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The Impact of Urban Green Spaces and Built Environments on Air Quality in Kampala City: A Comparative Analysis

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Abstract

Purpose: The study analyzed the multifaceted dynamics between green vegetated areas and built environments on air quality within Kampala City. Six (6) streets were sampled: - Nasser Lane, 6th Street, Namirembe Road, Owino Kafumbe- Mukasa, Makindu Close, and Nakasero Lane. Makindu Close and Nakasero Lane are known for green vegetation, 6th Street is known for buildings and industrial zones, while Namirembe Road and Owino Kafumbe- Mukasa are known for car parks.

Methodology: The survey used cross-sectional studies and quantitative approaches during data collection and analysis. The air quality parameters sampled included Particulate Matter (PM2.5 and PM10), Nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Carbon monoxide (CO) from various points within the city center.

Findings: Results showed that the 6th Street industrial area was the most polluted area of the city, with PM2.5, PM10, and NO2 exceeding the World Health Organization's (WHO) recommended 2021 Air Quality Guidelines (AQG) levels by 100%, 86.96% and 100%, respectively**.** Namirembe Road and Owino Kafumbe- Mukasa were also polluted with Carbon monoxide, Sulphur dioxide and Nitrogen dioxide. However, Owino Kafumbe-Mukasa's Carbon monoxide levels exceeded WHO's recommended Air Quality Guidelines (AQG) levels by 95.65%. Nkrumah-Nasser Lane and Nakasero Lane had mostly non-significant or less significant effects on pollutant levels. Makindu Close was less polluted; results indicated better air quality, especially with NO_2.

Unique Contribution to Theory, Policy and Practice: Increasing green vegetation within the city is thus recommended to improve air purity, as evidenced in the Makindu Close and Nakasero Lane analysis. This research demonstrates a clear inverse relationship between green cover and pollutant levels, offering empirical evidence to support the promotion of urban greening initiatives as a practical solution to air quality challenges in rapidly developing cities like Kampala.

Keywords: *World Health Organization, Air Quality Guidelines, Particulate Matter, Kampala Capital City Authority, Volatile Organic Compounds.*

Introduction

Urban areas globally face escalating challenges related to air quality, posing significant threats to public health and environmental sustainability (World Health Organization, 2016).

Uganda ranks among the top 25 of countries with the highest amount of Particulate Matter (PM), an airborne contaminant which negatively affects human health (IQ Air AirVisual, 2000). In 2019, Uganda scored third on the African continent for recording the highest and most dangerously polluted air, while Kampala registered a mean annual $PM_{2.5}$ concentration of 29.1 µg/m³, thus bouncing the capital to number 21 of the world's capitals with the unhealthiest air (Fuchs & Kasirye, 2020). The 2021 World Air Quality Report also listed the city as having filthy air five to seven times higher than the WHO annual recommended levels.

Cities like Kampala have higher levels of air pollution due to rapid urbanisation and shifting land use practices. (Ghaffarpasand,2024). Studies have found that the expansion of urban areas leads to higher concentrations of air pollutants, such as particulate matter (PM), nitrogen dioxide (NO2), and sulfur dioxide (SO2), due to increased vehicular traffic, industrial activities, and energy consumption (Zhang *et al.*, 2024). Air pollution is a pressing environmental issue in urban areas, posing significant risks to public health and the overall quality of life (Jonidi Jafari, Charkhloo and Pasalari, 2021). Chronic exposure to these pollutants can irritate the respiratory system, worsen asthma symptoms, and increase the risk of respiratory infections (Ninsiima *et al.*, 2022). Land use changes, such as deforestation, conversion of agricultural land to urban use, and the proliferation of informal settlements, exacerbate air pollution by reducing green spaces and increasing impervious surfaces (Dzierzanowski *et al.*, 2011).

Transportation-related emissions are also significant contributors to urban air pollution in Kampala and other cities in sub-Saharan Africa (Ghaffarpasand,2024). Studies have shown that the use of motor vehicles, particularly older, poorly maintained vehicles, is a significant source of air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) (Nguyen *et al.*, 2022). Inadequate public transportation infrastructure and reliance on informal modes of transportation, such as minibuses and motorcycles, contribute to traffic congestion and emissions in urban areas. (Janhäll, 2015).

Urbanisation, characterised by the growth of cities and increased industrial activities, has led to elevated levels of pollutants in the atmosphere, such as particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and carbon monoxide (CO) (Zhang *et al.*, 2024). These pollutants are primarily emitted from vehicles, power plants, and industrial facilities. (Wang and Tassinary, 2024).

While the potential of green vegetated areas in mitigating air pollution is acknowledged (Nowak *et al.*, 2018). There is a critical gap in understanding how various urban features, such as roads, buildings, and industrial zones, influence the correlation between green vegetated areas and air quality within cities. Existing research recognises the importance of green spaces in urban environments for air quality improvement (Dadvand *et al.*, 2015).

Literature Review

Dense urban environments with tall buildings can obstruct airflow, reducing ventilation and pollutant dispersion (Wu and Liu, 2023). This can result in the trapping of pollutants within street canyons, exacerbating local air quality issues (Janhäll, 2015). These features also affect the dispersion and deposition of pollutants in the atmosphere. Additionally, surfaces like buildings and roads can act as sinks for pollutants, causing deposition and accumulation over time (Müller *et al.*, 2020). Tall buildings can also change wind patterns and generate turbulence, influencing pollutants' transport and dispersion (Li *et al.*, 2023).

Urban areas with high traffic density, including car parks and congested roads, are significant sources of air pollution. Vehicle emissions contribute to the release of pollutants such as nitrogen oxides (NOx), particulate matter (PM), volatile organic compounds (VOCs), and carbon monoxide (CO) (Zhang,2024). These pollutants can accumulate near roadways, especially in areas with heavy traffic congestion (Dzierzanowski *et al.*, 2011). Urban areas with extensive impervious surfaces such as buildings, roads, and parking lots can experience the urban heat island effect. This phenomenon leads to higher temperatures than surrounding rural areas (Klemm *et al.*, 2015). Elevated temperatures can enhance the formation of secondary pollutants such as ground-level ozone (O3) through photochemical reactions involving precursor pollutants like NOx and VOCs (Nguyen *et al.*, 2022)

Industrial zones often contain manufacturing facilities, power plants, and other industrial sources that also emit pollutants into the atmosphere such as hazardous air pollutants (HAPs) in addition to those mentioned above (Kim *et al.*, 2021). Depending on the proximity of industrial zones to residential or commercial areas, these emissions can significantly impact local air quality and public health (Hirabayashi, Kroll and Nowak, 2011). Prolonged exposure to PM, especially fine particles (PM2.5 and PM10), can cause respiratory and cardiovascular issues by penetrating deeply into the lungs and entering the bloodstream (Wang and Tassinary, 2024). Parks, urban woodlands, and gardens are green spaces with various health and environmental benefits. (Nowak, Hirabayashi and Bodine, 2013). Vegetation helps mitigate air pollution through

absorption, deposition, and filtration. Plants can capture airborne pollutants, including PM and gases, through their leaves and roots, improving local air quality (Gawronska *et al.*, 2012). Additionally, green areas enhance biodiversity, provide habitat for wildlife, reduce urban heat island effects, and contribute to overall aesthetics and well-being. There is many health benefits associated with having access to green places. Reduced stress, better mental health, more excellent cognitive function, and higher physical activity levels have all been linked to spending time in nature or close to green spaces. (Ottosen and Kumar, 2020). Green spaces can serve as areas for recreation, relaxation, and social interaction, promoting overall well-being and quality of life for urban residents (McKenzie Karen, Murray Aja and Booth Tom, 2013)

Because they lower pollutant concentrations and provide cleaner air, green, vegetated spaces in cities can help lessen the negative health impacts of air pollution. (Kiss *et al.*, 2015). By lowering pollutant concentrations and supplying cleaner air, green vegetation spaces in cities might lessen the harmful health consequences of air pollution (Hongshan,2023). Green areas reduce the incidence of pollution-related illnesses and promote respiratory health (Ninsiima *et al.*, 2022). Additionally, spending time in green places has physiological and psychological benefits that can help people become more resilient and cope with the detrimental effects of air pollution. Green infrastructure must be integrated into urban planning and design for healthier, more sustainable cities. (Klemm *et al.*, 2015). Policymakers can prioritise preserving and expanding green spaces, promoting green building practices, and encouraging urban forestry initiatives to enhance air quality and public health (Giedych & Maksymiuk, 2017). Governmental institutions, urban planners, environmental groups, and community members must work together to adopt laws and initiatives that effectively address air pollution and the availability of green, vegetated city areas. (Jonidi *et al.*, 2021).

Table 1. World Health Organization's Recommended AQG levels

Pollutant	**Average Time**	**2021 AQGs**
$PM_{2.5}$ µg/m3	Annual	5
	24- hours	15
PM_{10} µg/m3	Annual	15
	24- hours	45
Nitrogen dioxide NO_2 µg/m3	Annual	10
	24- hours	25
Sulfurdioxide SO_2 µg/m3	24- hours	40
Carbon monoxide (CO) mg/m3	24- hours	4

Source: WHO Global Air Quality Guidelines, 2021

Study area

The study focused on Kampala Capital City of Uganda, from which six streets were sampled and these included: - Nasser Lane, 6th Street Industrial area, Namirembe Road, Owino Kafumbe-Mukasa, Makindu Close and Nakasero Lane

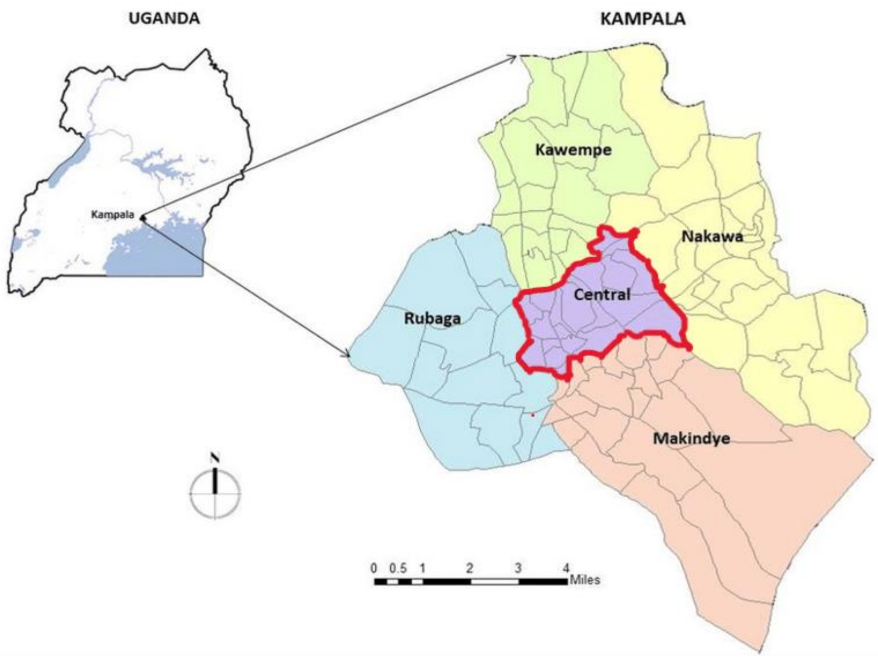

Figure 1: Five divisions of Kampala, the Capital City of Uganda, from which the highlighted central division was considered.

Makindu Close and Nakasero Lane are known for green vegetation, 6th Street Industrial area is known for buildings and industrial zones while Namirembe Road and Owino Kafumbe- Mukasa are known for car parks. From each street, samples were taken 3 times a day (Morning, Midday and Afternoon) for 7 days. The sampling frequency of every spot was thus 21 times. These samples were used to obtain the quantitative data required for this research

The air quality variables under review were Particulate Matter (PM), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2), and Ccarbon monoxide (CO).

Methodology

Cross-sectional studies were employed in the survey. Sampling, data collecting, quality control, and analysis all used quantitative methods. Air quality monitors were used in the quantitative design throughout the data collection phase. While inferential statistics was used to make assumptions, test hypotheses, or make predictions about a population based on a sample, descriptive statistics was used in this study to characterise and summarize the key elements of a data set obtained.

Data Collection and Measurement of Variables

Ambient gaseous emissions

Levels of ambient gaseous emissions were measured using the Gas Monitor type "Aeroqual M 500Series" with sensor detectors for the targeted gases and an MX6 iBrid serial number 2112IUM-001 gas detector, following the recommended equipment manufacturer's operational methods.

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Parameters that were measured include Carbon monoxide (CO), Sulphur dioxide (SO_2), and Nitrogen dioxide (NO_2).

Particulate Matter (PM_{10} and $PM_{2.5}$)

Levels were determined using a hand-held instrument known as portable dust Sensor (BRAMC BR-SMART-128SE). Particulate Matter assessment was carried out on at selected points. The portable handheld particulate matter instrument was used to carry out the assessment. This instrument operates by using a modulated beam of infra- red light which is projected into a measurement chamber. The instrument offers four real time measurement ranges and for purposes of this report and sensitivity of the project its expected output we used a range of 001-999 µg/m^3 Ranges used for measurement of particulate matter.

During the sampling, the equipment was fixed at a breathing height above the ground for PM_{10} & $PM_{2.5}$ determination in all selected monitoring stations. The instruments offer real time measurement ranges. The instruments were connected to power, switched on and placed at a height of 1.5 meters above ground level where there is free movement of air particles and the equipment collects the air by diffusion and analyses it using infrared radiation and gives the readings which are noted on field data collection forms.

The monitoring stations were along the selected roads. At each station, a convenient point without disturbance from human activities and vehicles was chosen, and the equipment was set up ready for the monitoring. The monitoring was done for 15 minutes using calibrated equipment, and averages of the results at the stop of the run were recorded.

Findings and Discussion

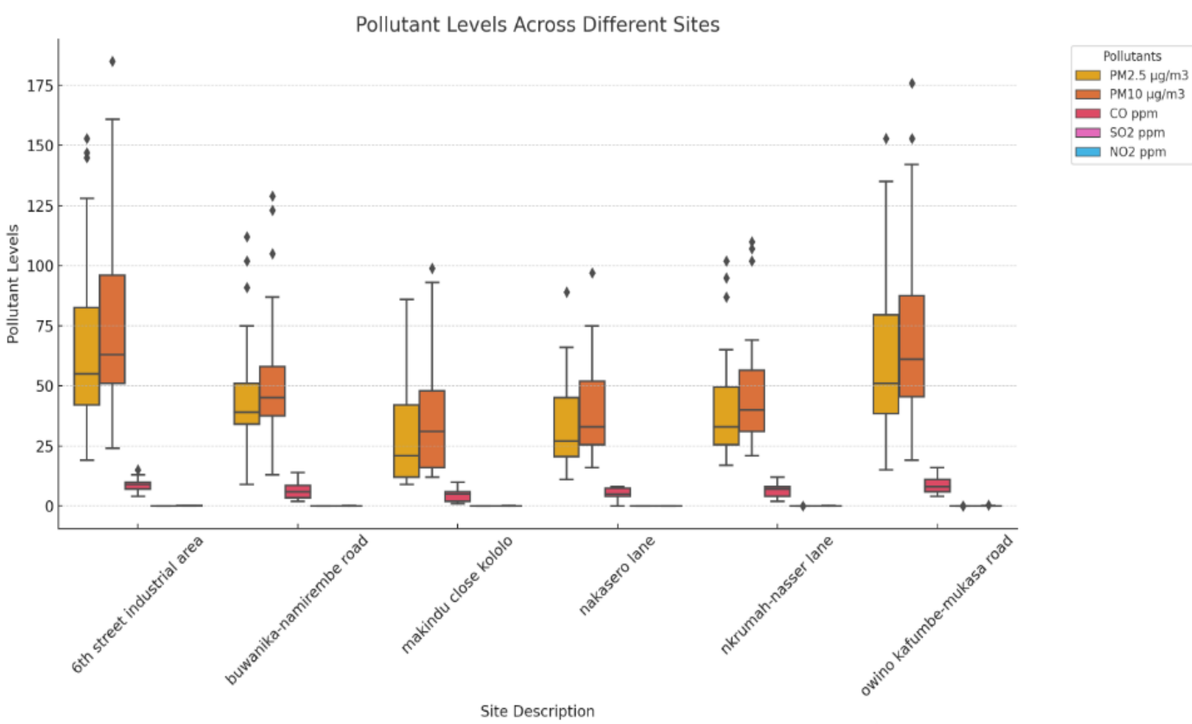

Figure 2: Average Pollutant Levels by Site

The box plot illustrates each site's influence on specific pollutants, showing how different locations contribute to the levels of $PM_{2.5}$, PM_{10}, CO, SO_2, and NO_2. 6th Street Industrial Area shows higher levels for most pollutants, indicating a higher air pollution concentration. Makindu Close Kololo and Nakasero Lane generally show lower levels of pollutants, suggesting relatively better air quality. The spread of the pollutant levels (indicated by the width of the boxes) suggests variability in air quality across sites, with some sites showing a broader range in concentrations. A regression analysis was also conducted to explain how each site influences different pollutants, and the following was observed.

Observations

Areas with urban features such as buildings, car parks and industrial zones were Owino Kafumbe-Mukasa Road, 6th Street Industrial Area, Buwanika-Namirembe Road and Nasser Lane. The P-values for 6th Street Industrial Area and Owino Kafumbe-Mukasa Road were all less than 0.05 for most of the parameters such as Particulate matter (PM), Carbon monoxide (CO), Nitrogen dioxide (NO2) and Sulfur dioxide (SO2). This confirmed a positive relationship between Urban Features and Air Quality

6th Street Industrial Area has a significant favourable influence on all pollutants, particularly NO_2 (Coefficient = 0.061, $p < 0.001$) and SO_2 (Coefficient = 0.0036, $p = 0.002$).

Owino Kafumbe-Mukasa Road showed a significant positive influence on all pollutants except for SO_2, (Coefficient = 0.0016, $p < 0.001$) where it is slightly less impactful.

Makindu Close Kololo showed a negative influence, indicating better air quality, especially with NO_2 (Coefficient = -0.020, $p = 0.04$) and CO (Coefficient = -1.28, $p = 0.02$)

Buwanika-Namirembe Road showed a significant positive influence only on NO_2 (Coefficient = 0.0055, $p = 0.58$).

Nkrumah-Nasser Lane and Nakasero Lane had mostly non-significant or less significant effects on pollutant levels.

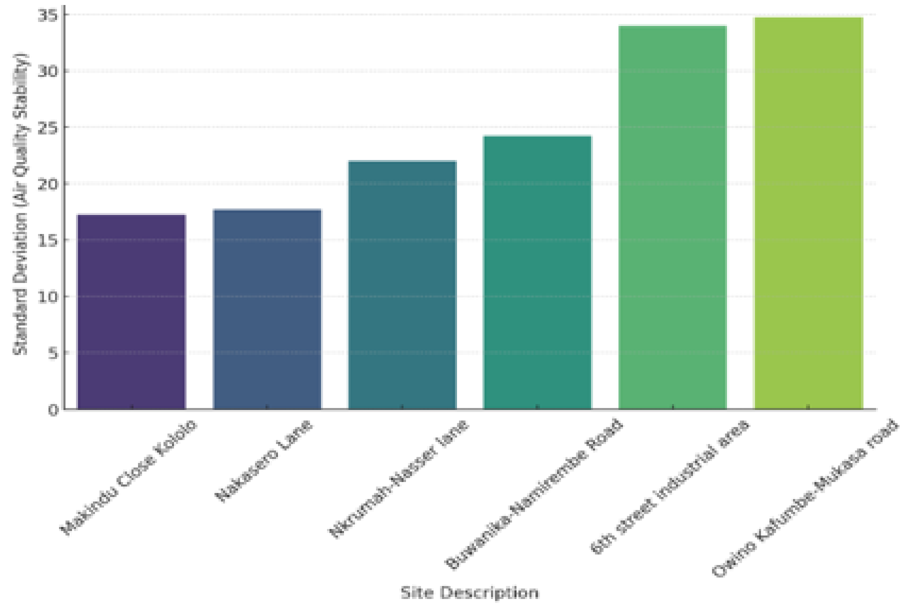

Figure 3: Air Quality Stability Across Different Sites

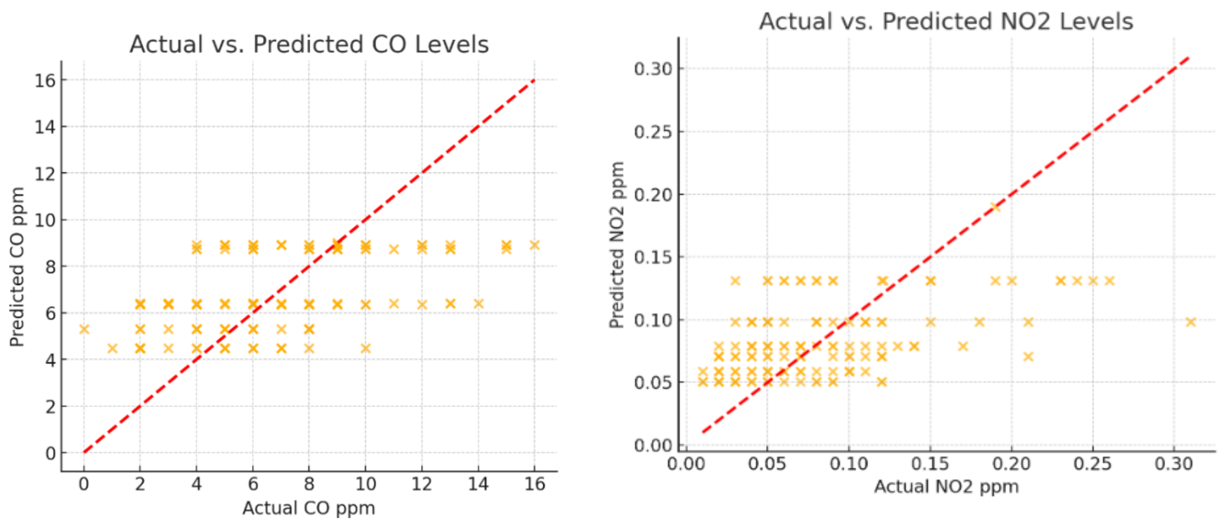

Figure 4: Regression results for CO and NO_2 Levels

Interpretation

CO levels: The plots indicate how well the regression model captures CO levels across different sites.

NO_2 Levels: The actual vs. predicted plot shows better alignment, especially for mid-range values.

Table 2: Air Quality Exceedances vs WHO's recommended AQG levels Across Sites

Pollutant	Value Used for Comparison	Site with Highest Exceedance	Exceedance Rate (%)
$PM_{2.5}$	15 µg/m³	6th Street Industrial Area	100
PM_{10}	45 µg/m³	6th Street Industrial Area	86.96
CO	4 ppm	Owino Kafumbe-Mukasa Road	95.65
SO_2	0.04 ppm	No sites exceed WHO standards for SO_2	0
NO_2	0.025 ppm	6th Street Industrial Area	100

Discussion of results

Makindu Close and Nakasero Lane are known for green vegetation, results show that these sites are less polluted and thus, results resonate with Sillars-Powell, Tallis and Fowler, 2020 whose research concluded that Vegetation, particularly trees and shrubs with dense foliage, can act as natural filters, capturing airborne particulate matter such as dust, pollen, and pollutants

6th Street is known for its buildings and industrial zones. Results show that this was the most polluted area of the city, with PM2.5, PM10 and NO2 exceeding WHO's recommended AQG levels by 100%, 86.96 and 100%, respectively**.** According to Wu and Liu, 2023, Dense urban environments with tall buildings can obstruct airflow, reducing ventilation and pollutant dispersion. This can result in the trapping of pollutants within street canyons, exacerbating local air quality issues. This partly explains the levels of pollution within this area. It was also noted that road maintenance works along this street may have partly contributed to the higher levels of particulate matter.

Namirembe Road and Owino Kafumbe Mukasa were also polluted with gases such as carbon monoxide, Sulphur dioxide, and Nitrogen dioxide, with Owino Kafumbe Mukasa's Carbon monoxide levels exceeding WHO's recommended AQG levels by 95.65%. These areas are surrounded by car parks (Kisenyi Bus Terminal and New Tax Park). In Kampala and other sub-Saharan African cities, transportation-related emissions constitute a significant source of urban air pollution (Ghaffarpasand, 2024).

General Concluding Remarks

NO_2 and $PM_{2.5}$ levels frequently exceeded WHO's recommended AQG levels across multiple sites, indicating a widespread issue with vehicular emissions or combustion-related pollution. SO_2 levels were below WHO's recommended AQG levels at all sites, suggesting that sulfur dioxide may not be a significant pollutant in these areas, possibly due to lower industrial emissions of this specific gas. CO levels show notable exceedances at several sites, reflecting possible emissions from traffic.

Ongoing interventions

The government has embarked on strategies to improve public transportation systems in Kampala to reduce vehicular emissions and traffic congestion. This includes investments in modernising public transit infrastructure, expanding public transportation networks, and promoting cleaner and more fuel-efficient vehicles such as buses (Kayoola Buses). The city's greening is also ongoing to ensure that the population of carbon sinks is enhanced along the various streets within the different divisions.

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