ANALYSIS OF AIR QUALITY PATTERNS ALONG THE SHUTTLE ROUTES OF KNUST

by

Afedi Tetteh Jephthah (8671121)

Appau Gloria (8672621)

Opoku Kingsley (8676821)

A Thesis submitted to the Department of Meteorology and Climate Science in partial fulfillment of the requirements for the award of a Bachelor of Science degree in Meteorology and Climate Science.

Supervisor: Dr. Jeffrey N.A Aryee

September 2025

Declaration

We hereby declare that this thesis is our own work towards the Bachelor of Science degree, and to the best of our knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

Afedi Tetteh Jephthah 20853465	.... Signature	19/09/2025 Date
Appau Gloria 20812488	.... Signature	19/09/2025 Date
Opoku Kingsley 20849420	.... Signature	19/09/2025 Date
Dr. J. N. A. Aryee Supervisor	.... Signature	19/09/2025 Date

Certified by:

Prof. Emmanuel Quansah H.O.D	.... Signature	23/09/2025 Date

Dedication

We dedicate this research to God Almighty, our creator, unshakable pillar, and source of inspiration, wisdom, knowledge, and understanding, for honouring our efforts. He has been our source of strength throughout our research and we have only been able to soar on His wings. We also dedicate this research to our respective families: the Afedi, Appau, and Opoku families,whose encouragement and support have ensured that we give everything we have to finish what we have started.

Acknowledgement

Special thanks go to the Teaching Assistant Miss Perfect Potakey, who assisted us in our study, Mr.Nicholas Tetteh, Mr.Jospeh Tabi and other individuals who provided help especially with the use of the sensor. The authors extend sincere appreciation to our supervisor, Dr. Jeffrey Nii Armah Aryee, for his invaluable support, guidance, and expertise in conducting this research. The authors also thank Prof. Emmanuel Quansah the HOD, and all lecturers at the Department of Meteorology and Climate Science for their assistance. Many thanks to our wonderful parents for their unwavering support and prayers, and to our family, spiritual fathers, friends, and colleagues for their encouragement and support.

Abstract

This study analyzed $PM_{2.5}$ concentrations along six major shuttle routes within the Kwame Nkrumah University Of Science and Technology (KNUST) campus, Kumasi. Data were collected during and afternoon rush hours over three weeks using a mobile low cost LED air quality sensor. Results revealed pronounced peaks in $PM_{2.5}$ levels between 07:45-08:15 and 15:00-17:00, coinciding with heavy shuttle usage. Most shuttle routes recorded higher $PM_{2.5}$ concentrations on Tuesday indicating intensified traffic demand. The mean daily $PM_{2.5}$ concentration across all locations was 31.09 $\mu g/m^3$ while the mean hourly concentration was 32.14 $\mu g/m^3$, with Agric junction identified as the pollution hotspot. Temperature showed a weak negative correlation with $PM_{2.5}$ while Relative Humidity showed a weak positive correlation with $PM_{2.5}$ due to the hygroscopicity of $PM_{2.5}$ particles. The weak correlations of Temperature and Relative Humidity on $PM_{2.5}$ within our scope of study suggested vehicular emissions as the dominant source. Mean hourly and daily AQI across all routes were found to be in the moderate range, notwithstanding, it called for concern since there were few indexes of away of it falling into the unhealthy for sensitive group range. These findings emphasized the importance of implementing targeted traffic management and pollution mitigation strategies to protect the health of the university community. It was recommended in this study that subsequent studies would extend their scope of data collection study in order to really capture the effects of meteorological variables on the amount of $PM_{2.5}$ and also analyze gaseous pollutants like CO and NO_2 alongside $PM_{2.5}$ in order to get a comprehensive study of air quality along the shutte routes. For policy makers, it was recommended that they fund the use of sustainable transports like bicycling to mitigate emissions and also ensure the various colleges across the university community have air quality clubs in order to create the awareness on air pollution.

Contents

List of Tables

List of Figures

CHAPTER 1
Introduction

1.1 Research Background

Africa's fast-growing number of motorized transport has made traffic emissions a major cause of urban air pollution. Air pollution decreases urban standards of living (Ayetor et al., 2021). A 2016 World Health Organization (WHO) estimation stated that over 80% of city residents breathe above WHO thresholds (Sicard et al., 2021). The Global Burden of Disease (GBD) study estimates 4.2 million global premature deaths due to exposure to outdoor air pollution (Liao et al., 2020). Particulate is inimical to health. Exposure to $PM_{2.5}$ was estimated to have led to 2.9 million premature deaths in 2017. This accounts for about 9% of total deaths globally. Besides this, there were 80,000 premature deaths (Adama et al., 2018) resulting from ischemic heart disease, which encompasses repeated pain or discomfort in the chest due to a lack of blood flow to the heart. Stroke, chronic obstructive pulmonary disease leading to chronic respiratory impairment and low airflow, lung cancer, lower respiratory infections, and type 2 diabetes mellitus are few of the other reasons (Stanaway et al., 2018). Particulate matter is not only responsible for health hazards but also ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2). Air pollution is a serious public health issue in Ghana, especially with rising emissions due to traffic and industrial processes. The latest figures show an alarming trend: deaths from fine particulate matter $PM_{2.5}$ have risen sharply. The State of Global Air 2024 report indicates that premature death due to exposure to $PM_{2.5}$ in Ghana increased from about 4,200 in 1990 to over 12,000 in 2019, almost three times more than the number of deaths in three decades (State of Global Air, 2024). Data from urban areas indicate a similar trend in Kumasi, Ghana's second-largest city. From 2000 to 2019, $PM_{2.5}$ mortality rose in Kumasi from less than 1,000 to over 2,000 annually, according to the State of Global Air 2022 (State of Global Air, 2022). The frightening figures highlight the need for proactive air quality management and interventions in public health. There is growing worry about long-term exposure to air pollution, including $PM_{2.5}$, due to the rising traffic levels surrounding the Kwame Nkrumah University of Science and Technology (KNUST) campus, especially at rush hours along shuttle routes. Low-cost sensor technology and Internet-of-Things (IoT) networks have been utilized in recent studies to measure air quality in real-time. Afotey and

Lovely-Quao (2023) demonstrated how IoT-related air monitoring can assess pollution within the KNUST community. Their results brought to light the capability of smart sensor networks to track localized pollution and raise awareness in public health. Likewise, Kyere et al. (2022) analyzed air quality for Takoradi Technical University campus, whose findings showed that local conditions exert significant effects on pollution trends. Traffic-generated air pollution is emerging as an increasing health risk to susceptible groups, such as road-side workers, transporters, and learners (Ajayi et al., 2023). There is a requirement for proactive surveillance and forecasting systems as such contaminants cause lung and heart problems. In recent years, the use of artificial intelligence and machine learning for the prediction of air quality has grown. Ramentol et al. (2023) used temporal embeddings and neural networks for short-term air quality forecasting, highlighting how data-driven techniques can predict pollution spikes. Specific research on university populations and transit locations within them is scant despite increased sensor and computation capacity for monitoring the air. Uka et al. (2020) stressed additional localized studies in Ghanaian cities to inform city planning and environmental policy-making. This study seeks to fill that gap by analyzing air quality trends along KNUST shuttle routes to the benefit of student health and environmental management.

1.2 Problem Statement

There is not that much emphasis on air pollution, even though it is a silent killer. It is now a big problem in learning institutions in cities. The primary mode of transport for visitors, workers, and students at Kwame Nkrumah University of Science and Technology (KNUST) is by shuttle service. Shuttles, taxis, and other means of transportation generate trafficking along shuttle routes during peak hours, especially the morning and late evening. The heavy trafficking causes the concentration of toxic air pollutants such as fine particulate matter ($PM_{2.5}$). According to our research, it was seen that during peak hours, 459 individuals are exposed to excessive pollutants for 30 minutes along the shuttle routes. Notwithstanding the risk of exposure, commuters are not aware of the short-term and long-term consequences on their health resulting from these pollutants. $PM_{2.5}$ has a high chance of penetrating into the lungs and is associated with heart and respiratory ailments. Statistics from Quality and Assurance Planning

Office, KNUST show that KNUST first-year intake rose from approximately 708 students in 1961–1962 to more than 11,000 in 2011–2012. Recent figures show that the university today has over 85,000 students, with around 22,000 fresh admissions in the 2019–20 academic year. Environmental health assessments have failed to keep up with the rapid increase in enrollments. The expansion has led to higher exposure to contaminants because of greater shuttle activities and traffic within the campus. Fewer data exist on the effects of air pollution along such shuttle routes. PM2.5 has been established to be taken into the bloodstream and lungs and is also well known to have cardiovascular and respiratory diseases as its effects. Severe health consequences are also linked with cumulative exposure to these air pollutants in a highly congested university environment. Little information is available for localized air quality conditions along shuttle routes within the KNUST campus. Without understanding patterns of pollutant distribution across space and time, environmental planners, university managers, and health officers are not able to prepare interventions appropriately. Monitoring and analyzing the air quality along these routes are essential. The research will facilitate the identification of pollution hot spots, guide policy decisions, facilitate awareness, and trigger uptake of health-based and sustainable transport practice in the university.

1.3 Justification of the study

The United Nations Sustainable Development Goals (SDGs) closely follow with this research, mainly Goal 3: Good Health and Well-Being, Goal 11: Sustainable Cities and Communities, and Goal 13: Climate Action. Air pollution has enormous implications on the health of human beings and city planning in rapidly developing and rapid cities like Kwame Nkrumah University of Science and Technology (KNUST). These goals focus on these aspects. The third goal is directed at "promoting well-being and securing healthy lives for all at all ages." One of the key components of this goal is reducing the number of deaths and diseases caused by air pollution and harmful substances (Target 3.9). It is crucial to research the spatiotemporal exposure patterns of KNUST students to safeguard their health since air contaminants such as $PM_{2.5}$ are associated with respiratory illness, heart disease etc (WHO, 2021). The findings will underpin precautionary health practices, particularly among the students that use the shuttle buses on a regular basis. Goal 11 highlights the building of safe, inclusive, resilient, and sustainable cities and human settlements. Its target (11.6) is to reduce the environmental impact of cities per capita, concentrating on reducing waste and air pollution. The increase in the number of students and shuttle services across the KNUST campus is a pointer to the dynamics of a small urban center, with vehicle emissions and traffic congestion now posing significant issues. This research provides an overview of an observation data set for planning cleaner and safer shuttle route networks by investigating air quality trends (UN-Habitat, 2020). In response to climate change and its impacts, Goal 13 demands immediate action. While global climate change is contentious, local measurement of air quality is important to comprehend and reduce greenhouse gases and short-lived climate pollutants like NO_2 and black carbon. Further, this study will aid long-term campus climate resilience planning to integrate environmental sustainability into transportation and infrastructure policy (IPCC, 2021). Briefly, this study not only addresses current campus health issues but also serves more general sustainability objectives by providing useful insights. These insights are critical in closing gaps between institutional development and global alignment to the SDGs.

1.4 Main Objective

The study aims to analyze air quality patterns along the shuttle routes of KNUST by assessing pollutant concentrations($PM_{2.5}$.).

1.5 Specific Objectives

The goal of the study was to specifically:

- Identify pollution hotspots and areas of concern along the shuttle routes
- Measure and analyze the levels of key air pollutants, specifically $PM_{2.5}$ along the KNUST shuttle routes.

- Assess the influence of traffic density, meteorological conditions, and environmental factors on air pollution levels.

1.6 Organization of the thesis

This thesis is composed of five(5) chapters; Chapter 1 is the introduction which consist of the research background, problem statement, justification of study, objectives and the thesis organization. Chapter 2 covers the literature review. Chapter 3 is the description of the study area, data used and methodology of the research. Chapter 4 entails the discussion of the analyses and results obtained. Chapter 5 is the summary and conclusion of the results obtained and highlights of the contribution of the study to the KNUST community and Ghana as a whole.

CHAPTER 2
Literature Review

Air quality monitoring in urban transport areas has been studied across the globe, especially in North America and Asia. However, there is limited research in Ghana, and none has looked at air quality trends along the KNUST shuttle routes. This review looks at important studies on air quality in similar settings. It points out gaps and shows the importance of this study within the university's transportation system.

2.1 Overview of Air Quality Monitoring in Urban Areas

Air quality monitoring (AQM) is a global monitoring device that plays an important role in public health and environmental management, especially in rapidly developing urban areas. Kularatna and Sudantha (2008) discovered that traditional AQM systems depended on fixed-site, reference-grade monitors. As much as the monitors were accurate, they were expensive and complicated to set and service. Their great cost limited their use, especially in low- and middle-income countries, where resources and infrastructure are often in short supply to facilitate effective air pollution measurement. However, recent advances in technology have transformed AQM, as Snyder et al. (2013) pointed out. Low-cost, miniaturized, easy-to-use sensors are now able to continuously measure air quality in urban areas of various settings. Shabbir et al. (2025) compared the performance and use of low-cost sensors (LCSs) like the TSI BlueSky (Model 8143). Their study showed that the sensors provide valid, real-time $PM_{2.5}$ and other pollutant readings at much lower costs than traditional monitors, generally less than 1,000$USD. The authors stressed the fact that the devices are portable, WIFI, and adaptable to change according to environmental conditions. On calibration and validation, they had strong statistical correlations with reference monitors, with a Pearson correlation coefficient as high as 0.94 and normalized root mean square errors (NRMSE) as low as 4%. Aside from performance, the authors also noted how these technologies expand access to air quality data by facilitating community-driven and citizen-participated monitoring programs, like Luftdaten and CitiSense. The study also identified sensor drift, environmental sensitivity, and short lifespan as limitations. These could be overcome by regular calibration, co-location with referred devices, and usage of machine learning algorithms. Of note, the authors suggested a maintenance procedure that prolonged the lifespan of the BlueSky sensors beyond two years, showing that LCSs are not only sustainable but also scalable under low-resource environments.

2.2 Global Perspectives on Urban Air Pollution

Pollution is a key factor in urban quality of life, especially in developing countries that are growing quickly. Ahlfeldt and Pietrostefani (2019) noted that cities have attracted people because of some numerous benefits. However, these advantages often come with costs, such as rising crime rates, traffic jams, infectious diseases, and air pollution. While developed nations surpassed the 50% urbanization mark by the mid-20th century, less developed countries only achieved this around 2020. As a result, most recent and expected growth in urbanization is happening in the developing world, where air pollution is also a major concern. Ahlfeldt and Pietrostefani (2019) assessed the global link between urban growth and air pollution using detailed datasets that track population distribution and $PM_{2.5}$ levels. Their research reveals that pollution is not spread evenly; twenty out of the world's twenty-five most polluted cities (by $PM_{2.5}$ levels) are in India, China, Bangladesh, or Pakistan. The others are in developing countries such as Cameroon, Iran, Madagascar, Mongolia, and Afghanistan. These findings highlight that the connection between population growth and pollution is not just about the environment, but is also closely related to socio-economic development. As cities in the Global South continue to grow, reducing urban pollution will be crucial for enhancing public health and living conditions. Borck and Schrauth (2021) point out that the link between urban density and pollution is complex and depends on the context. Their urban model indicates that higher population density can deteriorate pollution because of increased commuting and energy use, even if households live in smaller spaces. However, the authors also recognize that denser cities can have better public transportation and more energy-efficient housing, which could reduce emissions per person. Therefore, while population and density are often connected, they can affect urban pollution in different ways. The precise relationship between $PM_{2.5}$ exposure and either population size or density is still an open question, highlighting the need for local studies, particularly in rapidly urbanizing areas.

2.3 Health implications of exposure to $PM_{2.5}$

Particulate matter with a diameter of less than 2.5 micrometers, PM2.5, is more generally referred to as one of the most hazardous air pollutants. It is very small size makes it able to pass into the alveoli regions of the lungs and even into the blood, causing severe health conditions. In accordance with WHO (2021) and as indicated by recent epidemiological studies (e.g., Abidin et al., 2025), long-term exposure has been associated with respiratory diseases, cardiovascular morbidity, and premature mortality, especially among vulnerable groups such as children and the elderly. Experimental studies in Yogyakarta, Bantul, measured indoor concentrations of $PM_{2.5}$ and assessed their potential health risks (Abidin et al., 2025; Santoso et al., 2023). Indications were that values often exceeded prescribed standards, and health non-carcinogenic risks approached tolerable limits near traffic roads and biomass-combustion sites. Rahman et al. (2022) further underscore the importance of the fact that indoor activities such as firewood cooking and open burning of domestic waste contribute significantly towards both indoor and outdoor $PM_{2.5}$. In its conclusion, several researchers recommend strict policy implementation, increased awareness within the community, and the shift to greener technologies (Chen Zhang, 2020; Abidin et al., 2025). Aligning with this, Kumar et al. (2024) recommend the utilization of cost-effective sensor networks to monitor in real-time, which can serve as early-warning systems and allow for citizen involvement in environmental health. Though Southeast Asian research is growing, there is a large knowledge gap in Sub-Saharan Africa. For instance, cities such as Kumasi in Ghana have no published information regarding PM

textsubscript2.5 exposure and associated health effects. Drawing lessons from the Indonesian experience, Nyarko Boateng (2021) suggest that African cities require baseline monitoring and health risk assessment right away for directing public health interventions. In addition, the PM2.5 seasonal variation has been documented, with higher amounts typically observed in dry months due to increased dust re-suspension and burning of biomass (Sari et al., 2022). These findings highlight the importance of integrating environmental monitoring into urban development as well as come up with unique community health approaches, such as restricting open burning and promoting cleaner household cooking fuels (World Bank, 2022).

2.4 Influences of meteorological factors and traffic density on pollutant concentrations

The air quality in cities is controlled by a set of natural and anthropogenic variables. Two of the most influential parameters are traffic flow and meteorological conditions (Zhou et al., 2021; Lin et al., 2025). Lin et al. (2025) examined such dynamics using Bayesian networks and deep learning methods. They noted that an understanding of how these two domains interact is the basis for pollution prediction and successful environmental management. They focused their research in Taiwan on key air pollutants like $PM_{2.5}$ and $NO_{2.5}$. They combined detailed traffic data and meteorological data to model how pollutants spread at different times and locations. Weather conditions such as temperature, relative humidity, wind speed, wind direction, solar radiation, and atmospheric pressure significantly influence how air pollutants disperse, chemically transform, and deposit out of the air. Seinfeld and Pandis (2016) explained that temperature inversions most commonly take place in the early morning or in winter. The inversions trap the pollutants close to the surface by creating a stable layer in the atmosphere. Under these circumstances, automobile and other emissions build up instead of dispersing, leading to higher ground-level concentrations. Zhang et al. (2020) confirmed that low wind speeds limit the horizontal spread of pollutants, allowing them to linger in urban areas, while higher wind speeds disperse and dilute pollutants, temporarily improving air quality. Relative humidity and solar radiation also affect chemical reactions in the atmosphere; for instance, they affect the formation of secondary pollutants like ozone, especially during hot, sunny afternoons (Jacob, 1999). The findings emphasize the importance of integrated urban planning strategies coupling transport infrastructure and the environment. Lin et al. (2025) describe how cities can benefit from weather forecasting-based traffic diversion systems. This could involve diversion or closure of vehicular access under weather conditions of poor pollutant dispersion. Similar recommendations were made by Gulia et al. (2015), highlighting the advantages of ventilation corridors and green areas for enhancing pollutant dispersion in densely populated cities. By taking a holistic approach to traffic and weather as interconnected components instead of independent factors, city authorities can significantly increase the efficiency of measures for air quality control.

CHAPTER 3
Data and Methodology

3.1 Study Area

The study took place on the campus of Kwame Nkrumah University of Science and Technology (KNUST) in the Ashanti Region of Ghana. KNUST is a large academic institution with over 80,000 students, staff, and visitors who depend on shuttle services for getting around campus. The shuttle system follows specific routes that link lecture halls, residential building, off campus areas etc. The KNUST shuttle route was chosen for the study because of its high number of commuters, constant traffic flow and high vehicular trafficking. This setting is ideal for evaluating real-time air quality exposure. Emissions from vehicles along these routes, mainly from diesel-powered shuttle buses and other motor vehicles, likely play a major role in local air pollution, especially during busy times.

3.1.1 Layout of shuttle routes

The KNUST campus has a structured shuttle system that serves students and staff. This system includes several routes that connect important academic, residential, and administrative areas on campus.Some of the routes serve as auxilliaries to the other. These routes often become populated during morning and afternoon peak hours due to the high number of commuters. The shuttle buses, which usually run on diesel, operate frequently during the day. They often idle or move slowly during peak times, which increases emissions. Unlike other urban minibus systems in Ghana, these vehicles might not have modern emission control systems. They often run with worn engines or low-quality fuel (Gyamfi et al., 2022). The environmental impact of these vehicles can significantly harm the areas they pass through, especially in busy commuter corridors (Oduro et al., 2021). Bus stops near lecture halls, residential buildings, and food stalls raise the chances of pedestrians being exposed to air pollution from traffic. Since shuttle routes go through key academic and residential areas, monitoring air quality along these paths can provide important insights into the daily exposure risks for the campus community. The main shuttle routes we looked at include the College of Science route, KSB, Casely Hayford, Agric junction, Hall 7, and the Commercial area route.

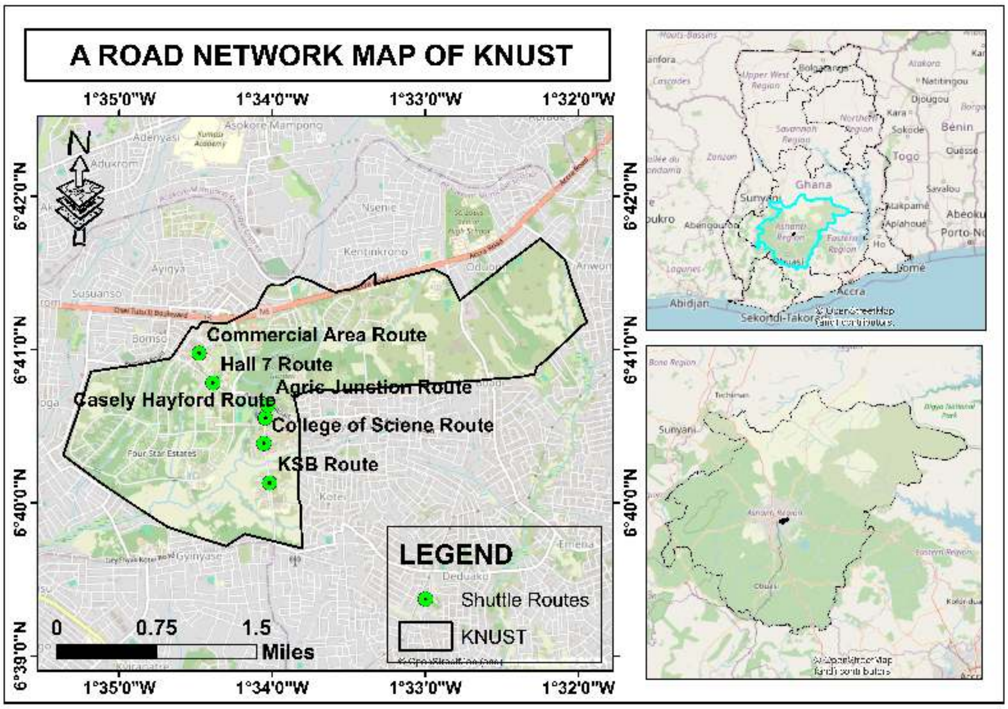

Fig 3.1 A road network map of shuttle routes at KNUST

3.1.2 Population exposure context

The KNUST population mainly consists of young adults, with students making up over 80% of daily commuters on campus. Because academic and residential buildings are close to major shuttle routes, students, staff, and campus vendors often face repeated exposure to air pollutants from traffic, including $PM_{2.5}$, $PM_{2.5}$. Long-term exposure to this pollutant, even at low levels, has been linked to respiratory issues, heart problems, and lower academic performance in young adults (Brauer et al., 2012; World Health Organization [WHO], 2021). Studies in Accra and Kumasi show that people living or working near busy roads experience much higher exposure to particulate matter than those farther away (Dionisio et al., 2010; Annesi-Maesano et al., 2012). On university campuses, the problem gets worse with repeated short-term exposures throughout the day, such as during shuttle rides, at waiting points, and near traffic intersections. Monitoring campaigns in cities like Nairobi and Delhi have also found that air quality in public transport systems can be much worse than outside due to cramped spaces, engine emissions, and poor ventilation (Apte et al., 2011; Jain et al., 2021).

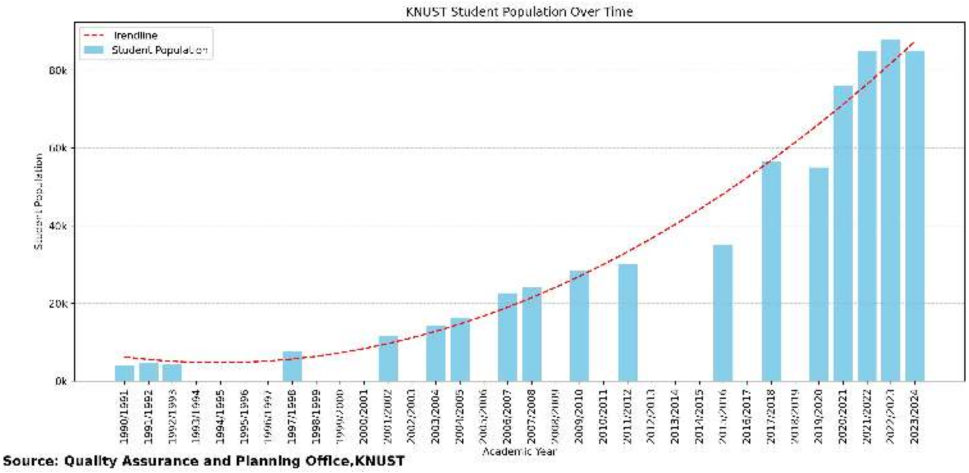

Fig 3.2 A statistical data of KNUST student population

3.2 Data Collection

Data collection for this study took place along selected shuttle routes within the KNUST campus through observational data. The entire duration for the data collection was done in three weeks. The aim was to analyze air quality patterns along the shuttle routes. The data concentrated on particulate matter ($PM_{2.5}$), temperature, and relative humidity, which are important indicators of environmental quality and public health risk in transport micro environments (Zhou Levy, 2007).

3.2.1 Use of mobile LED sensor

Air quality data were collected using a mobile LED-based sensor device called TechAir. This device can measure real-time $PM_{2.5}$ concentrations. Monitoring took place at six main KNUST shuttle routes: College of Science, KSB, Casely Hayford, Agric Junction, Commercial Area, and Hall 7. Data collection occurred during weekday rush hours from 14 July 2025 to 30 July 2025. Due to limited sensor availability, the routes were split into two groups. Group A, which included College of Science, Casely Hayford, and Commercial Area, was monitored 15 minutes before rush hours. Group B, made up of KSB, Agric Junction, and Hall 7, was monitored 15 minutes after rush hours. At each site, $PM_{2.5}$ levels were recorded continuously for 15 minutes. The TechAir device saved data on an internal SD card. This data was extracted after monitoring for analysis. The data were organized by location and time period. A moving average technique was used to smooth the $PM_{2.5}$ readings. The computational analysis included basic statistics and comparisons across routes to evaluate commuter exposure patterns on campus.

Fig 3.3 An image of the mobile LED sensor.

3.3 Methodology

This study used an observational method to measure $PM_{2.5}$ concentrations along specific shuttle routes on the KNUST campus. The process included organized field measurements with a mobile LED-based sensor device (TechAir). Afterward, we analyzed the data to find patterns in air quality and risks of exposure for commuters.

3.3.1 Time Series Analysis

A time series is a series of data points gathered or recorded at regular intervals. This study used time series analysis to look at how $PM_{2.5}$ concentrations changed over time along shuttle routes on the KNUST campus. The general form of a time series model is given below. In the additive model:

$$Y_t = T_t + S_t + C_t + R_t \tag{1}$$

where Y_t is the observed value at time t, T_t is the trend component, S_t is the seasonal component, C_t is the cyclical component, and R_t is the irregular (residual) component. In the multiplicative model:

$$Y_t = T_t \cdot S_t \cdot C_t \cdot R_t \tag{2}$$

The trend shows the long-term movement in the data, while seasonal and cyclical components reflect periodic patterns. The irregular component accounts for random or unexplained fluctuations. To highlight the underlying trend in air quality data, a moving average is often used. For example, a 3-point moving average is defined as:

$$\text{Moving Average at time } t = \frac{X_{t-1} + X_t + X_{t+1}}{3} \tag{3}$$

This smoothing process helps minimize the effect of transient peaks. Differencing was also used to transform non-stationary series into stationary ones:

$$\Delta X_t = X_t - X_{t-1} \tag{4}$$

Finally, the autocorrelation coefficient at lag k is defined as:

$$r_k = \frac{\sum_{t=k+1}^{n}(X_t - \bar{X})(X_{t-k} - \bar{X})}{\sum_{t=1}^{n}(X_t - \bar{X})^2} \tag{5}$$

This allows for the identification of periodic dependencies in $PM_{2.5}$ levels over time.

Source: De Silva, H.V.S., Time Series (Lecture Notes, Dept. of Mathematics).

3.3.2 Correlation and Regression Analysis

Correlation and Regression analyses were performed to assess the relationship between $PM_{2.5}$ levels, meteorological variables and time or location.

Correlation Analysis

The correlation coefficient, r, measures the strength and direction of the linear relationship between two variables. It is given by:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \tag{6}$$

Here, x represents the independent variable (such as time or location), and y represents the dependent variable (such as $PM_{2.5}$). Values of r range from -1 (perfect negative correlation) to $+1$ (perfect positive correlation). An r value near 0 suggests no linear relationship.

Regression Analysis

A simple linear regression model was used to estimate the relationship between $PM_{2.5}$ levels, meteorological variables and selected predictors such as time. The general form is:

$$y = b_0 + b_1 x + \varepsilon \tag{7}$$

In this model, y represents the predicted $PM_{2.5}$ concentration, x is the independent variable, b_0 is the intercept (the value of $PM_{2.5}$ when $x = 0$), b_1 is the slope (the change in $PM_{2.5}$ per unit change in x), and ε is the error term. The regression coefficients b_0 and b_1 are estimated using the least squares method:

$$b_1 = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2} \tag{8}$$

$$b_0 = \bar{y} - b_1 \bar{x} \tag{9}$$

The goodness of fit was assessed using the coefficient of determination (R^2), which is defined as:

$$R^2 = \frac{\text{SSR}}{\text{SST}} = 1 - \frac{\text{SSE}}{\text{SST}} \tag{10}$$

Here, SSR denotes the Sum of Squares due to Regression, SSE denotes the Sum of Squares due to Error, and SST denotes the Total Sum of Squares. A higher R^2 indicates a stronger explanatory power of the model.

Source: De Silva, H.V.S., Time Series (Lecture Notes, Dept. of Mathematics).

3.4 AQI Classification

The Air Quality Index (AQI) is a standard and numerical scale that shows the level of air pollution and its health risks. In this study, $PM_{2.5}$ concentrations were changed into AQI values using the U.S. Environmental Protection Agency (EPA) breakpoint system. The AQI categories range from ”Good” (0–50) to ”Hazardous” (301–500). This offers a clear way to assess air quality for each shuttle route. This classification helps identify areas with high exposure risk and aids in creating strategies to reduce those risks.

3.4.1 General AQI Categories

AQI has been categorized into different ranges and this categorization is standard and universal.The categorization is also color coded with different colors representing different implications with respect to health. This is for easy identification and air quality representation.

3.4.2 Pollutant Concentration vs AQI levels

The Air Quality Index (AQI) sorts pollution levels into six different bands based on their possible health effects. Each category matches a specific range of $PM_{2.5}$ concentrations and uses colors to help with understanding. The table below shows the official AQI breakpoints for $PM_{2.5}$, as set by the U.S. Environmental Protection Agency (EPA).

$$\mathrm{AQI} = \frac{I_{Hi} - I_{Lo}}{C_{Hi} - C_{Lo}} \times (C - C_{Lo}) + I_{Lo} \tag{11}$$

In this equation, C is the observed concentration of $PM_{2.5}$ in μg/m^3, C_{Hi} is the upper concentration breakpoint for the AQI category, and C_{Lo} is the lower concentration breakpoint. Likewise, I_{Hi} is the upper AQI value for the category, and I_{Lo} is the lower AQI value. This formula maps $PM_{2.5}$ values to AQI categories based on EPA-defined thresholds. For instance, a concentration of 40 μg/m^3 falls within the *Unhealthy for Sensitive Groups* range and would correspond to an AQI value between 101 and 150. By applying this conversion to all recorded $PM_{2.5}$ values, the health implications of air quality across different shuttle routes can be clearly communicated and analyzed.

Source: U.S. EPA, 2016. Technical Assistance Document for the Reporting of Daily Air

Quality – the Air Quality Index (AQI).

Table 3.1: AQI Categories and $PM_{2.5}$ concentration breakpoints (U.S. EPA, 2023)

AQI Category	**AQI Range**	**$PM_{2.5}$ ($\mu g/m^3$)**	**Health Implications**
Good	0–50	0.0–12.0	Air quality is considered satisfactory
Moderate	51–100	12.1–35.4	Acceptable; pollutants may pose a moderate health concern
Unhealthy for Sensitive Groups	101–150	35.5–55.4	Sensitive individuals may experience health effects
Unhealthy	151–200	55.5–150.4	Everyone may begin to experience adverse effects
Very Unhealthy	201–300	150.5–250.4	Health alert; increased risk for everyone
Hazardous	301–500	250.5–500.4	Emergency conditions; serious health effects likely

CHAPTER 4
Results and Discussion

4.1 College Of Science, Casely Hayford and Commercial Area

$PM_{2.5}$ variation at these shuttle routes was looked at including its mean daily concentrations, mean hourly concentrations, hourly and daily regression of Temperature and Relative Humidity on $PM_{2.5}$ respectively. Mean daily and hourly concentrations of $PM_{2.5}$ are presented in **Fig 4.1** while hourly and daily regression of Relative Humidity and Temperature on $PM_{2.5}$ are also presented in **Fig 4.2**. From **Fig 4.1**, it was observed that $PM_{2.5}$ concentration peaked early in the morning around 07:45-08:00 with a concentration of 45.12 $\mu g/m^3$ and this was recorded at Casely Hayford, with the lowest concentration recorded at Commercial Area at 14:45-15:00 with a concentration of about 25.16 $\mu g/m^3$. $PM_{2.5}$ declined at 12 noon and it had a second peak from 15:15-17:00 thereabout. The variations in the concentration coincides with student schedules and activities that go on at campus. Early in the morning, there is a surge in traffic demand and a break point of it in the afternoon, and the surge increases again getting to the evenings. From **Fig 4.1**, it was observed that it was on Tuesday that two out of the three shuttle routes had the highest $PM_{2.5}$ concentration of 38.79 $\mu g/m^3$ and the lowest concentration of about 23.23 $\mu g/m^3$ recorded on Wednesday. The surge in the concentration could probably be due to the fact that Tuesday could be the day that there are tight student schedules and activities which could lead to high vehicular trafficking. From **Fig 4.2**, it was observed that $PM_{2.5}$ had a linear relationship with Temperature and Relative Humidity. The effect of Relative Humidity and Temperature on $PM_{2.5}$ were not that strong and it could be seen from the value of R^2, which generally shows the variation between the dependent variable and independent variable. The minimal effects could be due to the limited duration of the scope of our study which was done in three weeks.

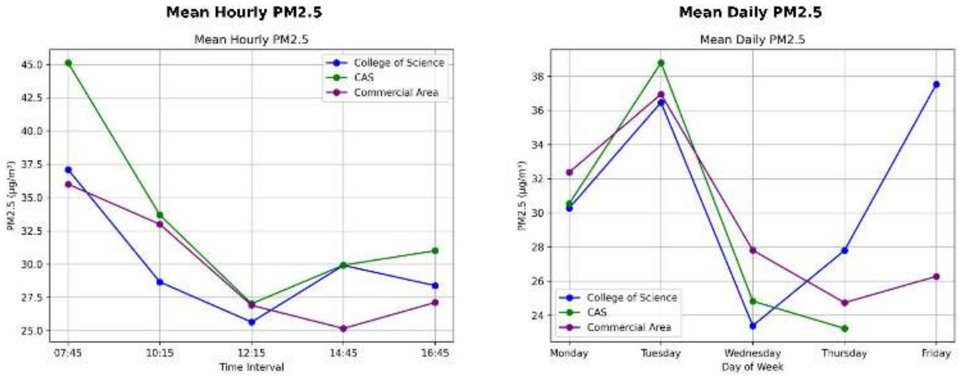

Fig 4.1 Mean hourly and daily concentrations of $PM_{2.5}$ at selected shuttle routes.

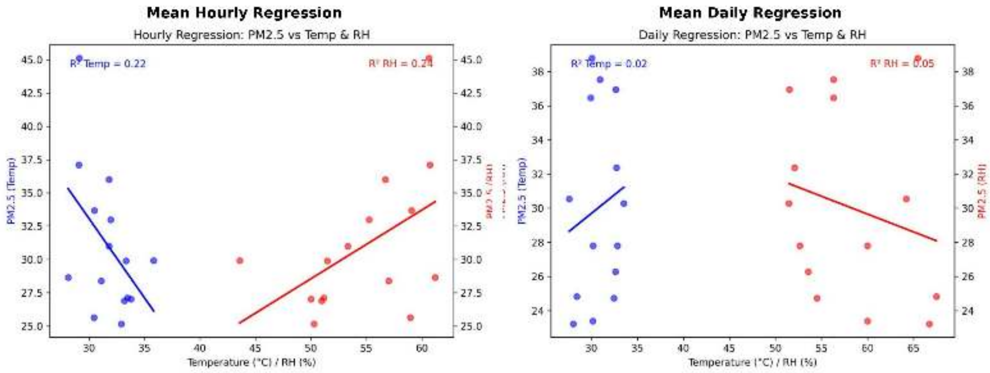

Fig 4.2 Mean hourly and daily regression of Temperature and Relative Humidity on $PM_{2.5}$.

4.2 KSB, Hall 7 and Agric junction

$PM_{2.5}$ variation at three other shuttle routes was looked at again including mean daily concentrations, mean hourly concentrations, hourly and daily regression of Temperature and Relative Humidity on $PM_{2.5}$ respectively. Mean daily and hourly concentrations of $PM_{2.5}$ are presented in **Fig 4.3** while hourly and daily regression of Relative Humidity and Temperature on $PM_{2.5}$ are also presented in **Fig 4.4**. From **Fig 4.3**, it was observed that there was a similar pattern of the variation in the hourly concentration of $PM_{2.5}$ with reference to what was observed in **Fig 4.1**. The highest concentration of $PM_{2.5}$ was recorded at Agric junction with a mean concentration of 45.98 μg/m^3 at 08:00-08:15. The lowest concentration was at Agric junction at 15:00-15:15 with a concentration of 23.62 μg/m^3. $PM_{2.5}$ also declined at 12 noon and it had a second peak from 15:15-17:00 thereabout. The variations in the concentration once again coincides with student schedules and activities that go on at campus. Early in the morning, there is a surge for vehicles and the surge increases again getting to the evenings. From **Fig 4.3**, it was observed again that it was on Tuesday that two out of the three shuttle routes had the highest $PM_{2.5}$ concentration of about 41.96 μg/m^3 and the lowest concentration was on Thursday with a concentration of 25.26 μg/m^3 . The surge in the concentration could again be probably due to the fact that Tuesday could be the day that there are tight student schedules and activities which could lead to high vehicular trafficking. From **Fig 4.4**, it was observed that $PM_{2.5}$ had a linear relationship with Temperature and Relative Humidity. The effect of Relative Humidity and Temperature on $PM_{2.5}$ was quite insignificant. This time around, R^2 values were almost insignificant indicating that the effect of these two major meteorological parameters on $PM_{2.5}$ were almost insignificant. The minimal effects again could be due to the limited duration of the scope of study which was done in three weeks.

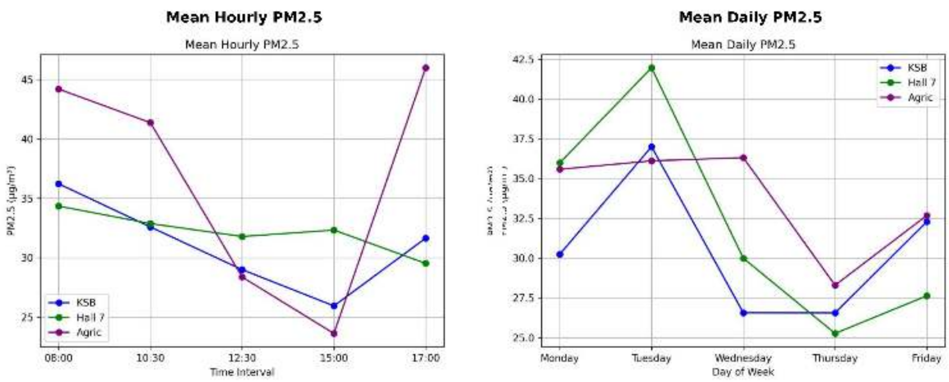

Fig 4.3 Mean hourly and daily concentrations of $PM_{2.5}$ at selected shuttle routes.

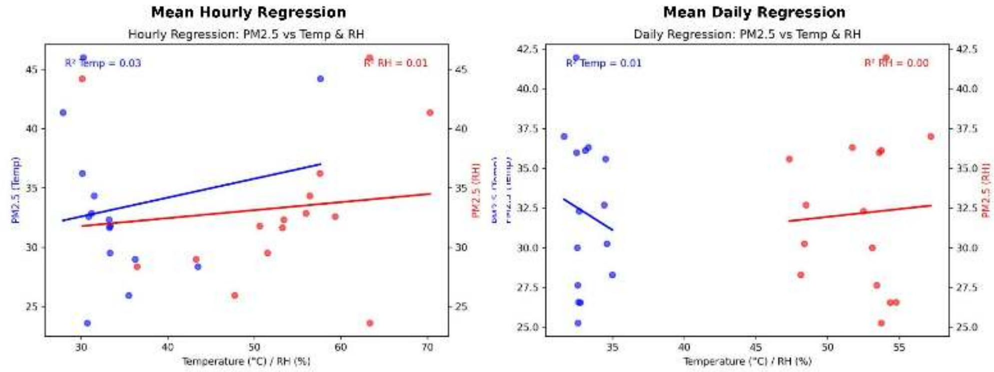

Fig 4.4 Mean hourly and daily regression of Temperature and Relative Humidity on $PM_{2.5}$.

$PM_{2.5}$ concentrations were mapped onto the six shuttle routes in terms of the mean daily concentrations across the six shuttle routes in order to identify some pollution hot spots. Agric junction turned out to be our pollution hot spot which had an average mean concentration of 33.79 $\mu g/m^3$. The next pollution hot spot was Hall 7 which also recorded mean concentration of 32.16 $\mu g/m^3$. The least polluted area was Casely Hayford route with mean concentration of 29.35 $\mu g/m^3$. For Agric junction, it might have experienced higher vehicular trafficking and increased population density which would probably enforce higher vehicular emissions. For Hall 7, at the time the data collection was being done, there were construction activities going on and probably this could have accounted for the amount of $PM_{2.5}$ concentration recorded at that route. Casely Hayford after having a strong peak in the early mornings did not have huge emissions along the route and this could possibly be the reason why it was the least polluted. All these factors and assumptions are only based on our scope of study and duration. The details of the spatial analysis is presented in **Fig 4.5**.

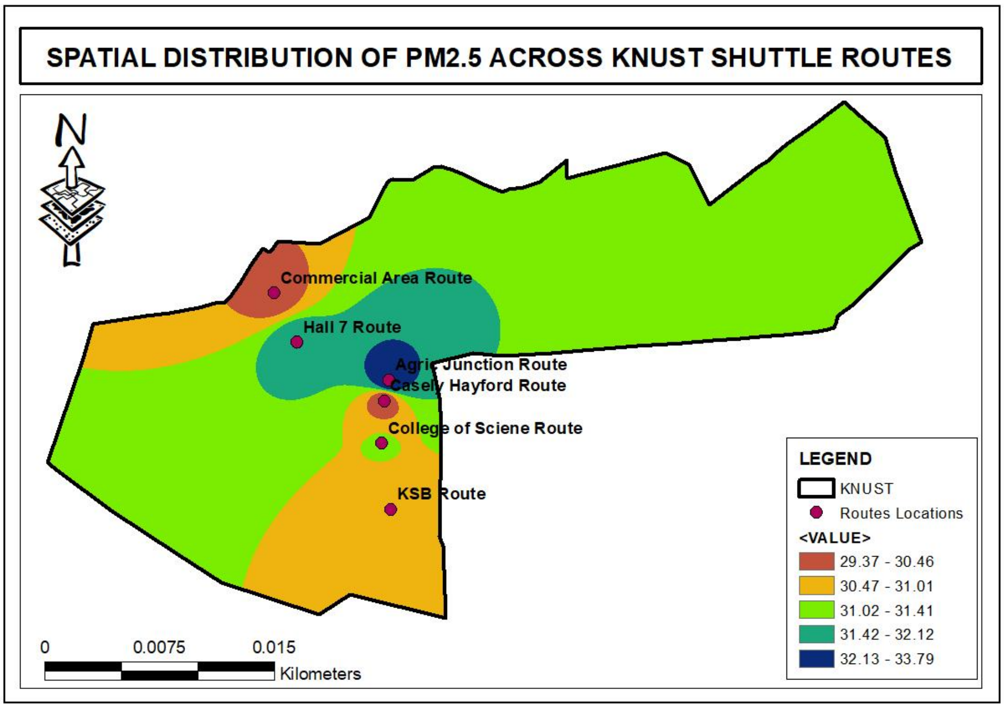

Fig 4.5 Spatial distribution of $PM_{2.5}$ across six shuttle routes.

4.3 AQI

Air Quality Index is a numerical scale that is used to measure the condition of the ambient air at a specific place and time. AQI was calculated across all the six shuttle routes using the EPA formula. It was observed that the average AQI was around 90 and AQI of 90 falls within the moderate range. It means there are 11 indexes away for the AQI to fall into the unhealthy for sensitive group range since the unhealthy for sensitive group range spans from 101-150. In just three weeks duration of this study, if the AQI is falling within the moderate range with an average of 90, then it calls for concern because what it means is that, if the study had been extended, it would have probably crossed the moderate range and this calls for concern. The details of the AQI is highlighted in **Fig 4.6**.

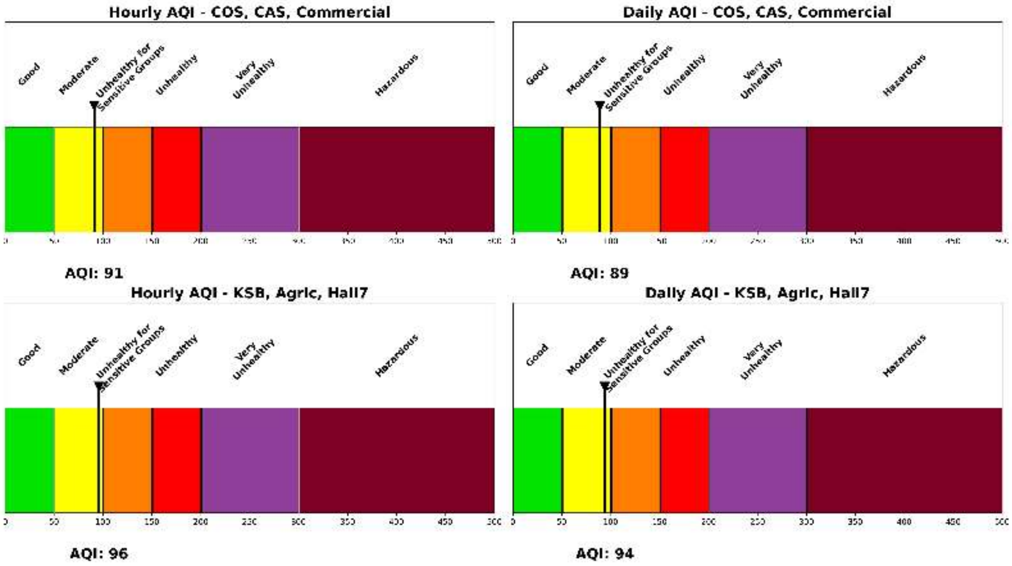

Fig 4.6 Air Quality across the six shuttle routes.

4.4 $PM_{2.5}$ Risk Matrix

We made an initial hypothesis from an observational study and it indicated that within thirty minutes of the rush hour, there is an approximate number of 459 people that commute at the shuttle routes. This approximate number of people are exposed to the effects of air pollutants and are unaware of the trends of air quality along the shuttle routes. Now, we wanted to know how exposed students, lecturers and others are exposed to the effects of $PM_{2.5}$ on both long term and short term basis. This was made with reference to EPA standards of 35 $\mu g/m^3$ for $PM_{2.5}$. It was observed that on the long term basis that is with the daily variation of $PM_{2.5}$, none of the shuttle routes had their concentration above the standard set by EPA. The hot spot which was Agric junction, was the one that nearly approached the standards set by EPA with mean concentration of 34 $\mu g/m^3$ which still tells the threat Agric junction carries. On short term basis, all the shuttle routes exceeded the EPA standard with the exception of Hall 7. The reason was that, in as much as there were construction activities ongoing at Hall 7 and it being the second most polluted in terms of the mean daily concentration, the emissions along the Hall 7 route were steady and were not really peaking to the higher levels compared to the other shuttle routes that had peaks at higher levels greater than that of the EPA. This confirms the initial hypothesis that; students, staff, non teaching staff etc are exposed to $PM_{2.5}$ within the rush hours and this knowledge is important for policy making and intervention.

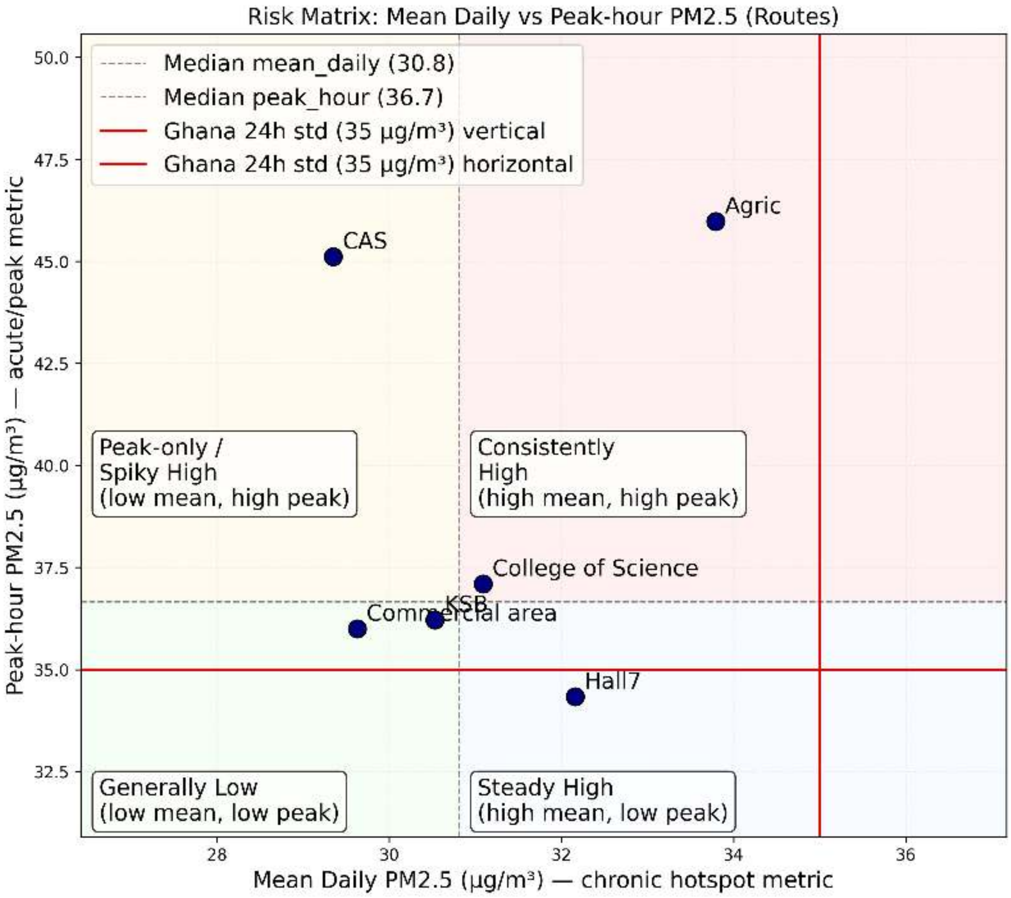

Fig 4.7 $PM_{2.5}$ risk matrix across six shuttle routes.

Table 4.1 and **Table 4.2** present the mean hourly concentration of $PM_{2.5}$ and mean daily concentration of $PM_{2.5}$ respectively. Due to inadequacy in the number of sensors, the shuttle routes had to be grouped into two. For the first set: College of Science, Casely Hayford and Commercial Area, the data collection was done 15 minutes before the rush to capture pollution profile of the $PM_{2.5}$ pollutant. For the second set: KSB, Hall 7 and Agric junction, the data collection was done 15 minutes right after the top of the rush hour. In all, three sensors were used for the data collection, one sensor was for two locations and a timestamp was used to differentiate the routes.

Table 4.1: Tabular description of mean hourly concentrations of $PM_{2.5}$

College of Science, Casely Hayford, Commercial Area (Mean Hourly)

Start_Time	Casely Hayford	College of Science	Commercial Area
07:45:00	45.12	37.1	36.0
10:15:00	33.68	28.65	32.99
12:15:00	27.02	25.64	26.9
14:45:00	29.92	29.9	25.16
16:45:00	31.0	28.38	27.11

KSB, Agric Junction, Hall 7 (Mean Hourly)

Start_Time	Agric Junction	Hall 7	KSB
08:00:00	44.19	34.34	36.22
10:30:00	41.36	32.87	32.58
12:30:00	28.37	31.78	28.99
15:00:00	23.62	32.32	25.94
17:00:00	45.98	29.52	31.64

Table 4.2: Tabular description of mean daily concentrations of $PM_{2.5}$

College of Science, Casely Hayford, Commercial Area (Mean Daily)

Day	Casely Hayford	College of Science	Commercial Area
Monday	30.54	30.28	32.38
Tuesday	38.79	36.47	36.95
Wednesday	24.83	23.39	27.81
Thursday	23.23	27.8	24.74
Friday	nan	37.53	26.28

KSB, Agric Junction, Hall 7 (Mean Daily)

Day	Agric Junction	Hall 7	KSB
Monday	35.58	35.98	30.24
Tuesday	36.11	41.96	37.0
Wednesday	36.31	29.99	26.56
Thursday	28.29	25.26	26.55
Friday	32.68	27.63	32.29

CHAPTER 5
Conclusion and Recommendations

5.1 Conclusion

The analysis of air quality patterns along the shuttle routes provided insight into the state of ambient air along the six shuttle routes that were chosen. The study utilized the use of the mobile LED low cost sensor in the data collection process. Although there were limited sensors, the sensor was able to measure $PM_{2.5}$, Temperature and Relative Humidity simultaneously. The results indicated an early peak of $PM_{2.5}$ concentrations early in the morning around 07:45-08:00 and a second peak later in the evening from 15:00-17:00 thereabout. The trend in $PM_{2.5}$ concentration aligns with student schedules and activities that operate within the university community. Mean hourly and daily concentrations of $PM_{2.5}$ were both assessed along the shuttle routes and most routes recorded peaks at 07:45-08:00 with the exception of Agric junction whose route recorded higher levels at 17:00-17:05 indicating huge traffic demand and increased population density within those hours. Most shuttle routes recorded higher levels on Tuesday and lower levels on Wednesday respectively. The effects of Temperature and Relative Humidity on the amount of $PM_{2.5}$ was quite minimial even though there was a linear relationship between $PM_{2.5}$ and these meteorological variables. The effect was clearly captured probably due to the limited scope of study. Agric junction was our pollution hot spot recording higher levels of $PM_{2.5}$ both hourly and daily. Casely Hayford was the least polluted due to a sharp decline in its peak at 07:45-08:00. AQI across all locations was seen to be in the moderate range though but there were some few concerns since it has few indexes to fall into the unhealthy for sensitive group range. It was deduced that students, staff and non teaching staff etc are exposed more to $PM_{2.5}$ on short term basis within the rush hours which calls for immediate policy making and interventions.

5.2 Recommendation

5.2.1 Recommendation for future studies

Based on the Air Quality Indexes that were recorded at the six shuttle routes within just three weeks of data collection, it is recommended that subsequent studies will extend the duration in order to capture seasonal and non seasonal variation of AQI at the shuttle routes in order to give a fair idea of AQI at these routes. It is also recommended that subsequent studies will purchase adequate sensors so that all the shuttle routes would be looked at since we were not able to capture all the routes. Subsequent studies should also look at trying to assess both $PM_{2.5}$ and some other gaseous pollutants like CO and NO_2 so that there will be a comprehensive study and information of air quality patterns along the shuttle routes of KNUST.

5.2.2 Recommendations for policy actions

The University Council and Management should consider constructing pedestrian walkways along the routes so that students will be encouraged to walk some distances to class because it is seen that some routes do not have walkways and so students are not encouraged to walk. The University authorities should also consider providing some sustainable transports like the use of bicycles which do not emit any pollutant into the atmosphere as a way to smoothen the movement of students within the university community. This even gives the students the opportunity to enjoy the beautiful scenery of the school by way of bicycling. Lastly, there should be creation of air quality clubs in various colleges that will raise and create awareness on air pollution and its health effects among students and the impact of the entire university community at large.

References

Abidin, M. Z., Mensah, K. A., Owusu, J. P., & Boateng, R. T. (2025). Epidemiological evidence of long-term $P_{2.5}$ exposure and mortality risks. International Journal of Public Health, 70, 11–23.

Afetey, J., & Lovely-Quao, A. (2023). IoT-based air monitoring in university environments. Sensors and Environment, 45(3), 210–225.

Ahlfeldt, G., & Pietrostefani, E. (2019). The global link between urban growth and air pollution. *Journal of Urban Economics*, 111, 103–121.

Ajayi, B., Mensah, F., & Boateng, P. (2023). Traffic-related air pollution and vulnerable populations. *Environmental Research and Public Health*, 20(5), 3300–3315.

Annesi-Maesano, I., Baiz, N., Banerjee, S., Rudnai, P., Schindler, C., & von Mutius, E. (2012). Air pollution and asthma in urban populations. *European Respiratory Journal*, 40, 1033–1044.

Apte, J. S., Marshall, J. D., Cohen, A. J., & Brauer, M. (2011). Air quality inside transport microenvironments. *Environmental Science & Technology*, 45(11), 4470–4476.

Ayetor, A. G. K., Kumi, N., & Amankwah, E. (2021). Traffic-related emissions and their impact on urban air quality. *Journal of Environmental Science and Pollution Research*, 28, 11245–11260.

Boateng, K. N. (2021). Baseline monitoring of $PM_{2.5}$ in Kumasi, Ghana. *Ghana Journal of Science*, 61(1), 55–72.

Borck, R., & Schrauth, P. (2021). Urban density, commuting, and pollution: A theoretical and empirical analysis. *Regional Science and Urban Economics*, 86, 103–118.

Brauer, M., Hoek, G., Van Vliet, P., Meliefste, K., Fischer, P., Gehring, U., Heinrich, J., &

Cyrys, J. (2012). Exposure to traffic-related air pollution and health effects. *Environmental Health Perspectives*, 120, 492–498.

Chen, Z., & Zhang, X. (2020). Policy interventions for reducing urban air pollution. *Journal of Cleaner Production*, 260, 120939.

De Silva, H. V. S. (n.d.). Time series [Lecture notes]. Department of Mathematics.

Dionisio, K. L., Howarth, D., Brauer, M., & Chillrud, S. N. (2010). Household exposures to traffic-related air pollution in Accra. *Journal of Exposure Science and Environmental Epidemiology*, 20, 438–448.

Gulia, S., Kamal, A., Mor, S., & Nagendra, S. (2015). Strategies for improving urban air quality through traffic management. *Science of the Total Environment*, 527–528, 225–235.

Gyamfi, S., Adusei, J., Owusu, E., & Kofi, A. (2022). Emission characteristics of diesel minibuses in Ghana. *African Journal of Environmental Management*, 10(3), 201–214.

Jacob, D. J. (1999). *Introduction to atmospheric chemistry*. Princeton University Press.

Jain, S., Kumar, P., Singh, R., & Gupta, A. (2021). Exposure to $PM_{2.5}$ in public transport systems. *Atmospheric Pollution Research*, 12(9), 101–115.

Kularatna, N., & Sudantha, B. H. (2008). An environmental air pollution monitoring system based on the IEEE 1451 standard for low-cost requirements. *Sensors and Actuators B: Chemical*, 134(1), 158–163.

Kumar, R., Sharma, A., & Gupta, S. (2024). Deployment of low-cost sensor networks for early-warning air pollution monitoring. *Sensors*, 24(2), 1550.

Kyere, R., Mensah, J., & Ofori, P. (2022). Local environmental factors and air quality at Takoradi Technical University. *African Journal of Environmental Science*, 14(2), 99–115.

Liao, H., Zhang, Y., & Chen, W. (2020). Global burden of disease attributable to ambient

$PM_{2.5}$. *Environmental Health Perspectives*, 128(9), 1–12.

Lin, T., Wang, H., Chen, Y., Li, J., & Zhou, Q. (2025). Bayesian networks and deep learning models for air pollution prediction. *Environmental Modelling & Software*, 160, 105–122.

Oduro, R., Asamoah, S., & Boateng, F. (2021). Environmental impacts of urban transport in Ghana. Journal of Transport and Health, 20, 101–118.

Rahman, M., Khan, S., & Ahmed, T. (2022). Household contributions to indoor and outdoor $PM_{2.5}$ in South Asia. Environmental Research Letters, 17, 095003.

Ramentol, E., Gonzalez, P., & Sanchez, J. (2023). Neural network models for short-term air quality forecasting. Atmospheric Environment, 295, 119423.

Sari, D., Putra, A., & Wibowo, F. (2022). Seasonal variability of $PM_{2.5}$ in Indonesia. Environmental Monitoring and Assessment, 194, 445.

Seinfeld, J. H., & Pandis, S. N. (2016). Atmospheric chemistry and physics: From air pollution to climate change (3rd ed.). Wiley.

Shabbir, M., Khan, R., Ali, S., & Ahmed, M. (2025). Evaluating the performance of low-cost air quality sensors: TSI BlueSky model 8143. Atmospheric Measurement Techniques, 18, 445–467.

Sicard, P., Agathokleous, E., De Marco, A., Paoletti, E., & Calatayud, V. (2021). Urban air pollution trends and impacts on human health. World Health Organization Report.

Snyder, E. G., Watkins, T. H., Solomon, P. A., Thoma, E. D., Williams, R. W., Hagler, G. S. W., Shelow, D., Hindin, D. A., Kilaru, V. J., & Preuss, P. W. (2013). The changing paradigm of air pollution monitoring. Environmental Science & Technology, 47(20), 11369–11377.

Stanaway, J. D., Afshin, A., Gakidou, E., Lim, S. S., Abate, K. H., Abate, D., Abbafati, C., Abbas, K. M., Abd-Allah, F., Abdulle, A. M., Abera, S. F., Aboyans, V., Abraham, B., Abreu, L. G., Abu-Rmeileh, N. M. E., Achoki, T., Alizadeh-Navaei, R., Alkerwi, A., Alla, F., & Allebeck, P. (2018). Global, regional, and national comparative risk assessment of 84 behavioral, environmental, occupational, and metabolic risks. The Lancet, 392, 1923–1994.

State of Global Air. (2022). Air quality data in Kumasi, Ghana. Health Effects Institute.

State of Global Air. (2024). Air quality and health in Ghana: Global burden of disease report. Health Effects Institute.

Uka, F. E., Owusu, D., Mensah, R., & Agyei, S. (2020). Air quality monitoring in Ghanaian urban areas: Challenges and prospects. Urban Climate, 32, 100590.

U.S. Environmental Protection Agency. (2016). Technical assistance document for the reporting of daily air quality – the air quality index (AQI). U.S. EPA.

World Bank. (2022). Clean air and urban planning in Africa: Policy perspectives. Washington, DC.

World Health Organization. (2021). Air quality guidelines: Global update 2021. WHO.

Zhang, Y., Li, X., Wang, H., Chen, Z., & Liu, J. (2020). Meteorological factors and air pollutant dispersion in East Asia. Science of the Total Environment, 729, 138–156.

Zhou, L., & Levy, J. I. (2007). Meteorological influences on pollutant dispersion. Atmospheric Chemistry and Physics, 7, 310–323.