AMBIENT PARTICULATE MATTER CONCENTRATIONS AND ASSOCIATION WITH METEOROLOGICAL PARAMETERS AT THE UNIVERSITY OF BENIN, NIGERIA.

BY

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AN UNDERGRADUATE PROJECT SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA; IN PARTIAL FUFILMENT OF THE REQUIREMENTS FOR AWARD OF BACHELOR OF SCIENCE (B. Sc) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY

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CERTIFICATION

This is to certify that the research titled **"Ambient Particulate matter concentrations Air Pollutant Concentrations and Association with Meteorological Parameters in the University of Benin, Nigeria"** was carried out by **Christabel Osemudiamen Ojehanon** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Edo State; in partial fulfilment of the requirements for the award of Bachelor of Science (B. Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised, and subsequently approved as having met the requirements for the award of Bachelor of Science degree in Environmental Management and Toxicology.

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Head Of Department

DECLARATION

I, Christabel Osemudiamen Ojehanon declare that **“Ambient Particulate Concentrations and Association with Meteorological Parameters in the University of Benin, Nigeria** is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other university.

Christabel Osemudiamen Ojehanon

Date

DEDICATION

This project report is dedicated to God Almighty, family, friends and my lecturers who have been with me throughout my freshman year up until this point, especially my late dad, Prof P. I Ojehanon for his contribution in training me to this point until his demise.

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ABSTRACT

Meteorological conditions play an important role in ambient air pollution by influencing the emissions, transport, formation, and deposition of air pollutants both directly and indirectly. The relationships between meteorological parameters and particulate matter concentrations were investigated in ten (10) randomly selected locations within the University of Benin, Benin City, Nigeria. The particulates ($PM_{1.0}$, $PM_{2.5,}$ and PM_{10}), relative humidity (RH), and temperature were quantified using Dienmern DM106A Air Quality Detector, while the wind speed (WS) was monitored using the Holdpeak 866B digital anemometer respectively for four weeks. The ambient temperature and relative humidity and the concentrations of $PM_{2.5}$ and PM_{10} obtained in this study were 34.1 to 36.1°C; 62.9 to 38.1%; 0.;8 to 1.9m/s 25.9 and 30.5μg/m^3.and 57.0 to 62.2 μg/m^3. The values obtained were all above the recommended allowable limits. There were generally weak associations between air pollutants and meteorological parameters (R=-0.261, - 0.282, and -0.271; $p<0.001$)). The air quality index assessment revealed that the particulate matter AQI status was primarily unhealthy. The high levels of particulate matter obtained in the study call for the urgent need for awareness of air pollution-related health effects and preventive measures to reduce the concentrations of Particulate matter pollution. within the University.

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CHAPTER ONE

1.0 INTRODUCTION

One of the vital roles of school management is to ensure a healthy, safe, and optimal school environment that caters for all aspects of the student's school experience. Students spend a lot of their time in and around the school environment, hence, a major part of the exposure of students to air pollution could occur in school. Air pollution is one of the leading determinants of mortality and morbidity rates of humans worldwide (Gordon *et al*., 2014). Air pollution has become a topical issue and an important challenge, Globally, about 4.2 million premature deaths due to outdoor air pollution have been reported (WHO, 2018a).

The predominantly affected groups of people by the negative effects of air pollution are children, the elderly, and people with underlying cardiovascular or respiratory diseases (Kelishadi and Poursafa, 2014; Kloog *et al*., 2014; Rodopoulou *et al*., 2014). The negative health impacts of air pollution vary from the reduction of cognitive development to cardiovascular or respiratory effects in exposed individuals (Annavarapu and Kathi, 2015) These outcomes can impact the socioeconomic status including the low performance of students at school, consequently, the poor wellbeing of the individual later (Ross and Van Willigen, 1997). Several studies in developed countries have reported on the relationships between exposure to ambient air pollutants in schools and health effects such as allergic rhinitis, bronchial asthma, eczema, reduced arterial diameter, increased blood pressure, childhood obesity in students (Li *et al*., 2015; Kim *et al*., 2016, de Bont *et al*., 2019, Pieters *et al*., 2015; Provost *et al*., 2017).

Particulate matter (PM) is one of the established air pollutants largely linked with adverse health outcomes (Kim. 2015). PM is a mixture of solid and liquid particles suspended in the air, and it occurs in different sizes, shapes, origins, and compositions (PHE, 2018). Exposure to particulates has been associated with a wide range of negative health outcomes such as cancer and cardiovascular diseases (COMEAP, 2010; Kim *et al*., 2015). Ambient air gaseous pollutants such as Nitrogen (iv) oxide (NO_2), Sulphur (iv) oxide (SO_2), Ozone (O_3), Volatile organic compounds (VOCs) and Carbon monoxides (CO) are important gases released through different anthropogenic activities in the school premises process of incomplete combustion produced in combustion processes have also been linked to respiratory and cardiovascular morbidity (COMEAP, 2015; PHE, 2018).

Various factors reportedly influencing air pollution concentrations around the school environments include; the proximity of classrooms to nearby roads (Alzuhairi *et al*., 2016; Brown *et al*., 2017; Fuller *et al*., 2017; Minguill´on *et al*., 2015), Vehicle drop-offs and idling (Adams and Requia, 2017), planning, design and soil types (Amato *et al*., 2014; Minguill´on *et al*., 2015; Rivas *et al*., 2014), meteorological conditions, diurnal and seasonal patterns also contribute to variations of concentrations of ambient air pollutants in school environs (Boniardi *et al*., 2019; Buonanno *et al*., 2013; Mainka *et al*., 2015; Tofful and Perrino, 2015).

Studies related to exposure to air pollutants at school is very key because a large percentage of students' life is lived in the school environment, where they are vulnerable to harmful pollutants (Wallner *et al*., 2012). Previous research on air quality in schools has tended to focus on indoor environmental quality with little or no studies on the pollutant concentration outside and around the school environment. Hence this study seeks to assess the levels of outdoor concentrations of particulate matter, and the association between meteorological parameters and the distribution of pollutants levels around the University of Benin, Nigeria. This study will provide the school management with recommendations for possible interventions to minimise the exposure of students to air pollutant concentrations in outdoor school environments.

1.1 Aim and objectives

This aim of this study was to assess the concentrations of ambient particulate matter and their relationship with the meteorological parameters at the University of Benin, Nigeria

The objectives of the study were:

1. Determine the concentrations of $PM_{1.0}$, $PM_{2.5}$, PM_{10} and meteorological parameters in selected locations within the University.
2. Examine the association between meteorological parameters and the particulate matter concentrations in the selected locations.
3. Determine the Air Quality Index of the monitored particulate matter in the selected locations

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Ambient Air Quality in Higher Schools

Ambient air pollution is the introduction of harmful substances into the air environment which cause a deterioration in air quality and may have adverse effects on human and environmental health (WHO, 2021). The most common ambient air pollutants are oxides of carbon, nitrogen and sulphur, and particulate matter. Others include polycyclic aromatic hydrocarbons, volatile organic compounds, and ozone (Edwards *et al.,* 2010).

Several studies have been carried out to assess the presence and effects of these ambient air pollutants in the school environment. Some of the effects of ambient air pollutants have been documented to include direct adverse health impacts such as respiratory problems, cardiovascular problems and irritation of the eyes and nose (Van der Zee *et al.,* 2017). Other more serious effects may include the worsening of pre-existing health conditions such as asthma, allergic reactions, and hospitalization of exposed students in extreme cases (Patrick *et al.,* 2015).

There are many sources of ambient air pollutants in schools. These include traffic activity in and around the school, open burning of waste, use of electricity generators, sports activities on dusty fields and in some cases, the occurrence of high winds that may transport air pollutants from other locations into the school environment (Smedje *et al.,* 2006).

Due to the adverse effects of ambient air pollution on students' health and performance, along with a better understanding of factors such as air quality, ventilation and moisture on health, there has been a lot of attention given to this area of public health (Gartland *et al.,* 2022).

2.2 Sources of Ambient Air Pollutants in the School Environment

Several factors affect the exposure of school students to air pollutants. Some of these factors are discussed below.

2.2.1 Traffic Emission

Vehicular traffic is one of the major sources of outdoor air pollutants in almost every country of the world. The combustion of fossil fuels in motor engines produces oxides of carbon and sulphur, and particulate matter in some cases (Sunyer *et al.,* 2015).

Proximity to high-traffic areas and the amount of traffic activity within schools is a factor that affects the number of air pollutants to which students are exposed. The proximity of schools to high-traffic roads exposes students in those schools to higher levels of air pollutants (Watanabe *et al.,* 2021). Schools further away from such roads have lower concentrations of air pollutants because as distance increases, the concentration of air pollutants decreases due to dissipation in the air. Schools which experience high levels of vehicular traffic within their premises also tend to have higher levels of air pollutants than those with lesser traffic activity (Gartland *et al.,* 2022). Other traffic-related factors include drop-offs from diesel vehicles and the idling of vehicles around schools (Van der Zee *et al.,* 2017). El-Sharkawy (2013) found that traffic activity is the major source of air pollutants in different parts of Damman University in Saudi Arabia. The study revealed that the mean concentrations of particulate matter at the sampling sites were above the limits recommended by the air quality guidelines.

2.2.2 Planning and Urban Design

Urban planning determines the location of industries, residential and commercial areas, and agricultural areas. In cities or towns which are properly planned, industries and other places that generate large amounts of air pollutants are sited away from areas where schools are located. This limits the level of air pollutants which are present in the school environment and thus limits the exposure of students to these substances.

The amount of green space which surrounds the school environment also contributed to the levels of air pollutants present in the school area (Smedje *et al.,* 2006).

2.2.3 Structures in the School Environment

Dusty and sandy places such as fields, walkways and dirt tracks are prime sources of particulate matter in the school environment. These particulates may enter the air as a result of sports activities, traffic activities, etc.

The presence of landscaping features in the school environment influences air pollutant levels. These features may include lawns which are properly taken care of, paved walkways and tarred roads. These features eliminate the entry of dust and other particulate matter into the air thereby preventing exposure to higher levels of air pollutants (Osborne *et al.,* 2021).

2.2.4 Presence of Ventilation Systems

The presence of air pollutants in ambient air affects indoor air quality as these pollutants can accumulate in the indoor environment. In schools, these pollutants may enter into and accumulate in classrooms, laboratories and eateries. The availability of proper ventilation in these parts of schools continually dilutes these pollutants in the indoor air and can reduce their concentrations to levels which pose no harm to the health of students (Mohammadyan *et al.,* 2017).

2.3 Air Pollutants in the School Outdoor Environment

There are several outdoor sources of pollutant emissions in the school environment. The predominant pollutants with public health significance include Particulate matter (PM), gaseous pollutants such as Nitrogen oxides, Carbon monoxide (CO), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), ozone (O_3), lead (Pb), volatile organic compounds (VOCs) (Han and Naeher, 2006).

2.3.1 Particulate matter

Particulate matter is defined as a complex mixture of solid particles and liquid droplets, with different physicochemical characteristics. Those that are emitted directly introduced into the atmosphere in a solid or liquid state are referred to as primary particulate matter, while secondary particles are formed in the air by the transformation of gaseous precursors (Kulkarni *et al*., 2011). The behaviour of particles in the air and its associated health effects are dependent on the aerodynamic sizes which vary from 0.001 – 100 µm (Chow *et al*., 2002; Morawska and Zhang, 2002). PM_{10} (coarse particles) constitutes those with an aerodynamic diameter of fewer than 10 µm (Chow *et al*., 2002, Morawska and Zhang, 2002, Kulkarni *et al*., 2011). In the outdoor air, coarse particles mostly originate from construction activities, farming, mining, windstorms, and the resuspension of dust by wind and traffic.

$PM_{2.5}$ (fine particles) are those with a metric size of fewer than 2.5 µm (Chow *et al*., 2002, Morawska and Zhang, 2002, Kulkarni *et al*., 2011). The fine particles in the outdoor environments are introduced by combustion activities such as fossil fuels (by vehicles, power plants and other industries), and biomass. The penetration and deposition of PM_{10} in the respiratory pathway are limited to the thoracic region, while $PM_{2.5}$ can easily reach gas exchange regions (Peltier *et al*., 2011). Particulate matter has been associated with mortality and morbidity from respiratory and cardiovascular diseases, exacerbation of asthma, chronic bronchitis, and hospital admissions (D'Amato *et al*., 2002).

2.3.2 Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless and tasteless gas, emitted during the incomplete combustion of carbonaceous fuels (Spengler *et al*., 2001b). Because of these properties, CO cannot be detected by human senses (WHO, 2010). CO is relatively inert and is not absorbed by building materials and filter systems (Jantunen *et al*., 1999, WHO, 2010). In urban areas, street traffic is the major source of CO (Jantunen *et al*., 1999). It is also emitted by natural sources such as wildfires (Han and Naeher, 2006). The toxic nature of CO comes from its affinity to haemoglobin in the blood (~ 250 times more than oxygen), resulting in the formation of carboxyhaemoglobin (COHb) and cutting oxygen supply to tissues (Spengler *et al*., 2001b). COHb levels as low as 5.1 – 8.2% can result in transient neurological impairments, while 13 levels above 25 – 35% can result in unconsciousness, and eventually death above 60% (WHO, 2010).

2.3.3 Nitrogen dioxide

Nitrogen dioxide (NO2) has a characteristic pungent odour, which is reddish brown and water soluble (Jones, 1999). Major outdoor sources, along with power plants and other sources burn fossil fuels (D'Amato *et al*., 2002, WHO, 2010). NO (nitric oxide) and NO_2 are two principal oxides of nitrogen formed during high-temperature combustion. Most NO is readily oxidized to NO_2 and therefore, NO2 is used as an index of pollution among the oxides of nitrogen (Spengler *et al*., 2001b). In the ambient air, oxidation of NO to NO_2 is limited by the availability of ozone (O_3). Wheezing and exacerbation of asthma, respiratory infection and reduced lung functions are some of the health effects associated with exposure to NO_2 (Kattan *et al*., 2007, Kim *et al*., 2011).

2.3.4 Volatile organic compounds

Volatile organic compounds (VOCs) are a class of organic compounds with boiling points ranging from 50 – 100 °C, lower limit and 240 – 260 °C, upper limit, and high volatility in ambient air and room temperature (Han and Naeher, 2006, Barro *et al*., 2009). Because of this property, many VOCs off-gas readily, leading to a rapid reduction of 14 in concentrations over a short period (Jones, 1999). The primary sources of VOCs in the outdoor air are fossil fuel combustion by the transportation sector and industrial processes (Demirel *et al*., 2014), and gasoline loss due to evaporation from fuel stations (Lan *et al*., 2013). In general, VOCs can result in both acute and chronic health effects, and most have the potential to cause sensory irritation, allergic skin reactions, fatigue and dizziness, and impairment of the central nervous system (Zhang and Smith, 2003, Barro *et al*., 2009).

2.4 Effects of Poor Air Quality on Students

Air pollutants are known to have adverse effects on human health. The top air pollutants are a particulate matter of various sizes, ozone, nitrogen dioxide and sulphur dioxide. These pollutants are recorded as being the cause of about 4.2 million deaths around the world (Aghababaeian *et al.,* 2021). About 16 per cent of deaths due to lung cancer, 25 per cent of chronic obstructive pulmonary disease deaths, 17 per cent of ischemic heart disease and stroke, and about 26 per cent of deaths due to respiratory infections around the world have been attributed to outdoor air pollution (Watanabe *et al.,* 2021).

Some of the effects of poor air quality on students' health are discussed below.

2.4.1 Absence from School

The effects of air pollutants on students' health include irritation of the eyes and respiratory pathways, respiratory problems such as cough, wheezing, difficulties in breathing and tightness of the chest. Chronic effects include exacerbation of existing health problems such as asthma and increased risk of developing heart problems (Patrick *et al.,* 2015).

These problems contribute to an increased rate of absence of students from school upon exposure to outdoor air pollutants around schools. On the other hand, there is an increase in the number of hospitalizations, hospital visits and emergencies when such exposures occur (Watanabe *et al.,* 2021).

2.4.2 Adverse Effects on Working Memory

Working memory refers to "the mechanisms or processes which are involved in controlling, regulating or actively maintaining information relevant to the task at hand especially when complex cognition is involved in a novel or skilled tasks" (Chai *et al.,* 2018). Domains of working memory are postulated to include the focus of attention, maintenance, manipulation and update of information, inhibitory controls, limits of capacity, etc. all of which rely on the efficiency of executive control (D'Esposito and Postle, 2015).

Studies have shown that exposure to high levels of ambient air pollutants especially polycyclic aromatic hydrocarbons (PAHs), nitrogen dioxide and the particulate matter had adverse effects on the development of working memory (Gartland *et al.,* 2022). One study showed that exposure to high levels of pollution for one year slowed the improvement of the development of working memory (measured by the 2-back numbers test) by 22 per cent and improvement of superior working memory (measured by the 3-back numbers test) was slowed by 30 per cent (Basagana *et al.,* 2016). Another study showed that exposure of school children to high levels of air pollutants resulted in lesser growth in cognitive development (7.4%) than those from schools where pollution levels were lower (11.5%) (Sunyer *et al.,* 2015).

2.4.3 Adverse Effects on Attention Span

Air pollution has been implicated in adverse effects on various forms of attention in students including inattention, sustained attention, attention switching and selective attention. A study by Saenen *et al.* (2016) showed that selective attention in school children was affected by air pollution with increases in reaction time. Exposure to outdoor PAHs especially from traffic sources has also been discovered to adversely affect the development of attention with about 11 per cent impedance (Gartland *et al.,* 2022).

2.4.4 Adverse Effects on Other Measures of Cognition

Air pollution and its effects on measures of cognition such as the speed at which students process visual information, eye-hand coordination, episodic memory, simple reaction time and non-verbal reasoning have been evaluated (Gartland *et al.,* 2022). Carneiro *et al.* (2020) assessed the effects of air pollution on students' cognitive performance and reported that air pollution has adverse effects on the cognitive performance of students.

Saenen *et al.* (2016) discovered that high levels of air pollution with particulate matter increased the delay involved in visual processing.

Watanabe *et al.* (2021) reported an association between school absences and illnesses including fever, headaches, cough, diarrhea, abdominal pain, vomiting, rashes, influenza infections and other symptoms of high fever in Masue city of Japan. The study showed that the increment in

$PM_{2.5}$ and desert sand dust particles in the air increased the risk of overall absence from school by 1.28 and 2.15, respectively. The effects of nitrogen dioxide were not significant from any of the sampling locations.

Gartland *et al.* (2022) opined that $PM_{2.5}$ were implicated in adverse effects on attention span, reasoning capacity and reduction of academic test scores in a study that assessed the effects of traffic air pollution around schools.

2.5 Ambient Air Quality Standards

The air quality standard of a compound or air pollutant is the maximum amount of that pollutant averaged over a period which can exist in the outdoor air environment and would not cause adverse health effects. Air quality standards are used to define air which is clean and that which is not (Bishoi *et al.,* 2009).

Ambient air quality is the wholesomeness or condition of the air in the outdoor environment. The most common air pollutants used in the determination of air quality include particulate matter especially PM_{10} and $PM_{2.5}$, nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone, ammonia and lead (IES, 2015).

Some common air quality standards are discussed in the following selections.

2.5.1 The US EPA National Ambient Air Quality Standards (NAAQS)

The United States Environmental Protection Agency set primary National Ambient Air Quality Standards aimed at protecting human health while secondary NAAQS were set to protect environmental components such as plants, forests, and other materials from damages that exposure to air pollutants may cause. The six air pollutants which are designated priority pollutants by the US EPA are particulate matter, ozone, nitrogen oxides, sulphur oxides, carbon monoxide and lead (Kanchan and Goyal, 2015).

The measurement of ambient air quality is carried out using indices of pollution standards also known as PSI. Data for PSI are distributed to areas which are occupied by at least 200,000 people for ease of access to air quality information. PSI covers periods maxing out at 24 hours and allows individuals to take measures to avoid acute health effects (Buccholz, 2018).

The standards set for ambient air quality by the US EPA are shown in table 1.

Table 1: National Ambient Air Quality Standards (US EPA, 2014)

Category	AQI Level	O_3	$PM_{2.5}$	CO	SO_2	NO_2
		(ppm) 8-hour	($\mu g/m^3$) 24-hour	(ppm) 8-hour	(ppm) 1-hour	(ppm) 1-hour
Good	0 - 50	0.00 - 0.054	0.0 - 12.0	0.0 - 4.4	0 - 0.035	0 - 0.053
Moderate	51 - 100	0.055 - 0.07	12.1 - 35.4	4.5 - 9.4	0.036 - 0.075	0.054 - 0.10
Unhealthy for sensitive groups	101 - 150	0.071 - 0.085	35.5 - 55.4	9.5 - 12.4	0.076 - 0.185	0.101 - 0.36
Unhealthy	151 - 200	0.086 - 0.105	55.5 - 150.4	12.4 - 15.4	0.186 - 0.304	0.361 - 0.649
Very unhealthy	201 - 300	0.106 - 0.20	150.5 - 250.4	15.5 - 30.4	0.305 - 0.604	0.650 - 1.249
Hazardous	301 - 500	> 0.20	250.5 - 500.4	30.5 - 100.4	0.605 - 1.004	1.25 - 2.049

2.6 Air Quality Index

The air quality index is a method which is commonly used to report and communicate information concerning air quality or the level of air pollution in a manner which is easily expressible and understandable (Kanchan and Goyal, 2015). The rating of air quality indices depends on the index used in the determination of air quality. Some air quality indices and their ratings are discussed below.

2.6.1 The Air Quality Rating

This index is based on the National Ambient Air Quality Standards (NAAQS) set by the United States Environmental Protection Agency and was developed in 1999. The determination of the air quality index considers the concentrations of the six priority air pollutants designated by the USEPA, viz., carbon monoxide, ozone, nitrogen dioxide, lead, sulphur dioxide and particulate matter (Bishoi *et al.,* 2009). The US EPA air quality index is calculated as follows:

$$I_p = \frac{(I_{HI} - I_{LO})}{BP_{HI} - BP_{LO}} (C_P - BP_{LO}) + I_{LO}$$

Where I_P = index for pollutant P,

C_P = rounded concentration of pollutant P,

BP_{HI} = Breakpoint that is equal to or greater than C_P,

BP_{LO} = Breakpoint that is equal to or less than C_P,

I_{HI} = AQI value corresponding to BP_{HI},

I_{LO} = AQI value corresponding to BP_{LO} (Bishoi *et al.,* 2009; Kanchan and Goyal, 2015).

Table 2: Air quality rating and associated health impacts for each level

AQI Level of Health Concern	Numerical Value	Meaning	Colour Code
Good	0 – 50	Air quality is satisfactory and air pollution poses little or no health risk	Green
Moderate	51 - 100	Air quality is acceptable; however, for some pollutants, there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution	Yellow
Unhealthy for sensitive groups	101 - 150	Members of sensitive groups may experience health effects. The public is not likely to be affected	Orange
Unhealthy	151 - 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects	Red
Very unhealthy	201 - 300	Health warnings of emergency conditions. The entire population is more likely to be affected	Purple
Hazardous	301 - 500	Health alert: everyone may experience more serious health effects	Maroon

Source: (US EPA, 2014)

2.7 Measures of Air Quality Control in Schools

Several measures to control ambient air quality in schools exist. Some of these measures are discussed in the following sections.

2.7.1 Siting of schools away from ambient sources of air pollutants

The major pollutants of ambient air in schools have been shown to include carbon monoxide, nitrogen dioxide, polycyclic aromatic hydrocarbons, and volatile organic compounds (El-Sharkawy, 2013). In some cases, heavy metal dust has been recorded in the ambient air of schools (Di Gilio *et al.,* 2017).

The presence of these compounds or pollutants is reported to be more prevalent in schools which are located close to industrial areas or roads which accommodate heavy traffic. Carbon monoxide, nitrogen dioxide, polycyclic aromatic hydrocarbons and volatile organic compounds are released into the air during industrial activities such as energy generation and fossil fuel combustion; they are also released from the complete and incomplete combustion of fuels in vehicles (Gartland *et al.,* 2022). Heavy metal dust and oxides are released into the ambient air from industries which are involved in mining, metallurgy and smelting activities (Di Gilio *et al.,* 2017).

For these reasons, the siting of schools in areas away from these sources of ambient air pollutants is an important method to reduce the exposure of students to these substances. Zoning laws in such areas have a role to play in protecting students' health.

2.7.2 Control of air pollutants at the sources

The major sources of ambient air pollutants have been listed to include industrial activities and transportation. The installation of air pollution control devices in industries and as part of the exhaust systems of various vehicles used for transportation will greatly reduce the amounts of these pollutants which are released into the environment during these activities. Examples of air pollution control devices include scrubbers, mist collectors, cyclones, air filters, electrostatic precipitators and biofilters (Nathanson, 2015). For air pollution control in vehicles, mechanisms used include catalytic converters, positive crankcase ventilation, exhaust gas recirculation, pretreatment of fuels and use of fuel additives (Dey and Mehta, 2020). The reduction in atmospheric concentrations of air pollutants will produce lesser adverse effects on students.

2.7.3 Installation of ambient air quality monitors in schools

The installation of monitors for real-time measurement of ambient air quality in schools is another critical measure in the control of air quality in schools. Ambient air quality monitors provide information about the concentrations of various pollutants in the air and this information dictates which protective measures can be implemented at a particular time. The only drawback of this method is that some schools may not be able to afford enough air quality monitors (US EPA, 2021).

2.7.4 Reducing time spent outside and using appropriate ventilation systems indoors

Exposure to ambient air pollutants often occurs during break periods when students go out of the class or when going from one lecture hall to another. It can also occur in sports fields or during other outdoor activities which are part of the normal school system.

To reduce the adverse effects of these ambient air pollutants on students, students should spend more time indoors than outdoors.

While spending time indoors may reduce exposure to ambient air pollutants, these pollutants may drift into indoor areas through windows, doors or even the walls, combine with indoor air pollutants and assert their adverse effects on health (Mohammadyan *et al.,* 2017). In cases like that, proper ventilation and venting systems are required to continually remove these pollutants from the indoor air environment (Abdullahi *et al.,* 2013).

2.7.5 Planting of Trees on School Grounds

The presence of trees in schools is a way to improve air quality as outdoor concentrations of oxides of carbon are removed by trees and the photosynthetic process produces oxygen which aids in the dissipation of air pollutants. Trees also cause a decrease in atmospheric temperatures in areas where they are planted. This mechanism is useful in places where volatile pollutants are present as the low temperatures can prevent their entry into the atmosphere. Trees decrease the concentration of particulate matter in the air through the capture of particulate matter from the air that blows through them (Osborne *et al.,* 2021).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This study was conducted at the University of Benin in Benin City, Edo State, Nigeria. The geographic location of the university is situated at 6°20'1.32" N and 5°36'0.53" E, within Ovia North-East Local Government Area. The study area n a humid tropical region. Its rainfall component substantially influences the occurrence of wet and dry seasons. The overall annual rainfall recorded in Benin City is between 2,000 and 3,000 mm. The rainy season lasts from April to October, with a brief dry spell around August. The dry season lasts from November to April, with a sultry and dusty harmattan phase between December and January. In addition, the region is frequently subjected to high relative humidity levels ranging from 75 to 85 per cent (Okhakhu, 2014). The university was founded several decades ago with more than ten faculties. The school has several tarred roads and accommodated thousands of lecturers and students. The onsite assessment revealed that there are several possible sources of air pollution within the school environment. These include emissions from the high number of cars, use of gasoline-powered generators as power sources, untarred surfaces which generate road dust within the school, open dumping and combustion of wastes generated by students and lecturers and within the school environment,

3.2 Sampling Locations, Frequency and Duration

The sampling locations for this study are shown in Figure 3.1. Ten different locations from ten different faculties across the university were randomly selected for air quality and meteorological parameters measurements. The sampling was done between the hours of 8 am to 12 noon every week for one month. The measurements of particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) and meteorological parameters (temperature, relative humidity, and wind speed) were taken in triplicates such that 30 samples were taken weekly across the ten sampling locations within the school.

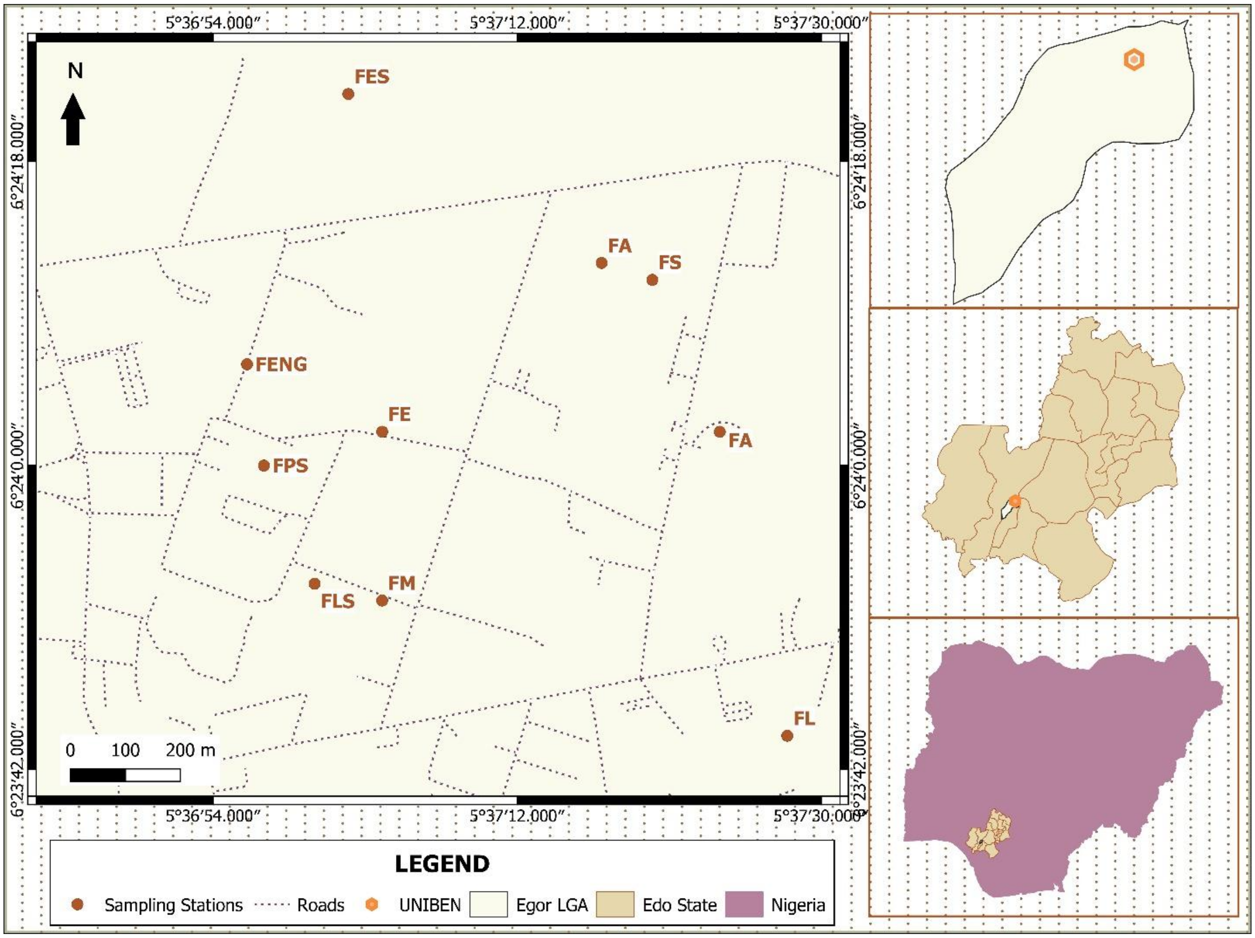

Figure 3.1: Map of the study area showing the sample locations

3.3 Air Quality Sampling Procedure

The concentrations of particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10}) were measured weekly. A hand-held multi-gas detector (Smart Sensor Model AS8700A) was used for particulate matter pollution levels across the sampling locations. Before and after the sampling activity, the samplers were calibrated following the manufacturer's instructions. This was done in the laboratory to guarantee that the specified parameters were read accurately. Before the appropriate readings and documentation, air quality monitoring was done numerous times at each sample site. Measurements were taken in triplicate at a height of 2 meters above ground (the level at which humans are most likely to be exposed). Once the sampler reached the maximum level, the digitally displayed value of each parameter was recorded. The measurements taken were collated and the mean concentrations were taken.

3.4 Determination of Meteorological Parameters

Meteorological variables within the study area including temperature, relative humidity, and wind speed were obtained concurrently with air pollution measurements at each sample location. Throughout the sample period, which lasted for one month between January and February 2022, the measurements were taken monthly in duplicate. Wind speed and temperature were measured using an anemometer (BTMETER BT-100 model), while the humidity was measured using a Smart Sensor Model AS8700A.

3.5 Determination of Air Quality Index

The AQI values were calculated for all the sampling sites using the 24-hourly average concentrations of measured air pollutants. The mean levels of particulate matter were calculated using an excel spreadsheet. The individual air quality index for a given pollutant concentration (Cs) based on the linear segmented principle was calculated as follows:

$$\text{AQI} = \frac{Ihigh - Ilow}{BPhigh - BPlow} X\ (Cp - Bplow) + Ilow \qquad \text{(Equation1)}$$

Where: AQI = Index of the pollutant.

Cp = the rounded concentration of pollutant p.

BP_{high} = the breakpoint greater or equal to Cp.

BP_{low} = the breakpoint less than or equal to Cp.

I_{high} = the AQI corresponding to BP_{high}.

I_{low} = the AQI corresponding to BP_{low}.

Air quality index is divided into six levels of health concern and their implications namely: good (0–50), which implies that AQI is satisfactory; moderate (51–100), AQI is acceptable; unhealthy for sensitive groups (101–150), implies that this AQI range may not affect the public, but could affect persons with heart and lung diseases, older adults, and children. Unhealthy (151–200), everyone may begin to experience some adverse health effects; very unhealthy (201–300), everyone may experience adverse health effects and hazardous (301–500), this triggers health warning of emergency conditions.

CHAPTER FOUR

4.0. RESULTS

This section presents the results of data analyzed for the mean concentrations of particulate matter concentrations and mean values of meteorological parameters across the sampling locations. It also shows the associations between the in situ meteorological parameters obtained and the concentrations of ambient PM in the study area. The AQI values obtained from the monitored PM concentrations are also presented in this section.

4.1 Mean Values of Observed Meteorological Parameters

The average values of observed temperature, relative humidity and wind speed in the study area are presented in Figures 4.1 to 4.3. The results revealed that the ambient temperature observed during the sampling ranged from 34.1 to 36.1℃ throughout the sampling locations. (Figure 4.1). The temperature was highest in sampling area 10 (SA10) and lowest in SA1. The ambient relative humidity ranged from 62.9 to 38.1% with the highest value obtained in SA7, while the lowest RH was determined at SA6. The average wind speed across the sampling areas varied from 0.8 to 1.9m/s with the highest recorded at SA1.

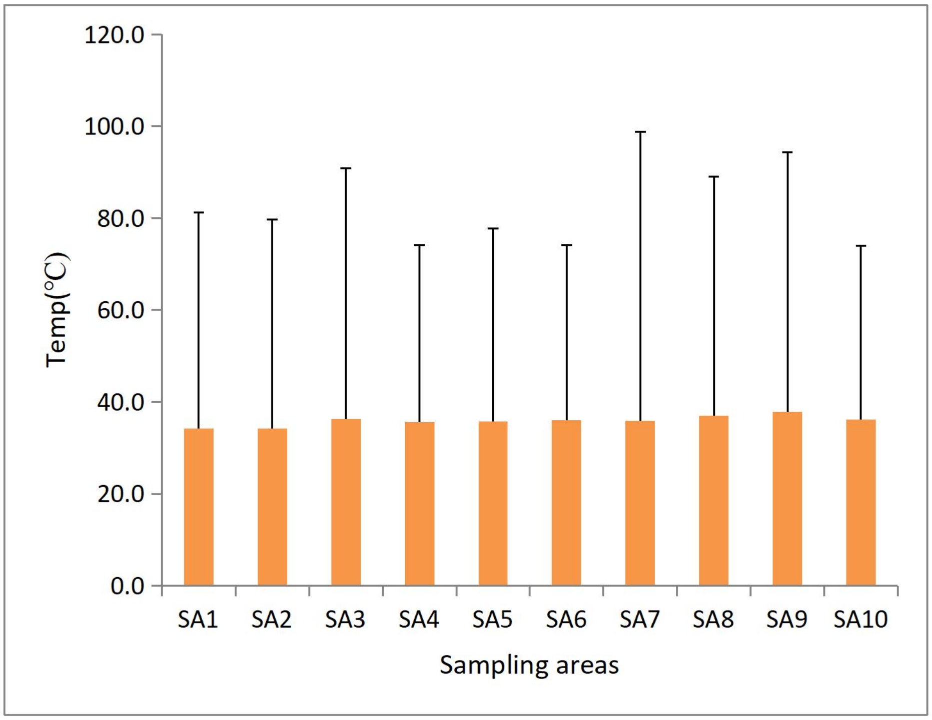

Figure 4.1: Average ambient temperature across the sampling locations

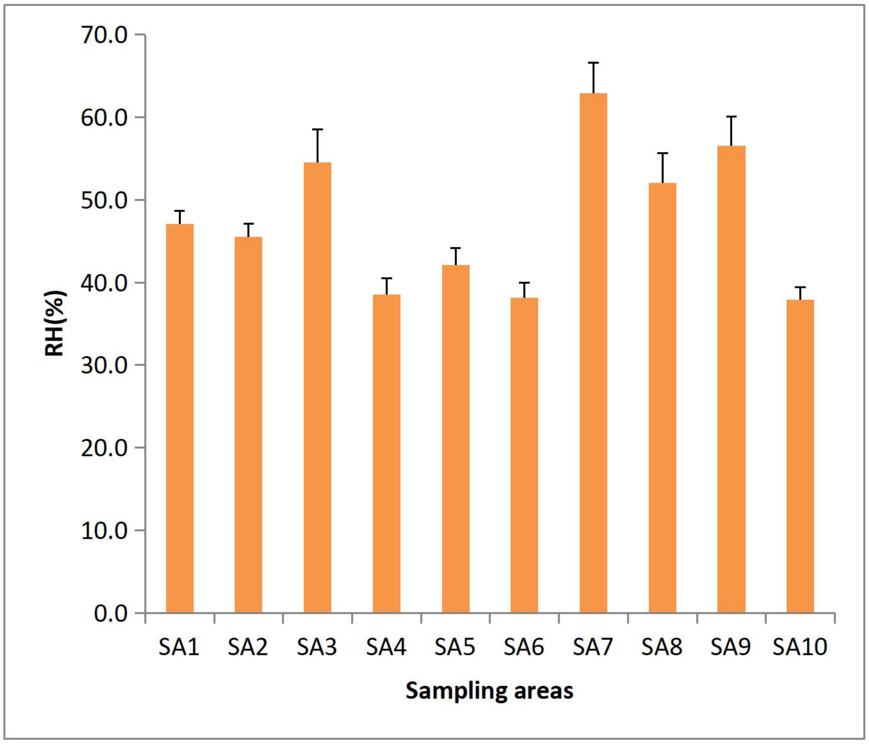

Figure 4.2: Average ambient RH across the sampling locations

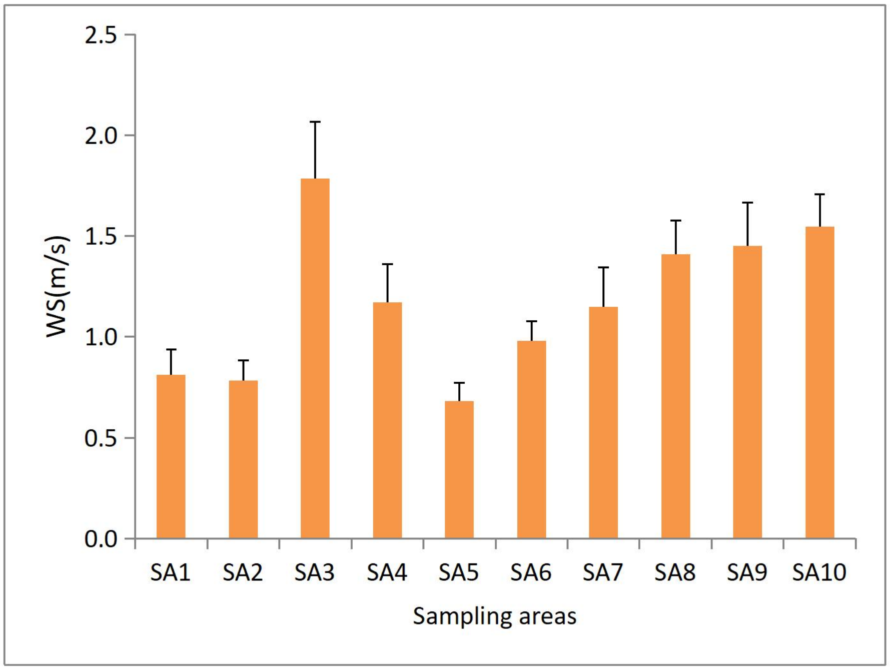

Figure 4.3: Average ambient Wind speed across the sampling locations

4.2 Mean Concentrations of Ambient Particulate Matter across the Sampling Locations

The mean levels of ambient $PM_{1.0}$, $PM_{2.5}$ and PM_{10} concentrations within the University environment are presented in Figures 4.4 to 4.6. Figure 4.4 showed that the mean concentrations of $PM_{1.0}$ ranged between 25.9 and 30.5µg/m^3. The highest value of $PM_{1.0}$ was obtained in SA6 while the lowest was recorded at SA2 across the sampling areas. The mean concentrations of ambient $PM_{2.5}$ across the sampling locations ranged from 40.9 µg/m^3 at SA to 48,6 µg/m3 at SA6. The concentrations of the monitored coarse particles (PM_{10}) ranged from 57.0 to 62.2 µg/m^3. The highest PM_{10} value was recorded at SA5 while the lowest was obtained at SA2.

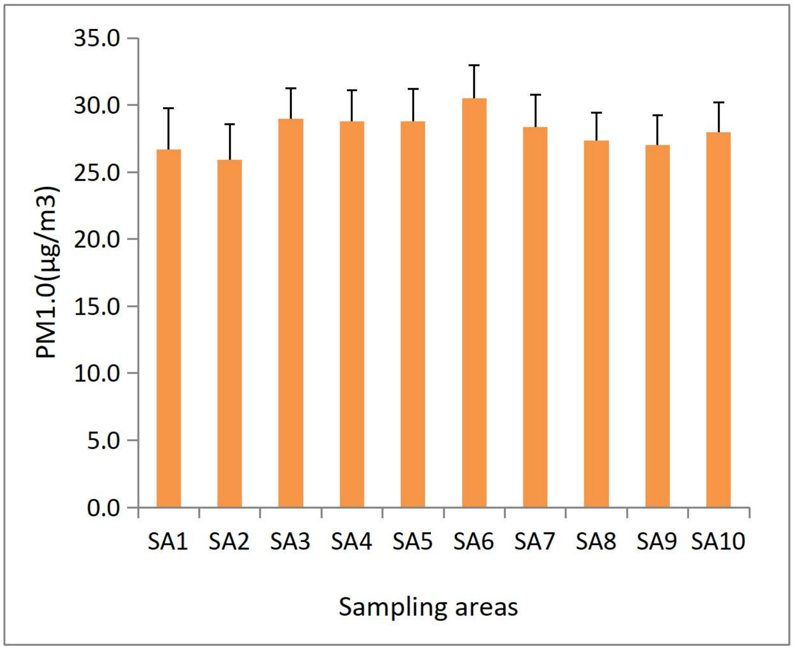

Figure 4.4: Mean concentrations of $PM_{1.0}$

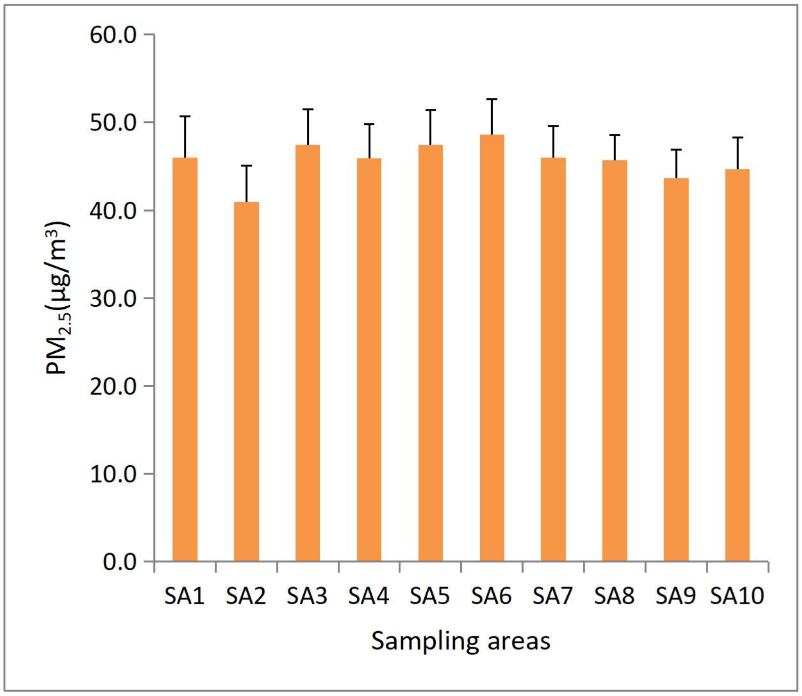

Figure 4.5: Mean concentrations of $PM_{2.5}$

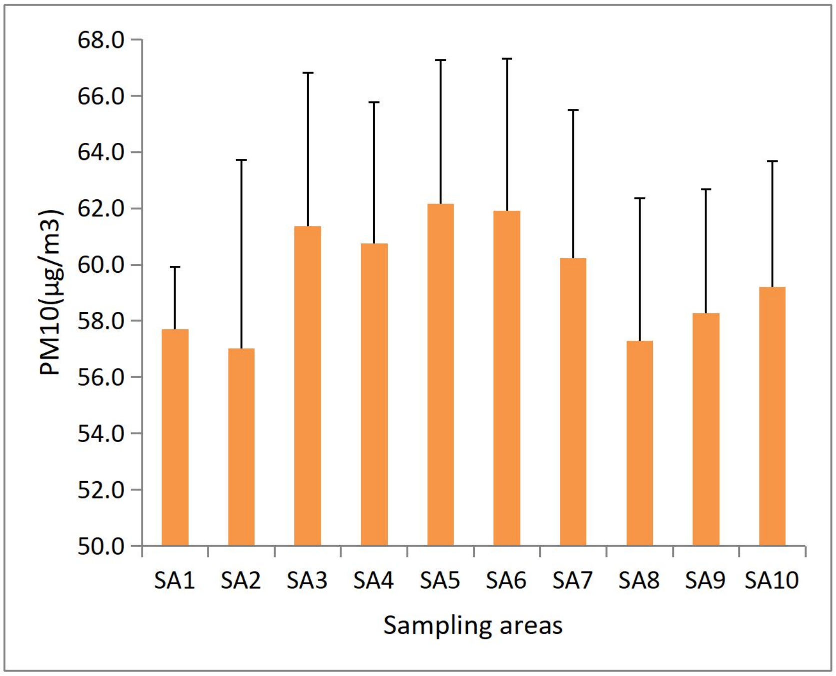

Figure 4.6: Mean concentrations of PM_{10}

4.3 Variations Among Particulate Matter Concentrations and Meteorological Parameters across the Selected Locations

The variations in mean concentrations of PM and values of meteorological parameters throughout the sampling locations were obtained from the ANOVA results as presented in Table 4.1. The table shows that the obtained particulate matter concentrations did not vary significantly across the sampling areas ($p = 0.967$, 0.973, 0.998 at $p > 0.05$). Contrarily, the recorded meteorological values were different significantly across the sampling areas($p < 0.05$).

Table 4.1: Variations in particulate matter concentrations and meteorological parameters across the sampling locations

		Sum of Squares	df	Mean Square	F	Sig.
$PM_{2.5}$	Between Groups	1538.344	9	170.927	0.322	0.967
	Within Groups	185591.556	350	530.262		
$PM_{1.0}$	Between Groups	581.725	9	64.636	0.306	0.973
	Within Groups	74036.806	350	211.534		
PM_{10}	Between Groups	1230.836	9	136.760	0.141	0.998
	Within Groups	340436.139	350	972.675		
WS	Between Groups	43.462	9	4.829	4.558	0.000
	Within Groups	370.820	350	1.059		
TEMP	Between Groups	404.271	9	44.919	13.000	0.000
	Within Groups	1209.388	350	3.455		
RH	Between Groups	24628.692	9	2736.521	10.238	0.000
	Within Groups	93551.083	350	267.289		

Temp= Temperature; RH= Relative humidity; WS= Wind speed

4.4 Correlations among the PM concentrations and between the Meteorological Parameters

The associations between the ambient particulate matter concentrations and the observed meteorological parameters obtained from the bivariate person's correlation analysis are presented in Tables 4.2 and 4.3. In table 4.2, the PM fractions correlated strongly and positively significantly with one another. The $PM_{1.0}$ correlated with $PM_{2.5}$ and PM_{10}(R = 0.979 and 0.979; P<0.001), $PM_{2.5}$ correlated with $PM_{1.0}$ and PM_{10} (R= 0.979, 0.982; P<0.001). The ambient temperature correlated negatively significantly with the monitored particulate matter fractions across the sampling location. Although the association was weak (R=-0.261, - 0.282 and -0.271; p<0.001). In contrast, the ambient Relative humidity and wind speed had no significant relationship (R=0.025, 0.047 and 0.050 for wind speed and R= 0.061, 0.080 and 0.062 for RH) with the observed particulate matter concentrations in the study area

Table 4.2: Correlation among outdoor particulate matter concentrations

Air parameter	$PM_{1.0}$	$PM_{2.5}$	PM_{10}
$PM_{1.0}$	1	0.979^{**}	0.979^{**}
$PM_{2.5}$	0.979^{**}	1	0.982^{**}
PM_{10}	0.979^{**}	0.982^{**}	1

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.3: Correlation between meteorological parameters and ambient PM concentrations

Air parameter	WS	TEMP	RH
$PM_{1.0}$	0.025	-0.261**	0.061
$PM_{2.5}$	0.047	-0.282**	0.080
PM_{10}	0.050	-0.271**	0.062

**. Correlation is significant at the 0.01 level (2-tailed).

4.5 Air Quality Index of Particulate Matter Concentrations

The AQI values and the associated health risk is presented in table 4.5. The result showed that the AQI ranged for $PM_{2.5}$ and PM_{10} from 101 to 105 and 51 to 53 respectively. The AQI status of the university environment ranged from moderate to unhealthy for sensitive groups.

Table 4.4: AQI of ambient particulates and the level of health risks

	$PM_{2.5}$		PM_{10}	
Locations	**AQI**	**Ranking**	**AQI**	**Ranking**
SA1	103.85	Unhealthy to sensitive individual	52.48	Moderate
SA2	101.26	Unhealthy to sensitive individual	51.98	Moderate
SA3	104.31	Unhealthy to sensitive individual	53.45	Moderate
SA4	105.33	Unhealthy to sensitive individual	53.45	Moderate
SA5	104.31	Unhealthy to sensitive individual	53.94	Moderate
SA6	105.33	Unhealthy to sensitive individual	53.94	Moderate
SA7	105.33	Unhealthy to sensitive individual	52.96	Moderate
SA8	105.33	Unhealthy to sensitive individual	51.98	Moderate
SA9	102.78	Unhealthy to sensitive individual	52.48	Moderate
SA10	103.29	Unhealthy to sensitive individual	53.46	Moderate

CHAPTER FIVE

5.0. DISCUSSION

5.1. Discussion

The ambient temperature and relative humidity across the sampling locations within the University environment were slightly higher than the FMEnv (FMEnv, 1999) and ASHRAE (ASHRAE, 2013) regulatory limits. There were variations in the temperature and RH across the locations. This could be due to the variations in the weather conditions at each sampling point during the sampling. This finding is like the report of Eghomwanre et al. (2022). The low wind speed values obtained in this study are consistent with the work of Ukpebor *et al* (2010) who reported that wind speed is generally low throughout the year in Benin City. The concentrations of $PM_{2.5}$ and PM_{10} obtained in this study were above the allowable limit prescribed by the WHO, (2018). The high concentrations of ambient particulate matter obtained in this study could be largely attributed to the predominant unpaved land area in the school environment which generates dust particles. Emissions from vehicle exhaust may also be a source of unhealthy levels of PM in the sampling areas due to relatively dense traffic on major roads and within the school that are prominent throughout the areas, these particles could also infiltrate the classrooms and cause indoor air pollution. This observation is in line with Ediagbonya *et al*. (2013) who reported that unpaved roads are contributory sources of particulate matter emission in different areas. The strong significant positive correlation between the particulate matter fractions implies that an increase in one of the particulates increases the concentrations of the other. Hence the particulate pollution in the school environment is contributed by the different metrics of monitored particulate matter.

The negative association between the ambient temperature and the monitored PM concentrations implies that an increase in the atmospheric temperature in the study area results in a decrease in the particulate matter concentrations. This finding disagrees with the findings of Eghomwanre et al. (2022) who reported that an increase in atmospheric temperature increases the concentrations of air pollutants. The AQI of the particulate matter across the study area was not good but ranged from moderate to unhealthy for sensitive individuals. This could pose health risks to the students and lecturers especially those with underlying illnesses.

5.2. Conclusion

The levels of $PM_{2.5}$ and PM_{10} in all locations exceeded the WHO regulatory limits. As a result, prolonged and continuous exposure may be hazardous to the health of the occupants, particularly those with underlining diseases. There were generally poor associations between air pollutants and meteorological parameters. This suggests that other factors unaccounted for during this study may be influencing the distribution of particulates in the study area. The air quality index assessment revealed that the particulate matter AQI status was primarily unhealthy. This means that persons in the study area are exposed to unhealthy levels of particulate matter. This study emphasizes the importance of routine air quality monitoring within the higher institution of learning as well as awareness programs about the health effects of exposure to air pollutants, particularly particulates.

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APPENDIX

Air quality monitor

Digital Anemometer