staff.

High NO_2 levels in indoor environments, particularly near roads where kindergarten schools are located, pose a significant risk to children's respiratory health (Pozzer et al., 2022). Sources include traffic emissions, combustion processes, and inadequate ventilation within schools, deviating substantially from air quality standards (Pierina Ielpo et al., 2019). Automobile emissions, especially from diesel-powered cars, are a major contributor to elevated NO_2 levels near roads, impacting schools close to highways. Limited pollutant dispersion near roads and intermittent traffic exacerbate NO_2 concentration. Despite increased NO_2 levels in residential areas, the pervasive air quality issues in Dhaka call for mitigation strategies such as traffic control, emission regulations, and urban planning to protect children's health (Zaman et al., 2021). Urgent intervention is essential to address these concerns and safeguard young children from the adverse effects of high NO_2 exposure.

The results of investigation into sulfur dioxide (SO_2) levels in kindergarten schools revealed an important observation regarding the distinction between roadside and residential locations. Surprisingly, the SO_2 concentrations in both settings were found to be statistically nonsignificant, indicating that proximity to traffic, typically a major source of SO_2 emissions, did not significantly influence the observed levels. Additionally, it was noted that no school was located adjacent to an industrial sector, whether it was on a residential or roadside basis. The average SO_2 concentration in both roadside and residential areas exceeded the World Health Organization (WHO) standard of 8 parts per billion (ppb), emphasizing a concerning air quality scenario (Tian et al., 2019) within the studied kindergarten school environments. The fact that both roadside and residential areas exhibit SO_2 concentrations exceeding the WHO standards underscores the urgent need for comprehensive air quality management strategies in and around kindergarten schools. Mitigating the adverse health effects associated with elevated SO_2 levels necessitates not only broader emission reduction policies but also school-specific measures such as improved ventilation systems and awareness campaigns to protect the health and well-being of the young students (Pierina Ielpo et al., 2019).

Elevated ozone (O_3) levels near roads result from proximity to vehicular traffic in urban environments, where precursor pollutants like nitrogen oxides (NOx) and volatile organic compounds (VOCs) react in the presence of sunlight, forming ozone (Huang et al., 2019). Both roadside and residential areas exhibit increased O_3 concentrations, emphasizing the pervasive nature of ozone pollution around kindergarten schools. Ozone exposure is linked to respiratory issues, necessitating air quality management strategies. Mitigation efforts should include broader emissions reduction policies and targeted interventions like green buffers, improved ventilation systems, and awareness campaigns to protect the health of young students (Mizen et al., 2020; Ahmad et al., 2017).

The investigation into $PM_{2.5}$ levels in kindergarten schools reveals significantly higher concentrations along roadsides compared to residential areas, with both exceeding the WHO guideline of 25 $\mu g/m^3$. Vehicular traffic, including exhaust emissions, tire and brake wear, and road dust resuspension, is a primary contributor to elevated $PM_{2.5}$ levels near roads (Tian et al., 2019). Industrial activities and anthropogenic sources near roadways further exacerbate particle concentrations (Roy et al., 2023). The pervasive nature of $PM_{2.5}$ pollution in both settings raises concerns about air quality around kindergarten schools. Fine particulate matter poses health risks, particularly for children, emphasizing the need for mitigation strategies targeting vehicular emissions and local pollution sources (Xing et al., 2016).

Vehicular traffic emerges as a primary contributor to heightened PM_{10} levels, releasing particulate matter through exhaust emissions, tire and brake wear, and road dust resuspension (Roy et al., 2023). The proximity of kindergartens to busy roads intensifies exposure, exacerbating PM_{10} levels. The study underscores that PM_{10} pollution is a widespread challenge around kindergarten schools, posing health risks, especially for children (Kumar et al., 2023). Mitigation strategies should address both vehicular emissions and local pollution sources, emphasizing the need for tailored interventions to reduce exposure levels (Mizen et al., 2020). This research highlights the intricate network of sources influencing PM_{10} levels and stresses the importance of targeted strategies to combat particulate matter pollution in educational environments (Roy et al., 2023)

4.2.2. Comprehensive Analysis of Survey Findings

The survey results underscore a heightened awareness of indoor air quality concerns among respondents in both roadside and residential areas. The prevalence of respiratory symptoms, coupled with reported health issues, suggests a need for focused interventions in kindergarten schools. The disparities in smoking practices, vegetation presence, and school initiatives highlight the diverse conditions influencing indoor air quality.

Despite the majority expressing satisfaction with cleanliness standards, the lack of awareness regarding monitoring measures raises questions about transparency and communication between schools and parents. The varied recommendations for improvement emphasize the multifaceted approach needed, incorporating increased ventilation, reduced pollutant use, and the incorporation of green elements (Annesi-Maesano et al., 2013).

In delving into the survey results, it becomes evident that the intricate web of factors influencing indoor air quality concerns in kindergarten schools requires a nuanced and comprehensive approach. The implications for respiratory health are stark, necessitating targeted interventions to safeguard the well-being of young attendees (Kinshella et al., 2001). The survey highlights the urgent need to address household smoking practices and advocate for smoke-free environments, given the well-established risks of secondhand smoke, especially for young children (Ahmad et al., 2017). The positive acknowledgment of ventilation systems within kindergarten schools is a positive note, but the apparent lack of awareness regarding monitoring measures suggests an opportunity for improved communication strategies between educational institutions and parents.

The role of vegetation and green elements in contributing to improved air quality and aesthetic enhancements is an area with untapped potential (Pegas et al., 2012). Integrating more plants into kindergarten school environments could be a practical step towards creating healthier spaces for children (Pegas et al., 2012). The survey's revelation of varying perceptions regarding school initiatives emphasizes the importance of clear communication channels and collaborative efforts to create a shared commitment to indoor air quality improvement.

The recommendations provided by respondents offer a roadmap for improvement, emphasizing the adoption of recognized best practices such as increased ventilation and the use of air purifiers (Sadrizadeh et al., 2022). This diversity in suggestions underscores the need for a flexible and context-specific approach to address the unique challenges faced by each kindergarten school. Additionally, the expressed desire for parental awareness and involvement underscores the role of education in fostering a collective responsibility for indoor air quality. Workshops and awareness programs emerge as potential effective tools for achieving this, serving as platforms to educate both parents and school staff on the crucial importance of maintaining a healthy indoor environment for the youngest members of our community (Sadrizadeh et al., 2022). In conclusion, the survey results not only shed light on existing concerns but also point towards actionable strategies for creating healthier and safer indoor spaces for kindergarten schoolchildren.

4.2.3. Consideration of Roadside vs. Residential Disparities

Examining the survey results within the contexts of both roadside and residential areas underscores shared concerns regarding indoor air quality in kindergarten schools, while revealing nuanced differences that warrant specific attention. Notably, the significantly higher levels of PM_{10} along roadways align with expectations based on vehicular emissions, emphasizing the need for targeted interventions in roadside schools to mitigate the impact of traffic-related pollution (Tian et al., 2019). The close proximity to busy roads intensifies exposure to particulate matter, making it imperative to address this issue through focused strategies.

Another divergence between the settings is the potential for indoor smoking practices, which may be more pronounced in residential environments despite similar percentages of households with smokers. This suggests that indoor air quality concerns related to smoking could be more prevalent in residential areas (Ahmad et al., 2017), prompting the need for stricter policies within schools to tackle this specific issue.

The varying levels of vegetation and indoor plants may be influenced by the urban landscape, with roadside schools facing potential limitations in available green space (Pegas et al., 2012). However, recognizing the importance of vegetation in improving air quality, efforts should be made to adapt green initiatives to the specific constraints of roadside schools, ensuring that even limited space is optimized for maximum impact.

Positive acknowledgment of ventilation systems is a commonality in both settings, but the potential impact of roadside pollution on indoor air quality emphasizes the need for enhanced ventilation systems in schools located near busy roads (Kinshella et al., 2001). Furthermore, effective communication regarding monitoring measures becomes even more critical in roadside schools to address specific concerns related to traffic emissions.

Parental awareness and involvement emerge as vital components for fostering a healthier indoor environment in both settings, with active engagement becoming particularly crucial in roadside areas where exposure to outdoor pollutants is potentially higher. The recommendations provided by respondents, such as increasing ventilation, reducing pollutants, and incorporating green elements, are universally applicable but may require tailored solutions in roadside schools, considering the heightened impact of external factors on indoor air quality (Ahmad et al., 2017). Addressing indoor air quality concerns in kindergarten schools demands a context-sensitive approach that recognizes and responds to the unique challenges posed by both roadside and residential environments.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions and Recommendations

The comprehensive study on the determination of indoor air quality and estimation of potential health risks at kindergarten schools in Dhaka City, Bangladesh, particularly focusing on students under the age of 6, has yielded critical insights into the environmental conditions within these educational spaces. The research not only focused on overall indoor air quality but also conducted a thorough analysis by comparing results between kindergarten schools located near roadways and those situated in residential areas. The data collected through comprehensive monitoring and analysis highlight several key findings. The concentrations of indoor pollutants such as PM_{10}, $PM_{2.5}$, SO_2, NO_2 and O_3 surpassed recommended WHO guidelines in certain areas within the kindergarten schools. The findings reveal significant variations in air quality parameters between kindergarten schools near roadways and those in residential zones. The presence of pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), CO_2, CO, NO_2 and O_3 were consistently higher in schools situated on the roadside. This discrepancy underscores the impact of traffic emissions on indoor air quality, posing potential health risks for students, teachers and staff in these locations. The absence of industry surrounding kindergartens contributed to the lack of significance observed in the relationship between roadside and home SO_2 levels. Moreover, the estimation of health risks associated with indoor air pollution indicates a heightened vulnerability for individuals attending kindergarten schools near roadways. Exposure to elevated levels of pollutants may lead to respiratory issues, allergies, and other health concerns, particularly in the long term. The identification of specific pollutants and their concentrations provides a basis for targeted intervention strategies to mitigate indoor air pollution in these high-risk areas. As a recommendation, implementing effective ventilation systems, utilizing air purifiers and incorporating green spaces as buffers against outdoor pollutants could be crucial steps in improving indoor air quality at kindergarten schools, especially those located in proximity to busy roads. Additionally, regulatory measures to control vehicular emissions and promote sustainable transportation practices are essential for creating a healthier indoor environment for young children. This study emphasizes the need for ongoing monitoring of indoor air quality in educational institutions and the formulation of comprehensive policies to address the unique challenges faced by schools located in urban environments with high traffic density.

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APPENDICES

APPENDIX A: Supplementary Tables and Figures

Table A1. Concentration (Mean ± SD) of indoor air quality parameters collected from roadside and residential areas along with their statistical analysis

Parameters	Roadside Mean ± SD	Residential Mean ± SD	T-test (Roadside, Residential)
CO_2 (ppm)	1028.523 ± 9.37	780.895 ± 26.42	t =68.40631016 p <0.001
CO (ppb)	1573.922 ± 268.24	1402.261 ± 291.70	t= 3.355258052 p= 0.00106702
NO_2 (ppb)	128.584 ± 3.50	63.001 ± 6.15	t=71.74128298 p <0.001
SO_2 (ppb)	30.156 ± 7.17	29.705 ± 6.65	t= 0.35670213 p= 0.721951864
O_3 (ppb)	128.979 ± 5.13	70.786 ± 7.50	t= 49.54644741 p <0.001
PM2.5 (ug/m^3)	74.433 ± 3.34	56.955 ± 10.43	t= 12.35932075 p <0.001
PM10 (ug/m^3)	138.959 ± 15.21	102.387 ± 12.37	t=14.44446654 p <0.001

Table A2. Latitude and Longitude of Selected Locations

Location	Kindergarten School ID	Latitude	Longitude
Mirpur	S1	23°49'22"N	90°21'50"E
	S2	23°48'51"N	90°21'44"E
Uttara	S3	23°52'15"N	90°23'59"E
	S4	23°52'19"N	90°23'52"E

Dhanmondi	S5	23°44'43"N	90°22'58"E
	S6	23°44'51"N	90°23'27"E

APPENDIX B: Questionnaire Survey

Questionnaire Survey

On

Possible Health Risks at

Kindergarten Schools Due to Indoor Air Quality

Demographic Information:

1. Name:

2. Relationship to the Kindergarten:

- [ ] Guardian
- [ ] Teacher
- [ ] Staff

3. Location (City/State):

Concerns about Indoor Air Quality:

Q1. How concerned are you about indoor air quality in kindergarten schools?

a. Very concerned

b. Somewhat concerned

c. Not concerned at all

Health Experiences:

Q2. Did you or your child ever experience asthma like/ whistling sound in the chest?

a. Yes

b. No

Q3. Have you or your child experienced any health issues that you believe are related to poor indoor air quality at kindergarten school? (Check all that apply)

a. Coughing

b. Allergies

c. Headaches

d. Skin irritations

e. Other (please specify)

f. None

Household Smoking Habits:

Q4. Do any member of your household smoke?

a. Yes

b. No.

Q5. If any member of your household is a smoker, do they smoke indoors?

a. Yes

b. No

Facility Conditions:

Q6. Have you noticed any ventilation systems within the kindergarten school?

a. Yes

b. No

Q7. Are you satisfied with the cleanliness and hygiene standards within the school, including the sanitation of play areas, restrooms, and shared facilities?

a. Yes

b. No

Environmental Factors:

Q8. Is there any vegetation present within the kindergarten school area?

a. Yes, a significant amount

b. Yes, a few

c. No vegetation

Q9. Are there indoor plants present in the kindergarten school?

a. Yes, a significant amount

b. Yes, a few plants

c. No indoor plants

School Initiatives and Awareness:

Q10. How would you rate the kindergarten school's efforts in addressing air quality concerns?

a. Excellent

b. Good

c. Fair

d. Poor

e. No efforts made

Q11. Are you aware of any indoor air quality monitoring or assessment measures taken by the kindergarten school?

a. Yes, regularly

b. Yes, occasionally

c. No

Recommendations and Additional Comments:

Q12. In your opinion, what steps should kindergarten schools take to improve air quality?

a. Increase ventilation and fresh air intake

b. Use air purifiers or filtration systems

c. Reduce the use of chemicals or pollutants

d. Incorporate more vegetation and indoor plants

e. Other (please specify)

Q13. Please share any additional comments or concerns related to air quality, vegetation, health risks, or safety at kindergarten schools.