GEOSPATIAL ANALYSIS OF PARTICULATE MATTERS AND SELECTED GASEOUS POLLUTANT AROUND CAR PARKS IN UGBOWO CAMPUS UNIBEN.

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PLAGIARISM

This work **GEOSPATIAL ANALYSIS OF PARTICULATE MATTERS AND SELECTED GASEOUS POLLUTANTS AROUND CAR PARKS IN UGBOWO CAMPUS, UNIBEN** by UGEGE, Oghenemarho Christopher with Number ENG2002142 of the Department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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DEDICATION

I dedicate this work to the Almighty God who has been my source of strength, Grace and Wisdom through whose Grace and favor I have been able to run my course and scale through the hurdles of my academic pursuit.

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ABSTRACT

Air pollution arising from increasing vehicular activities has become a growing environmental concern in urban environments, including university campuses. Vehicular emissions contribute significantly to the release of particulate matter and gaseous pollutants, which may adversely affect human health and environmental quality. This study aimed to evaluate the spatial distribution of selected air pollutants around major car parks within the University of Benin (UNIBEN), Ugbowo Campus, using Geographic Information System (GIS) techniques.

A field-based experimental research design was employed. Air quality data for particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutants, including formaldehyde (HCHO), total volatile organic compounds (TVOCs), and carbon dioxide (CO_2), were collected from seven selected car parks using portable air quality monitoring devices. Geographic coordinates of sampling locations were obtained using GPS devices and integrated into a GIS environment for spatial analysis. Spatial interpolation using the Inverse Distance Weighting (IDW) method was applied to generate pollution distribution maps, while descriptive statistical analyses and comparisons with World Health Organization (WHO) air quality standards were performed.

Results revealed spatial variations in pollutant concentrations across the study area. The Back Gate Car Park recorded the highest concentrations of $PM_{2.5}$ (49 $\mu g/m^3$) and PM_{10} (55 $\mu g/m^3$), while the Medical Complex and Hall 2 car parks exhibited comparatively lower concentrations. $PM_{2.5}$ concentrations exceeded the WHO guideline value (15 $\mu g/m^3$) at all sampling locations, whereas PM_{10} slightly exceeded the guideline limit only at selected locations. Concentrations of HCHO, TVOCs, and CO_2 remained within acceptable limits. GIS analysis identified high-traffic areas as pollution hotspots, indicating that vehicular activities significantly influence air quality within the campus environment. The study therefore recommends improved traffic management, enforcement of no-idling policies, and increased vegetation cover to mitigate air pollution exposure on campus.

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CHAPTER ONE

INTRODUCTION

1.1 Background of The Study

According to the World Health Organization, Air pollution can be defined as contamination of indoor or outdoor environment by any chemical, physical, or biological element that modifies or changes the natural characteristics of the atmosphere. It is widely believed among scholars that the cause of global warming in our planet is mainly due to atmospheric pollution which is as a result of human activities. The atmospheric component of the environment consists of a mixture of gases that support human, plants and animal life. Under ideal circumstances, the gaseous component include: Nitrogen, Oxygen, Carbon dioxide and noble gases in the percentage ratio of 78:21:0.4:0.6 respectively. Atmospheric pollution occurs when contaminants such as SO2, CO, Ozone and chlorofluorocarbons are introduced at toxic levels, making the atmosphere unfit for inhabitation. (WHO,2024)

Nigeria like most other developing countries in the world is susceptible to atmospheric pollution due to the impact of industrial, commercial and vehicular actives, more so universities such as the University of Benin, University of Lagos, Delta state university Abraka etc. According to studies carried out by (Ukpebor et al 2021), air borne particulate is the most obvious form of pollution in most Nigerian universities. Studies carried out by (Ukpebor et al 2021) at 5 different sites in Benin city showed that the average air borne particulate matter concentration measured using a haze-dust air monitor, ranged from 240ugm-3 to 675ugm-3. The study carried identified that the major causes of high particulate matter concentration are automobile exhaust, solid waste incineration, industrial emission, fugitive dust from roads and harmattan dust, all of which are highly concentrated in carparks all across Benin, more so at a highly busy place such as the University of Benin. (Ukpebor et al, 2021)

Particulate matter (PM) can be defined as a mixture of solid particles and liquid droplets suspended in the air, these particles vary in size, and composition. There are two types of particle pollution, PM_{10} and $PM_{2.5}$. PM_{10} are inhalable particles, their diameter is typically in the range of 10micrometer or less, while $PM_{2.5}$ are finer inhalable particles with diameters generally smaller than 2.5 micro-meter. As mention previously particulate can be harmful to the human health, it is also important to note that the main source of particulate matter is human activities such as fumes from automobile, construction, unpaved roads and fire. (EPA, 2024)

Geospatial analysis of particulate matters is the process of collecting, mapping, and analyzing data on particulate matter (tiny solid or liquid particles suspended in the air, such as $PM_{2.5}$ and PM_{10}) to understand their spatial distribution and patterns across different geographic areas. This approach uses tools like Geographic Information Systems (GIS) to visualize where particulate pollution is highest, identify pollution hotspots, and assess potential sources and impacts on health and the environment.

Urban environments, especially university campuses like the University of Benin (UNIBEN) in Ugbowo, Benin City, are experiencing increased vehicular activities due to population growth and expanding campus operations. Car parks within these campuses serve as major hubs for vehicle movement, leading to the emission of particulate matter and various gaseous pollutants from exhausts. These pollutants can accumulate in and around car parks, posing health risks to students, staff, and visitors, and potentially affecting the campus environment.

The Ugbowo Campus, as the main campus of UNIBEN, is a vibrant academic and administrative center with significant daily traffic from private vehicles, public transport, and service vehicles. Given the strategic location and the high density of activities, understanding the spatial distribution of air pollutants around car parks is essential for effective environmental management and the well-being of the campus community.

Geospatial analysis provides advanced tools to assess, map, and visualize the concentration of pollutants in relation to car park locations. This approach supports data-driven decision-making for campus planning, air quality management, and the development of targeted interventions to reduce exposure to harmful pollutants.

1.2 Statement of the Problem

Despite the strategic importance and high population density of the Ugbowo Campus at the University of Benin, there is limited information on the spatial distribution and concentration levels of particulate matter and selected gaseous pollutants around its car parks. Increased vehicular activity in these areas is likely contributing to elevated air pollution, which poses health risks to students, staff, and visitors. However, without detailed geospatial analysis, it is difficult to identify pollution hotspots, understand the extent of exposure, or develop effective mitigation strategies. This lack of localized air quality data hinders informed decision-making for campus environmental management and the protection of public health.

1.3 Aim and Objective of the study

The aim of this work is to carry out Geospatial analysis of particulate matters on the car parks in Ugbowo Campus UNIBEN, Benin City, Edo state, Nigeria

The objectives are to:

i. measure and map the distribution of particulate matter and selected gaseous pollutants around car parks in Ugbowo Campus using GIS techniques.

ii. identify pollution hotspots and assess exposure levels to harmful air pollutants among campus users.

iii. provide data-driven recommendations to improve air quality and guide policy on campus and its car parks.

1.4 Scope of the study

1. Study Design and Planning:

    i. Define research objectives and select specific car parks within Ugbowo Campus for analysis.

    ii. Develop a sampling strategy, including the number and location of monitoring points, based on site characteristics and expected pollution sources.

2. Data Collection:

i. Deploy air quality monitoring equipment to measure concentrations of particulate matter (PM2.5, PM10) and selected gaseous pollutants (e.g., NO2, CO, O3) at georeferenced locations around car parks.
ii. Record meteorological data (temperature, wind speed/direction) and traffic density during sampling periods to contextualize pollution readings.
iii. Ensure quality assurance and calibration of instruments to maintain data reliability

3. Geospatial Data Integration

i. Collect or create spatial data layers, such as campus maps, land use, and road networks, for GIS analysis
ii. Integrate pollutant concentration data with spatial coordinates for mapping and analysis.

4. Data Analysis

i. Use GIS tools to visualize and map the spatial distribution of pollutants across the study area.
ii. Apply geostatistical methods (e.g., kriging) to interpolate pollutant concentrations and identify pollution hotspots.
iii. Conduct statistical analysis to explore relationships between pollutant levels, meteorological factors, and traffic patterns.

1.5 Justification of the Study

This study is relevant for the following reason because with the increasing occurrences of health issues and harmful effects of air pollution in urban areas such as public schools due to the continuous and major human activities carried out in the school, it is vital to observe and monitor the environment and take steps toward minimizing the pollution of the atmosphere and in doing so improve livelihood among students, staff and other individuals that carry out activities within the schooling area.

This study was aimed at tackling the problem of gaseous pollutants around car parks in Ugbowo campus UNIBEN by monitoring the environment, i.e collecting data on air quality levels such as PM2.5, PM 10, CO2, HCHO and TVOC in and around car parks, identifying what locations the concentration of pollutants is highly concentrated and keeping track of the spread across the campus, in doing so detect the potential health risks to individuals on campus, design better campus transportation policies, offer scientific evidence to support environmental regulations and traffic management, contribute to the growing knowledge of geospatial techniques and lastly raise awareness among campus users about the impact of vehicle emissions on local air quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Environmental pollution, air pollution in particular, has become a world-wide concern due to its negative impacts on human health and ecological balance and urban sustainability (WHO, 2021). In a densely populated area, especially one that is prone to heavy traffic such as car parks, the quality of air tends to degenerate due to emissions from vehicles present in the carpark and human activities. The university of Benin's Ugbowo Campus is no exception, as its car park experience frequent vehicular movement., that contributes immensely to the localized air pollution. This chapter will contain a thorough review of the applicable literature that underlie the study of particulate matters and selected gaseous pollutants within such environments.

The review begins with conceptualizing air pollution and its classification, with a particular focus on the behavior of particulate matter (PM), their sources and types such as Formaldehyde (HCHO), Volatile compounds (TVOC) and Carbon dioxide (CO2), it will also explore the health and environmental effects of exposure to these pollutants, mainly in an enclosed or semi-enclosed environment such as car parks.

This chapter also dives into the principles and applications of geospatial technologies, especially GIS (Geographic Information System) and Remote sensing, as equipment for monitoring the environment (EPA, 2022). Emphasis would be placed on how these items can be used to assess the spatial distribution and concentration of pollutants over a selected area.

Also, it will examine formal studies related to air quality assessments in institutional settings such as campuses, it will also document common analytical techniques and research gaps. By taking a look at these studies, the chapter will provide a foundation for selecting appropriate methods for current study.

Ultimately this chapter's goal is to establish a framework that informs the geospatial analysis of air pollutants in Ugbowo Campus UNIBEN. It highlights the significance of applying field measurements with spatial analysis to improve the understanding of pollution distribution patterns and support evidence bases environmental planning and management.

2.2 Concept of Air Pollution

2.2.1 Definition and types of air pollution

Air pollution is defined as the presence of one or more contaminants or pollutant substances in the atmosphere at a concentration and duration that is harmful to human health, living organisms and the environment as a whole (WHO, 2021). It can also be described as the introduction of harmful gases and particulate matter into the atmosphere capable of affecting infrastructure and buildings. These contaminants may exist in solid, liquid or gaseous forms and originate from both natural and anthropogenic sources such as industrial activities, vehicular emissions and fossil fuel combustion (EPA, 2022). Vehicular emission is regraded as one of the major contributors to urban air pollution, especially in densely populated areas.

2.2.2 Sources of air pollution

In urban settings, major sources of air pollution include industrial facilities, construction activities, domestic energy use such as cooking, and vehicular emissions (WHO, 2021). Highly active environments such as university car parks have been identified as micro-environments with elevated pollution levels due to the frequent movement and idling of vehicles. Incomplete combustion of fuel during vehicle idling or slow movement leads to increased emission of pollutants such as particulate matter, carbon monoxide, hydrocarbons, sulphur dioxide and nitrogen oxides (EPA, 2022).

Air pollutants can be classified based on their physical state:

i. **Particulate Pollutants**: These are solid or liquid particles suspended in the atmosphere, such as PM_{10} and $PM_{2.5}$.

ii. **Gaseous Pollutants**: These include gases such as CO_2, HCHO and TVOCs.

Understanding the behavior of air pollutants is important for monitoring their distribution, evaluating their impacts and implementing effective control measures. This is especially important in semi-enclosed areas such as car parks where pollutant concentrations may exceed permissible limits, thereby posing health risks to students, staff and visitors (Rao, 2006).

Considering the global pursuit of sustainable development and environmentally friendly practices, studies focused on local air quality monitoring using geospatial techniques are important for institutions and policymakers in making data-driven decisions aimed at improving public health and environmental management.

2.2.3 Effects of air pollution

On health: Air pollution is one of the most serious threats to public health all over the world. Fine particulate matter, especially $PM_{2.5}$ and gaseous pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) are known to be able deeply penetrate into the respiratory system of human beings, causing a large range of chronic health conditions. According to the World Health Organization (WHO), exposure to air pollutants increases the risks of cardiovascular diseases, respiratory infections, chronic obstructive pulmonary disease (COPD), stroke, and lung cancer (WHO, 2021).

Individuals with pre-existing health conditions are vulnerable to the health impacts of air pollution. Studies have shown that even short-term exposure to high levels of pollutants in semi-enclosed environments, such as car parks, can lead to health effects such as reduced lung function, eye irritation, fatigue, headaches etc (Landrigan et al., 2017; Lelieveld et al., 2015). Prolonged exposure can also affect cognitive function and increase the risk of neurodegenerative diseases.

In campus environments like UNIBEN, students and staff who frequent car parks for long periods may be at risk of these health complications, especially during peak traffic periods when pollutant concentrations are at their highest.

On the environment: Apart from human health, air pollution also has major effects on the environment. One major consequence is the depletion of air quality, which contributes to a mixture of air pollutants that reduces visibility and harms plant life.

Gaseous pollutants such as nitrogen oxides and sulfur dioxide can merge with water vapor in the atmosphere to form acid rain, which causes soil acidification, tarnishes the aquatic ecosystems, and reduces agricultural productivity (Seinfeld and Pandis, 2016).

Particulate matter can rest on plant leaves, preventing photosynthesis and reducing crop yields. Pollutants also disrupt the balance of ecosystems by harming wildlife. High pollution levels increase the heat island effect and degrade the overall livability of urban areas, making them uncomfortable and dangerous over time.

On Infrastructure and Buildings: It has been observed that air pollution also takes a major toll on physical infrastructure. Acid rain, which is formed by the reaction between sulphur dioxide and nitrogen oxides with water molecule in the atmosphere, is particularly corrosive to buildings and metallic structures. Over time, this leads to the weakening of construction materials such as limestone, concrete, steel, and paint, thereby increasing maintenance costs and reducing the lifespan of structures.

Particulate matter can accumulate on road surfaces, reducing skid resistance and leading to wear and tear. In car parks, these effects are increased by direct vehicle emissions, increased dust levels from tire wear, and the accumulation of soot on surfaces. In university campuses, this may result in the deterioration of roads and structural components exposed to open air, and resulting in frequent repairs and renovations.

2.3 Particulate Matter (PM)

Particulate matter is a term used to describe a mixture of extremely small solid particles and water molecule suspended in the air. These particle sizes, composition and origin vary and are among the most common and significant air pollutants in urban and semi-urban environments, especially in an area with high vehicular activity such as car parks.

2.3.1 Types of Particulate Matter

PM is classified into two based on their size:

Coarse particle (PM10): These are particles with diameters less than 10 micrometer but greater than 2.5 micrometers. These particles are small enough to be inhaled and can pose serious health risks when they enter the respiratory system. The main sources of particulate matter are Road dust, construction activities, pollen spores, industrial emissions and smoke from combustion. As mentioned before when exposed to particulate matter, the effects are harmful, some of these health hazards may include irritation of the eyes, nose and throat, worsening of asthma and bronchitis, coughing sneezing and shortness of breath. (EPA, 2025)

Fine particles (PM2.5): this refers to particulate matter with diameter of 2.5 micrometers or less, it is stated that the width of human hair is 30 times bigger than it. The main sources include combustion from the engines of vehicles, industrial actions, burning of woods and fossil fuels, cooking, tobacco smoke and formation from chemical reactions involving gases like sulfur dioxide and nitrogen oxide. The common health effects that result from exposure to this particulate matter include stroke, lung and health diseases and asthma. This PM also affects our environment by contributing to smog and producing haze. (EPA,2025)

2.3.2 Characteristics of Particulate Matters

Particulate matter (PM) is characterized by a few physical and chemical properties that determine its behavior, source and health impacts:

i. **Size and size distribution:** PM is classified by aerodynamic diameter into coarse particles (PM10, diameter 2.5-10 micrometer), fine particles (PM2.5 diameter< 2.5 micrometer) and ultrafine particles (diameter<0.1micrometer). The size is a major influence on how the particle behaves in the atmosphere and how deeply it can penetrate into the respiratory system. (Subhasis B. 2008)

ii. **Shape and Morphology:** PM can vary in shapes, the shapes include spherical, elongated, flocculent and irregular agglomerates. The soot particle from combustion often comes in fractal-like agglomerates with high surface areas, while mineral particles tend to have a more regular shape. The shape and morphology affect the particles toxicity and ability to adsorb harmful substances. (Zhang et al, 2018)

iii. **Chemical composition:** Pm consists of a complex mixture of inorganic ions such as sulfate and nitrate, organic carbon, metals, ammonium and other trace elements. The source and the season majorly affect the composition and influences the toxicity of the particulate matter as well as the environmental effects. (Subhasis B. 2008)

iv. **Mass and number concentration:** Mass concentration and number concentration are the units in which PM is measured. Ultrafine particles dominate in number, while fine particles contribute significantly to surface area and mass. (Subhasis B. 2008)

v. **Volatility and Reactivity:** Some PM components are volatile or semi-volatile, changing with temperature and atmospheric conditions. Diesel particles tend to have higher non-volatile content compared to gasoline emissions. (Subhasis B. 2008)

vi. **Sources and Formation:** PM originates from primary emissions (e.g., dust, combustion) and secondary formation through atmospheric chemical reactions involving precursor gases. This affects physical and chemical characteristics. (Subhasis B. 2008)

vii. **Surface Area and Density:** Particles have varying specific surface areas, which influence chemical reactivity and interaction with biological tissues. Effective density depends on particle shape and composition; combustion particles often have low density due to porous agglomerate structures. (Fresnel BC., 2023)

2.3.3 Sources of Particulate Matter

Sources of particulate matter (PM) are diverse and can be broadly categorized into primary sources, which emit particles directly, and secondary sources, where particles form in the atmosphere through chemical reactions.

Primary PM is emitted directly into the atmosphere from the sources such as construction sites, wild fires, agricultural activities and vehicle emission.

Combustion processes: Vehicle exhaust (gasoline and diesel engines), power plants (especially coal-fired), industrial activities, residential heating (wood, coal, oil burning), and wildfires.

Natural sources: Wildfires, volcanic eruptions, windblown dust from arid regions, and biological materials such as pollen and bacteria fragments contribute to particulate matter.

Mechanical processes: Construction sites, unpaved roads, mining, agriculture, road dust from tire and brake wear, and demolition activities produce coarse particles through physical breakdown of materials.

Secondary particulate matter forms in the atmosphere from chemical reactions involving gaseous precursors such as sulfur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs), and ammonia. These gases, emitted by power plants, vehicles, industrial processes, agriculture, and residential energy use, react to form fine particles (PM2.5) like sulfates, nitrates, and secondary organic aerosols.

2.3.5 Composition of Particulate Matter

Particulate Matter isn't a single pollutant but a complex mixture of components that may include:

i. Organic compound
ii. Heavy metals (such as lead, cadmium, arsenic)
iii. Sulfates and nitrates
iv. Elemental carbon (soot)

The composition of particulate matter is highly influenced by the emission source, meteorological condition and atmospheric chemical reaction. In a university carpark, Particulate Matter may have high levels of carbonaceous material and metallic particles due to vehicular emission and road dust.

2.3.6 Health and Environmental Impacts of Particulate Matter

As discussed in section 2.2, particulate matter is associated with a wide range of health risks, respiratory and cardiovascular in particular. Fine particle ($PM_{2.5}$) are considered to be significantly more dangerous than coarse particles (PM_{10}) because of their ability to penetrate deeper into the lungs and enter the blood stream. In a campus setting, students with asthma or respiratory allergies are at great risk when exposed to high concentration of Particulate Matter.

Environmentally, particulate matter contributes to the formation of haze, acid rain and damage to plant life due to the deposition of toxic elements on leaf surfaces. Lastly particulate Matters can also degrade the surface of a building and of a vehicle through soiling and chemical reaction with the materials.

2.3.7 Monitoring and Measurement of Particulate Matter

i. **Gravitational method**: This uses filters and precise weighing to determine mass concentrations (typically used for regulatory monitoring)
ii. **Optical sensors**: Use laser-based light scattering to estimate particle concentrations (e.g low-cost devices like the PMS5003 or Air Visual)
iii. **Beta attenuation monitors (BAM)**: This makes use of beta radiation absorption to quantify particle mass.
iv. **Tapered element oscillating microbalance (TEOM):** Measure mass based on frequency changes in a vibrating element. A recent studies have included geospatial tools like GIS and spatial interpolation techniques such as inverse distance weighting, to map and visualize PM distribution in urban areas. These tools are extremely important in order to know where localized pollution is highly concentrated and plan effective control strategies.

2.3.8 Regulatory Standards for Particulate Matters

Various national and international organizations have established permissible limit for Particulate matter exposure. Example of such organization and permissible limit are as follow:

WHO (2021) air quality guidelines recommend:

i. $PM_{2.5}$: 5 µg/m³ (annual mean), 15 µg/m³ (24-hour mean)

ii. PM_{10}: 15 µg/m³ (annual mean), 45 µg/m³ (24-hour mean)

iii. **Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA)** also sets standards aligned with or similar to WHO guidelines, although enforcement and monitoring remain limited in many urban areas.

2.4 Selected Gaseous Pollutants

This section focuses on the major pollutants commonly associated with vehicular emission around car parks Carbon monoxide (CO), Nitrogen dioxide (NO2), Sulfur dioxide (SO2) and ozone (O3). It covers each of their sources, propagation in urban spaces, human and environmental effects and regulatory guidelines.

2.4.1 Carbon Dioxide (CO2)

Carbon dioxide (CO2) is a colorless gas produced mainly through fuel combustion and vehicular exhaust emissions (EPA, 2022). The concentration of CO2 is often elevated around car parks due to the high number of moving and parked vehicles as well as limited ventilation. Although CO2 is not generally considered toxic at normal outdoor concentrations, elevated levels may indicate poor air circulation and increased pollutant accumulation. In ventilation and combustion studies, CO_2 is commonly used as a tracer gas for assessing indoor and semi-enclosed air quality conditions (ASHRAE, 2019). The World Health Organization (WHO) does not provide a formal global outdoor guideline value for CO_2; however, indoor environmental studies commonly use 1000 ppm as a benchmark for ventilation adequacy.

2.4.2 Formaldehyde (HCHO)

Formaldehyde (HCHO) is a highly reactive and colorless gas produced mainly from fuel combustion, vehicular exhaust emissions and secondary atmospheric reactions involving volatile organic compounds (VOCs) (WHO, 2010). In car park environments, formaldehyde is commonly generated during vehicle idling and incomplete fuel combustion. It contributes to ground-level ozone formation and the generation of fine particulate matter in the atmosphere. Exposure to formaldehyde may cause irritation of the eyes, nose and throat, and prolonged exposure has been associated with carcinogenic effects in humans (EPA, 2022). Elevated concentrations are often recorded in enclosed or poorly ventilated parking environments where pollutant dispersion is limited.

2.4.3 Total Volatile Organic Compounds (TVOC)

Total Volatile Organic Compounds (TVOCs) represent the combined concentration of various volatile organic compounds released from fuel evaporation, vehicular exhaust and lubricants (EPA, 2022). Elevated TVOC levels are commonly observed around car parks due to exhaust fumes and fuel vapors, particularly during engine start-up, idling and periods of high ambient temperature. TVOCs contribute significantly to the formation of photochemical smog and ground-level ozone in urban environments. Short-term exposure to high concentrations of TVOCs may result in headaches, dizziness, eye irritation and respiratory discomfort, while long-term exposure may pose serious health risks depending on the specific compounds involved (WHO, 2010).

2.4.4 Dispersion Dynamics in Urban Car Parks

Urban car parks often act as pollution hotspots due to restricted airflow, vehicle congestion and prolonged engine idling. These conditions facilitate the accumulation of air pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2) at ground level, thereby increasing the risk of human exposure (WHO, 2021).

To understand and visualize pollutant behavior in such environments, geospatial tools such as Geographic Information Systems (GIS) and atmospheric dispersion models, including the Gaussian plume model, are commonly applied for hotspot detection and spatial analysis of air quality patterns.

2.4.5 Regulatory Standards and Exposure Thresholds

A summary table of the international guideline is shown below:

Table 2.1: Regulatory standards and Exposure Thresholds.

Pollutant	**Short-term Limit (1hr or 8hr)**	**Long-term Limit**

CO_2	35ppm (1hr); 9ppm (8hr)	---------
TVOC	100ppb (1hr)	20ppb annual
HCHO	0.14ppm (24hr)	0.03ppm annual

Source: US EPA NAAQS and WHO, Health Canada.

Noting the concentration around enclosed car parks, pollutant level often exceeds these permissible standards, therefore enforcing the need geospatial assessment and controlled mitigated strategies.

2.5 Air Pollution in Urban Car Parks

Urban car parks have shown to contribute significantly to air pollution, more so in densely populated areas such as campuses, commercial zone and transport terminals (WHO, 2021; EPA, 2022). These location serves as major hotspots for vehicle movement, prolonged idling and frequent engine start up, all of which are known to emit pollutants, most notably Particulate matter and gaseous emissions such as carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO_2) and volatile organic compounds (VOCs)

2.5.1 Pollution Dynamic in Car Parks

Car parks show a unique pollution dynamic due to the limit in air circulation, frequent movement and deceleration of vehicles and engine idling especially during peak hours (WHO, 2021). Unlike locations such as open roads, the semi enclosed or fully enclosed nature of some parking structures (such as basements or covered lots) can cause pollutant accumulations, creating poor air quality hotspots (EPA, 2022).

Studies have revealed that vehicles release higher concentrations of pollutants when moving at low speed, typically around car-parks. The heat island effect can also worsen pollutant concentration in urban environment by enhancing chemical reactions that form secondary pollutants such as ground level ozone.

2.5.2 Primary Sources of Pollutants

i. **Exhaust emissions**: Emissions from cars tailpipes releases CO, NOx, hydrocarbons and particulate matter

ii. **Evaporative emissions:** When the engines of vehicles are turned off VOCs are released

iii. **Tire are brake wear:** These generate fine particles (PM2.5 and PM10), especially during frequent starting and stopping of vehicles.\

iv. **Resuspension of road dust**: Dust particles are displaced and suspended whenever vehicles move increasing the particulate matter load in the air.

2.5.3 Health implications

In campus such as the University of Benin Ugbowo, their car-parks are heavily used by staff, students and visitors. In such a microenvironment, exposure to pollutants can lead to serious health risks and prolonged exposure to high levels of CO can deplete the amount of oxygen that enters the body, NO2 can trigger an asthma attack and other respiratory diseases, while particulate matter has been associated with cardiopulmonary disorders, reduced cognitive functions and lung cancer in both children and adults (WHO, 2021; EPA, 2022). Adults (especially those above 65) and children are extremely prone to the effects of air pollution in car parks due to their weak immune responses in the elderly and higher respiratory rate in children (WHO, 2021).

2.5.4 Environmental Impact

i. **Smog formation,** more so in areas with hot climate with NOx and VOC levels.
ii. **Soiling and material degradation,** due to settlement of particles around structures.
iii. **Vegetation damage,** in which photosynthesis is affected by pollutants.

2.5.5 Case studies

Research by Ogundele et al. (2020) in Lagos found that air pollutant levels in open car parks were 2-3 times higher than in surrounding urban areas. Similar studies in South Africa showed elevated NO_2 and PM_{10} levels near university parking areas during peak hours. However, there's a significant gap in data from Nigerian universities, particularly using geospatial mapping. This project aims to address this gap and provide insights into localized pollution patterns.

2.5.6 Need for Monitoring and Spatial Analysis

Traditional fixed monitoring stations might not accurately capture pollutant level variations in car parks due to their transient and frequent use. However, geospatial tools like GIS, remote sensing, and spatial interpolation can help researchers better understand and track these changes. These tools allow for more precise monitoring and analysis of pollutant levels in dynamic environments like car parks.

i. Map pollutant concentrations across car park zones.
ii. Identify hotspot**s** and zones of concern.
iii. Correlate pollution data with traffic intensity and meteorological conditions.
iv. Propose strategic interventions like improved ventilation, green buffers, and policy controls.

In campus settings, such insights can guide better campus planning**,** traffic management, and public health policies**.**

Air pollution in car parks poses a significant yet often overlooked threat to human health and the environment. As vehicle ownership and urbanization increase, particularly in university settings like Nigeria, assessing pollutant distribution in these areas is crucial. This study uses geospatial analysis to address the knowledge gap and provide data-driven solutions to reduce pollution on UNIBEN's Ugbowo Campus.

2.6 Geospatial Analysis and GIS in Environmental Monitoring

2.6.1 Introduction to Geospatial Analysis

Geospatial analysis is the process of examining data that’s tied to specific locations over time. It helps identify patterns, trends, and relationships in how things are distributed across space, like changes in land use, air pollution levels, or temperature. In environmental monitoring, it allows researchers to map and understand how environmental factors vary from place to place.

What makes geospatial analysis so useful is its ability to link environmental data with geographic locations. This makes it possible to create detailed maps, pinpoint problem areas, and track changes over time. These insights are especially valuable for making informed decisions in urban planning, managing public health, and tackling environmental issues like pollution.

2.6.2 Overview of Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are valuable tools that help us collect, manage, analyze, and display data tied to specific locations. By combining hardware, software, and georeferenced data, GIS makes it easier to create maps and uncover patterns in spatial information (Longley et al., 2015).

When it comes to studying air quality, GIS is especially useful. It allows researchers to:

I. Visualize how pollutants are spread across different areas.

II. Estimate pollution levels in places where data hasn’t been collected.

III. Understand how close certain areas are to pollution sources like car parks.

IV. Track how air quality changes over time.

V. Provide insights that support better environmental planning and public health decisions.

2.6.3 GIS Applications in Air Pollution Studies

GIS has become a very vital tool in monitoring air pollution because of its strength in managing the complex and uneven nature of environmental data. In urban studies, it's been widely used to:

i. Pinpoint areas with high pollution levels, such as busy markets, roadsides, and car parks.
ii. Explore how pollution relates to factors like weather and population patterns.
iii. Model how pollutants spread, based on land use and atmospheric conditions.
iv. Assess public health risks by linking pollution data to where people live.

For instance, GIS has been used to study traffic-related air pollution in cities like Abuja, Lagos, and Accra, where heavy vehicle use and poor traffic flow have led to high levels of particulate matter and harmful gases.

2.6.4 Spatial Interpolation Techniques in GIS

One important part of geospatial analysis is using interpolation techniques to estimate pollution levels in areas where no direct measurements have been taken. Some commonly used methods include:

i. **Inverse Distance Weighting (IDW):** This method is based on the idea that locations closer to a known data point are more similar than those farther away. It's straightforward and often used in environmental studies.
ii. **Kriging:** A more advanced statistical method that not only considers distance between points but also how much values vary from place to place. It's known for being more accurate than IDW and also provides an estimate of uncertainty.

iii. **Spline Interpolation:** This technique creates a smooth surface through the known data points, making it useful for representing gradual changes in variables like temperature or air pollution levels.

These interpolation methods are vital for understanding how pollutants like $PM_{2.5}$, NO_2, and CO are spread across large areas, such as a university campus.

2.6.5 Remote Sensing and Satellite Data Integration

Remote sensing is the process of gathering information about the Earth's surface using images captured from satellites or aircraft. When combined with GIS, it becomes a powerful tool for tracking environmental changes. It helps by:

i. Offering wide-area, real-time data on land use, vegetation, and atmospheric conditions.
ii. Helps in identify pollution sources and urban heat zones.
iii. Making it possible to analyze how pollution levels change over time using time-series data.

While high-resolution satellite imagery like those from Sentinel-5P or Landsat might not be precise enough to detect small-scale pollution in places like car parks, they still play an important role by supporting ground-based data in larger-scale environmental assessments.

2.6.6 Benefits of GIS in Campus-Level Air Quality Monitoring

In a university setting like the University of Benin, GIS offers a range of practical benefits:

i. It helps identify and map areas with higher pollution risks, such as student car parks or busy administrative zones.
ii. It supports better campus planning, especially when deciding where to place facilities that are sensitive to air quality.
iii. GIS allows for real-time tracking and display of pollution levels, which can be useful for issuing health alerts to the campus community.
iv. It also aids decision-makers in implementing environmental strategies like creating green buffer zones, adjusting traffic flow, or limiting vehicle access in certain areas.

Geospatial analysis, especially using Geographic Information Systems (GIS), offers a powerful tool for understanding how air pollutants behave spatially. By applying GIS to map, model, and analyze environmental data around Ugbowo Campus car parks, this study identifies pollution hotspots and informs effective mitigation strategies. This approach supports environmental sustainability and advances knowledge on air pollution at the campus level in Nigeria.

2.7 Interpolation Techniques in Pollution Mapping

Interpolation is a very vital component of geospatial analysis, more so in environmental monitoring and air pollution studies. Interpolation is defined as the process of estimating unknown values around areas that hasn't been measured directly, using values recorded at known sample points. Air pollutant concentrations are typically collected at discrete locations (e.g monitoring station) interpolation techniques are used to develop surfaces of estimated values across a study area (Longley et al, 2015).

Interpolation helps in understanding how pollutants such as particulate matters and selected gaseous pollutants are distributed around the car parks in Ugbowo campus of the university of Benin. These processes allow us to identify pollution hotspots and gain access to exposure risks and aids decision-making in environment management. Interpolation methods in air quality studies include:

2.7.1 Inverse Distance Weighting (IDW)

IDW is among the simplest and most used interpolation methods. It assumes that the influence of a measured data point on an unknown location decreases with distance.

Features:

i. Easy to use and computational efficient
ii. Most suitable for datasets that possess evenly distributed sample points
iii. Works properly for smooth variation in environmental parameter

Limitation:

No estimate of uncertain is provided

Might not capture local variability properly if data is sparse

Application:

Inverse Distance Weighting (IDW) can be applied to generate initial pollution concentration maps, particularly when multiple car park zones have available field measurement data.

2.7.2 Kriging

Kriging is a sophisticated interpolation technique that considers both distance and variation between known data points. By analyzing spatial autocorrelation via a semi-variogram, Kriging generates predicted values and quantifies the uncertainty associated with these estimates, offering a more comprehensive understanding of the data.

Features:

i. It produces statistically optimal prediction.
ii. It accounts for spatial heterogeneity and trends in data.
iii. It offers a reliable interval for prediction.

Limitations:

i. It requires high expertise to interpret variogram models properly.
ii. It is computationally intensive.

Applications:

Kriging is especially effective in areas where pollution levels are affected by factors like changing traffic flow, the layout of buildings, or the presence of vegetation barriers near car parks.

2.7.3 Spline Interpolation

Spline interpolation creates a smooth surface that precisely fits known data points, minimizing curvature to model gradual environmental changes, making it ideal for generating continuous surfaces.

Features:

i. It generates a visually smooth surface.
ii. It is perfect for gently varying dataset like light pollutant dispersion.

Limitations:

i. It introduces artifacts in areas with sharp gradient or sparse data.
ii. It can over smooth the data, potentially hiding local extremes or peaks.

Applications:

On campuses like UNIBEN, spline interpolation can effectively visualize gradual pollutant transitions across open spaces, including car parks and green areas.

2.74 Techniques Comparation

Table 2.2: Techniques Comparation

Method	**Nature**	**Strengths**	**Limitations**	**Suitability for Air Pollution**
IDW	Deterministic	Simple, fast and no assumption	Limited accuracy in sparse data	Suitable for dense sampling and smooth gradients
Kriging	Geostatistical	Accurate	Complex and requires variogram modeling	Ideal for detailed studies with sufficient data
Spline	Deterministic	Smooth surfaces, good visualization	Less accurate with abrupt changes	Suitable for generating trends and visualization

2.7.5 Selection of Interpolation Method for the Study

In this study, the choice of interpolation method will be guided by the type, density, and spatial distribution of pollution data gathered from car parks within Ugbowo Campus. If the data points are relatively dense and evenly spread, methods like IDW or spline should be sufficient. However, if the goal is a more refined spatial analysis and the dataset supports it, Kriging may be the preferred option due to its statistical strength and ability to estimate uncertainty.

GIS tools like ArcGIS or QGIS will be used to apply these interpolation techniques and visualize how pollution varies across the campus. The resulting maps will help highlight high-risk areas, evaluate the exposure of students and staff, and inform targeted environmental management efforts.

2.8 Review of Previous Related Studies

In a study conducted by **Jing Wei et al (2023) Ground-Level Gaseous Pollutants in China** it was established that Gaseous pollutants at the ground level seriously threaten the urban air quality environment and public health. There are few estimates of gaseous pollutants that are spatially and temporally resolved and continuous across China. This study takes advantage of big data and artificial-intelligence technologies to generate seamless daily maps of three major ambient pollutant gases, i.e., NO_2, SO_2, and CO, across China from 2013 to 2020 at a uniform spatial resolution of 10 km. Cross-validation between our estimates and ground observations illustrated a high data quality on a daily basis for surface NO_2, SO_2, and CO concentrations, with mean coefficients of determination (root-mean-square errors) of 0.84 (7.99 $\mu g\, m^{-3}$), 0.84 (10.7 $\mu g\, m^{-3}$), and 0.80

(0.29 mg m^{-3}), respectively. We found that the COVID-19 lockdown had sustained impacts on gaseous pollutants, where surface CO recovered to its normal level in China on around the 34th day after the Lunar New Year, while surface SO_2 and NO_2 rebounded more than 2 times slower due to more CO emissions from residents increased indoor cooking and atmospheric oxidation capacity. Surface NO_2, SO_2, and CO reached their peak annual concentrations of 21.3 ± 8.8 µg m^{-3}, 23.1 ± 13.3 µg m^{-3}, and 1.01 ± 0.29 mg m^{-3} in 2013, then continuously declined over time by 12 %, 55 %, and 17 %, respectively, until 2020. The declining rates were more prominent from 2013 to 2017 due to the sharper reductions in anthropogenic emissions but have slowed down in recent years. Nevertheless, people still suffer from high-frequency risk exposure to surface NO_2 in eastern China, while surface SO_2 and CO have almost reached the World Health Organization (WHO) recommended short-term air quality guidelines (AQG) level since 2018, benefiting from the implemented stricter "ultra-low" emission standards. This reconstructed dataset of surface gaseous pollutants will benefit future (especially short-term) air pollution and environmental health-related studies. **Methodology:** In this study, the researchers combined ground-based monitoring data, satellite observations (such as OMI and MODIS), meteorological variables, land use, and population data to train a machine learning model that predicted daily concentrations of NO_2, SO_2, and CO across China at a 10 × 10 km resolution, producing seamless pollution maps from 2013 to 2020, which were then validated against real-time ground measurements with high accuracy ($R^2 \approx 0.80$–0.84), and used to analyze spatial patterns and temporal changes in pollution, including the impact of COVID-19 lockdowns.

In a study conducted by **Lala et al on Particulate matters pollution in selected areas of Nigeria: Spatial analysis and risk assessment,** it was found that the increasing rate of unregulated emissions of particulate matter from different sources in Nigeria is of great concern. This study therefore focused on monitoring particulate matters ($PM_{2.5}$ and PM_{10}) level in some municipal areas in Nigeria. The study also simulated the dispersion pattern of the particulate matters and assessed the health risk of particulate matter exposure. $PM_{2.5}$ and PM_{10} level in the selected areas were quantified for 8 months using Centre for Atmospheric Research (CAR) satellite-based sensors. Hybrid single-particle Lagrangian integrated trajectory (HYSPLIT) model was used to simulate the dispersion pattern and the dispered particulate matter position. The risk assesment was estimated by air quality index (AQI) using World Health Organization (WHO) guideline for $PM_{2.5}$ and PM_{10} as the standard. The result showed that the levels of $PM_{2.5}$ and PM_{10} on monthly average basis for the selected areas were all above the WHO guideline. The dispersion model and potential particulate matter position revealed that it takes almost 12 hours for any released particulate matter to be fully dispersed and that majority of the dispersed particles were found within 100 m. The AQI level of $PM_{2.5}$ ranged from 65.13 to 927.07 while PM_{10} AQI ranged from 73.51 to 256.65 for the selected regions, which showed poor and unhealthy air quality. Also, the inhabitants of the studied areas are at high risk of particulate matters exposure which may lead to a reduced life expectancy over a long period of exposure. This study however concluded that a more robust measure should be put in place to ensure an improved air quality. **Methodology**: The researchers conducted its study over eight months, using satellite-based sensors from the Centre for Atmospheric Research (CAR) to measure $PM_{2.5}$ and PM_{10} levels across several Nigerian municipalities. They then applied the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory) to simulate how particulate matter disperses and to track its movement. Finally, air quality and associated health risks were evaluated using the Air Quality Index (AQI) based on World Health Organization guidelines

In a study conducted by **Ezeonyejiaku et al on air quality in Nigerian Urban Environments: A Comprehensive Assessment of Gaseous Pollutants and Particle Concentrations (2022)** showed that the rise in gaseous pollutants and particulate concentrations is a serious problem for the environment. This study examined the air quality within four urban areas (Awka, Ekwulobia, Nnewi, and Onitsha) in Anambra State, Nigeria. The concentrations of known air pollutants including suspended particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), methane (CH_4), volatile organic compounds (VOCs), hydrogen sulfide (H_2S), ammonia (NH_3), ozone (O_3), carbon dioxide (CO_2) and carbon monoxide (CO) were assessed at various locations within the study areas using Aeroqual air quality monitoring devices, and the results were compared with the WHO air quality guidelines for health impact assessment. The air quality index (AQI) was interpolated from the pollutant concentrations in order to show hazard categories of air quality conditions over the study locations. The mean concentrations of SO_2, CH_4, and VOCs within the residential locations of Awka, Ekwulobia, and Nnewi were in the range of 200-8000 $\mu g\ m^{-3}$ and exceeded WHO limits for air quality. While the levels of CO_2, SO_2, and CH_4 (3.25-1,027,000 $\mu g\ m^{-3}$) within the commercial locations of Awka, Ekwulobia, and Nnewi exceeded WHO limits, only VOCs (500-1100 $\mu g\ m^{-3}$) within Awka and Ekwulobia exceeded the limits. The 62-181 $\mu g\ m^{-3}$ and 40-295 $\mu g\ m^{-3}$ ranges of PM2.5 and PM10, respectively within the Nnewi and Ekwulobia commercial locations were the only particle concentrations at which the World Health Organization (WHO) recommended limits for health aspects of air pollution were exceeded. The AQI calculations showed air quality within some of the locations may have potential risks for public health. **Methodology:** The researchers tracked $PM_{2.5}$ and PM_{10} concentrations over eight months in various Nigerian municipalities using satellite-based sensors from the Centre for Atmospheric Research (CAR). They modeled how these particulates spread using the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model to simulate dispersion and particle travel distances. Finally, they assessed health risks by calculating the Air Quality Index (AQI) for $PM_{2.5}$ and PM_{10}, referencing WHO guidelines to evaluate pollution severity and potential impacts on public health

In a study conducted by **Samson Olugbenga Daramola and Esther Oluwafunmilayo Makinde on Modeling air pollution around major dumpsites in Lagos State using geospatial methods with solutions (2024)** showed that air pollution is increasingly becoming a significant global health concern, with Nigeria particularly vulnerable to its effects. Available data identifies major sources of air pollution in Lagos State to include vehicular traffic, industrial activities, wildfires, and biomass burning, all contributing to the presence of harmful pollutants such as Particulate Matter (PM), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2), and Volatile Organic Compounds (VOCs). This study aims to carry out geospatial modelling of air pollution around the Olusosun and Solous dumpsites in Lagos State by analysing, assessing, and predicting emission levels and evaluating their potential health impacts on nearby residents. Both ground-based measurements and satellite data were utilized, employing various GIS techniques including Kriging, Regression Analysis, and the Landfill Gas Emissions Model (LANDGEM) to map and predict pollutant concentrations in the areas under study.

Results show that the average PM2.5 concentration over a 24-hour period was 94.29 $\mu g/m^3$ in Olusosun and 94.12 $\mu g/m^3$ in Solous—values significantly higher than the World Health Organization (WHO) guideline of 15 $\mu g/m^3$. Similarly, NO_2 levels were recorded at 237.64 $\mu g/m^3$ in Olusosun and 255.84 $\mu g/m^3$ in Solous, far exceeding the WHO's recommended limit of 25 $\mu g/m^3$. SO_2 concentrations also surpassed safe levels, with Olusosun recording 109.27 $\mu g/m^3$ and Solous 43.82 $\mu g/m^3$, both above the WHO's guideline of 40 $\mu g/m^3$. However, the CO levels of 0.55 mg/m^3 in Olusosun and 0.52 mg/m^3 in Solous remained within the WHO's acceptable range, suggesting that CO is not a major pollutant in these locations. Similarly, concentrations of PM5 and PM10 were within WHO's safe limits.

Satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS) indicated a steady increase in PM2.5 concentration over the five-month study period, correlating directly with rising waste disposal levels, suggesting that increased waste generation leads to higher air pollution levels. Based on these findings, the study recommends that residential areas should be located at least 15 km away from major dumpsites to minimize health risks. Additionally, proper waste management practices, including efficient incineration and regular site maintenance, are essential to reducing air and environmental pollution around these sites. **Methodology:** The researchers combined ground-based pollution measurements with satellite imagery (MODIS) to model air pollutant levels including $PM_{2.5}$, NO_2, SO_2, and CO around the Olusosun and Solous dumpsites in Lagos. They employed GIS techniques such as Kriging and regression analysis, alongside the Landfill Gas Emissions Model (LANDGEM), to evaluate current pollutant distributions and predict future concentrations. The final outputs included spatial maps of pollution hotspots and health risk assessments, benchmarked against WHO air quality guidelines.

In a study carried out by **Leonard Chukwuemeka Anyika and Chidi Obi on Predictive Air Pollution Assessment Using Matrix Algebra And GIS/GPS in Aguleri Anambra State (2025),** evaluated the air pollution levels of Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), and Particulate Matter (PM_{10}) in Aguleri, Anambra State, Nigeria, using matrix algebra in conjunction with Geographic Information System (GIS) and Global Positioning System (GPS) tools integrated with MATLAB. SO_2 and NO_2 concentrations were measured using the Crowcon Gas Monitor (Model CE 89/336/EEC), while PM_{10} levels were recorded using the Crowcon Particulate Monitor (Model No. 1000, Serial No. 298621). Pollution characteristics across the study area were simulated using a polynomial model of the form: yi=k+k1x1+k2x2+k3x3…..+knxn, where the constants "k" was derived by solving simultaneous equations using matrix algebra.

Curve fitting was performed using MATLAB 7.9 to develop predictive equations for SO_2, NO_2, and PM_{10} variations across different locations in Aguleri during both the rainy and dry seasons. However, the study found discrepancies between the constants obtained from fitted curves and those derived from initial theoretical calculations. GIS and GPS-generated contour and surface plots indicated that approximately 50% of the area exhibited significant pollutant concentration levels.

Despite these concentrations, the air quality index ratings for the monitoring stations in Aguleri were considered satisfactory. Overall, the study enhances the methodology for air quality assessment and offers a valuable framework for environmental monitoring, management, and policy formulation. **Methodology:** The study measured SO_2 and NO_2 using a Crowcon Gas Monitor and PM_{10} with a Crowcon Particulate Monitor at multiple locations in Aguleri, covering both rainy and dry seasons. Each sampling site was geolocated using GPS and integrated into GIS. Pollution data were then modeled using a polynomial regression equation of the form:

yi =k+k1 x1 +k2 x2 +⋯+kn xn

The coefficients (k-values) were determined by solving this system of equations using matrix algebra. These polynomial models were fitted in MATLAB 7.9, generating equations that describe pollutant levels as a function of location and season. The final models were visualized in GIS/GPS-based contour and surface maps, revealing spatial pollution distributions. The results confirmed acceptable air quality levels and demonstrated the method's effectiveness for local pollution management.

In a study conducted by **Omokungbe et al on the evolution of gaseous air pollutants with prevailing meteorology across selected sites within a pollution hotspot in Ile-Ife, Southwestern Nigeria (2023)** discovered that the evolution of gaseous pollutants with prevailing meteorology using a network of Alpha sense low-cost portable air monitoring devices deployed to six selected sampling sites namely the Iron steel smelting factory (ISSF), Modomo, Eleweran, Fire service station, staff quarters, and OAU Teaching and research farm (OAUTRF). All six sampling sites were chosen along the pollution hotspot in Ile-Ife. The low-cost sensor has Optical particle counters (OPC-N2) which measured particulate matter and the gaseous pollutants were monitored with electrochemical sensors. At the sites, each sensor unit measured gaseous pollutants: carbon dioxide (CO_2), ozone (O_3), carbon monoxide (CO), and oxides of nitrogen (NO and NO_2). Inbuilt into the monitoring device are temperature and relative humidity (RH) probes as well as a 2-D sonic anemometer to measure wind speed and directions. The directional dependence of the local source of the gaseous pollutant affecting each site was determined using the conditional probability function (CPF) model. The results showed that the highest mean values of 470.6 ppm, 7.2 ppb, and 20.6 ppb for CO_2, NO, and NO_2, respectively were recorded at the Modomo site while ISSF and Fire service sites were found to have the highest mean values of 67.9 ppb and 517.6 ppb, respectively for O_3 and CO during the observational period. The mean values for temperature were noticed to increase in trend from OAUTRF (24.9 °C) to ISSF (26.0 °C). Also, CO_2 gave a good relationship with meteorological parameters with R^2 value ranging from 0.26 to 0.89 in all the sampling sites except ISSF. On contrary, weak relationships were found between the meteorological variables and other gaseous pollutants other than CO_2 for both day and nighttime periods. The CPF model indicated that a larger percentage of the elevated O_3, NO and NO_2 were associated with pollutant transport at wind speed >2m/s due to low event number. This study concludes that there is evidence of a significant effect of meteorological parameters on the gaseous pollutants as observed, while, the CPF plot shows a good agreement with the location of known pollution sources. **Methodology:** The study conducted continuous air quality monitoring of Carbon Monoxide (CO), Ozone (O_3), Nitrogen Dioxide (NO_2), and fine Particulate Matter ($PM_{2.5}$) at various locations in Ile-Ife, including sites near university campuses and major roadways. Alongside pollutant concentration measurements, meteorological parameters such as wind speed, wind direction, and temperature were also recorded over several days to capture fluctuations under varying weather conditions. To investigate the sources and distribution patterns of pollutants, the researchers employed Conditional Probability Function (CPF) plots, which identified the wind directions most commonly associated with elevated pollutant levels at each monitoring site. This analysis provided insight into how wind patterns facilitated the transport of pollutants from nearby sources such as campus roads and highways to the measurement locations.

In a study conducted by **Aleksandras Chlebnikova and Raimondas Jasevičius on Air Pollution with Fine Particles in Closed Parking and Theoretical Studies of the Interaction of Inhaled Particles in Respiratory Tract (2022)** discovered that indoor air quality must be considered important in regards to its possible harmful effects on the human body. Premises such as underground garages, covered car parks and other similar structures remain crucial in assessing the level of air pollution. In such an environment, the main sources of pollution are motor vehicles, emissions from the heating-ventilation-air-conditioning systems of the engineering networks of the joint building, and pollution. When visiting such premises, a person inhales the air, which contains fine particulate matter and a variety of gaseous pollutants harmful to health. The aim of this study is to assess indoor air pollution with fine particulate matter of 0.3–10 µm depending on the nature of the source, aerodynamic parameters in relation to the potential location of a person, and the mechanical behavior of inhaled particles with respiratory tissues. In this work, the interaction of a fine particle with an alveolar cell is theoretically studied when the particle enters the lungs through the human respiratory tract. Based on the results of this study, it would be possible to assess the extent of pollution and the movement or accumulation of particles in the respiratory system. **Methodology:** Researchers investigated particulate matter concentrations within semi-enclosed parking structures through field sampling using laser-based particle counters. Measurements of PM_1, $PM_{2.5}$, and PM_{10} were taken at multiple strategic locations typically at the entrance, exit, and central areas at human breathing height (approximately 1.0–1.5 m). Sampling was conducted during both peak and off-peak traffic periods, as well as across different seasons, such as summer and autumn. Data were logged continuously at one-minute intervals and included accompanying meteorological parameters such as temperature, atmospheric pressure, and humidity. To ensure data reliability, repeated sampling was performed. The collected datasets were subjected to statistical analysis using methods like the Kruskal–Wallis test, Kolmogorov–Smirnov test, and Pearson correlation to evaluate pollution variations across different floors, locations, and environmental conditions.

In a study carried out by **Idhoko Kingsley et al on the Application of GIS Technique for Mapping of Day Time Air Quality Index in Nnamdi Azikiwe University, Awka Campus (2024)** found that air quality models are essential tools for developing effective air pollution control and management strategies, as they provide critical insights for more efficient environmental planning. This study focused on mapping and monitoring the Air Quality Index (AQI) across various locations within Nnamdi Azikiwe University, Awka Campus. The methodology was based on Geographic Information System (GIS) techniques for data analysis and visualization, aiming to assess pollution levels within the campus environment.

Key air quality parameters measured included Carbon Dioxide (CO_2), Total Volatile Organic Compounds (TVOC), Formaldehyde (HCHO), temperature, and humidity. Data were collected using a portable digital air quality monitoring device, while sampling locations were geo-referenced with a high-precision handheld Global Positioning System (GPS) receiver. GIS technology was employed to integrate database operations such as querying and statistical analysis with spatial mapping capabilities, allowing for efficient data modeling and conversion across formats, unlike traditional database or statistical software.

Data collection spanned one month, with measurements taken during both morning and evening periods to capture daily variations. The study area was digitized using maps sourced from Google Earth, and digitization was carried out using ArcMap software. ArcGIS 10.1 was used primarily to map and visualize the spatial distribution of recorded air pollution levels based on computed values. **Methodology:** In this study, air quality parameters including CO_2, total volatile organic compounds (TVOC), formaldehyde, temperature, and humidity were measured over a one-month period at multiple locations across Nnamdi Azikiwe University's Awka campus using portable air quality detectors. Each sampling point was georeferenced with a handheld GPS device. The spatial data were digitized using Google Earth and processed in ArcGIS 10.1, where statistical analyses and spatial interpolation techniques were applied to produce Air Quality Index (AQI) maps, visually illustrating pollution distribution and highlighting high-risk areas within the campus.

In a study carried out by **Oliver Mbaoma et al on the Geospatial and Machine Learning Driven Air Pollution Modelling Using Vehicular Load and Climatic Variables in Agbarho, Delta State, Nigeria (2022)** prove that Modeling air pollution concentration is a crucial component of environmental quality assessment and the management of ecological resources. In this study, in-situ measurements of three major pollutants—Volatile Organic Compounds (VOC), Carbon Monoxide (CO), and Nitrogen Dioxide (NO_2)—were carried out during field campaigns conducted in three phases. These measurements were primarily influenced by climatic variables and vehicle load. In addition to pollutant data, meteorological variables such as temperature, wind speed, and precipitation rate were obtained from an online weather forecasting platform.

Analysis of the data, including computed mean values and plotted graphs, revealed that **Five Junction**, which recorded the highest vehicular traffic (approximately 50 vehicles every two minutes) and the most intense human activity, had the highest pollution levels. It recorded a VOC mean concentration of **980 ppm** with a standard error of **40.60 ppm**, a CO mean of **11.04 ppm** (standard error: **0.41 ppm**), and an NO_2 concentration of **0.35 ppm**.

Express Junction, with the next highest traffic volume (47 vehicles every two minutes), followed with a VOC mean concentration of **713.91 ppm** (standard error: **59.56 ppm**), CO level of **8.05 ppm**, and NO_2 concentration of **1.88 ppm**.

Ekwere Road ranked next in VOC concentration with a mean of **524.18 ppm** (standard error: **20.64 ppm**) and showed a CO mean concentration of **9.20 ppm** (standard error: **0.69 ppm**), which was notably higher than that of Express Junction.

Ughughelli Road had a VOC mean concentration of **426 ppm** (standard error: **31.53 ppm**), a CO mean of **4.14 ppm**, and a standard error of **0.32 ppm**.

CDI and **Agofure Park**, which experienced similar levels of vehicular activity, recorded VOC levels of **323.05 ppm** and **327.08 ppm**, respectively, with CO values of **4.03 ppm** and **3.29 ppm**.

Finally, **Ekwere Less Residential**, characterized by minimal vehicular and human presence, was found to be the least polluted site, with a VOC mean concentration of **193.42 ppm**, a CO mean of **0.25 ppm**, and an NO_2 concentration of **0.14 ppm**. **Methodology:** In the study, researchers conducted field measurements of VOCs, CO, and NO_2 at multiple locations in Agbarho, alongside collecting local meteorological data (e.g., temperature, wind speed). Each sampling location was georeferenced using GPS and imported into GIS. They then used **Inverse Distance Weighting (IDW)** within the GIS environment to interpolate spatial pollution distribution. Finally, the study applied a **regression/machine learning model** likely trained on the field and meteorological data—to predict pollutant concentrations at unmonitored sites, producing detailed surface pollution maps for analysis

In a study conducted on **Particulate Matter Characterization in a Hospital's Underground Car Park by Hector Garcia-Gonzalez et al (2022)** showed that air quality in hospital underground car parks is a significant concern, particularly due to the exposure of vulnerable individuals such as patients attending medical consultations to diesel emissions. This study aimed to assess the potential health risks associated with a specific hospital's underground car park. Particulate matter was monitored using a range of direct-reading instruments capable of detecting particle number and mass concentrations, including the CPC 3007, EEPS 3090, Trolex Air XD, Nanozen, and Grimm 1109. Elemental and total carbon levels were determined in accordance with the NIOSH 5040 method, while Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs) were analyzed through laboratory techniques, including Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX) analysis.

The results indicated nanoparticle concentrations exceeding 80,000 particles/cm^3 more than double the benchmark set by the German Institute für Arbeitsschutz (IFA). Diesel particulate matter, measured as elemental carbon, reached approximately 35% of the occupational exposure limit. Of the 49 VOCs analyzed, only 13 were detected, all in concentrations below 0.1% of the occupational threshold. Similarly, all 13 PAHs assessed were found to be below the laboratory's limit of quantification.

The study concludes that particulate pollution in the underground car park can surpass safe nanoparticle exposure levels and may pose a health risk, especially to vulnerable populations. As a precaution, it is recommended that such individuals use the outdoor car park when possible or limit their time spent in the underground facility. **Methodology:** The study was conducted in Car Park 1 of the Central University Hospital of Asturias (HUCA) in Oviedo, Spain. Located 2.5 km from the city center, the car park is adjacent to residential and commercial areas and serves over 1,000 vehicles daily on weekdays. It consists of two floors one partially ventilated and one fully underground with 722 car and 22 motorcycle spaces. Due to COVID-19 restrictions, vehicle usage dropped from 20,000 to about 15,000 cars per month, and one of the three parking areas was closed for vaccination activities.

To assess air quality under worst-case conditions, continuous monitoring was conducted on the fully underground level (-2) between 15 November and 3 December 2021. Instruments used included the Trolex Air XD, EEPS 3090, CPC 3007, Nanozen, and GRIMM 1109. Nearby outdoor air quality met legal standards in 2021, with PM_{10} and $PM_{2.5}$ annual averages of 23 μg/m³ and 13 μg/m³, respectively.

A **Study on Mapping and Identifying Risk Areas for Multiple Particulate Matter Pollution at the Block Scale Based on Local Climate Zones by Wen Wu et al (2024)** established that as urbanization in China continues to accelerate, air pollution has become an increasingly urgent environmental challenge particularly because fixed factors such as meteorology and topography are difficult to alter. Consequently, optimizing urban architectural patterns presents a practical approach to mitigating air pollution. This study focuses on the Wenhua Road block in Shenyang, China, using both fixed and mobile monitoring to collect concentration data for three types of particulate matter (PM_1, $PM_{2.5}$, and PM_{10}). Spatial distribution characteristics of Local Climate Zones (LCZs) and particulate matter were analyzed using the ArcGIS platform to identify pollution hotspots and examine the influence of LCZ types on pollutant concentrations.

Findings reveal that PM_1, $PM_{2.5}$, and PM_{10} share similar spatial distribution patterns under the same pollution conditions, though their spatial heterogeneity increases across different pollution levels. Time-weighted analysis showed that PM_1 concentrations ranged from 44 to 51 $\mu g/m^3$, $PM_{2.5}$ from 75 to 86 $\mu g/m^3$, and PM_{10} from 87 to 99 $\mu g/m^3$. Pollution hotspots were consistently located in the central, eastern, and western areas of the block.

The study also found that the correlation between particulate matter concentrations and LCZ types strengthens as particle size increases. Built-up LCZs exhibited higher average concentrations of particulate matter compared to natural LCZs, largely due to factors such as building height and density. Based on these insights, the study recommends that urban design strategies in high-risk areas prioritize increasing the proportion of natural vegetation or water bodies, reducing building density, and regulating building height. This approach can significantly enhance spatial optimization of urban architectural forms aimed at reducing particulate matter pollution. **Methodology:** the researchers deployed **low-cost, portable air-quality sensor units** (Alpha Sense OPC-N2 for PM; electrochemical sensors for CO_2, O_3, CO, NO, and NO_2), alongside **2D sonic anemometers** to measure wind speed and direction, and built-in probes for temperature and relative humidity at **six strategically chosen locations** across the Ile-Ife pollution hotspot.

Each site recorded continuous pollutant and meteorological data, which were then analyzed using **Conditional Probability Function (CPF) plots**. These CPF plots linked elevated pollutant concentrations to prevailing wind directions and speeds, helping to identify the most likely pollutant source sectors for each gas at different times of day.

This method effectively combined real-time pollutant monitoring with meteorological modeling to pinpoint local emission sources and paths, a useful approach for understanding how campus car parks like those at UNIBEN might contribute to pollution hotspots.

In a study of **Modeling Spatial Distribution and Determinant of $PM_{2.5}$ at Micro-Level Using Geographically Weighted Regression (GWR) to Inform Sustainable Mobility Policies in Campus Based on Evidence from King Abdulaziz University, Jeddah, Saudi Arabia** by **Alok Tiwari and Mohammed Aljoufie (2021):** Air pollution is fatal. Fine particles, such as $PM_{2.5}$, in ambient air might be the cause of many physical and psychological disorders, including cognitive decline. This is why educational policymakers are adopting sustainable mobility, and other policy measures, to make their campuses carbon-neutral; however, car-dependent cities and their university campuses are still lagging behind in this area. This study attempts to model the spatial heterogeneity and determinants of $PM_{2.5}$ at the King Abdulaziz University campus in Jeddah, which is ranked first among the Saudi Arabian universities, as well as in the MENA region. We developed four OLS and GWR models of different peak and off-peak periods during weekdays in order to estimate the determinants of the $PM_{2.5}$ concentration. The number of cars, humidity, temperature, windspeed, distance from trees, and construction sites were the estimators in our analysis. Because of a lack of secondary data at a finer scale, we collected the samples of all dependent and independent variables at 51 locations on the KAU campus. Model selection was based on RSS, log-likelihood, adjusted R2, and AICc, and a modal comparison shows that the GWR variant of Model-2 outperformed the other models. The results of the GWR model demonstrate the geographical variability of the $PM_{2.5}$ concentration on the KAU campus, to which the volume of car traffic is the key contributor. Hence, we recommend using the results of this study to support the development of a car-free and zero-carbon campus at KAU; furthermore, this study could be exploited by other campuses in Saudi Arabia and the Gulf region. **Methodology:** The researchers collected $PM_{2.5}$ concentration data and associated variables including vehicle counts, humidity, temperature, wind speed, distance to trees, and proximity to construction sites at 51 locations across the King Abdulaziz University campus, conducting measurements during both peak and off-peak hours; they then used Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR) models to analyze spatial heterogeneity in pollutant concentrations, comparing models based on goodness-of-fit metrics (RSS, adjusted R^2, AICc, and log-likelihood), with results showing that the GWR model best captured local variations and identified vehicular traffic volume as the most significant contributor to $PM_{2.5}$ levels.

In a study of **Spatio-Temporal Analysis of CO_2 Emissions from Vehicles in Urban Areas: A Satellite Imagery Approach** by **Nur Fatma Fadilah Yaacob (2024)** it was shown that Carbon dioxide (CO_2) emissions are a significant global environmental concern, widely notable as a major cause of climate change. Meanwhile, transportation is the main sector contributing to CO_2 emissions, which are escalating at a faster rate than Gross Domestic Product Growth. This study attempted to evaluate the spatial–temporal pattern of CO_2 emissions from vehicles using the Sentinel 5P satellite image. The Sentinel 5P image was acquired from the European Space Agency from 2019 until 2022. Utilizing ArcGIS 10.5, these data were analyzed to extract the CO_2 values, which were then displayed as the total column amount. Thereafter, the extraction by point method was conducted on road features based on the Mukim Kajang basemap to obtain the value of CO_2 emissions from transportation. Spatial–temporal mapping was then accomplished through kernel density analysis, enabling the identification of CO_2 emission hotspot areas. The findings show that the spatial–temporal pattern of CO_2 emissions was higher in September 2019 (0.06964 mol/m^2), March 2020 (0.03596 mol/m^2), December 2021 (0.0437 mol/m^2), and January (0.03384 mol/m^2), respectively. Based on eight cities in Mukim Kajang, Bandar Kajang has been a hotspot area for carbon dioxide emissions from motor vehicles for four consecutive years, starting in 2019 until 2022. In summary, the results of this study could provide guidelines to researchers and policymakers to develop effective strategies to reduce the level of CO_2 emissions from transportation in urban areas. **Methodology:** Researchers used **Sentinel-5P satellite imagery** (covering 2019–2022) to extract CO_2 column concentrations over urban road networks and then employed **ArcGIS 10.5** for spatial–

temporal mapping. Road feature data from a local basemap were used to extract emission values, which were processed through **kernel density analysis** to identify CO_2 emission hotspots across the study area. The result: seasonal and spatial emission patterns, highlighting high-emission periods such as September 2019, March 2020, December 2021, and January 2022.

2.9 Research Gap

Although many studies have looked into air pollution in urban areas and the use of geospatial tools to monitor it, there are still important gaps especially when it comes to assessing pollution at a local level within institutions like university campuses. This section highlights the main shortcomings in existing research that this study aims to address.

2.9.1 Limited Focus on Car parks In Campus

Most air pollution studies tend to focus on busy urban roads, industrial areas, and crowded residential neighborhoods. While these locations are undeniably major sources of pollution, campus car parks—where idling vehicles are often concentrated—have received far less attention. Despite their potential to become localized pollution hotspots, especially during rush hours, there's a noticeable lack of detailed research on pollutant buildup in these areas, particularly within universities in Nigeria and across West Africa.

2.9.2 Inadequate use of GIS in Campus Based Pollution Studies

Although GIS has become a well-established tool in urban environmental planning and large-scale air quality studies (Longley et al. 2015), its use within academic institutions remains relatively limited, especially when it comes to analyzing pollution at a smaller scale, such as in university car parks. These localized environments often go unexamined in geospatial studies, despite being potential hotspots for vehicle-related emissions. Many existing studies continue to rely solely on traditional air quality monitoring techniques, which, while valuable, often lack the spatial depth needed to understand how pollutants are distributed across campus areas or how they interact with surrounding infrastructure (EPA, 2022). As a result, valuable insights into localized exposure risks and planning opportunities are often missed.

2.9.3 Scarcity of Integrated Studies on Both Particulate and Gaseous Pollutants

A number of studies have examined either particulate matter (such as $PM_{2.5}$ and PM_{10}) or specific gaseous pollutants like NO_2, CO, and SO_2 independently (WHO, 2021). However, only a few have looked at both types together within the same, site-specific analysis. In reality, especially in places like car parks, these pollutants are often present at the same time and typically originate from the same source; vehicle emissions (EPA, 2022). Since they interact and contribute jointly to air quality problems, there’s a clear need for a more integrated approach to properly evaluate their combined environmental and health impacts.

2.9.4 Lack of Empirical Data from University of Benin (UNIBEN)

Up to this point, there has been no publicly available geospatial study focused on air pollution within the University of Benin's Ugbowo Campus, particularly in specific high-traffic zones such as car parks, where vehicle emissions are likely to be concentrated. Despite the growing concerns about environmental health on campuses, the absence of location-specific, spatially referenced data means that critical areas of concern often go unrecognized. Without this empirical evidence, it becomes challenging for campus planners, environmental health officers, and university administrators to properly assess pollution exposure risks, identify vulnerable zones, or develop targeted interventions. As a result, efforts to implement environmentally sustainable policies or infrastructure, such as green buffers, traffic control strategies, or improved ventilation in surrounding buildings; are often based on assumptions rather than data-driven insights (EPA, 2022).

2.9.5 Limited Use of Interpolation Techniques in Local Contexts

While techniques like Inverse Distance Weighting (IDW) and Kriging are commonly used in air quality research around the world, their application in Nigerian environmental studies is still quite limited. In cases where they are used, these methods tend to focus on large regional or city-wide scales, often overlooking the finer spatial details that matter in smaller, more complex environments like university campuses. As a result, important local variations in pollutant levels may go undetected, making the resulting pollution maps less precise and less useful for making informed decisions at the campus or neighborhood level (WHO, 2021).

2.9.6 Underutilization of Remote Sensing in Small-Scale Pollution Assessment

Remote sensing has been widely used to monitor air quality across large regions and even at the global level (WHO, 2021). However, its application in smaller, more specific areas like university car parks has received little attention. This is somewhat surprising, given the growing access to high-resolution satellite data such as that from Sentinel-5P. There's still a lot of untapped potential in combining this satellite data with ground-based measurements and GIS tools, especially for more localized environmental studies (EPA, 2022).

2.8.7 Identified Gaps

Table 2.3: Identified Gaps

Identified Gap	Implication	How this study Addresses it
Lack of research on campus car parks as pollution hotspots	Incomplete understanding of localized exposure risk	Focus specifically on UNIBEN car park
Limited use of GIS in Nigerian Campus studies	Missed opportunity for spatially targeted solution	Integrated GIS pollution mapping
Few combined PM and gas pollutant studies	Fragmented understanding of air quality impacts	Simultaneously analyzes both pollutant types
Underexplored use of remote sensing in local studies	Missed chance for enhanced spatial analysis	Explores remote sensing integration possibilities

This project helps bridge an important gap in existing research by focusing on the geospatial analysis of both particulate and gaseous pollutants specifically within car parks on UNIBEN's Ugbowo Campus. Through the combination of field measurements, GIS technology, and interpolation methods, it tackles both the methodological shortcomings and location-specific limitations seen in earlier studies. The outcome is not just a more accurate understanding of pollution patterns on campus, but also a useful dataset and framework that can support future environmental planning in similar academic settings.

CHAPTER THREE

(METHODOLOGY)

3.1 STUDY AREA DESCRIPTION

This study was carried out within Ugbowo Campus of the University of Benin, located in Benin City, Edo State, Nigeria. The campus lay approximately between latitude **6.3997845°N** and longitude **5.6098630°E**. The campus location was a mix of academic, residential, commercial, and administrative facilities. It was populated by thousands of students, staff, and visitors daily, which caused a large amount of vehicular movement within its premises.

Table 3.1: LIST OF SELECTED AREAS

CAR PARK NAME	FACULTY	LATITUDE (°*E*)	LONGITUDE (°*N*)
ENGINEERING CAR PARK	ENGINEERING	5.616202778	6.402805556
MAIN GATE CAR PARK	MAIN GATE	5.609944444	6.398638889
SMALL GATE CAR PARK	SMALL GATE	5.609182	6.40192
BACK GATE CAR PARK	ART	5.62131	6.404728
MEDICAL COMPLEX CAR PARK	MEDICINE AND SURGERY	5.62325	6.395222222
HALL 2 CAR PARK	MANAGEMENT SCIENCE	5.6205	6.3977222222
LAW CAR PARK	LAW	5.622104	6.40084

The main focus of this study was on selected car parks within the campus, mainly those with high traffic and daily vehicular activities such as the Faculty of Engineering, Faculty of Arts, and the University Main Gate area.

These locations were selected due to their high vehicular activity, usage frequency, size, and density. The Ugbowo Campus featured a relatively flat terrain with gentle undulations and was situated in a humid tropical climate zone, which could impact pollution dispersal. The area had distinct wet and dry seasons, and factors such as dominant wind direction, temperature, and humidity were taken into account during sampling.

The study began with the creation of a digital map of the campus from satellite photographs using a Geographic Information System (GIS). This map served as the foundation, helping to accurately pinpoint locations and providing the backdrop for all pollution data. GPS was then used to record the exact locations where each sample was taken, and these points were plotted directly onto the campus map, providing a clear spatial picture for analysis.

A thorough comprehension of the study area's configuration, traffic flow, and land utilization was crucial for analyzing spatial differences in pollutant levels and evaluating their possible effects on human health and the environment across the campus.

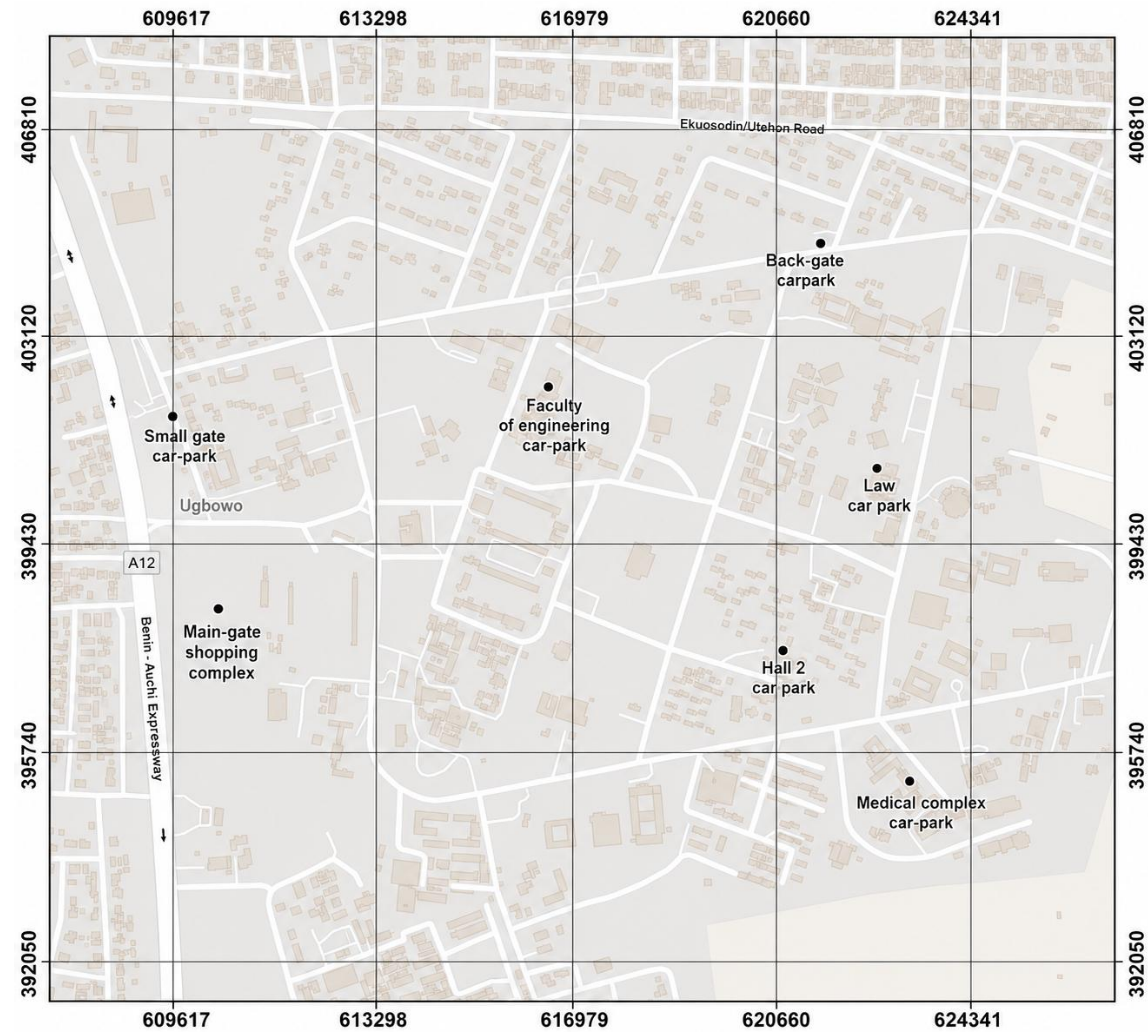

Figure 3.1: Map of Study area.

3.2 Research Design

This research employed a field-based experimental approach conducted within the car parks of the Ugbowo Campus at the University of Benin, with the primary objective of examining the spatial distribution patterns of particulate matter alongside selected gaseous pollutants in this specific environment. To achieve a comprehensive understanding, the study integrated quantitative data collection methods with advanced spatial analysis techniques. Geographic Information Systems (GIS) served as a critical tool in the study, enabling the precise mapping and detailed examination of pollutant concentrations across different locations within the study area. By combining empirical field measurements with geospatial analytical methods, the research provided valuable insights into the environmental quality and pollutant dispersion dynamics around the campus car parks.

The study involved the systematic collection of air quality data from a series of carefully chosen sampling locations distributed throughout several car parks on the campus. The selection of these sites was informed by initial assessments that considered factors such as traffic volume, levels of human activity, and their proximity to known or suspected sources of pollution. At each designated sampling point, concentrations of various pollutants were accurately measured using calibrated, portable air quality monitoring instruments to ensure data reliability and precision. Additionally, the exact geographic coordinates of each sampling site were recorded using GPS-enabled devices, facilitating precise spatial referencing and subsequent geospatial analysis. This comprehensive data collection strategy was designed to capture a detailed and representative snapshot of the air quality conditions across the campus car parks.

The research was conducted over a specified timeframe, strategically encompassing multiple periods throughout the day, namely morning, afternoon, and evening, to effectively capture temporal fluctuations in pollutant concentrations that corresponded with varying traffic flow patterns. This temporal coverage was essential in understanding how pollutant levels changed in response to daily human and vehicular activities. Furthermore, data collection was carefully scheduled to occur under relatively stable and consistent weather conditions, thereby minimizing the potential confounding effects of external environmental variables such as wind speed, precipitation, and extreme temperatures. By controlling for these meteorological factors, the study aimed to ensure that the observed variations in air quality were primarily attributable to local pollutant sources rather than transient atmospheric influences.

To meet these objectives, the research combined established environmental sampling techniques with geospatial analysis methods. This integrated approach allowed for both the measurement of pollutant concentrations and the visualization of their distribution across the university environment. Ultimately, the study design aimed to provide a thorough insight into the impact of car park activities on ambient air quality.

3.3 Data Collection

The data collection phase of the study consisted of on-site air quality monitoring coupled with geolocation mapping. This section detailed the categories of data gathered, the specific instruments employed, the sampling methodologies followed, and the environmental parameters assessed. The primary goal was to acquire precise, spatially referenced measurements of particulate matter and selected gaseous pollutants within the vicinity of designated car parks on the Ugbowo Campus of the University of Benin.

3.3.1 Parameters Employed for the study

This study concentrated on the assessment of the following air pollutants:

Table 3.2: List of Parameters Employed for the study

DATA TYPE	SOURCE	RELIVANCE TO STUDY
Particulate Matter ($PM_{2.5}$ and PM_{10})	Vehicular emissions dust, particles, fuel combustion	Used to assess the concentration of fine and coarse airborne particles within car parks
Formaldehyde (HCHO)	Vehicle exhaust, incomplete fuel combustion, atmospheric reactions	Used to determine the presence of harmful gaseous pollutants associated with poor air quality.
Total Volatile Organic Compounds (TVOCs)	Fuel evaporation, lubricants, vehicle exhaust fumes	Used to evaluate gaseous emissions contributing to air pollution within the study area.
Carbon Dioxide (CO2)	Vehicle emissions, fuel combustion and respiration	Used as an indicator of air circulation pollutant accumulation and vehicular activities within car parks.

3.3.2 Equipment Used For the Study

The data collection process utilized the following instruments:

Table 3.3: Table of equipment used for the study

EQUIPMENT	MODEL	RELEVANCE TO THE STUDY
Portable Air Quality Monitor	PO-147-04355220278390265	Measures air pollutant concentrations.
GPS Device/Smartphone with GPS Application	SM-G965U	Captures sampling coordinates.
Weather Meter/Mobile Weather Application	SM-G965U	Records meteorological conditions.

All equipment was carefully calibrated in accordance with the manufacturer's guidelines prior to deployment in the field, to ensure the accuracy and reliability of the data collected.

3.3.3 Sampling Method Employed

Sampling locations for this study were carefully selected from major car parks within the Ugbowo Campus of the University of Benin based on traffic intensity, car park usage patterns, and surrounding environmental characteristics. Areas with varying levels of vehicular movement and parking density were considered in order to capture spatial variations in air pollutant concentrations. The selected locations included student, staff, and visitor car parks to ensure broad representation of different transportation activities within the campus environment. Consideration was also given to nearby buildings, vegetation cover, and physical structures, as these factors influenced airflow and pollutant dispersion (EPA, 2022).

A total of three to five sampling points were selected across the study area to provide adequate spatial coverage. Each sampling location was geo-referenced using a GPS device or smartphone GPS application to obtain accurate latitude and longitude coordinates. The coordinates were later integrated into a Geographic Information System (GIS) environment for spatial mapping and analysis of pollutant distribution patterns (ESRI, 2021).

At each sampling location, the air quality monitor was positioned approximately 1.5 meters above ground level to represent the average human breathing zone, following standard air quality sampling recommendations (WHO, 2021). Prior to data collection, the monitoring device was allowed to stabilize for several minutes to ensure accurate and reliable readings. Measurements of PM2.5, PM10, CO2, HCHO, and TVOCs were then recorded during three distinct periods of the day: morning (7:00 AM – 9:00 AM), afternoon (12:00 PM – 2:00 PM), and evening (5:00 PM – 7:00 PM), in order to capture temporal variations associated with traffic activity and environmental conditions.

All measurements obtained were manually recorded and geotagged with the corresponding GPS coordinates of each sampling point. Sampling was conducted over multiple days to account for daily fluctuations in vehicular movement and meteorological conditions. Repeated measurements were also taken at selected locations, and average values were computed to improve the reliability, consistency, and accuracy of the dataset.

3.3.4 Data Recording and Storage

All data collected during the field sampling process were systematically recorded in a structured digital format using Microsoft Excel spreadsheets and electronic databases to ensure proper organization, accuracy, and ease of analysis. The recorded parameters included the type of pollutant measured, pollutant concentration values, date and time of sampling, sampling location, and the corresponding GPS coordinates of each sampling point.

Following data collection, all field records were carefully cross-checked to identify possible errors, inconsistencies, or missing entries before final storage. Duplicate observations and repeated measurements obtained from the same sampling locations were averaged to improve data reliability and consistency. The validated dataset was subsequently saved in compatible digital formats for further processing and analysis.

The compiled spatial and attribute data were later imported into Geographic Information System (GIS) software for spatial interpolation, visualization, and the generation of pollution distribution maps across the study area. Proper digital storage procedures were maintained throughout the study to prevent data loss and ensure easy retrieval of information for analysis and interpretation (ESRI, 2021; EPA, 2022).

3.4 Data Processing and Analysis

Following data collection, all air quality measurements and spatial datasets were subjected to systematic processing prior to analysis. The raw pollutant data were first screened for completeness, accuracy, and consistency to ensure data quality. Erroneous or missing values were checked and treated using standard data validation procedures. The datasets were then organized and coded using Microsoft Excel to prepare them for statistical and spatial analysis. GPS coordinate data were converted into decimal degree format to ensure compatibility with Geographic Information System (GIS) software.

Spatial analysis was carried out by importing the cleaned datasets into ArcGIS/QGIS environment. All spatial data were projected using the WGS 84 coordinate system to ensure spatial consistency. Spatial interpolation using the Inverse Distance Weighting (IDW) method was applied to generate continuous surface maps of pollutant concentration distribution across the selected car parks. This method was widely applied in environmental studies for predicting spatial variability of air pollutants based on measured point data (ESRI, 2022; Ochieng et al., 2020).

Descriptive statistical analysis was performed to summarize pollutant concentrations, including measures such as mean, standard deviation, minimum, and maximum values. Comparative analysis of spatial and temporal variations in pollutant levels was conducted using statistical tools in SPSS. The results were interpreted against relevant air quality standards to assess pollution intensity and spatial distribution patterns within the study area (WHO, 2021; US EPA, 2023).

3.4.1 Geospatial Mapping

Geospatial analysis of air quality data was carried out using a Geographic Information System (GIS) such as ArcGIS or QGIS. The georeferenced sampling points were first imported into the GIS platform and projected using the WGS 84 coordinate reference system to ensure spatial consistency. Each sampling location was mapped as a point feature layer, with associated pollutant concentration values linked as attribute data. These values were visualized using graduated symbols and thematic (choropleth) mapping techniques to provide an initial representation of spatial variability across the study area.

To generate continuous spatial distribution surfaces of air pollutant concentrations, the Inverse Distance Weighting (IDW) interpolation technique was employed as the primary geospatial method. IDW was a deterministic interpolation method that estimated values at unsampled locations based on the principle that points closer in space had more influence on the estimated value than those further away. This made it particularly suitable for environmental datasets where spatial dependence was assumed but data points were discrete and irregularly distributed.

The IDW method is mathematically expressed as:

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{Z_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}}$$

Where:

$Z(x_0)$= estimated pollutant concentration at an unsampled location

Z_i= known concentration at sampled location i

d_i= distance between sampled point $i$and the estimation point x_0

p= power parameter controlling the influence of distance

n= number of nearby sampled points used in estimation

A power value (p) of 2 was assumed, which is commonly adopted in environmental spatial analysis to balance local influence and smoothing effects.

Although IDW was selected as the primary interpolation method due to its simplicity and suitability for point-based environmental data, geostatistical methods such as Kriging and Spline interpolation were also considered. Kriging was more statistically robust as it accounted for spatial autocorrelation and prediction error, while Spline produced smoother surfaces; however, these were not adopted as the primary methods due to the study's focus on deterministic spatial representation rather than probabilistic modelling.

The resulting interpolated surface maps were used to identify pollution hotspots, visualize spatial gradients of air quality, and assess the influence of surrounding anthropogenic activities such as traffic density and infrastructure proximity.

3.4.3 Statistical Analysis

Statistical analysis of the air quality data was conducted to quantify pollutant characteristics and support the interpretation of spatial patterns obtained from GIS analysis. The cleaned dataset was imported into Microsoft Excel and/or IBM SPSS Statistics for computation of both descriptive and inferential statistics.

Descriptive statistical methods were first applied to summarize the distribution of each measured pollutant across all sampling locations. Parameters computed included the arithmetic mean, minimum, maximum, standard deviation, and variance. The arithmetic mean was used to represent the average pollutant concentration and was expressed as:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Where:

$\bar{X}$= mean pollutant concentration

X_i= individual pollutant measurement

n= total number of observations

The variability of pollutant concentrations was assessed using the standard deviation, given by:

$$\boldsymbol{\sigma} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} (\boldsymbol{X_i} - \bar{\boldsymbol{X}})^2}$$

Where:

σ= standard deviation

X_i= individual observation

$\bar{X}$= mean value

n= number of observations

These descriptive statistics were used to determine the dispersion and central tendency of air pollutant concentrations across the study area, providing a quantitative summary of air quality conditions.

In addition, Pearson's correlation analysis was conducted to examine the relationship between different air pollutants and to assess possible associations between pollutant levels, temporal variations, traffic intensity, and meteorological conditions. The Pearson correlation coefficient was expressed as:

$$\boldsymbol{r} = \frac{\sum(\boldsymbol{X_i} - \bar{\boldsymbol{X}})(\boldsymbol{Y_i} - \bar{\boldsymbol{Y}})}{\sqrt{\sum(\boldsymbol{X_i} - \bar{\boldsymbol{X}})^2 \sum(\boldsymbol{Y_i} - \bar{\boldsymbol{Y}})^2}}$$

Where:

r= correlation coefficient

X_i, Y_i= paired pollutant or variable values

$\bar{X}, \bar{Y}$= mean values of variables

The correlation results were interpreted to identify the strength and direction of relationships between variables, where values close to +1 or −1 indicated strong positive or negative relationships, respectively.

Overall, the statistical analysis complemented the GIS-based spatial outputs by providing quantitative evidence of pollutant variability, interrelationships, and distribution trends across the study area (Montgomery et al., 2021; Field, 2018).

3.4.4 Comparison with Air Quality Standards

The measured concentrations of air pollutants were evaluated against established ambient air quality standards to assess compliance levels and potential health implications. The primary reference standard employed in this study was the World Health Organization (WHO, 2021) Global Air Quality Guidelines, which provided updated threshold limits for key ambient air pollutants including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO).

The WHO (2021) guideline values used for comparison were summarized as follows:

Table 3.4: WHO (2021) Air Quality Guideline Values

POLLUTANTS	AVERAGE TIME	WHO LIMIT
PM2.5	24 hours	15 ug/m^3
PM10	24 hours	45 ug/m^3
Formaldehyde (HCHO)	30 minutes	100 ug/m^3
Total VOC (TVOCs)	1-hour	No specific value (often <300 ug/m^3 used as safe indoor guideline)
Carbon-Dioxide (CO2)	1-hour	No direct WHO limit (ASHRAE recommends <100 ug/m^3)

These standards were used as benchmark values for evaluating the severity of pollution at each sampling location.

Comparison Method

Measured pollutant concentrations were compared directly with the corresponding WHO guideline limits using a ratio-based exceedance approach. For each pollutant at each sampling location, the measured concentration was assessed as either:

Compliant: when $C_{measured} \leq C_{standard}$

Non-compliant (exceedance): when $C_{measured} > C_{standard}$

To further quantify pollution intensity, an exceedance ratio was computed as:

$$E_r = \frac{C_{measured}}{C_{standard}}$$

Where:

E_r= exceedance ratio

$C_{measured}$= observed pollutant concentration

$C_{standard}$= WHO guideline value

Values of E_r > 1 indicated exceedance of acceptable air quality limits, while values less than or equal to 1 indicated compliance.

This classification was used to categorize air quality conditions across sampling locations into qualitative classes such as Good, Moderate, and Poor, based on the degree of deviation from WHO standards. This approach was consistent with environmental air quality assessment practices that integrated measured concentrations with internationally recognized health-based thresholds (WHO, 2021; US EPA, 2023).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SAMPLING LOCATIONS AND COODINATES

The table below, table 4.1 highlights the coordinates of the seven sampling points used for monitoring pollutants. The sites where samples were taken were strategically chosen to capture areas with variations in vehicular activities and crowd density.

Table 4.1: Sampling Locations and Geographic Coordinates

SAMPLING ID	LOCATION NAME	LATITUDE (°E)	LONGITUDE (°N)
1	ENGINEERING CAR PARK	5.616202778	6.402805556
2	MAIN GATE CAR PARK	5.609944444	6.398638889
3	SMALL GATE CAR PARK	5.609182	6.40192
4	BACK GATE CAR PARK	5.62131	6.404728
5	MEDICAL COMPLEX CAR PARK	5.62325	6.395222222
6	HALL 2 CAR PARK	5.6205	6.3977222222
7	LAW CAR PARK	5.622104	6.40084

4.1.1 Pollutant Concentration Data

Table 4.2: Concentrations of Air Pollutants at Each Sampling Site

SAMPLING ID	LOCATION	$PM_{2.5}$ (ug/m^3)	PM_{10} (ug/m^3)	HCHO (ug/m^3)	TVOC (ug/m^3)	CO_2 (ppm)
1	ENGINEERING CAR PARK	39	45	0.003	0.006	407
2	MAIN GATE CAR PARK	37	43	0.002	0.009	412
3	SMALL GATE CAR PARK	41	46	0.003	0.007	407
4	BACK GATE CAR PARK	49	55	0.004	0.006	412
5	MEDICAL COMPLEX CAR PARK	35	40	0.002	0.006	409
6	HALL 2 CAR PARK	35	43	0.002	0.006	406
7	LAW CAR PARK	38	43	0.003	0.007	410

4.2 Air Quality Index (AQI) Computation

To attain a better understanding of the implications of the measured concentrations of particulate matter and gaseous pollutants, the Air quality index (AQI) was computed for each sampling location. The AQI represents a standardized measure that translates complex pollutant concentration data into a single value reflecting the level of air quality and its potential impact on human health. In this study, the AQI for each pollutant: PM2.5, PM10, CO_2, TVOCs, and HCHO was calculated using the U.S. Environmental Protection Agency (USEPA) methodology, which relates the measured concentration of a pollutant to its corresponding index breakpoint. The computed AQI values were further categorized into qualitative descriptors such as “Good,” “Moderate,” “Unhealthy for Sensitive Groups,” and so on, to allow for easy interpretation of air quality status across the various car parks within Ugbowo Campus.

4.2.1 PM2.5 AQI RESULTS

The concentration of PM2.5 is presented in Table 4.3:

Table 4.3: PM2.5 AQI Results

LOCATION	PM2.5 (ug/m^3)	AQI	CATEGORY
ENGINEERING CAR PARK	39	110	Unhealthy for sensitive groups
MAIN GATE CAR PARK	37	105	Unhealthy for sensitive groups
SMALL GATE CAR PARK	41	115	Unhealthy for sensitive groups
BACK GATE CAR PARK	49	134	Unhealthy for sensitive groups
MEDICAL COMPLEX CAR PARK	35	99	Moderate
HALL 2 CAR PARK	35	99	Moderate
LAW CAR PARK	38	107	Unhealthy for sensitive groups

4.2.2 Interpretation of PM2.5 Air Quality Index (AQI) Results

The air quality readings showed that PM2.5 levels ranged from 99 to 134, which puts most areas in the "Unhealthy for Sensitive Groups" zone. This means that while the air quality is generally okay for most people, those with breathing problems, heart conditions, kids, and older adults might start to feel the effects if they're exposed for a long time. The Medical Complex and Hall 2 car parks were slightly better, coming in at "Moderate" with AQI scores around 99. However, areas like the Back Gate and Small Gate had higher AQI readings, likely due to heavier traffic and dust being kicked up. The air quality is being impacted by vehicle traffic and other nearby activities, which is worth keeping an eye on if you're part of a sensitive group.

4.2.3 PM10 AQI RESULTS

The concentration of PM10 is presented in Table 4.4:

Table 4.4: PM10 AQI Results

LOCATION	**PM10 (ug/m^3)**	**AQI**	**CATEGORY**
ENGINEERING CAR PARK	45	42	Good
MAIN GATE CAR PARK	43	40	Good
SMALL GATE CAR PARK	46	43	Good
BACK GATE CAR PARK	55	51	Moderate
MEDICAL COMPLEX CAR PARK	40	37	Good
HALL 2 CAR PARK	43	40	Good
LAW CAR PARK	43	40	Good

4.2.4 Interpretation of PM10 Air Quality Index (AQI) Results

For larger particles like PM10 the AQI values ranges from 37 to 51. Most of the sampling locations fell within the "Good" category, it means the air quality is considered healthy. The only exception was the Back Gate car park, which just edged into the "Moderate" range with an AQI score of 51. Overall, it looks like coarse particulate pollution isn't a major concern on campus. The air quality is safe for everyone, with little to no health risks. The slightly higher reading at the Back Gate is probably due to vehicle traffic, road dust, and more human activities going on around in that area.

4.2.5 HCHO AQI RESULTS

The concentration of HCHO is presented in Table 4.5:

Table 4.5 HCHO AQI Results

LOCATION	HCHO	AQI	CATEGORY
ENGINEERING CAR PARK	0.003	0.0015	Good
MAIN GATE CAR PARK	0.002	0.01	Good
SMALL GATE CAR PARK	0.003	0.015	Good
BACK GATE CAR PARK	0.004	0.02	Good
MEDICAL COMPLEX CAR PARK	0.002	0.01	Good
HALL 2 CAR PARK	0.002	0.01	Good
LAW CAR PARK	0.003	0.015	Good

4.2.6 Interpretation of HCHO Air Quality Index (AQI) Results

The measured formaldehyde (HCHO) levels across all sampling sites were extremely low (0.002–0.004 µg/m³), far below the WHO 1-hour guideline of 100 µg/m³ and even below the lowest detection range used in most indoor air standards. The computed AQI values (≈0) place all sites within the "Good" air quality category, implying no risk of irritation or odor and excellent air quality conditions. This suggests that formaldehyde emissions from sources such as vehicle exhausts, fuel vapors, or nearby combustion are minimal to negligible within the sampled areas. Compared to $PM_{2.5}$ and PM_{10}, which showed measurable pollution, HCHO concentrations are insignificant and do not contribute meaningfully to overall air quality deterioration on campus.

The concentration of TVOCs is presented in Table 4.6:

Table 4.6: TVOCs AQI Results

LOCATION	TVOCs	AQI	CATEGORY
ENGINEERING CAR PARK	0.006	0.005	Good
MAIN GATE CAR PARK	0.009	0.007	Good
SMALL GATE CAR PARK	0.007	0.005	Good
BACK GATE CAR PARK	0.006	0.005	Good
MEDICAL COMPLEX CAR PARK	0.006	0.005	Good
HALL 2 CAR PARK	0.006	0.005	Good
LAW CAR PARK	0.007	0.005	Good

4.2.8 Interpretation of TVOC Air Quality Index Results

The measured Total Volatile Organic Compounds (TVOCs) concentrations across all sampling locations were extremely low, ranging from 0.006 – 0.009 $\mu g/m^3$. According to international indoor air quality guidelines, these values fall well below the "Excellent" category (< 65 $\mu g/m^3$), indicating very clean air with negligible VOC contamination. The AQI-style calculations yielded values near 0, corresponding to the "Good" range on the Air Quality Index scale. This shows that VOC emissions within the University of Benin car parks are minimal, and likely dominated by trace background levels rather than active combustion or solvent sources.

4.2.9 CO_2 AQI RESULTS

The concentration of CO_2 is presented in Table 4.7:

Table 4.7: CO_2 AQI Results

LOCATION	CO2	AQI	CATEGORY
ENGINEERING CAR PARK	407	34	Good
MAIN GATE CAR PARK	412	34	Good
SMALL GATE CAR PARK	407	34	Good
BACK GATE CAR PARK	412	34	Good
MEDICAL COMPLEX CAR PARK	409	34	Good
HALL 2 CAR PARK	406	34	Good
LAW CAR PARK	410	34	Good

4.2.10 Interpretation of CO2 Air Quality Index Result

All seven locations recorded CO2 concentrations between 406–412 ppm, which fall well within the "Good" category (<600 ppm). The AQI-style values (≈34) confirm that indoor air ventilation/CO_2 accumulation is not a concern at the sampled times — the air is close to outdoor/background CO_2 levels and indicates adequate ventilation and low occupant-generated CO_2 buildup. This aligns with the low TVOC and HCHO results you measured, while $PM_{2.5}$ remains the primary pollutant of concern on campus.

The concentration of PM2.5 is presented in Table 4.8:

Table 4.8 Interpretation of overall AQI results.

LOCATION	$PM_{2.5}$ AQI	PM_{10} AQI	HCHO AQI	TVOC AQI	CO_2 AQI	Overall AQI	Category
ENGINEERING CAR PARK	110	42	0.0015	0.005	34	110	Unhealthy for sensitive groups
MAIN GATE CAR PARK	105	40	0.01	0.007	34	105	Unhealthy for sensitive groups
SMALL GATE CAR PARK	115	43	0.015	0.005	34	115	Unhealthy for sensitive groups
BACK GATE CAR PARK	134	51	0.02	0.005	34	134	Unhealthy for sensitive groups
MEDICAL COMPLEX CAR PARK	99	37	0.01	0.005	34	99	Moderate (51-100)
HALL 2 CAR PARK	99	40	0.01	0.005	34	99	Moderate (51-100)
LAW CAR PARK	107	40	0.015	0.005	34	107	Unhealthy for sensitive groups

Across all sampled locations, the overall air quality index (AQI) ranged from 99 to 134, with PM2.5 identified as the dominant pollutant at every site. The Back Gate Car Park recorded the highest overall AQI (134), indicating the poorest air quality, while the Medical Complex and Hall 2 Car Parks showed comparatively lower AQIs (≈99). According to the U.S. EPA classification, most sites fall within the "Unhealthy for Sensitive Groups" category, meaning that individuals with respiratory conditions, children, and the elderly may experience mild health effects from short-term exposure. The other measured pollutants (PM10, TVOCs, HCHO, and CO2) remained within the "Good" range, suggesting that particulate matter, particularly $PM_{2.5}$, is the major contributor to reduced air quality within the study area.

4.3 Geospatial Analysis (Mapping)

Geospatial analysis was carried out to visualize and interpret the spatial distribution of particulate matter and selected gaseous pollutants across the various car parks within Ugbowo Campus. This approach enabled the identification of pollution hotspots and spatial patterns influenced by vehicular activities and environmental factors. The measured pollutant concentrations were georeferenced using their respective sampling coordinates and analyzed with Geographic Information System (GIS) tools. Spatial interpolation techniques such as Inverse Distance Weighting (IDW) were employed to generate continuous surface maps showing the variation in pollutant levels across the study area. These maps provided a clearer understanding of how air quality differs from one location to another, highlighting areas with elevated concentrations that may pose higher health risks to users of the car parks.

4.3.1 GIS map for PM2.5

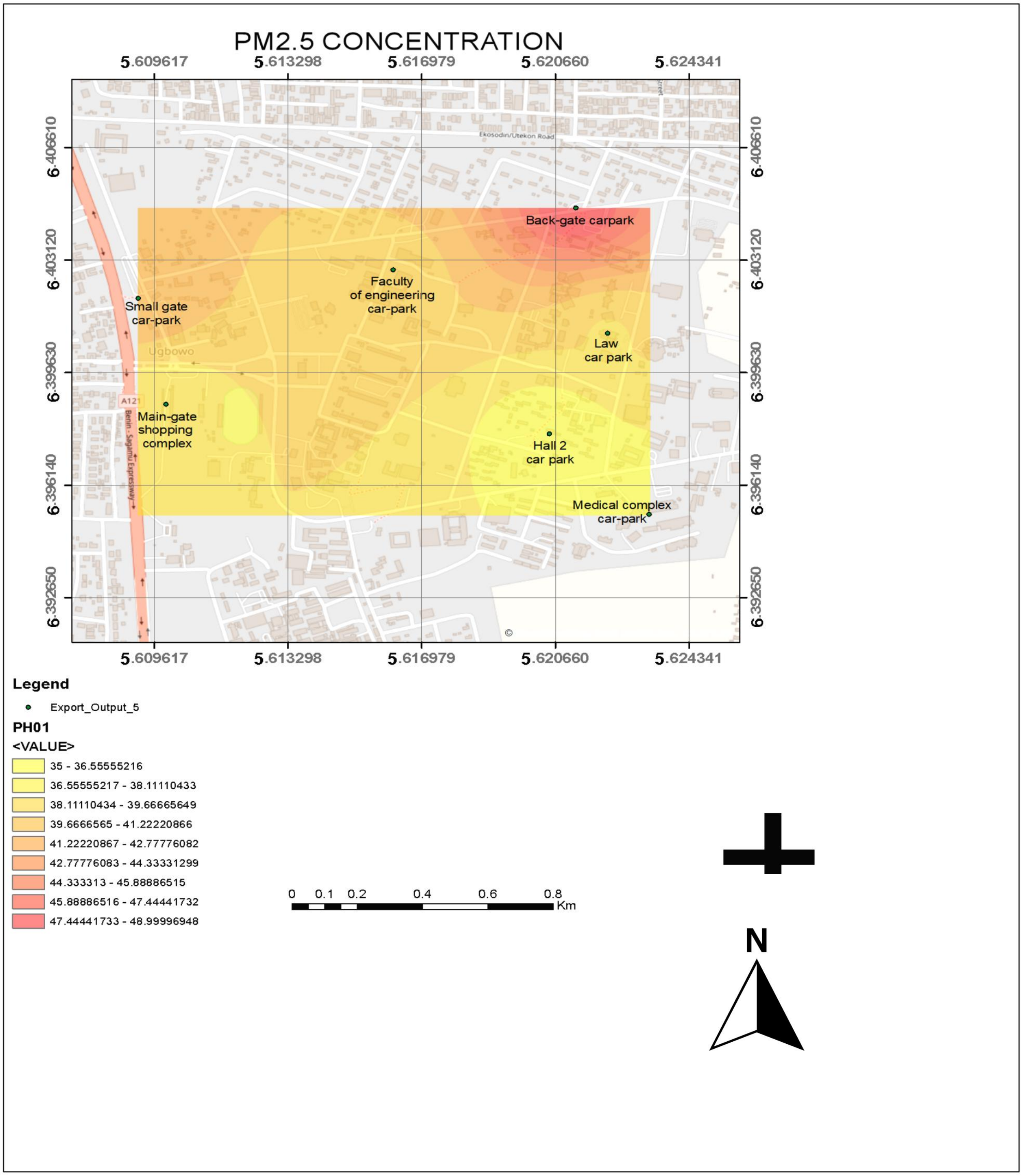

Figure 4.1 Interpretation of GIS Map for PM2.5 Distribution

The spatial distribution map illustrates clear variations in the concentration of PM2.5 across the different car parks within Ugbowo Campus. The highest PM2.5 levels are observed around the Back Gate Car Park, represented by the deep red zone, indicating a significant pollution hotspot. This elevated concentration can be attributed to intense vehicular movement, frequent engine idling, and limited natural ventilation within that area. Moderately high PM2.5 concentrations extend toward the Faculty of Engineering and Small Gate Car Parks, as shown by the orange and yellow regions, which correspond to zones of heavy traffic flow and continuous human activity. In contrast, the Medical Complex and Hall 2 Car Parks exhibit comparatively lower PM2.5 levels, represented by lighter shades, suggesting better air quality possibly due to lower vehicle density and improved air dispersion. Overall, the spatial pattern reveals a decreasing gradient of PM2.5 concentration from the northeastern (Back Gate) to the southwestern (Medical Complex) parts of the campus, highlighting the direct influence of vehicular emissions and localized environmental factors on fine particulate matter distribution.

4.3.2 GIS Map for PM10 Distribution

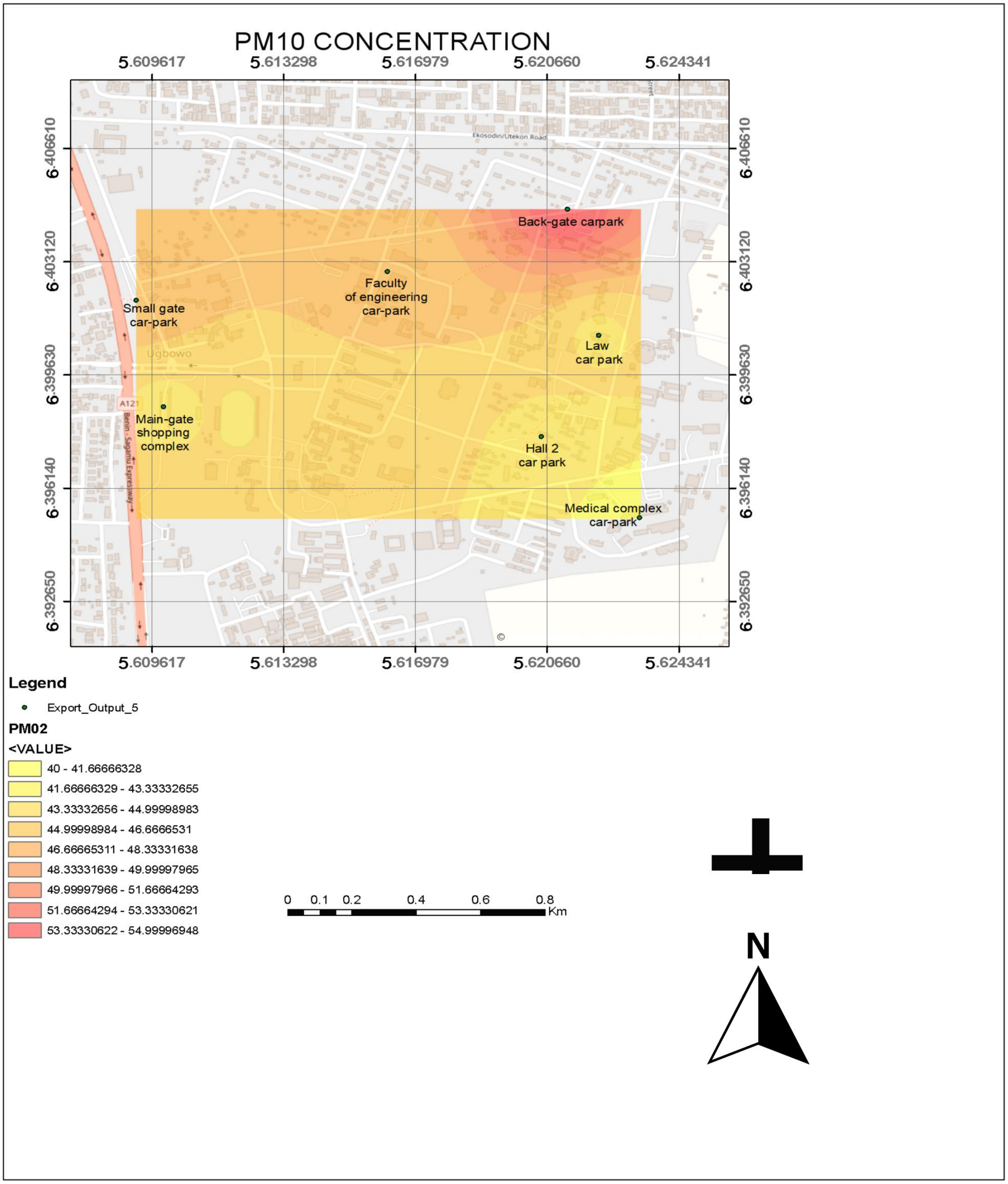

Figure 4.2 Interpretation of GIS Map for PM10 Distribution

The spatial distribution map for PM10 reveals distinct variations in coarse particulate concentrations across the different car parks within Ugbowo Campus. The highest PM10 concentrations are observed around the Back Gate Car Park, represented by the deep red zone, indicating an area of elevated particulate pollution. This may be due to high vehicular activity, road dust resuspension, and limited vegetation cover in that vicinity. Moderately high PM10 levels extend toward the Faculty of Engineering and Small Gate Car Parks, as shown by the orange and yellow regions, which correspond to zones with frequent vehicle movement and intermittent parking congestion. In contrast, the Medical Complex and Hall 2 Car Parks show lower PM10 concentrations, represented by lighter shades, suggesting relatively cleaner air conditions likely influenced by reduced traffic density and better air circulation. The overall spatial pattern demonstrates that PM10 concentration decreases from the northeastern part of the campus toward the southern and western sections, reflecting the combined influence of vehicular emissions, dust generation, and local meteorological conditions on coarse particulate matter dispersion.

4.3.3 GIS Map for

HCHO

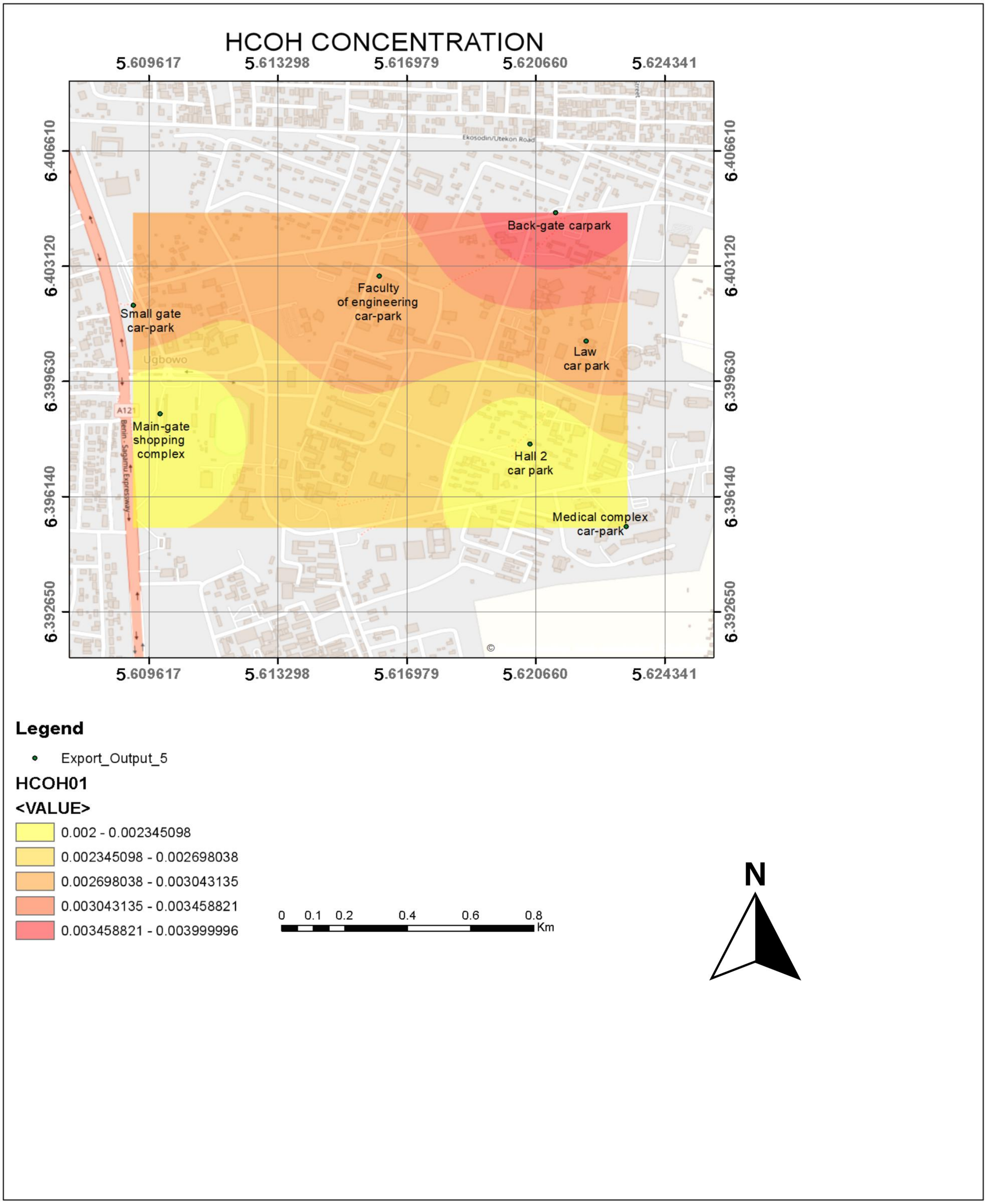

Figure 4.3 Interpretation of GIS Map for HCHO Distribution

The spatial distribution map for formaldehyde (HCHO) concentrations across the sampled car parks in Ugbowo Campus reveals noticeable spatial variability. The highest HCHO concentrations are recorded around the Back Gate Car Park, represented by the deep red zone, indicating an area of significant formaldehyde buildup. This elevated concentration is likely due to the high frequency of vehicle emissions and prolonged idling periods commonly observed in that zone. Moderately high levels are observed at the Faculty of Engineering and Small Gate Car Parks, as shown by the orange to yellow gradients, suggesting active vehicular presence and limited air dispersion. Conversely, the Medical Complex and Hall 2 Car Parks exhibit the lowest HCHO concentrations, depicted in lighter yellow shades, which may be attributed to reduced traffic activity, better air movement, and the presence of surrounding vegetation that aids in pollutant dilution. The overall distribution pattern indicates that HCHO concentration tends to decrease progressively from the northern and central parts of the campus toward the southern sections, reflecting the combined effects of emission intensity, atmospheric mixing, and microclimatic conditions on pollutant dispersion.

4.3.4 GIS Map for

TVOC

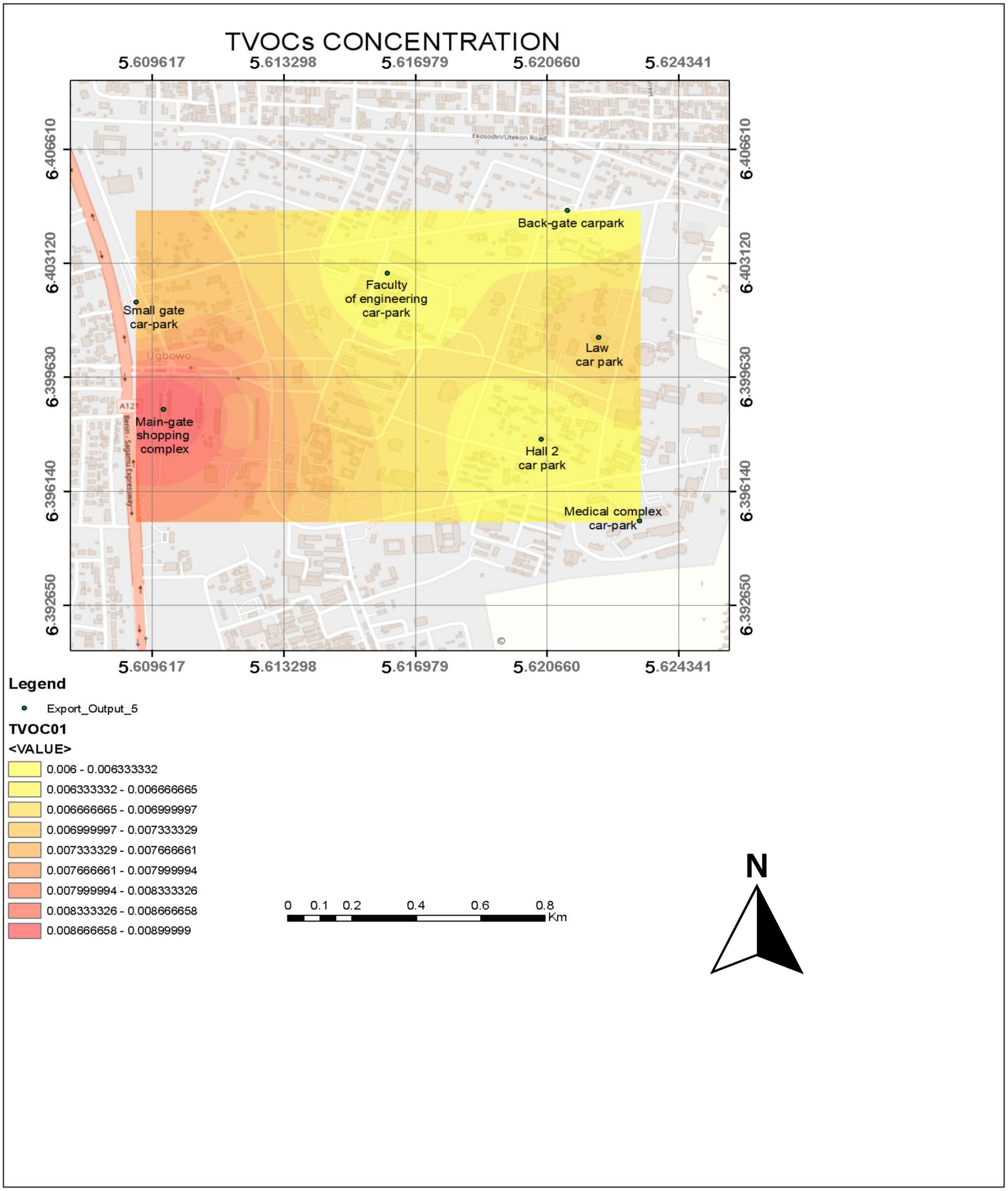

Figure 4.4 Interpretation of GIS Map for TVOCs Distribution

The spatial distribution of Total Volatile Organic Compounds (TVOCs) across the sampled car parks in Ugbowo Campus reveals a clear gradient in pollutant intensity. The highest TVOC concentrations are observed around the Main Gate Shopping Complex, represented by the deep red zone, indicating elevated emission levels likely caused by heavy vehicular movement, fuel evaporation, and frequent engine idling in this busy commercial area. Moderate concentrations are recorded at the Small Gate and Faculty of Engineering Car Parks, shown in orange and yellow shades, suggesting continuous but less intense vehicular and human activity. In contrast, the Back Gate, Hall 2, and Medical Complex Car Parks show relatively lower TVOC levels, denoted by lighter yellow tones, which may be attributed to lower traffic density and better air circulation. Overall, the map indicates that TVOC concentration decreases eastward across the campus, aligning with traffic distribution patterns and localized emission sources. This spatial variation underscores the role of anthropogenic activity and micro-environmental conditions in shaping air quality dynamics within the study area.

4.3.5 GIS Map for

CO2

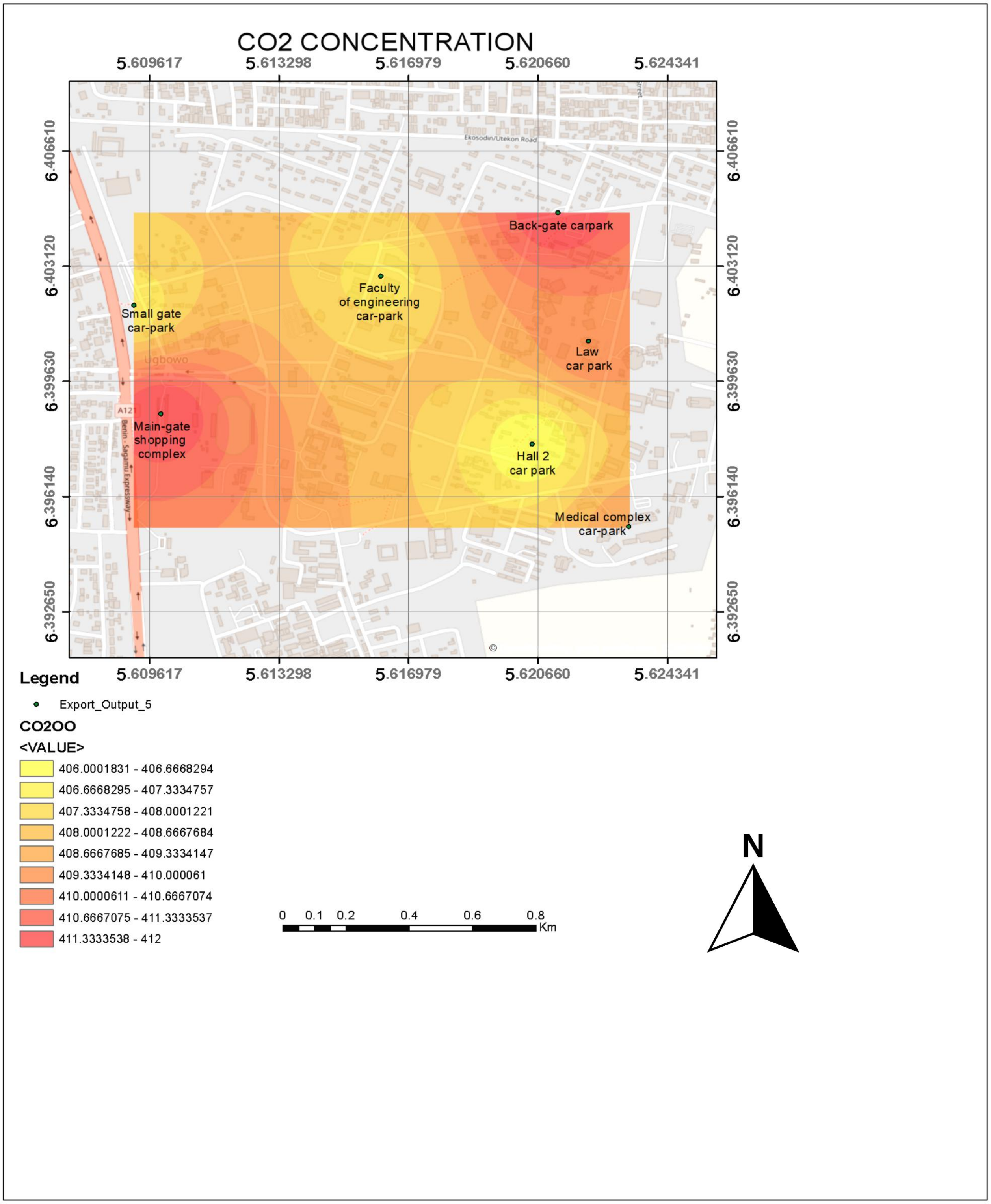

Figure 4.5 Interpretation of GIS Map for CO_2 Distribution

The GIS spatial distribution map for carbon dioxide (CO_2) across the study area reveals noticeable variations in concentration levels among the different car parks within Ugbowo Campus. The Back Gate Car Park exhibits the highest CO_2 concentration, represented by the deep red coloration, suggesting intense vehicular activity and limited dispersion in that region. Elevated concentrations are also observed around the Faculty of Engineering and Small Gate Car Parks, indicating areas of consistent traffic flow and combustion emissions. Moderate CO_2 levels are recorded at the Law and Hall 2 Car Parks, while the Medical Complex Car Park shows the lowest concentration, characterized by lighter yellow shades, possibly due to lower vehicle density and better ventilation. Overall, the spatial pattern shows a north-western dominance of CO_2 accumulation, gradually decreasing toward the southeastern sections of the campus. This distribution highlights the direct influence of vehicular emissions and traffic intensity on localized CO_2 buildup within the university environment.

4.3.6 Summary

In conclusion, the geospatial analysis of particulate matter and selected gaseous pollutants across the various car parks within the University of Benin, Ugbowo Campus, reveals distinct spatial variations that reflect differences in vehicular activity and environmental conditions. The back gate and small gate car parks consistently exhibited higher pollutant concentrations, particularly for $PM_{2.5}$, PM_{10}, and CO_2, indicating that these are areas with intense vehicular emission and limited atmospheric dispersion. Conversely, the medical complex and hall 2 car parks recorded comparatively lower pollutant levels, suggesting reduced traffic flow and better ventilation. The observed spatial trends demonstrate a general gradient of pollutant buildup from the southeastern to the northwestern parts of the campus, corresponding with traffic density and land-use patterns. These findings underscore the significant influence of transportation and human activity on localized air quality within the university environment and highlight the need for sustainable traffic management and pollution-control measures to mitigate exposure risks

4.4 Comparison with standards

This section presents the Air Quality Index (AQI) derived from the measured concentrations of $PM_{2.5}$, PM_{10}, HCHO, TVOCs, and CO_2 across the seven selected car parks within the University of Benin, Ugbowo Campus. The AQI serves as a standardized tool for translating complex pollutant data into easily understandable categories that reflect potential health implications. By applying established guideline values, the pollutant concentrations were converted into corresponding AQI scores to assess the overall air quality status and to compare the relative pollution burden among the various car park environments.

4.4.1 WHO Air Quality Guidelines (2021)

Table 4.9: WHO Air Quality Guidelines (2021)

POLLUTANTS	AVERAGE TIME	WHO LIMIT	NOTES
PM2.5	24 hours	15 ug/m^3	Daily exposure shouldn't exceed this value
PM10	24 hours	45 ug/m^3	Daily exposure shouldn't exceed this value
Formaldehyde (HCHO)	30 minutes	100 ug/m^3	To prevent eye and respiratory irritation.
Total VOC (TVOCs)	1-hour	No specific value (often <300 ug/m^3 used as safe indoor guideline)	Based on general indoor air quality standards
Carbon-Dioxide (CO2)	1-hour	No direct WHO limit (ASHRAE recommends <100 ug/m^3)	Used as an indicator of ventilation efficiency.

4.4.2 Comparison Table: Measured values against WHO standards.

Table 4.10: Comparison Table: Measured values against WHO standards.

LOCATION	PM2.5 (ug/m^3)	WHO LIMIT (15)	PM10 (ug/m^3)	WHO LIMIT (45)	TVOCs (ug/m^3)	WHO Ref (<300)	HCHO (ug/m^3)	WHO LIMIT (100)	C02 (ppm)	Ref. (100)
Engineering car park	39	Exceeds	45	Meets	0.006	Meets	0.003	Meets	407	Meets
Main Gate car park	37	Exceeds	43	Meets	0.009	Meets	0.002	Meets	412	Meets
Small gate car park	41	Exceeds	46	Meets	0.007	Meets	0.003	Meets	407	Meets
Back Gate car park	49	Exceeds	55	Meets	0.006	Meets	0.004	Meets	412	Meets
Medical Complex car park	35	Exceeds	40	Meets	0.006	Meets	0.002	Meets	409	Meets
Hall 2 car park	35	Exceeds	43	Meets	0.006	Meets	0.002	Meets	406	Meets
Law car park	38	Exceeds	43	Meets	0.007	Meets	0.003	Meets	410	Meets

4.4.3 Summary

When compared to WHO air quality standards:

i. PM2.5 concentrations exceeded the 24-hour limit (15 µg/m³) at all locations, indicating the main pollutant of concern across the study area.
ii. PM10 values were mostly within the WHO limit (45 µg/m³), except at the Small Gate and Back Gate car parks, which slightly exceeded it.
iii. TVOCs, formaldehyde (HCHO), and CO2 were well below their respective reference or guideline levels, indicating minimal gaseous pollution and adequate ventilation in those areas.

The overall findings suggest that particulate matter (especially PM2.5) is the primary factor reducing air quality, most likely from vehicle emissions and dust resuspension within car park environments.

4.5 Discussion of Findings

In this section I will discuss/interpret my results and link them to Vehicular emissions and idling cars at carparks Influence of traffic density, vegetation, and ventilation and comparison with findings from similar studies.

4.5.1 Relationship with Vehicular Emissions and Idling Cars

The elevated concentrations of PM2.5 (ranging from 33–49 µg/m³) and PM10 (40–49 µg/m³) across all sampling locations strongly suggest the influence of vehicular emissions as a major pollution source.

Car parks are known micro-environments where vehicles frequently start, idle, and stop, releasing fine and coarse particles through exhaust fumes, tyre and brake wear, and resuspension of dust from unpaved or semi-dusty surfaces.

The back gate car park recorded the highest PM2.5 and PM10 levels (49 µg/m³ and 49 µg/m³ respectively), likely due to high vehicle turnover and limited dispersion in that area.

Such elevated levels during idling are consistent with the findings of Kaur et al. (2007) and Joodatnia et al. (2013), who reported that pollutant concentrations within vehicle-dense parking spaces were significantly higher than in open roads or residential areas, mainly due to trapped exhaust emissions.

In contrast, gaseous pollutants like TVOCs (0.006–0.009 µg/m³) and HCHO (0.002–0.004 µg/m³) were relatively low. This could be attributed to the outdoor setting of the car parks, allowing volatile compounds to dilute quickly, as opposed to enclosed car parks where VOC accumulation is typically higher (as reported by Hieu and Lee, 2010).

The low levels of CO2 (406–412 ppm) further support the inference that air circulation was sufficient to prevent significant buildup of combustion gases.

4.5.2 Influence of Traffic Density, Vegetation, and Ventilation

Spatial variations in pollutant concentrations across the car parks can be explained by differences in traffic intensity, local vegetation cover, and ventilation patterns.

Traffic Density: Car parks with higher traffic inflow and longer idling times (e.g., back gate and small gate car parks) recorded higher PM values, suggesting that traffic volume and idling duration directly influenced particulate load.

Studies by Gurjar et al. (2016) and Okedere et al. (2020) also noted that proximity to high-traffic areas correlates with increased concentrations of PM2.5 and PM10 due to frequent acceleration, braking, and exhaust release.

Vegetation: Locations surrounded by more vegetation (such as medical complex and hall 2 car parks) had comparatively lower particulate levels. Vegetation acts as a natural sink for airborne particles by capturing them on leaf surfaces and facilitating atmospheric deposition.

This aligns with findings by Nowak et al. (2014), who reported that green cover around roadways can reduce ambient PM2.5 concentrations by 10–25%.

Ventilation: Since the study was conducted in open car parks, natural ventilation likely aided the dispersion of gaseous pollutants, keeping TVOCs, HCHO, and CO2 concentrations below their reference limits. This observation is consistent with the work of Kim et al. (2015), who found that open-air parking zones tend to exhibit lower VOC accumulation compared to underground garages, due to better airflow and solar-driven dispersion.

4.5.3 Comparison with findings from similar studies

Table 4.11: Comparison with findings from similar studies

STUDY	LOCATION	PM2.5	PM10	REMARKS
Adam and Unachukwu (2009)	Port Harcourt, Nigeria	40-60	60-90	High due to fuel combustion and dust resuspension
Ediagbonya et al. (2022)	Benin City road-side	30-55	40-80	Similar levels to current study, indicating local traffic effects
Kaur et al. (2007)	Urban Uk roadside	25-50	40-70	Comparable PM2.5 ranges observed near high traffic car parks
Current Study	UNIBEN car	33-49	40-49	Values are consistent with

(2025)	park			reported vehicular influence in open car parks

The close similarity in PM concentration ranges supports the assertion that vehicular movement and traffic density are the dominant determinants of air quality within car park environments, particularly where regular maintenance of vehicles and road surfaces is minimal.

4.5.4 Overall implication

The high levels of fine particles ($PM_2$2.5) in our car parks are a concern, especially since other pollutants are relatively low. Long-term exposure to these tiny particles can cause respiratory issues, aggravate asthma, and even affect heart health, as highlighted by the WHO.

To tackle this problem, we could consider a few strategies:

- Better vehicle management: Encouraging cleaner transportation options or improving ventilation in and around car parks would help reduce particle buildup.

- No-idling policies: Discouraging drivers from leaving their engines running when parked would make a big difference.

- Green spaces: Planting more trees and vegetation around car parks could help absorb pollutants and improve air quality.

These steps would be useful not just for our campus but for similar urban settings as well.

4.6 Implications for Human health and environment.

This section discusses the key findings obtained from the measurement and geospatial analysis of particulate matter ($PM_2$2.5 and PM10) and selected gaseous pollutants (HCHO, TVOCs, and CO_2) across the seven car park locations in the University of Benin, Ugbowo Campus. The discussion highlights the spatial distribution patterns, variations in pollutant concentrations, and the corresponding Air Quality Index (AQI) classifications observed at each site. These findings are interpreted in relation to vehicular activities, human movement, and surrounding land-use characteristics, with emphasis on how these factors contribute to the observed differences in air quality across the study area.

4.6.1 Discussion of Potential Health Impacts

1. Particulate Matters (PM2.5 and PM10)

The AQI values for PM2.5 ranged from 97 to 134, and for PM10 from 40 to 55, placing most sites in the "Moderate" to "Unhealthy for Sensitive Groups" range.

At these concentrations, short-term exposure can lead to:

i. Respiratory irritation, coughing, and shortness of breath.
ii. Aggravation of asthma and bronchitis symptoms in sensitive individuals.
iii. Eye and throat discomfort during prolonged outdoor presence.

Long-term exposure, especially to PM2.5, is associated with increased risk of:

i. Reduced lung function and chronic obstructive pulmonary disease (COPD).
ii. Cardiovascular effects, including elevated blood pressure and heart stress.
iii. Higher mortality risk in persons with pre-existing heart or lung conditions.

The dominance of PM2.5 in the AQI implies that fine particulate matter poses the primary health concern in the sampled car park environments, particularly for vulnerable groups such as children, the elderly, and individuals with respiratory disease.

2. Total Volatile Organic Compounds (TVOCs)

TVOC levels (0.006–0.009 $\mu g/m^3$) remained well below WHO indoor and outdoor reference limits, corresponding to "Good" air quality. At such low concentrations, acute effects are minimal. However, prolonged exposure to higher levels of VOCs typically from fuel vapors and incomplete combustion can cause:

i. Eye, nose, and throat irritation,
ii. Headaches and dizziness, and
iii. Potential liver and kidney stress after chronic exposure.

In this study, the low TVOC values suggest no immediate health risk, likely due to good outdoor ventilation and rapid dilution of emissions.

3. Formaldehyde (HCHO)

Measured HCHO concentrations (0.002–0.004 $\mu g/m^3$) fall within safe exposure limits and are classified as "Good" in AQI terms. At such levels, acute irritation is unlikely. However, at concentrations above 0.1 mg/m^3, formaldehyde can trigger:

i. Eye and nasal irritation,

ii. Sore throat and coughing

Long-term carcinogenic risk with chronic exposure. Although the measured values are far below harmful thresholds, the presence of HCHO confirms vehicular combustion and fuel evaporation as trace emission sources within the parking areas.

4. Carbon Dioxide (CO_2)

CO_2 levels (406–412 ppm) correspond to "Good" air quality and indicate adequate ventilation. These values are near the normal background range (400–450 ppm), suggesting minimal risk. Health effects are generally not observed until levels exceed 1000 ppm, where occupants might experience: Mild drowsiness, headaches, or reduced concentration due to decreased oxygen availability.

Since all car parks recorded CO_2 below this threshold, ventilation was sufficient, and no health hazard is expected from CO_2 accumulation.

4.6.2 Overall Health Implications

Overall, the air quality across all car parks ranged from Good to Unhealthy for Sensitive Groups, primarily due to PM2.5 concentrations.

While gaseous pollutants remained within acceptable limits, fine particulate pollution poses potential short-term and long-term health risks, particularly for: Individuals with asthma or chronic bronchitis, Children with developing lungs, and older adults with pre-existing heart or lung conditions.

Note: The car park at back gate, with the highest AQI (~134), presents the greatest health concern for sensitive individuals during periods of high traffic or vehicle idling.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study successfully measured and mapped the distribution of particulate matter ($PM_{2.5}$ and PM_{10}) and selected gaseous pollutants (TVOCs, HCHO, and CO_2) around major car parks within the Ugbowo Campus of the University of Benin using Geographic Information System (GIS) techniques. The results revealed spatial variations in pollutant concentrations across the study area, with particulate matter exhibiting higher concentrations in locations characterized by increased vehicular activity. The GIS-based maps effectively illustrated the distribution patterns of pollutants and provided a visual representation of air quality conditions within the campus.

The study further identified pollution hotspots and assessed the potential exposure levels of campus users to air pollutants. The Back Gate and Small Gate Car Parks recorded the highest concentrations of $PM_{2.5}$ and PM_{10}, indicating that these locations are more susceptible to pollution due to heavy traffic density, vehicle idling, and associated dust resuspension. In contrast, areas such as the Medical Complex and Hall 2 Car Parks exhibited lower pollutant concentrations, which may be attributed to better airflow and the presence of vegetation. Although the measured gaseous pollutants remained within acceptable limits, the elevated particulate matter concentrations in some locations highlight potential air quality concerns for frequent users of these areas.

Based on the findings, the study provides data-driven recommendations for improving air quality and supporting environmental management policies within the campus.

Measures such as improved traffic management, regular maintenance of road surfaces, reduction of vehicle idling, and increased planting of trees and other vegetation around car parks are recommended to mitigate particulate pollution. The spatial information generated through GIS can also serve as a valuable tool for campus planners and policymakers in developing sustainable strategies aimed at maintaining healthy air quality standards within the University of Benin environment.

5.2 Recommendations

In light of the findings, the following measures are recommended to improve air quality within car parks in Ugbowo Campus:

i. Enforce No-Idling Policies: Restrict prolonged vehicle idling in car parks to reduce particulate and VOC emissions.
ii. Enhance Vegetation Around Car Parks: Plant trees and shrubs as natural filters to absorb and trap airborne particulates and gaseous pollutants.
iii. Pave or Maintain Car Park Surfaces: Regular maintenance or paving of dusty car park areas can reduce dust resuspension and particulate load.
iv. Establish Routine Air Quality Monitoring: The university's environmental or works department should periodically assess air quality to track trends and ensure compliance with WHO standards.
v. Promote Awareness and Sustainable Mobility: Educate drivers and students about the effects of vehicular emissions and encourage carpooling, cycling, or walking for short distances within campus.

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