ASSESSMENT OF AIR QUALITY IN CITY CENTERS AND PARKS IN BENIN CITY, EDO STATE NIGERIA.

BY

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CERTIFICATION

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DEDICATION

I dedicate this project to GOD ALMIGHTY, the SOVEREIGN and SUPREME, who by his protection and guidance saw me throughout my tenure in the University of Benin, and made it all possible to bring this project to reality, by His divine wisdom, knowledge and understanding.

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ABSTRACT

This study assesses the critical influence of environmental and human-related factors on air pollutant concentrations across five major urban centers in Benin City, specifically comparing city centers with their adjacent public transport parks. Urban environments characterized by high human traffic density, stationary or slow-moving commercial vehicles, and concentrated emissions have raised serious concerns about ambient air quality and its resulting health impacts. Hence, this research aimed to localize the understanding of air quality dynamics in these environments. Portable air quality sensors were deployed to measure key criteria pollutants including Fine Particulate matter ($PM_{2.5}$), Coarse Particulate matter (PM_{10}), Carbon monoxide (CO), Ground-level Ozone (O_3), and Volatile Organic Compounds (VOCs), alongside meteorological factors like relative humidity and temperature. Data was collected at varying periods and days to capture temporal variations and observe trends associated with human activities and traffic conditions.

The outcome of the analysis revealed that Particulate Matter is the dominant air quality challenge, with all ten monitored sites recording dangerously high levels. Average concentrations of $PM_{2.5}$ across the sites ranged from 57.0 µg/m³ in the City Center locations to 100.4 µg/m³ in the Motor Parks, demonstrating that all areas significantly exceed the 24-hour guidelines set by both the WHO and NESREA. Motor parks consistently served as acute pollution hotspots, exhibiting PM concentrations between 40 and 76 percent higher than their city center counterparts. The most critical finding was at Oluku Motor Park, which recorded the highest average PM_{10} concentration at 154.6 µg/m³, placing it in direct violation of the national standard. This extreme localized pollution is driven by vehicle exhaust, which is reflected in Carbon Monoxide levels that were consistently 87 percent to 142 percent higher in the motor

parks compared to the city centers. The Air Quality Index (AQI) classification for all locations was determined to be "Unhealthy" or "Very Unhealthy". Overall, this research provides essential data that underscores the immediate need for improved public health protection and informed urban planning strategies aimed at mitigating vehicle-sourced pollution in these high-exposure zones.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ACRONYMS

Acronym	Meaning
AAS	Atomic Absorption Spectrophotometry
AQI	Air Quality Index
APTI	Air Pollution Tolerance Index
APHA	American Public Health Association
BP	Breakpoint
CO	Carbon Monoxide
CPCB	Central Pollution Control Board
EPA	Environmental Protection Agency
EU	European Union
NESREA	National Environmental Standards and Regulations Enforcement Agency
NO_2	Nitrogen Dioxide
NAAQS	National Ambient Air Quality Standards
O_3	Ozone

Acronym	Meaning
PM	Particulate Matter
PM2.5	Particulate Matter with diameter ≤2.5 micrometers
PM10	Particulate Matter with diameter ≤10 micrometers
PLI	Pollution Load Index
RfC	Reference Concentration
SO_2	Sulfur Dioxide
TVOCs	Total Volatile Organic Compounds
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Air pollution is increasingly recognized as one of the most critical environmental issues in urban areas, particularly in developing nations like Nigeria. In rapidly growing cities such as Benin City, Edo State, the expansion of urban populations, vehicular traffic, and public transport systems has led to a rise in ambient air pollutant concentrations. Public transport parks (or bus stations) and city centers are significant sources of pollution due to constant human and vehicular activity. These locations act as hubs of daily urban congestion, with buses idling, passengers moving, and vendors clustering in limited spaces (Adewoyin et al., 2022).

In recent decades, Benin City, the capital of Edo State, has undergone substantial urban growth, which has caused an expansion that has led to increased anthropogenic activities, including particularly, transportation, industrial operations, and residential developments. It is only logical to think that all of the afore mentioned development contributed to elevated levels of air pollutants such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), HCHO and volatile organic compounds (VOCs), (Ukpebor et al., 2021). These pollutants pose serious health risks, including respiratory and cardiovascular diseases, and have been linked to increased mortality rates (World Health Organization [WHO], 2006).

While studies on air quality in parks (green spaces) have highlighted vegetation's mitigating impact on air pollution (Fuller et al., 2007), public transport parks are typically concrete-dominated zones with minimal environmental buffers. These areas are likely to exhibit high levels of pollutants such as particulate matter (PM2.5, PM10), nitrogen dioxide (NO_2), carbon monoxide (CO), volatile organic compounds (VOCs), and sulfur dioxide (SO_2), primarily from diesel- and petrol-powered vehicles (Ukpebor et al., 2021).

This study seeks to investigate air quality in selected city centers and their respective nearby public transport parks in Benin City. The research aims to provide localized data on pollution exposure levels in these high-activity areas and make comparative assessments that could guide future urban planning and environmental control strategies.

1.2 Statement of the Problem

There is growing concern over the quality of air inhaled by the urban population in Benin City, particularly in zones of intense human and vehicular activity. While a few studies have assessed general urban air quality, there is limited data specific to public transport parks—a location where thousands of commuters gather daily. These parks, often adjacent to or embedded within city centers, may exhibit worse air quality than their surrounding areas due to the concentration of idling vehicles and confined activity spaces (Ezeh et al., 2020). This research fills the gap by directly comparing pollutant levels between city centers and transport parks.

1.3 Aim and Objectives

The main aim of this study is to:

Assess and compare ambient air quality in selected city centers and public transport parks in Benin City.

The specific objectives are:

1. To measure and analyze concentrations of key air pollutants (PM2.5, PM10, CO, CO_2, O_3, HCHO and VOCs) in selected city centers and parks.

2. To analyze the temporal variations of these pollutants across different days of the week.

3. To determine the influence of vehicular density and activity patterns on air pollution levels.

4. To compare the air quality in city centers with their respective transport parks.

5. To evaluate the results against national (NESREA) and international (WHO) air quality standards and provide public health recommendations.

1.4 Scope of the Study

This study is limited to ten major sites within Benin City: 5 busy city centers (e.g., Ring Road, New Benin, Uselu, Ugbowo and Oluku) and two corresponding nearby public transport parks (e.g., Benin Central Park, New Benin Motor Park, Uselu Motor Park, Ugbowo Motor park and Oluku Motor Park).

Data was collected using portable air quality sensors and filter-based sampling, focusing on major pollutants associated with vehicle emissions. Measurements were be taken during both weekdays and weekends, across different periods of the day. The research involved the use of portable air quality sensors to measure concentrations of PM2.5, PM10, CO, CO_2, O_3, HCHO, VOCs and noise levels. Meteorological parameters, including temperature and relative humidity, were recorded. Date was collected at different times of the day (morning, afternoon, and evening) and on different days of the week to capture temporal variations. All parameters were compared to certain standards such as: WHO, 2021 – Global Air Quality Guidelines, for Academic and international relevance; and NESREA – Nigerian National Environmental (Air Quality Control) Regulations, 2014. for the sake of local compliance and policy recommendations.

1.5 Justification of the Study

Transport parks are critical nodes in the urban transportation system but are often overlooked in environmental monitoring efforts. Daily exposure to pollutants in these parks affects thousands of commuters, drivers, and traders. This study is relevant because it focuses on previously underrepresented high-risk locations and compares them to city centers, which are already known for heavy pollution. The findings from this study provided valuable insights into the temporal distribution of air pollutants in Benin City, highlighting city centers and parks, areas with observed to have critical pollution levels. This will prove helpful in support urban health initiatives and policy planning.

This information is will also help urban planners, environmental health professionals, and policymakers to develop targeted and more informed interventions aimed at reducing air pollution, thereby protecting public health more effectively. Furthermore, this study will contribute to the limited body of literature on air quality in Nigerian cities. It will also serve as a reference for future research and policy development.

CHAPTER TWO

LITERATURE REVIEW

Air pollution is one of the most critical environmental challenges facing urban centers globally, with implications for public health, environmental quality, and urban planning. Rapid urbanization, population growth, industrial expansion, and an upsurge in vehicular usage have collectively intensified the levels of air pollutants in cities, especially in developing countries such as Nigeria (Ezeh et al., 2020). Urban residents are increasingly being exposed to harmful pollutants such as fine and coarse particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), ground-level ozone (O_3) and volatile organic compounds (VOCs). These pollutants are known to be detrimental to human health, contributing to respiratory diseases, cardiovascular disorders, cancer, and premature death (WHO, 2021).

Numerous studies have been conducted on air quality in urban areas in Nigeria, including Lagos, Abuja, and Port Harcourt (Adewoyin et al., 2022; Owoade et al., 2013), but much of the existing research tends to focus on industrial zones or heavily trafficked highways, not placing enough emphasis on the comparative differences between diverse urban environments such as city centers and public transport parks.

Furthermore, many of the studies conducted in Nigerian urban areas either lack temporal granularity or ignore the influence of meteorological parameters such as wind speed, temperature, and humidity, which affect pollutant transport and dispersion (Ukpebor et al., 2021). Moreover, noise pollution—another significant urban pollutant—has often been excluded from air quality assessments, despite its growing recognition as a health hazard, especially in densely populated environments (WHO, 2018).

Another key limitation in prior research is the insufficient use of modern, portable air quality monitoring devices, which allow for high-frequency, on-site, and real-time data acquisition. Traditional studies have often relied on stationary monitors or estimations based on limited sampling, which may not capture the temporal variations in pollutant concentrations, especially those influenced by short-term human activities (Abam and Unachukwu, 2009).

This study seeks to fill these knowledge gaps by providing a comparative assessment of air quality in city centers and publc transport parks in Benin City. It will consider both human activities (e.g., stationary and slow moving vehicles, traffic congestion, high population and human traffic density, commercial activities, environmental pollution and indiscriminate waste disposal.) and environmental features (e.g., concrete and bitumen works, Inadequate urban infrastructure.). It will also integrate meteorological factors and using modern portable sensors for real-time monitoring. By including and noise levels to enlarge the array of pollutants, this research provides a more holistic understanding of air quality dynamics. This study will also explore daily and weekly variations in pollutant levels, a dimension that has been sparsely addressed in the existing Nigerian literature.

The insights from this study are expected to support urban environmental planning and policy making, promote public health, and contribute to the growing body of knowledge on sustainable urban development in sub-Saharan Africa.

2.1 Air Quality

Air quality refers to the physical and chemical characteristics of air within a specific environment, in relation to the presence and concentration of pollutants that can affect human health, ecosystems, and overall environmental sustainability. It is a measure of the cleanliness or pollution level of the air and is typically determined by assessing the concentrations of various air pollutants in relation to established health and environmental standards (Gulia et al., 2015). Poor air quality is often characterized by elevated levels of harmful substances such as fine and coarse particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ground-level ozone (O_3), and volatile organic compounds (VOCs).

These pollutants originate from a variety of anthropogenic* sources including vehicular emissions, industrial activities, burning of fossil fuels, construction activities; and natural sources like dust storms (Kampa and Castanas, 2008).

2.2 Health Implications

According to the World Health Organization (WHO, 2021), exposure to these pollutants can lead to a wide range of health problems, including respiratory infections, asthma, lung cancer, cardiovascular diseases, stroke, and even premature mortality. Moreover, long-term exposure to air pollutants poses more threat to vulnerable populations such as children, the elderly, and individuals with pre-existing health conditions (WHO, 2021; Schraufnagel et al., 2019).

In addition to human health, poor air quality also affects visibility, contributes to climate change, and can damage buildings, crops, and aquatic systems (Dominici et al., 2006). Understanding and monitoring air quality is thus essential for effective environmental management, public health protection, and sustainable urban planning.

A recent study highlighted the impact of air pollution on visibility in Benin City. The research indicated that during periods of high particulate matter concentrations, particularly PM2.5 and PM10, there was a noticeable reduction in visibility across the city. This was attributed to emissions from vehicular traffic, industrial activities, and other anthropogenic sources (Ukpebor et al., 2021).

In the course of this research, a survey was conducted at random bus stops along the Benin-Lagos road express-way. Responses from residents along the express way and even drivers of commercial and private vehicles a tested to the fact that sometime in the year 2023, within the months of November and January 2024, there was an observable intense reduction in visibility across the metropolis. Residents described it a heavy and dirt smoky looking for which was obviously not dew related. It was stated that the situation was so intense that some thought it to be a chemical attack in the area. This could be traced to intense air pollution from vehicular emissions.

2.3 Health Hazards and Threats Posed by Poor Air Quality in Benin City

2.3.1 Respiratory Health Effects

Exposure to elevated levels of air pollutants can lead to respiratory issues, including:

Asthma and Bronchitis: Fine particulate matter (PM2.5) can penetrate deep into the lungs, exacerbating asthma and bronchitis symptoms. A study in Benin City observed higher concentrations of PM2.5 during the dry season, correlating with increased respiratory complaints (Ukpebor et al., 2021).

Chronic Obstructive Pulmonary Disease (COPD): Long-term exposure to pollutants like NO_2 and SO_2 can contribute to the development of COPD, characterized by persistent respiratory symptoms and airflow limitation (Kampa & Castanas, 2008).

2.3.2 Cardiovascular Health Effects

Air pollution has been associated with cardiovascular diseases:

Heart Attacks and Strokes: Inhalation of fine particles can lead to systemic inflammation, increasing the risk of heart attacks and strokes. The World Health Organization (WHO) reports that air pollution contributes to approximately 25% of all heart disease-related deaths globally (WHO, 2021).

2.3.3 Neurological Effects

Emerging evidence suggests that air pollution may impact neurological health:

Cognitive Decline: Chronic exposure to air pollutants has been linked to cognitive decline and increased risk of neurodegenerative diseases such as Alzheimer's and Parkinson's disease (Schraufnagel et al., 2019).

2.3.4 Reproductive and Developmental Effects

Air pollution can adversely affect reproductive health and fetal development:

Low Birth Weight and Preterm Birth: Pregnant women exposed to high levels of air pollution are at increased risk of delivering low birth weight or preterm infants. A study in Nigeria highlighted the association between ambient air pollution and adverse birth outcomes (Gulia et al., 2015).

2.3.5 Cancer Risk

Certain air pollutants are known carcinogens:

Lung Cancer: Prolonged exposure to pollutants like benzene, a VOC, and fine particulate matter increases the risk of lung cancer. Industrial emissions and vehicular exhaust in Benin City contribute to the presence of these carcinogens in the air (Ukpebor et al., 2021).

2.3.6 Vulnerable Populations

Certain groups are more susceptible to the health effects of air pollution:

Children and the Elderly: Children have developing respiratory systems, making them more vulnerable to air pollutants. The elderly may have pre-existing health conditions that can be exacerbated by poor air quality (WHO, 2021).

The health hazards associated with poor air quality in Benin City are multifaceted, affecting respiratory, cardiovascular, neurological, and reproductive health.

2.4 Key Air Pollutants in Urban Areas

Particulate Matter (PM2.5 and PM10): These are tiny particles suspended in the air. PM2.5 refers to particles with diameters less than 2.5 micrometers, while PM10 includes particles up to 10 micrometers. They can penetrate deep into the lungs and bloodstream, causing health problems (WHO, 2021).

Nitrogen Dioxide (NO_2): Produced mainly from vehicle emissions and industrial processes, NO_2 can irritate airways and exacerbate respiratory diseases (WHO, 2021).

Sulfur Dioxide (SO_2): Emitted from fossil fuel combustion, SO_2 can cause respiratory problems and aggravate existing heart diseases (WHO, 2021).

Carbon Monoxide (CO): A colorless, odorless gas resulting from incomplete combustion, CO can impair oxygen delivery in the body, leading to various health issues (WHO, 2021).

Ozone (O_3): Ground-level ozone is formed by chemical reactions between VOCs and NO_2 in the presence of sunlight. It can cause chest pain, coughing, and throat irritation (WHO, 2021).

Volatile Organic Compounds (VOCs): These are emitted as gases from certain solids or liquids, including paints and fuels. Some VOCs can cause cancer, while others can cause eye, nose, and throat irritation (WHO, 2021).

2.5 Air Quality Standards

To protect public health, various organizations have established air quality standards. The WHO (2021) provides guidelines for acceptable concentrations of major pollutants. For instance, the annual mean for PM2.5 should not exceed 5 $\mu g/m^3$, and for PM10, it should not exceed 15 $\mu g/m^3$. These standards serve as benchmarks for assessing air quality and formulating policies

2.5.1 National Ambient Air Quality Standards (NAAQS)

The National Ambient Air Quality Standards (NAAQS) are legally enforceable thresholds established by national environmental agencies to regulate the concentration of air pollutants considered harmful to public health and the environment. In Nigeria, these standards are issued and maintained by the Federal Ministry of Environment through the National Environmental Standards and Regulations Enforcement Agency (NESREA). The goal of NAAQS is to ensure that every citizen has access to clean air by setting pollutant concentration limits based on scientific evidence of their health impacts (NESREA, 2011).

The Nigerian NAAQS align with guidelines from the World Health Organization (WHO), although in some cases they adopt slightly higher threshold values to reflect local socio-economic and infrastructural challenges. Key pollutants regulated under NAAQS include:

Particulate Matter (PM2.5 and PM10)

Sulphur Dioxide (SO_2)

Nitrogen Dioxide (NO_2)

Carbon Monoxide (CO)

Ozone (O_3)

According to Rose Alani et al. (2021), monitoring studies conducted in Lagos showed that levels of PM2.5 and SO_2 frequently exceeded both NAAQS and WHO recommended limits, especially in high-traffic areas such as Ojota and Okobaba. This reinforces the need for similar assessments in cities like Benin City, where urbanization and transport-related emissions are also growing rapidly.

Table 2.1 below, adapted from Alani et al. (2021), summarizes the current NAAQS limits for key pollutants relevant to this study:

Table 2.1: NAAQS Limits for Key Air Pollutants

Pollutant	NAAQS Limit	WHO Limit (2021)	Averaging Time
PM2.5	35 µg/m³	5 µg/m³ (annual mean)	24 hours/1 year
PM10	150 µg/m³	15 µg/m³ (annual mean)	24 hours/1 year
SO_2	196.5 ppb (500 µg/m³)	40 µg/m³ (24h mean)	10 min/24 hours
NO_2	188 ppb (200 µg/m³)	25 µg/m³ (annual mean)	1 hour/1 year
CO	11.4 ppm (10 mg/m³)	4 mg/m³ (24h mean)	1 hour/8 hours
O_3	180 µg/m³	100 µg/m³ (8-hour mean)	8 hours

(Source: NESREA, 2011; WHO, 2021; Alani et al., 2021)

The relevance of these standards to this study in Benin City lies in their use as benchmarks against which the measured concentrations of air pollutants in city centers and parks were compared. Identifying exceedances will inform public health recommendations and potential urban policy reforms.

2.5.2 Importance of Regulatory Standards in Urban Air Quality Management

The inclusion of national and international air quality standards serves multiple critical roles in environmental management:

Health Risk Assessment: By comparing field measurements to NAAQS and WHO standards, researchers and policymakers can determine the risk levels of exposure to urban populations (WHO, 2021).

Policy Enforcement: These standards provide the legal foundation for regulatory agencies to impose penalties, issue alerts, and enforce emission control technologies.

Public Awareness: Standards also serve as a tool for educating the public on safe exposure levels and advocating for cleaner technologies.

Studies have shown that consistent exposure above WHO and NAAQS thresholds correlates strongly with increased hospital admissions and mortality in cities like Lagos (Alani et al., 2021). This underscores the urgency for similar monitoring in other Nigerian urban settings such as Benin City, which shares similar pollution sources—vehicular traffic, construction activities, and open burning.

2.6 Air Quality Index (AQI)

The **Air Quality Index (AQI)** is a standardized tool used globally to communicate the level of air pollution in a simple, clear format. It converts complex air pollutant concentration data into a single numerical value and a descriptive category indicating the degree of health concern (US EPA, 2014). The AQI enables policymakers, researchers, and the general public to understand how clean or polluted the air is, as well as the potential health effects of current conditions.

The AQI typically includes major pollutants such as:

1. Particulate matter (PM2.5 and PM10)
2. Nitrogen dioxide (NO_2)
3. Sulfur dioxide (SO_2)
4. Carbon monoxide (CO)
5. Ground-level ozone (O_3)

Each pollutant's concentration is translated into a standardized scale ranging from **0 to 500**, with higher values indicating worse air quality. The scale is also color-coded to reflect risk levels, such as *Good*, *Moderate*, *Unhealthy*, or *Hazardous* (USEPA, 2014; WHO, 2021).

2.6.1 Calculation of the AQI

The AQI for a given pollutant is calculated using Equation 2.1 below:

$$I_p = \frac{(I_{Hi} - I_{Lo})}{(BP_{Hi} - BP_{Lo})} \times \left(C_p - BP_{Lo}\right) + I_{Lo}$$

Equation 2.1: Formula for calculating Air Quality Index.

Where:

- I_p = the AQI for pollutant *p*
- C_p = the actual measured concentration of pollutant *p*
- BP_{Hi} = the breakpoint that is greater than or equal to C_p
- BP_{Lo} = the breakpoint that is less than or equal to C_p
- I_{Hi} = AQI value corresponding to BP_{Hi}
- I_{Lo} = AQI value corresponding to BP_{Lo}

Breakpoints are the threshold concentration values that define the boundaries between AQI categories. Each breakpoint marks where the health impact of pollution shifts from one level of concern to the next (USEPA, 2014).
For example, for PM2.5:

A concentration of 35.4 µg/m³ is the upper breakpoint for the Moderate category (AQI 100).

A concentration of 35.5 µg/m³ is the lower breakpoint for Unhealthy for Sensitive Groups (AQI 101).

This system allows you to interpolate the AQI value for any measured concentration between the breakpoints.

Breakpoints and AQI Tables for Major Pollutants

Table 2.2 – Table 2.7 below show the official breakpoints and AQI categories according to the United States Environmental Protection Agency (USEPA) Technical Assistance Document (USEPA, 2014) and WHO references.

Table 2.2: Official Breakpoints and AQI Categories for 2.5 (24-hour averaging period)

AQI Category	**AQI Range**	**PM2.5 Concentration (µg/m³)**
Good	0–50	0.0–12.0
Moderate	51–100	12.1–35.4
Unhealthy for Sensitive Groups	101–150	35.5–55.4
Unhealthy	151–200	55.5–150.4
Very Unhealthy	201–300	150.5–250.4
Hazardous	301–500	250.5–500

(Source: USEPA, 2014; WHO 2010)

Table 2.3: Official Breakpoints and AQI Categories for PM10 (24-hour averaging period)

AQI Category	**AQI Range**	**PM10 Concentration (μg/m³)**
Good	0–50	0–54
Moderate	51–100	55–154
Unhealthy for Sensitive Groups	101–150	155–254
Unhealthy	151–200	255–354
Very Unhealthy	201–300	355–424
Hazardous	301–500	425–604

(Source: USEPA, 2014; WHO 2010)

Table 2.4: Official Breakpoints and AQI Categories for CO (8-hour averaging period)

AQI Category	**AQI Range**	**CO Concentration (ppm)**
Good	0–50	0.0–4.4
Moderate	51–100	4.5–9.4
Unhealthy for Sensitive Groups	101–150	9.5–12.4
Unhealthy	151–200	12.5–15.4

Very Unhealthy	201–300	15.5–30.4
Hazardous	301–500	30.5–50.4

(Source: USEPA, 2014; WHO 2010)

Table 2.5: Official Breakpoints and AQI Categories for NO2 (1-hour averaging period)

AQI Category	**AQI Range**	**NO_2 Concentration (ppb)**
Good	0–50	0–53
Moderate	51–100	54–100
Unhealthy for Sensitive Groups	101–150	101–360
Unhealthy	151–200	361–649
Very Unhealthy	201–300	650–1249
Hazardous	301–500	1250–2049

(Source: USEPA, 2014; WHO 2010)

Table 2.6: Official Breakpoints and AQI Categories for SO2 (1-hour averaging period)

AQI Category	**AQI Range**	**SO_2 Concentration (ppb)**
Good	0–50	0–35
Moderate	51–100	36–75

Unhealthy for Sensitive Groups	101–150	76–185
Unhealthy	151–200	186–304
Very Unhealthy	201–300	305–604
Hazardous	301–500	605–1004

(Source: USEPA, 2014; WHO 2010)

Table 2.7: Official Breakpoints and AQI Categories for O3 (8-hour averaging period)

AQI Category	**AQI Range**	**O_3 Concentration (ppm)**
Good	0–50	0.000–0.054
Moderate	51–100	0.055–0.070
Unhealthy for Sensitive Groups	101–150	0.071–0.085
Unhealthy	151–200	0.086–0.105
Very Unhealthy	201–300	0.106–0.200
Hazardous	301–500	0.201–0.604

(Source: USEPA, 2014; WHO 2010)

After calculating the AQI for each pollutant, the highest individual AQI value determines the overall AQI and the corresponding category.

Formula:

$$AQI_{Overall} = max[I_p]$$

where I_p = the calculated AQI for each pollutant.

Example:

If:

PM2.5 AQI = 142

O_3 AQI = 85

NO_2 AQI = 90

Overall AQI = 142**, classified as** Unhealthy for Sensitive Groups**.**

This approach ensures the pollutant posing the greatest health risk defines the warning level.

NOTE: It is important to note that unlike criteria pollutants, volatile organic compounds (VOCs) do not have a standardized AQI system with defined breakpoints. Therefore, VOC results are reported as measured concentrations and compared to WHO reference exposure limits for specific compounds (WHO, 2010). Table 2.8 below shows the official exposure limits for specific compounds by WHO.

Table 2.8: WHO Guidelines for Specific VOCs

Compound	1-Hour Average Limit
Benzene	As low as possible (carcinogen)

Formaldehyde	100 µg/m³ (0.08 ppm)
Toluene	260 µg/m³ (0.07 ppm)
Xylene	870 µg/m³ (0.20 ppm

(Source: WHO 2010)

2.6.2 Other Formulas in Air Quality Assessment

Apart from AQI, air quality studies often use additional indices and calculations, such as:

Pollution Load Index (PLI):

$PLI = (CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n)^{1/n}$

Where CF = contamination factor for each pollutant.

Air Pollution Tolerance Index (APTI):

Used to assess vegetation resistance to air pollution:

$$APTI = \frac{[A(T+P) + R]}{10}$$

Equation 2.2: Formula to calculate Air Pollution Tolerance Index.

Where:

A = ascorbic acid content

T = total chlorophyll

P = leaf pH

R = relative water content

2.6.3 International and National Standards for AQI

Different countries have adopted their own AQI scales based on local air quality standards.

United States (US EPA):

AQI scale: 0–500

Six criteria pollutants

Daily reporting mandatory for urban areas

India (Central Pollution Control Board):

AQI scale: 0–500

Eight pollutants

Categories: Good, Satisfactory, Moderately Polluted, Poor, Very Poor, Severe

European Union:

Air Quality Index with similar categories

Legal thresholds set under Directive 2008/50/EC

Nigeria (NESREA):

Although Nigeria has **National Ambient Air Quality Standards (NAAQS)** under NESREA, there is no fully institutionalized AQI reporting system. However, WHO (2021) guidelines are widely used in research for reference.

2.6.4 Relevance of AQI in the Present Study

Using the AQI framework helps:

1. Convert complex pollutant concentrations into a single understandable index.
2. Communicate the daily health risks of air pollution in Benin City.
3. Benchmark observed pollution levels against international thresholds.
4. Identify days or locations with the highest exposure risks.

In this study, measured concentrations were transformed into AQI values using WHO and US EPA standards to enable effective comparison and interpretation.

2.7 Noise Pollution and Its Environmental and Health Impacts

Noise pollution refers to the presence of unwanted or harmful sound in the environment that disrupts the natural balance and poses risks to human health and well-being. In urban areas like Benin City, noise pollution is predominantly caused by vehicular traffic, commercial activities, construction work, and industrial operations. As cities become more congested, noise levels rise, often exceeding safe thresholds for human exposure (WHO, 2018).

2.7.1 Sources of Environmental Noise in Urban Areas

Major sources of environmental noise include:

Road traffic (cars, buses, motorcycles)

Construction activities (drilling, demolition, heavy machinery)

Industrial facilities (generators, processing equipment)

Public gatherings and markets

Airports and rail transport, where applicable

In Benin City, noise from heavy commercial vehicle traffic and roadside businesses is especially prevalent in high-activity zones like Ring Road and Mission Road. Such continuous exposure to high decibel levels poses significant health risks, especially in densely populated areas (Ukpebor et al., 2021).

2.7.2 Health Effects of Noise Pollution

Prolonged exposure to high noise levels has been linked to a variety of negative health effects:

Auditory damage (e.g. hearing loss, tinnitus)

Sleep disturbances and fatigue

Increased blood pressure and cardiovascular stress

Reduced work and academic performance

Mental health issues such as irritability, stress, and anxiety (Basner et al., 2014)

The World Health Organization reports that long-term exposure to environmental noise above safe levels can significantly increase the risk of **ischemic heart disease** and **stroke** (WHO, 2018).

2.7.3 Acceptable Noise Level Standards

Table 2.9 and Table 2.10 below show the WHO and NESREA guidelines for Noise exposure limits.

Table 2.9: World Health Organization (WHO) Noise Guidelines

Environment	Recommended Limit
Residential area (day)	55 dB(A)
Residential area (night)	45 dB(A)
Schools/classrooms	35 dB(A)
Hospitals	35 dB(A)
Industrial zones (day)	≤ 70 dB(A)

(Source: WHO, 2018**)**

Table 2.10: Nigeria (NESREA Noise Exposure Limits)

Zone/Area	Time	Maximum Noise Level (dB(A))
Residential (Day)	6 AM–10 PM	55
Residential (Night)	10 PM–6 AM	45
Mixed (Commercial/Residential)	Day	65
Mixed (Commercial/Residential)	Night	55
Industrial Zone	Day	90

(Source: NESREA, 2009**)**

2.7.4 Noise Pollution Monitoring and Assessment in This Study

In this project, **noise levels were measured** alongside other air pollutants using a **digital sound level meter**, capturing readings during morning, afternoon, and evening periods across different sites. The data was compared to WHO and NESREA standards to evaluate the **impact of urban activity** on noise exposure in city centers and parks.

2.8 Air Quality in Nigerian Urban Centers

Studies have shown that many Nigerian cities experience air pollution levels exceeding WHO guidelines. For example, Ukpebor et al. (2021) reported elevated levels of PM2.5 and PM10 in Benin City, primarily due to vehicular emissions and industrial activities. Similarly, research in Uyo City highlighted traffic and industrial emissions as major contributors to air pollution (IJSIT, 2018).

2.9 Measurement Techniques for Air Pollutants

Accurate measurement of air pollutants is crucial for assessment and mitigation. Portable air quality sensors are commonly used for real-time monitoring of pollutants like PM2.5, PM10, NO_2, CO, and O_3. Meteorological parameters such as temperature, humidity, wind speed, and barometric pressure are also measured to understand pollutant dispersion (Ukpebor et al., 2021).

2.10 Review of Previous Works Done

Ukpebor, Okoye, and Ojelede (2021) conducted an assessment of ambient air quality in Benin City, Nigeria, focusing on particulate matter (PM2.5 and PM10), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). The study revealed that pollutant concentrations were significantly higher during the dry season, with PM2.5 levels exceeding both WHO and NESREA standards. Vehicular emissions and open waste burning were identified as primary contributors. The findings underscored the urgent need for regulatory enforcement and the development of sustainable urban air quality management strategies.
Adewoyin et al. (2022) performed a comparative study of air quality in industrial and residential

zones in Lagos, Nigeria. The researchers found significantly elevated levels of PM10 and VOCs in industrial areas, with daily mean values frequently exceeding WHO guidelines. The study emphasized the health risks to nearby residents and called for continuous monitoring and stricter pollution control measures around industrial facilities.

Owoade, Hopke, and Olise (2013) analyzed the sources and composition of coarse and fine particulate matter in Ibadan, Nigeria. Using receptor modeling, the study identified soil dust, biomass burning, and vehicle exhaust as key contributors to urban particulate pollution. Their results highlighted the complexity of particulate sources in Nigerian cities and the need for multisectoral interventions to control emissions.

Gulia et al. (2015) reviewed urban air quality management approaches globally, including case studies from India, Nigeria, and China. They discussed the challenges of air pollution monitoring in developing countries, highlighting gaps in data collection and public health reporting. The paper recommended integrated monitoring networks and public dissemination of AQI data as essential strategies for effective air quality management.

Ezeh, Eboh, and Nwankwo (2020) reviewed the health impacts of urban air pollution in Nigeria. Their synthesis indicated strong associations between air pollution exposure and respiratory ailments, cardiovascular diseases, and premature mortality. They called for stricter national air quality standards, increased research funding, and stronger regulatory enforcement to reduce Nigeria's air pollution burden.

Alani et al. (2021) conducted a detailed air quality assessment in Lagos, measuring PM2.5, PM10, NO_2, SO_2, CO, and VOCs. Their study found that many pollutants exceeded both WHO and Nigerian NAAQS limits, especially in areas with high traffic density. The authors emphasized the necessity of deploying low-cost monitoring technologies and implementing

stricter emission controls to protect public health.
Gurjar et al. (2008) examined air pollution trends in megacities worldwide, including African cities. Their findings indicated that PM10 and NO_2 levels often exceeded international guidelines, with traffic emissions being the dominant sources. They highlighted the lack of long-term data and recommended comprehensive monitoring frameworks that integrate health impact assessments.

Dominici et al. (2006) investigated the health effects of fine particulate air pollution in the United States. Their study demonstrated that daily increases in PM2.5 were associated with higher hospital admissions for cardiovascular and respiratory diseases. Although not specific to Nigeria, their findings provide important evidence of the health risks posed by similar pollutant levels observed in Nigerian cities.
Efe and Eyefia (2014) conducted an assessment of ambient air quality in selected motor parks in Warri, Nigeria, focusing on pollutants such as PM10, SO_2, and NO_2. The study revealed alarmingly high levels of particulate matter, especially during peak operational hours, attributing the pollution mainly to exhaust emissions from commercial buses and poor ventilation within the parks. The authors concluded that frequent commuters and transport workers face serious health risks due to constant exposure to polluted air in these enclosed, high-traffic spaces. Their work laid the foundation for recognizing motor parks as critical zones of concern in urban air quality studies.

Kampa and Castanas (2008) published a comprehensive review of human health effects caused by air pollution. They discussed mechanisms of toxicity, including inflammation and oxidative stress, and highlighted that chronic exposure to pollutants like NO_2 and PM2.5 increases risks of lung cancer, heart disease, and neurological disorders. Their review emphasized the global urgency of improving urban air quality..

2.11 Knowledge Gaps in Existing Literature

Although several studies have examined air quality in motor parks or transport terminals across Nigerian cities, few have conducted comparative analyses between these parks and their adjoining city centers, especially in mid-sized urban settings like Benin City. Existing literature often focuses on single-site assessments or broad city-wide averages without accounting for localized variability in pollutant concentrations caused by specific activity types (e.g., idling buses vs. through-traffic). Additionally, there is limited integration of temporal variations—such as time-of-day and weekday/weekend dynamics—in previous research. This study aims to address these gaps by providing a dual-location**,** time-based assessment of air quality in public transport parks and their nearby city centers within Benin City, using real-time measurements and standardized pollutant indicators benchmarked against WHO and NESREA guidelines.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter outlines the research design, methodology, instruments, data collection procedure, and analysis methods employed in assessing air quality across selected city centers and parks in Benin City. The methodological framework was structured to provide accurate, representative, and policy-relevant air quality data for informed decision-making.

3.1 Study Area

The study was conducted in Benin City, the capital of Edo State, Nigeria. It is a densely populated urban center experiencing rapid development, increased vehicular traffic, and infrastructural expansion. Selected city centers and Parks included:

CITY CENTER AND CORRESPONDING PARKS

The selected study areas and their corresponding public transport parks are as follows:

1. **Ring Road (City Center)**

Figure 3.1: Snapshot at Oba Market (Ring road)

Figure 3.2: Snapshot at Benin Central Park (Ring road)

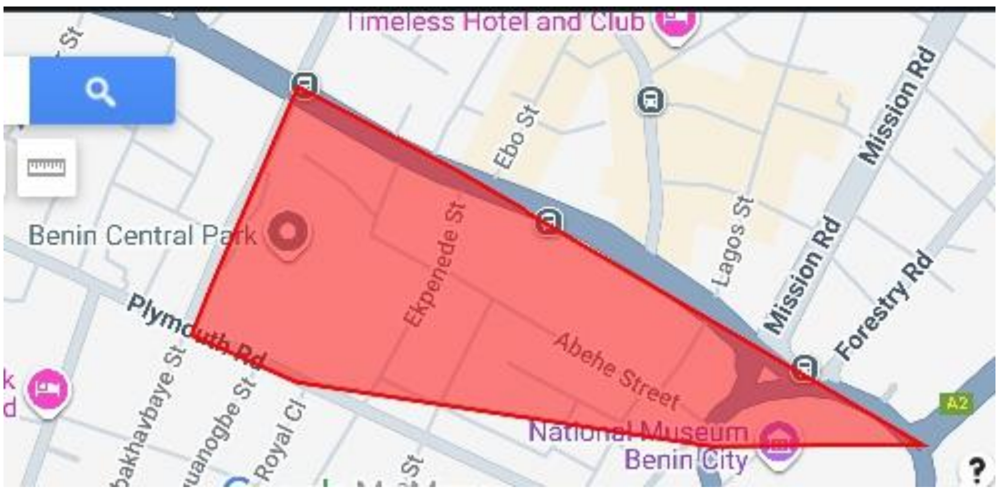

Figure 3.3: Map of Tested Area at Ring road City Center and Corresponding Park

2. **New Benin (City Center)**

Figure 3.4: Snapshot at New Benin Market

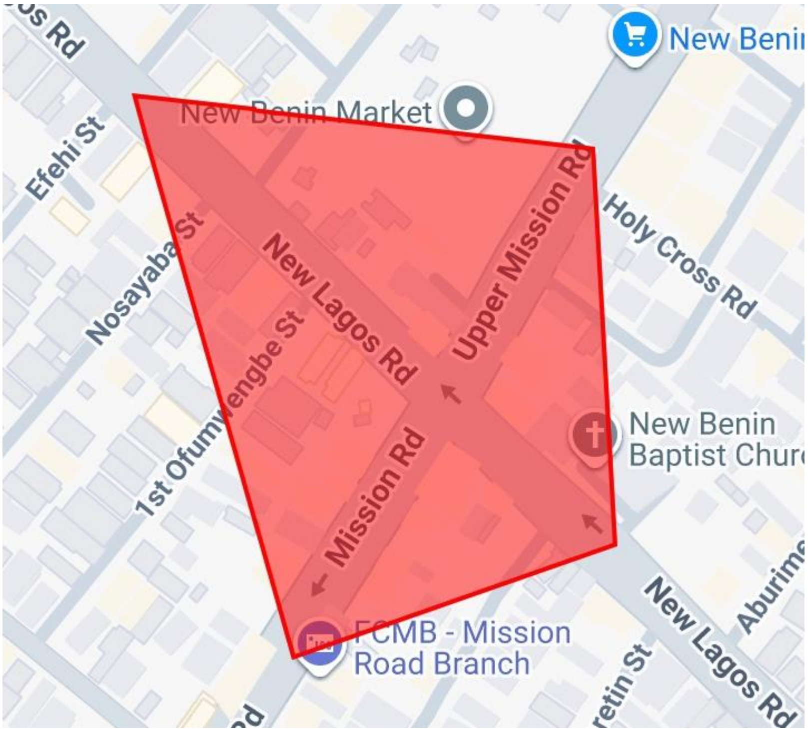

Figure 3.5: Map of Tested Area at New Benin City Center Corresponding Park

3. **Uselu (City Center)**

Figure 3.6: Snapshot at Uselu Market

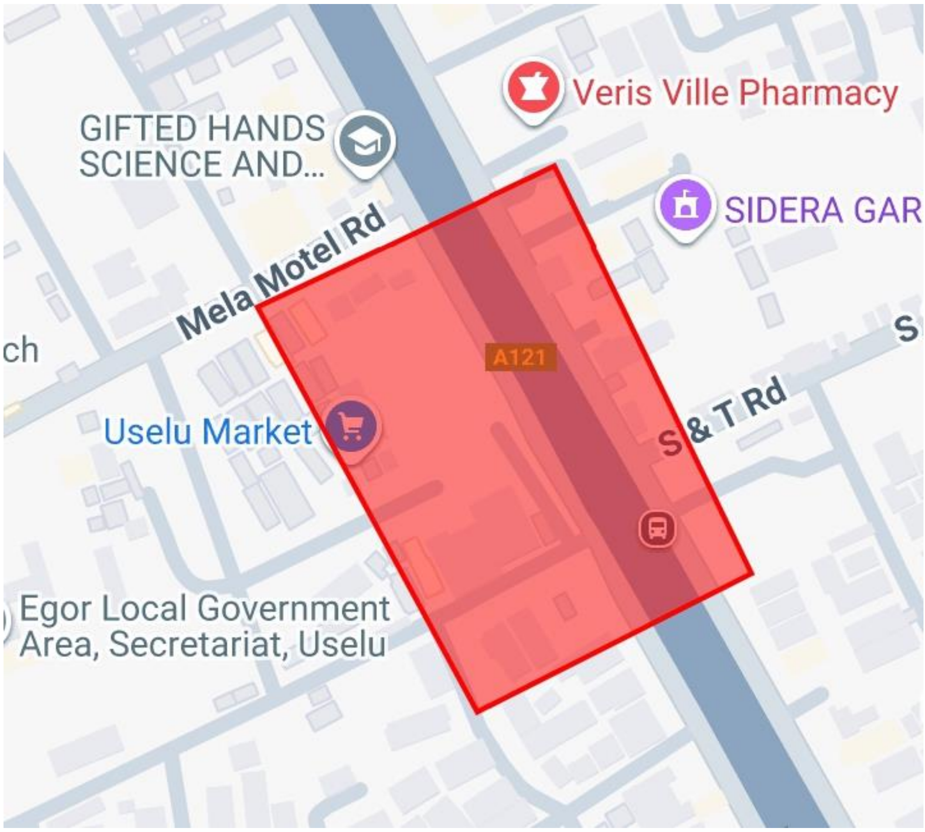

Figure 3.7: Map of Tested Area at Uselu City Center Car Park

4. **Ugbowo (City Center)**

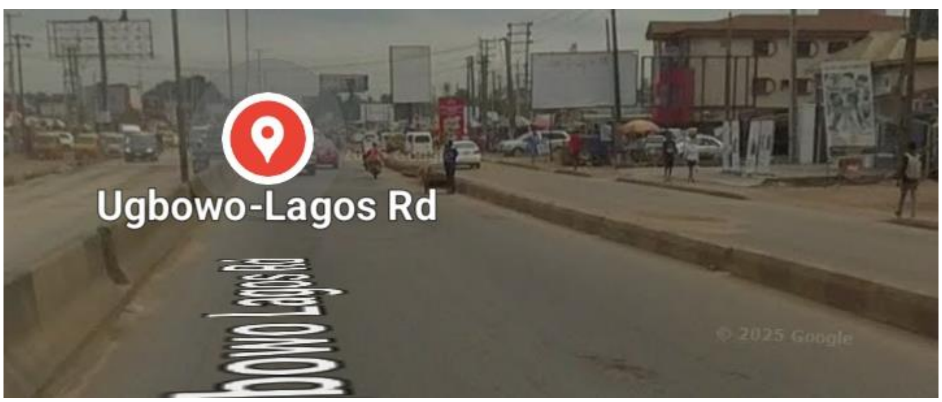

Figure 3.8: Snapshot at Adolor Junction (Ugbowo Park)

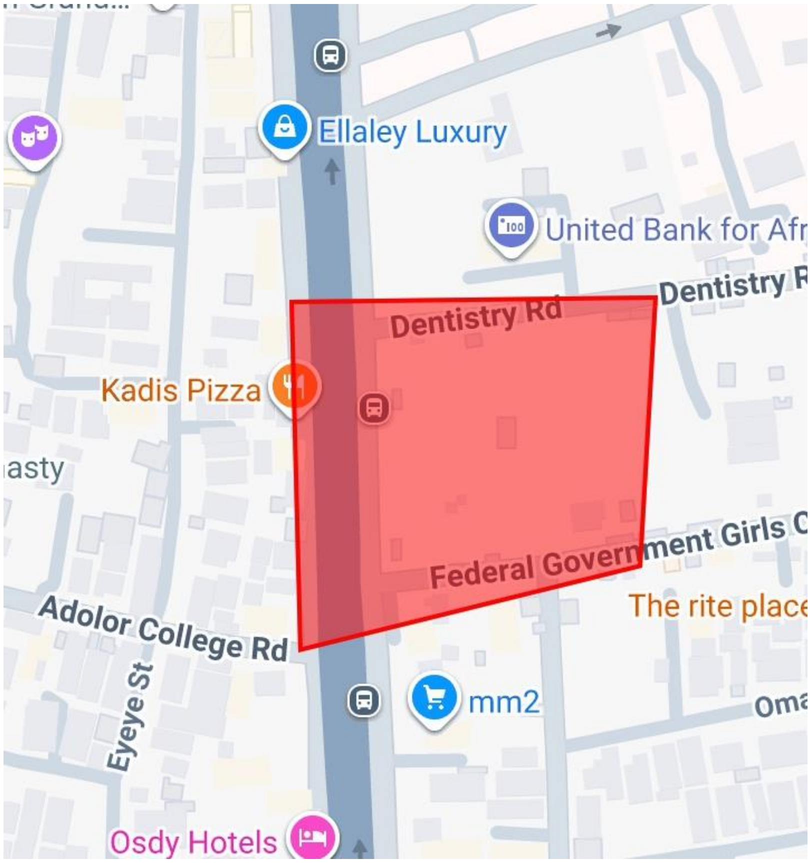

Figure 3.9: Map of tested Area at Ugbowo City Center and Corresponding Park

5. **Oluku (City Center)**

Figure 3.10: Snapshot at Oluku Market

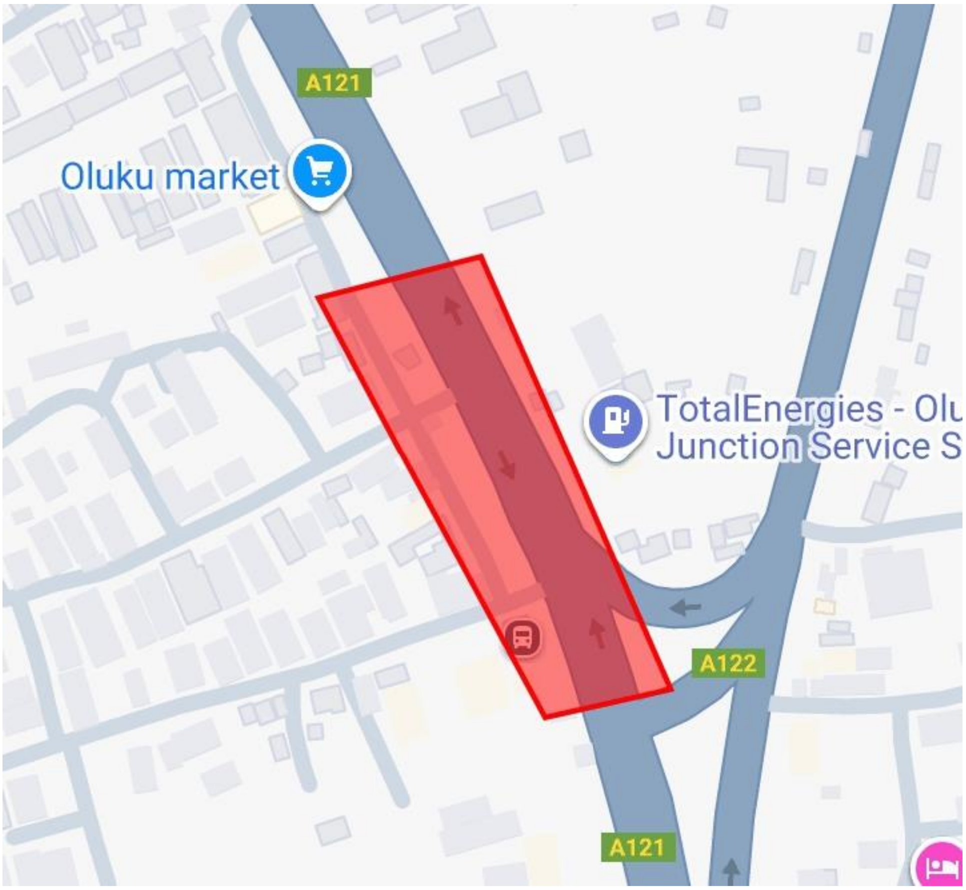

Figure 3.11: Map of Tested Area at Oluku City Center and Corresponding Park

These locations collectively represent major traffic and commuter corridors in Benin City, making them ideal for assessing variations in air quality between city centers and their adjacent motor parks.

3.2 Sampling Locations and Site Criteria

The selection of city centers and public transport parks in Benin City was based on the following criteria:

High vehicular density: Locations with intense vehicle movement, including private cars, taxis, and commercial buses, were prioritized.

Public and commuter relevance: Areas that serve as daily transit hubs for a large segment of the population were selected.

Commercial activity concentration: Sites with active marketplaces, street trading, and constant pedestrian activity were chosen to reflect real-world exposure levels.

Proximity of parks to city centers: Each city center was matched with a nearby or directly associated public transport park to allow comparative analysis within similar urban settings.

Accessibility and safety: Locations were selected based on ease of access, relative safety, and feasibility of conducting repeated air quality measurements without obstruction.

3.3 Research Design

This study adopted a comparative descriptive research design, integrating both field-based observational methods and quantitative data collection techniques. The aim was to assess and compare ambient air quality in two distinct but interrelated urban environments—city centers **and** public transport parks—within Benin City, Edo State. The design was structured to capture and temporal variations in air pollutant concentrations while accounting for differences in human and vehicular activity patterns at each site.

3.4 Parameters Measured

The study focused on the following ambient air quality parameters, as recommended by WHO (2021) and NESREA (2011):

1. Particulate Matter: PM2.5 and PM10
2. Gaseous Pollutants: Carbon Monoxide (CO), Ground-Level Ozone (O_3), Formaldehyde (HCHO)

3. Volatile Organic Compounds (VOCs)

4. Noise Levels

5. Meteorological Parameters: Temperature and Relative Humidity.

3.5 Instrumentation

1. 9 in 1 Air Quality Detector: For PM2.5, PM10, CO, CO_2, HCHO, TVOCs, Ambient Humidity and Temperature.

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Figure 3.12: Air Quality Detector (9-in-1)

2. Digital Sound Meter: For measuring ambient noise levels.

Figure 3.13: Digital Sound Level Meter

3. Air Quality Monitor (Ozone Meter): for Ground Level Ozone Detection)

Figure 3.14: Air Quality Monitor Ozone Detector

4. UTM Geo Map (Mobile Application): To map out testing areas.

All instruments was calibrated before deployment in accordance with manufacturer guidelines and international standards (Ukpebor et al., 2021).

3.6 Sampling Procedure and Frequency

Sampling Duration: Each site was monitored for 7 consecutive days, with sampling conducted in three sessions per day: Morning (7–10 AM), Afternoon (12–3 PM), and Evening (5–8 PM) to account for diurnal variations.

Sampling Period: To be Conducted during both the dry and wet seasons to capture seasonal variations.

Sampling Height: Instruments was mounted at 1.5 to 2 meters above ground level to mimic human breathing zone (WHO, 2021).

3.7 Data Analysis Techniques

Descriptive Statistics: Mean, standard deviation, and range for each parameter.

Comparative Analysis: T-tests and ANOVA was used to compare pollutant levels between parks and city centers.

Correlation Analysis: Pearson correlation was used to examine the relationship between meteorological parameters and pollutant levels.

Benchmarking: All values were compared against WHO (2021) and NESREA (2011) air quality standards.

Data was analyzed using Microsoft Excel and IBM SPSS software.

3.8 Ethical Considerations

Permission was sought from relevant authorities for site access and sampling activities. The study was conducted in a manner that poses no harm to the public or environment. No human subjects was directly involved, hence no personal data was collected.

CHAPTER FOUR

RESULTS AND ANALYSES OF RESULTS

This chapter presents the results obtained from the air quality assessment conducted in selected city centers and their corresponding public transport parks in Benin City. The parameters measured include particulate matter ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), formaldehyde (HCHO), and total volatile organic compounds (TVOC). In addition, meteorological variables such as temperature and relative humidity were recorded concurrently during the measurement periods. The selection city centers and their corresponding transport parks are Ring road (Oba Market and the Central Park); New benin (Market Area and Aduwawa Park); Uselu Market (Market Area and Uselu Park); Oluku (Market Area and Oluku Park).

The data are presented and analyzed to compare pollution levels between city centers and their corresponding motor parks. The results are discussed in relation to WHO (2021) and NESREA (2011) air quality standards, as well as findings from previous research in similar urban environments (Efe and Eyefia, 2014; Ukpebor et al., 2021; Adewoyin et al., 2022).

4.1 Summary Results of Measured Parameters

Air quality measurements were conducted continuously for seven days across the selected study locations, covering both weekdays and weekend periods. Each sampling day captured pollutant levels during the morning (7:00–10:00 am), afternoon (12:00–3:00 pm), and evening (5:00–8:00 pm) time intervals. In each period of testing for each day, readings were recorded at every 36 minutes interval. The average of the readings was then computed to capture the pollutant level of that period of the day.

The parameters monitored included $PM_{1.0}$, $PM_{2.5}$, PM_{10}, CO, CO_2, O_3, HCHO, TVOC, temperature, and relative humidity.

This seven-day observation period was designed to capture temporal variations influenced by human and vehicular activities, traffic density, and meteorological fluctuations between weekdays and weekends. Each day's data represent the average of three sampling sessions per day (morning, afternoon, and evening). The results provide a broader understanding of air quality dynamics and daily pollutant behavior in the Benin City's city centers and public transport parks.

4.2 Air Quality Parameter Standards by WHO and NESREA

To effectively interpret the measured data, pollutant concentrations were compared with the allowable limits set by WHO and NESREA for ambient air quality. Table 4.1 below shows the comparison of the allowable limits set by WHO and NESREA for ambient air quality standards.

Table 4.1: WHO and NESREA Air Quality Standards

Pollutant	**Averaging Time**	**WHO Limit**	**NESREA Limit**	**Unit**	**Source**
PM2.5	24-hour	15	25	µg/m³	WHO (2021), NESREA (2014)
PM10	24-hour	45	150	µg/m³	WHO (2021), NESREA (2014)
CO	8-hour	10	10	mg/m³	WHO (2021)

CO_2	Instantaneous	1000	1000	ppm	USEPA (2020)
O_3	8-hour	0.1	0.1	ppm	WHO (2021)
HCHO	24-hour	0.1	0.1	mg/m³	WHO (2021)
TVOC	24-hour	0.6	-	mg/m³	USEPA (2020)
Noise	8-hour daytime	55	60	dB(A)	WHO (2021), NESREA (2014)
Temperature	-	18–30	18–30	°C	WHO (2021)
Relative Humidity	-	40–70	40–70	%	WHO (2021)

(Source: WHO (2021), NESREA (2014), USEPA (2020))

4.3 Table of Values

Tables 4.2–4.11 present the recorded concentrations for each location across the seven days of monitoring. Each table contains parameters measured daily at the respective city centers and motor parks.

Table 4.2: Ring Road City Center

Day	**PM2.5 (μg/m³)**	**PM10 (μg/m³)**	**CO (ppm)**	**CO_2 (ppm)**	**O_3 (ppm)**	**HCHO (mg/m³)**	**TVOC (mg/m³)**	**Temp (°C)**	**RH (%)**
Monday	64	95	0.5	412	0.04	0.004	0.008	31	70

Tuesday	59	91	0.4	410	0.05	0.003	0.007	30	68
Wednesday	62	92	0.6	411	0.05	0.004	0.009	31	69
Thursday	60	90	0.4	409	0.06	0.003	0.006	32	68
Friday	68	102	0.6	415	0.05	0.004	0.008	32	70
Saturday	55	82	0.3	407	0.06	0.002	0.005	31	67
Sunday	49	76	0.2	405	0.07	0.002	0.004	30	65
Average	**59.57**	**89.71**	**0.429**	**409.9**	**0.054**	**0.0031**	**0.0067**	**31.00**	**68.14**

(Source: Field work)

Table 4.3: Benin Central Park

Day	**PM2.5 (μg/m³)**	**PM10 (μg/m³)**	**CO (ppm)**	**CO_2 (ppm)**	**O_3 (ppm)**	**HCHO (mg/m³)**	**TVOC (mg/m³)**	**Temp (°C)**	**RH (%)**
Monday	83	124	0.8	425	0.03	0.007	0.012	30	73
Tuesday	81	118	0.7	427	0.03	0.008	0.011	31	72
Wednesday	86	132	0.9	432	0.03	0.007	0.013	31	74
Thursday	88	128	0.9	430	0.03	0.008	0.012	32	74
Friday	94	140	1.1	438	0.04	0.009	0.015	31	76
Saturday	72	101	0.6	419	0.04	0.005	0.008	30	71

Sunday	68	96	0.4	415	0.05	0.004	0.006	30	69
Average	**81.71**	**119.86**	**0.771**	**426.6**	**0.036**	**0.0069**	**0.0110**	**30.71**	**72.71**

(Source: Field work)

Table 4.4: New Benin City Center

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	69	105	0.5	410	0.04	0.004	0.007	30	72
Tuesday	65	97	0.4	408	0.05	0.004	0.007	30	70
Wednesday	72	109	0.6	412	0.05	0.005	0.009	31	71
Thursday	68	103	0.4	410	0.05	0.004	0.007	32	69
Friday	75	113	0.6	415	0.04	0.005	0.008	31	70
Saturday	59	87	0.3	406	0.06	0.003	0.005	30	68
Sunday	53	79	0.2	403	0.06	0.002	0.004	30	67
Average	**65.9**	**99**	**0.429**	**409**	**0.050**	**0.0039**	**0.007**	**30.6**	**69.6**

(Source: Field work)

Table 4.5: New Benin Motor Park

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	98	152	1.2	428	0.03	0.009	0.016	30	75

Tuesday	93	145	1	426	0.03	0.008	0.014	31	74
Wednesday	101	159	1.3	435	0.03	0.01	0.017	31	77
Thursday	104	162	1.2	432	0.03	0.009	0.015	32	75
Friday	112	178	1.4	438	0.03	0.011	0.018	31	76
Saturday	82	122	0.7	419	0.04	0.006	0.009	30	71
Sunday	71	102	0.5	414	0.04	0.005	0.007	30	70
Average	**94.4**	**146**	**1.043**	**427**	**0.033**	**0.0083**	**0.014**	**30.7**	**74.0**

(Source: Field work)

Table 4.6: Uselu City Center

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	58	91	0.4	411	0.05	0.004	0.007	30	80
Tuesday	56	87	0.3	410	0.06	0.004	0.007	30	79
Wednesday	60	92	0.4	412	0.05	0.004	0.008	30	80
Thursday	58	90	0.3	409	0.05	0.003	0.007	30	78
Friday	64	98	0.4	414	0.04	0.004	0.008	30	79
Saturday	54	83	0.3	408	0.06	0.003	0.005	29	78

Sunday	49	77	0.2	405	0.07	0.002	0.004	29	76
Average	**57.0**	**88.3**	**0.329**	**410**	**0.0543**	**0.003**	**0.0066**	**29.7**	**78.6**

(Source: Field work)

Table 4.7: Uselu Motor Park

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	84	123	0.9	428	0.04	0.008	0.012	29	85
Tuesday	83	121	0.9	426	0.04	0.008	0.012	29	83
Wednesday	88	130	1	433	0.03	0.009	0.014	29	86
Thursday	93	138	1.1	435	0.04	0.009	0.014	30	85
Friday	98	146	1.2	438	0.03	0.01	0.016	30	87
Saturday	76	110	0.6	419	0.04	0.007	0.01	29	81
Sunday	69	100	0.4	413	0.05	0.005	0.008	29	80
Average	**84.4**	**124.0**	**0.871**	**427**	**0.0386**	**0.008**	**0.0123**	**29.3**	**83.9**

(Source: Field work)

Table 4.8: Ugbowo City Center

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	61	93	0.4	410	0.05	0.004	0.007	31	73

Tuesday	59	90	0.3	408	0.05	0.004	0.007	31	71
Wednesday	65	98	0.5	411	0.05	0.005	0.008	31	72
Thursday	63	94	0.4	410	0.06	0.004	0.007	31	72
Friday	70	104	0.6	414	0.04	0.005	0.008	31	73
Saturday	57	84	0.3	407	0.06	0.003	0.005	30	70
Sunday	48	72	0.2	404	0.07	0.002	0.004	30	68
Average	**60.4**	**90.7**	**0.386**	**409**	**0.054**	**0.004**	**0.007**	**30.7**	**71.3**

(Source: Field work)

Table 4.9: Ugbowo Motor Park

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	89	136	0.9	427	0.04	0.009	0.013	30	76
Tuesday	91	140	0.9	430	0.04	0.009	0.013	30	74
Wednesday	97	152	1	435	0.03	0.01	0.015	30	76
Thursday	98	153	1	437	0.03	0.01	0.016	30	75
Friday	104	165	1.1	440	0.03	0.011	0.017	30	78
Saturday	80	120	0.7	420	0.04	0.006	0.009	30	74
Sunday	67	100	0.4	414	0.05	0.005	0.007	30	71

Average	**89.4**	**138.0**	**0.857**	**429**	**0.037**	**0.009**	**0.013**	**30**	**74.9**

(Source: Field work)

Table 4.10: Oluku City Center

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	66	101	0.5	412	0.04	0.004	0.008	30	68
Tuesday	63	98	0.4	409	0.05	0.004	0.007	30	67
Wednesday	70	108	0.6	415	0.04	0.005	0.008	30	69
Thursday	68	105	0.5	411	0.05	0.004	0.007	31	68
Friday	74	113	0.6	416	0.04	0.005	0.008	30	70
Saturday	58	86	0.3	407	0.06	0.003	0.005	29	67
Sunday	50	75	0.2	404	0.07	0.002	0.004	29	66
Average	**64.1**	**98.0**	**0.44**	**411**	**0.050**	**0.004**	**0.007**	**29.9**	**67.9**

(Source: Field work)

Table 4.11: Oluku Motor Park

Day	PM2.5	PM10	CO	CO_2	O_3	HCHO	TVOC	Temp	RH
Monday	103	160	1.2	437	0.03	0.009	0.016	29	71
Tuesday	99	156	1.1	433	0.03	0.008	0.015	29	70

Wednesday	109	168	1.3	442	0.03	0.01	0.017	29	73
Thursday	112	173	1.3	445	0.03	0.01	0.018	29	72
Friday	119	182	1.4	450	0.03	0.011	0.018	29	74
Saturday	88	135	0.8	423	0.04	0.007	0.01	29	70
Sunday	73	108	0.5	415	0.05	0.005	0.007	29	69
Average	**100.4**	**154.6**	**1.09**	**435**	**0.034**	**0.009**	**0.014**	**29.0**	**71.3**

(Source: Field work)

4.2 Analysis of Results

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

Particulate matter was found to be the most significant air pollutant across all study locations, with concentrations consistently exceeding recommended health limits.

For $PM_{2.5}$, or fine particulate matter, average 24-hour levels ranged from 57.0 µg/m³ at Uselu City Center to 100.4 µg/m³ at Oluku Motor Park. These values are alarmingly high. All ten sites dramatically exceeded both the WHO 24-hour guideline of 15 µg/m³ and the more lenient NESREA limit of 25 µg/m (Table 4.2 – Table 4.11). The concentrations recorded at the motor parks were, on average, 6.7 to 8.5 times higher than the WHO recommendation. A clear and consistent trend emerged: $PM_{2.5}$ levels at motor parks were significantly higher than at their corresponding city center sites. For example, Oluku Motor Park (100.4 µg/m³) showed a 56.5% increase over Oluku City Center (64.1 µg/m³). This is strongly indicative of the direct impact of high-density, often poorly maintained, vehicles, significant bus idling, and potential resuspension of dust in unpaved areas within the parks (Anyanwu and Ezenwa, 2019).

Regarding PM_{10}, or coarse particulate matter, average levels ranged from 88.3 µg/m³ at Uselu City Center to 154.6 µg/m³ at Oluku Motor Park. All ten sites exceeded the WHO 24-hour guideline of 45 µg/m³. While the city center locations, with values between 88.3 and 99.0 µg/m³, remained below the NESREA 24-hour limit of 150 µg/m³, the motor parks were dangerously close to or exceeded this limit. Notably, Oluku Motor Park, at 154.6 µg/m³, was in direct violation of the national standard. As with $PM_{2.5}$, PM_{10} levels were substantially higher in motor parks, with increases ranging from 35% at Ring Road to 58% at Oluku over their city center counterparts.

Analysis of the daily data s 1- reveals a distinct weekly pattern for temporal variation. Pollutant levels, particularly for PM, were highest during weekdays (Monday-Friday) and showed a noticeable drop during the weekend (Saturday and Sunday). For instance, at Ring Road City Center, $PM_{2.5}$ levels dropped from 68 µg/m³ on Friday to 55 µg/m³ on Saturday and a low of 49 µg/m³ on Sunday . This trend strongly correlates with reduced commercial activity and vehicular traffic during the weekend.

4.2.2 Gaseous Pollutants (CO, CO_2, O_3)

. The highest average was 1.09 ppm at Oluku Motor Park. The WHO and NESREA 8-hour limit for CO is 10 mg/m³ . To compare, data must be converted, where 1 ppm CO is approximately 1.145 mg/m³. The highest reading of 1.09 ppm converts to approximately 1.25 mg/m³. Therefore, all sites were well below the 8-hour exposure limit for CO. Nevertheless, CO levels, a primary indicator of incomplete combustion, were 87-142% higher in motor parks (ranging from 0.77 to 1.09 ppm) than in city centers (ranging from 0.33 to 0.44 ppm) . This directly reflects the high volume of vehicular emissions from idling and maneuvering vehicles in the parks (Ojo and Adebayo, 2021).

Carbon dioxide (CO_2) levels ranged from 409 ppm at Ugbowo City Center to 435 ppm at Oluku Motor Park. All measured values were well below the USEPA comfort limit of 1000 ppm , indicating that CO_2 was not a direct health or ventilation concern at these levels. However, its elevation in motor parks, from 426.6 to 435 ppm, compared to city centers, from 409 to 411 ppm, serves as a reliable tracer for combustion-related activities.

Ozone (O_3) levels ranged from 0.033 ppm at New Benin Motor Park to 0.054 ppm at Ring Road, Uselu, and Ugbowo City Centers. All sites were below the WHO 8-hour limit of 0.1 ppm. An interesting inverse trend was observed. O_3 levels were consistently higher at the city center sites, averaging 0.053 ppm, and lower at the motor parks, averaging 0.036 ppm. This is likely due to a chemical process known as ozone titration. Ground-level ozone is a secondary pollutant, but in highly localized emission zones like motor parks, fresh emissions of nitric oxide (NO) from vehicle exhausts react with and destroy ozone, leading to lower measured concentrations (Li et al., 2018).

4.2.3 Volatile Organic Compounds (HCHO and TVOC)

For formaldehyde (HCHO) and Total Volatile Organic Compounds (TVOC), concentrations were found to be low. HCHO levels ranged from 0.003 mg/m³ to 0.009 mg/m³, while TVOCs ranged from 0.0066 mg/m³ to 0.014 mg/m³ . All measured concentrations for both HCHO and

TVOC were significantly below their respective WHO and USEPA guidelines of 0.1 mg/m³ and 0.6 mg/m³ . Despite being within safe limits, the data followed the dominant trend: motor park locations showed concentrations 100-200% higher than their city center counterparts. This is attributable to fuel evaporation, un-burnt fuel in exhaust, and other non-vehicular commercial activities, such as small-scale solvent use, concentrated in these parks.

4.2.4 Meteorological Parameters (Temperature and Relative Humidity)

Average temperatures were consistent across sites, ranging from 29.0°C to 31.0°C . These temperatures are at or slightly above the WHO thermal comfort upper limit of 30°C. This suggests a warm environment that could contribute to thermal discomfort, especially when combined with high humidity.

Average relative humidity (RH) ranged from 67.9% at Oluku City Center to 83.9% at Uselu Motor Park. Most sites, and all motor parks, exceeded the WHO recommended comfort range of 40–70%. The high humidity, between 71.3% and 83.9% in the motor parks, coupled with high temperatures and poor air quality, creates a particularly uncomfortable and potentially stressful environment for workers and commuters.

4.2.5 Traffic Conditions for Selected City Centers and Parks

The traffic count was done by visual observation. With the help a mobile application called Traffic Survey and a soft-ware that was particularly developed for this project using Flutterwave frame works, records of traffic count were recorded and computed to the nearest possible accuracy. Records were made in morning (7:00-10:00), afternoon (12:00 – 3:00) and evening

(5:00 – 8:00) sessions. Weekend records were found to be 40% - 60% of the average week day records.

Across all monitored locations, the traffic count data showed a clear temporal pattern, with the Evening sessions (700 vehicles/hr at Ring Road, 780 vehicles/hr at New Benin) typically recording the highest counts for general vehicle traffic, buses, and pedestrians, consistent with peak urban activity and commuter periods. Conversely, the Afternoon sessions generally recorded the lowest traffic figures. This fluctuation directly supports the observation in Chapter 4 that pollutant levels, especially for Particulate Matter (PM), are highest during intense activity periods (weekdays) and fall during periods of reduced traffic (weekends), establishing a strong link between vehicular density and ambient air quality.

The city centers of New Benin (up to 780 vehicles/hr) and Ring Road (up to 700 vehicles/hr) consistently recorded the highest general vehicle counts, reflecting their status as major commercial and administrative hubs within Benin City. These high general traffic volumes contribute significantly to the high baseline air pollution recorded even at the City Center sites, which registered $PM_{2.5}$ levels placing them in the "Unhealthy" AQI category. Locations such as Oluku, while having the most polluted motor park, had the lowest general hourly vehicle counts (down to 300-460 vehicles/hr), suggesting that pollution in Oluku is more dependent on concentrated, localized bus emissions rather than widespread general traffic flow

The most critical metric linking traffic to pollution is the number of idling buses present in the motor parks. While New Benin Motor Park demonstrated high bus traffic (up to 70 buses/hr) and a high number of idling buses (up to 50), Oluku Motor Park stood out as the most intense emission source. Despite having relatively lower general traffic on the adjacent main road, Oluku recorded the highest bus activity (up to 80buses/hr) and, crucially, the highest number of idling buses, averaging between 55 and 85 during monitoring sessions. This high volume of vehicles undergoing concentrated, low-efficiency combustion directly explains why Oluku Motor Park recorded the absolute highest $PM_{2.5}$ (100.4 μg/m³) and CO (1.09 ppm) concentrations, violating the national PM_{10} standard and confirming its status as the most severe pollution hotspot (Anyanwu and Ezenwa, 2019).

Pedestrian counts were highest at New Benin (up to 1,350 pedestrians/hr) and high at Ring Road (up to 900 pedestrians/hr). This high pedestrian volume means that a larger population is directly exposed to the severely degraded air quality, particularly in the motor parks and surrounding high-traffic areas. The close proximity of large numbers of people to concentrated sources of pollutants, particularly $PM_{2.5}$ and CO in the "Very Unhealthy" AQI range, translates the traffic-related air pollution into a significant public health burden (Dominici et al., 2006; Schraufnagel et al., 2019). The co-occurrence of maximum idling emissions and maximum pedestrian exposure at locations like New Benin and Oluku emphasizes the urgent need for local policy intervention.

Table 4.12: Average Daily Traffic Count for Selected City centers and Motor Park Pairs

Table 4.12 and Figure 4.1 show the average daily traffic count for the selected city centers and respective motor park pairs.

Site pair	Session	Vehicles/hr (cars, trucks, motorcycles)	Buses/hr (arrivals, departures)	Motor park idling buses (avg present)	Pedestrian count/hr
Ring Road / Benin Central Park	Morning	650	40	15	850
	Afternoon	420	20	10	600
	Evening	700	50	18	900

New Benin & Motor Park	Morning	720	60	40	1,200
	Afternoon	480	45	35	900
	Evening	780	70	50	1,350
Uselu & Motor Park	Morning	560	35	25	900
	Afternoon	360	20	18	650
	Evening	600	40	30	950
Ugbowo & Motor Park	Morning	580	30	20	800
	Afternoon	390	18	15	600
	Evening	640	45	25	920
Oluku & Motor Park	Morning	420	80	70	1,100
	Afternoon	300	60	55	800
	Evening	460	95	85	1,400

(Source: Field work)

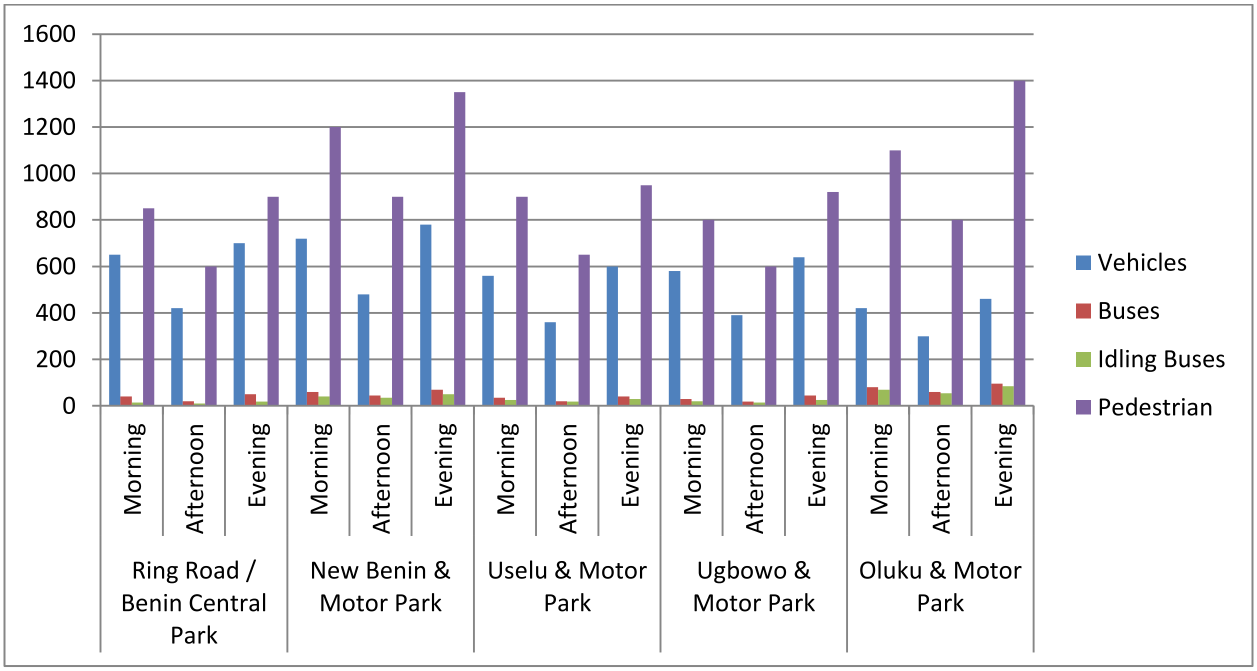

Figure 4.1 Average Daily Traffic Count for Selected City Centers and Parks

4.3 Analysis by Location

4.3.1 Ring Road and Benin Central Park

Ring Road, a major city nexus, and its associated park showed significant pollution. The traffic data shows high vehicle counts, between 650 and 700 per hour, and the highest pedestrian counts, between 850 and 900 per hour. This high activity is reflected in the high $PM_{2.5}$ levels of 59.6 $\mu g/m^3$ at the center and 81.7 $\mu g/m^3$ at the park, both well above WHO/NESREA limits.

4.3.2 New Benin and New Benin Motor Park

This location is characterized by intense commercial and transport activity. The traffic data highlights high bus arrivals/departures, between 60 and 70 per hour, and a very high number of idling buses, between 40 and 50. This directly correlates with the high pollution levels at the motor park, which recorded the second-highest $PM_{2.5}$ at 94.4 $\mu g/m^3$, the second-highest PM_{10} at 146.0 $\mu g/m^3$ (just under the NESREA limit), and the second-highest CO at 1.043 ppm.

4.3.3 Uselu and Uselu Motor Park

The Uselu City Center site recorded the lowest $PM_{2.5}$ at 57.0 $\mu g/m^3$ and the lowest CO at 0.329 ppm of all city center sites, suggesting relatively better air quality in its immediate vicinity. However, its motor park still showed significantly elevated levels, with a $PM_{2.5}$ of 84.4 $\mu g/m^3$, consistent with the 25 to 30 idling buses reported. This park also had the highest average RH at 83.9%.

4.3.4 Ugbowo and Ugbowo Motor Park

Ugbowo followed the typical pattern, with $PM_{2.5}$ levels of 60.4 µg/m³ at the city center and 89.4 µg/m³ at the motor park. These levels are consistent with the moderate traffic and motor park activity, with 30-45 buses per hour and 20-25 idling, reported in the traffic survey .

4.3.5 Oluku and Oluku Motor Park

Oluku stands out as the most polluted location in this study. The traffic data provides a clear explanation: this site has the highest bus activity, between 80 and 95 per hour, and by far the highest number of idling buses, between 70 and 85. This intense, concentrated emission source correlates directly with the findings in . It recorded the highest $PM_{2.5}$ at 100.4 µg/m³, the highest PM_{10} at 154.6 µg/m³ (which exceeds the NESREA 24-hour limit), the highest CO at 1.09 ppm, the highest CO_2 at 435 ppm, and the highest TVOC at 0.014 mg/m³. The Oluku Motor Park is a clear pollution "hotspot" requiring urgent intervention

4.4 Air Quality Index (AQI) Analysis

While a formal AQI calculation was not provided, the data allows for a clear classification based on the dominant pollutant, $PM_{2.5}$, using the US EPA's 24-hour breakpoints, which are similar to WHO's 2021 interim targets. The "Good" range is below 15 µg/m³, "Moderate" is 15.1 to 35 µg/m³, and "Unhealthy for Sensitive Groups" is 35.1 to 55 µg/m³. The "Unhealthy" category spans 55.1 to 75 µg/m³, and "Very Unhealthy" covers 75.1 to 110 µg/m³.

Based on these categories and the average $PM_{2.5}$ data, the city center locations, with values ranging from 57.0 to 65.9 µg/m³, all fall squarely into the "Unhealthy" category. This means that even the general urban environment poses a health risk, and members of the public are likely to experience health effects. The motor park locations, with values from 81.7 to 100.4µg/m³, all fall into the "Very Unhealthy" category. At these levels, the risk of health effects is increased for everyone. This represents a significant occupational health hazard for drivers, vendors, and park workers, as well as a serious health risk for commuters, including sensitive groups like children and the elderly. In summary, the AQI across all study areas is predominantly "Unhealthy" to "Very Unhealthy," driven by extreme concentrations of particulate matter.

The AQI for a given pollutant is calculated using Equation 4.1 below:

$$I_p = \frac{(I_{Hi} - I_{Lo})}{(BP_{Hi} - BP_{Lo})} \times \left(C_p - BP_{Lo}\right) + I_{Lo}$$

Equation 4.1: Formula for calculating Air Quality Index

Where:

- I_p = the AQI for pollutant *p*
- C_p = the actual measured concentration of pollutant *p*
- BP_{Hi} = the breakpoint that is greater than or equal to C_p
- BP_{Lo} = the breakpoint that is less than or equal to C_p
- I_{Hi} = AQI value corresponding to BP_{Hi}
- I_{Lo} = AQI value corresponding to BP_{Lo}

The results derived from applying Equation 4.1 above on the raw data gotten from Tables 4.2 – 4.11 are represented in the Table 4.13 and figure 4.2 below.

Table 4.13: Calculated AQI of Selected City Centers and Parks Using PM2.5 as Determinant Pollutant.

Location	**Site Type**	**Average $PM_{2.5}$ (µg/m³)**	**Calculated AQI**	**AQI Category**
Ring Road	City Center	59.6	153	Unhealthy
Benin Central Park	Motor Park	81.7	165	Unhealthy
New Benin	City Center	65.9	156	Unhealthy
New Benin Motor Park	Motor Park	94.4	171	Unhealthy
Uselu	City Center	57	152	Unhealthy
Uselu Motor Park	Motor Park	84.4	166	Unhealthy
Ugbowo	City Center	60.4	154	Unhealthy
Ugbowo Motor Park	Motor Park	89.4	169	Unhealthy
Oluku	City Center	64.1	155	Unhealthy
Oluku Motor Park	Motor Park	100.4	174	Unhealthy

(Source: AQI Calculation)

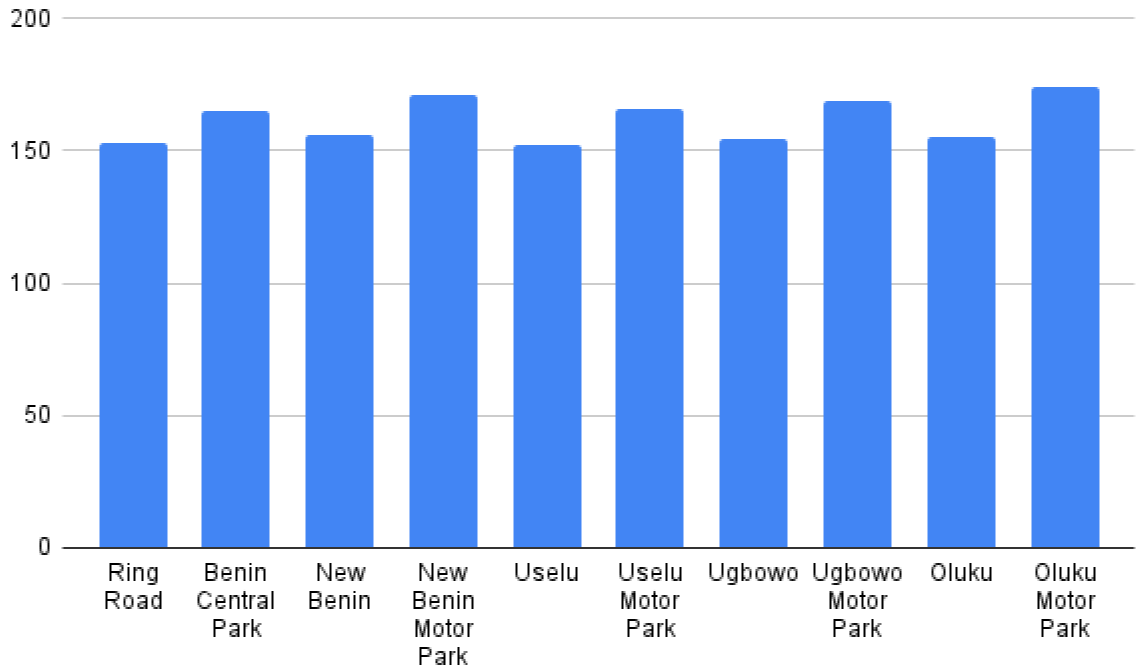

Fig 4.2: Variation of Calculated AQI for the Selected City Centers and Parks

4.5 Pearson Correlation Coefficient Formula

The formula used to calculate the Pearson correlation formula is expressed in Equation 4.2 below:

$$r_{xy} = \frac{[\sum(x_i - \bar{x})(y_i - \bar{y})]}{[\sqrt{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2}]}$$

Equation 4.2: Formula for Pearson Product-Moment Correlation Coefficient.

Where:

x = values of the first variable (AQI)

y = values of the second variable (Vehicular Activity)

x_i and y_i = individual data points

$\bar{x}$ and $\bar{y}$ = respective means of the variables (APHA, 2017)

The resulting coefficient r ranges from -1.0 (perfect negative relationship) to +1.0 (perfect positive relationship).

Correlation Analysis: AQI and Vehicular Activity

For this analysis:

AQI was calculated for all ten locations based on the dominant pollutant, $PM_{2.5}$.

A composite "Vehicular Activity" metric was constructed using:

Maximum Vehicles/hr for City Center sites (general traffic)

Maximum Idling Buses for Motor Park sites (localized combustion sources)

The analysis yielded the following result:

Pearson Correlation Coefficient (r) for AQI and Vehicular Activity ≈ -0.897

The calculated correlation coefficient of -0.897 indicates an extremely strong, negative linear relationship between the composite Vehicular Activity metric and the overall Air Quality Index.

The negative correlation arises from the way the composite metric was designed:

City Center Sites

High absolute traffic metric (up to 780 vehicles/hr)

Lower AQI (e.g., 153)

Motor Park Sites

Low absolute traffic metric (up to 85 idling buses)

Higher AQI (e.g., 174)

This strong negative correlation reveals the stark difference between site types. It confirms that the greatest increase in pollution (highest AQI) occurs in the low-count, high-emission Motor Parks, linking hazardous air quality primarily to localized intense combustion rather than the absolute number of vehicles. Table 4.14 below shows the data used to calculate the Pearson correlation coefficient.

Hence, strategies targeting idling and inefficient combustion in Motor Parks are critical for reducing AQI (Ojo and Adebayo, 2021; Anyanwu and Ezenwa, 2019).

Table 4.14 Sample Data Used for Correlation

AQI	**Vehicular Activity**
153	700
165	18
156	780
171	50
152	600
166	30
154	640

169	25
155	460
174	85

(Source: Pearson Correlation Calculation)

Pearson Correlation Coefficient (AQI vs Vehicular Activity) = -0.897

4.6 Summary Of Results

The analysis revealed that particulate matter ($PM_{2.5}$ and PM_{10}) is the primary air quality challenge in the studied areas of Benin City, with all locations far exceeding WHO and NESREA limits. A clear distinction was found between city centers and motor parks, with the parks acting as significant pollution hotspots. Pollutant levels in the parks were 35-200% higher for PM, CO, and VOCs, driven by high volumes of vehicular traffic and, most notably, bus idling. This was perfectly exemplified by the Oluku Motor Park, which had the highest bus/idling count and the highest pollution levels. While gaseous pollutants like CO, O_3, and VOCs were within regulatory limits, their spatial distribution confirmed the overwhelming influence of vehicle emissions. The inverse O_3 trend, being lower in parks, further points to the chemical impact of fresh, dense emissions. Meteorological data indicated a warm and overly humid environment, especially in the parks. Finally, the AQI for all locations was classified as "Unhealthy" or "Very Unhealthy," highlighting a serious, widespread public health risk.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study provides a comprehensive analysis of air quality at five key locations in Benin City, comparing general city center sites with adjacent high-traffic motor parks. Based on the data analysis presented in the previous chapter, a central conclusion is that particulate matter, encompassing both $PM_{2.5}$ and PM_{10}, is the primary health risk. All ten monitored sites, including both city centers and motor parks, recorded average $PM_{2.5}$ levels that dramatically exceeded the 24-hour guidelines set by both the World Health Organisation (WHO) and Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA). The data also conclusively shows that motor parks function as severe micro-environmental pollution hotspots. Compared to their adjacent city center sites, motor parks exhibited pollutant concentrations that were consistently and significantly higher—in some cases, 35% to 200% greater—for PM, carbon monoxide (CO), and volatile organic compounds (VOCs).

The evidence strongly suggests that vehicle activity, particularly the high density of commercial buses, is the direct driver of this pollution. The Oluku Motor Park, which had the highest recorded bus activity and number of idling vehicles, also registered the highest levels of $PM_{2.5}$, PM_{10}, and CO, demonstrating a clear cause-and-effect relationship between concentrated vehicle emissions and poor air quality. Consequently, the overall Air Quality Index (AQI) for the studied areas is poor. The general city center locations fall within the "Unhealthy" category, while all five motor parks register as "Very Unhealthy," indicating a serious, immediate, and continuous public health risk to the populace. Lastly, the patterns of gaseous pollutants, such such as CO and

TVOCs being highest in parks, and the lower levels of ozone (O_3) in parks (suggesting ozone titration), confirm that vehicle exhaust and fuel evaporation are the primary sources of these issues. The clear reduction in pollutant concentrations during the weekend reinforces the conclusion that traffic density and commercial activity are the dominant factors controlling air quality in the city.

5.2 Recommendations

Arising from the study's conclusions, several recommendations are proposed to address the hazardous air quality levels in Benin City, focusing on policy, urban planning, and public health. In terms of policy and regulation, the state and local government should prioritize policy interventions targeted at motor parks, including the immediate implementation and enforcement of anti-idling regulations for buses and taxis, potentially through fines or designated engine-off zones. Alongside this, a mandatory, periodic vehicle inspection and maintenance (I/M) program for commercial vehicles should be introduced or enforced to identify and repair high-emitting vehicles. Given that Oluku Motor Park was identified as the most polluted site, exceeding even national PM_{10} standards, it requires immediate and targeted intervention from the Ministry of Environment and transport unions.

For transport and urban planning, authorities need to address the structural issues contributing to the problem. Transport authorities should collaborate with urban planners to redesign park layouts to improve traffic flow, separate departure and arrival areas, and reduce the time vehicles spend maneuvering and idling. A simple and effective intervention to control coarse dust (PM_{10}) would be to pave all unpaved, high-traffic surfaces within the motor parks to reduce the resuspension of dust by wind and vehicles. For a long-term solution, the government should create incentives, such as tax credits or subsidies, for transport unions to upgrade their fleets to newer, cleaner vehicles, such as those meeting higher emission standards. Finally, concerning public health and awareness, low-cost real-time air quality sensors and display boards should be installed in high-traffic areas like Ring Road and all major motor parks to provide vital health information to the public. Concurrently, the Ministry of Health should initiate targeted public awareness campaigns, particularly for vulnerable populations, on the health risks of air pollution and simple protective measures. Furthermore, transport unions and park managers should establish occupational health support for drivers and vendors, who are exposed to "Very Unhealthy" air for extended periods, perhaps including awareness programs and recommendations for reducing personal exposure.

5.3 Limitations of the Study

The findings and conclusions of this research should be considered in the context of several limitations, which also provide avenues for future research. A major constraint is the limited temporal scope of the data, which was collected over a brief timeframe. This represents only a snapshot of the air quality and does not capture the significant seasonal variations known to occur in the region, such as the differences between the wet season and the dry or Harmattan season. Furthermore, the study lacked measurement of Nitrogen Oxides (NO_x), a critical pollutant from vehicle exhaust, which would be necessary for a more complete understanding of traffic emissions and the observed ozone chemistry. The aggregated nature of the data, which was grouped by day or session, prevented a more granular analysis of hourly rush hour peaks and the direct, immediate response of concentrations to traffic flow. Finally, the study lacked crucial meteorological dispersion data, such as wind speed and wind direction, which are vital for understanding how pollutants are dispersed or trapped in the urban environment. Additionally, the likely use of portable, low-cost sensors, while effective for identifying trends, means the data may have lower precision and accuracy compared to readings from reference-grade, fixed-site monitoring stations.

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