

Comparison of Indoor Air Quality in Schools: Urban vs. Industrial 'Oil & Gas' Zones in Akwa Ibom State – Nigeria

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Abstract This study was carried out to assess indoor air quality (IAQ) in schools in Akwa Ibom State of Nigeria during the rainy (June – July) and dry (November – December) seasons of 2018. IAQ parameters were examined to assess pollutant levels in schools within Akwa Ibom State in single setting only (naturally ventilated classrooms). Schools were randomly selected from two zones: zone 1 which is located within the Capital City (Uyo metropolis) and represents the 'urban sector', and zone 2 which is located within the southern part of the state in close proximity to the oil and gas industrial region and represents the 'industrial sector'. Indoor air investigation included the following parameters: particulate matter (PM₁, PM₂, PM₅, and PM₁₀), carbon monoxide (CO), carbon dioxide (CO₂) levels, temperature and relative humidity, which were simultaneously measured in fourteen (14) sampling days using Fluke 985 Particle Counter and Fluke 975 AirMeter. Multiple statistically analysis techniques were used to compare IAQ parameters and test for significant differences between the zones (urban vs. industrial) and annual seasonal variations. The concentrations of particulate matter (PM) in the naturally ventilated classroom in industrial zone during the rainy season ranged from 5152 – 5984 µg/m³ for PM₁; 2744 – 3207 µg/m³ for PM₂; 137 – 149 µg/m³ for PM₅; 38 – 46 µg/m³ for PM₁₀ and in urban zone, the concentrations of PM ranged from 1978 – 2491 µg/m³ for PM₁; 1010 – 1311 µg/m³ for PM₂; 38 – 56 µg/m³ for PM₅; 15 – 24 µg/m³ for PM₁₀. During the dry season, the concentrations of PM in the naturally ventilated classroom in industrial zone ranged from 6138 – 6999 µg/m³ for PM₁; 2984 – 3980 µg/m³ for PM₂; 146 – 159 µg/m³ for PM₅; 47 – 59 µg/m³ for PM₁₀ and in urban zone, the concentrations of PM ranged from 2556 – 3972 µg/m³ for PM₁; 1911 – 2311 µg/m³ for PM₂; 51 – 66 µg/m³ for PM₅; 18 – 34 µg/m³ for PM₁₀. Results of this study has revealed that the concentrations of PM₁, PM₂, PM₅, and PM₁₀ measured in the naturally ventilated classroom in industrial zone were significantly ($p < 0.001$) higher than those measured in the urban zone during both rainy and dry seasons. In this present study, the concentrations of PM₁₀ measured were found to be much lower than the ambient maximum contaminant level for airborne PM₁₀ standard promulgated by the United States Environmental Protection Agency (US-EPA) (150 µg/m³ daily average and 50 µg/m³ annual average) and World Health Organization (WHO) PM₁₀ guidelines values (50 µg/m³ daily average and 20 µg/m³ annual average). Apart from re-suspension of atmospheric particles, anthropogenic activities in industrial zone significantly influenced the measured concentrations of PM compared to those measured in urban zone. In addition, the lower concentration of CO and CO₂ measured indicated adequate air exchange at the time of the assessment in the naturally ventilated classrooms during the sampling period. The results obtained reveal important contributions towards understanding of airborne PM distribution patterns and the available data can be used for making public health policies.

Keywords: indoor air quality, particulate matter, schools; exposure, Akwa Ibom State, Nigeria

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1. Introduction

Air pollution associated with natural and/or anthropogenic activities may cause adverse effects on human health and

the environment. Over the past sixty years, advances in industrialization, urbanization, large volume of emissions from vehicles, and other activities in the petroleum industry associated with exploration and production of energy and/or chemicals have resulted in air pollution around the world [1,2,3]. According to Ite & Ibok [1], gas

flaring and venting of petroleum-associated gas in the petroleum industry in the Nigeria's Niger Delta has clearly impacted on the natural environment, human health, socio-economic environment and caused degradation of host communities. In addition, increasing energy consumption in terms of combustion of fossil fuels in the last century is responsible for the progressive change in the atmospheric composition as well as atmospheric pollution [4]. Most of the atmospheric pollutants, such as carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds (VOCs), ozone (O₃), heavy metals, and respirable particulate matter (PM_{2.5} and PM₁₀), differ in their chemical composition, reaction properties, time of disintegration and poor atmospheric dispersion conditions [4,5]. As a result, the particulate matter (the suspended material of the atmosphere) in both developed and developing countries has been heavily impacted over the years. Particulate matter (PM) is a complex mixture of extremely small particles (solids) and liquid droplets of primary and secondary origin that contain a wide range of inorganic and organic components [6,7]. It is known that the size distribution of PM in an ambient air is trimodal according to the aerodynamic diameter [8].

Although PM is found in both outdoor and indoor environment, coarse and fine particles sum up to particles with an aerodynamic diameter less than 10 µm (PM₁₀). PM can be suspended over long period of time and travel over long distances in the atmosphere, and as such significantly affect local and/or regional air quality, human health and climate change. It is known that the spatial and temporal distribution of PM is variable and is strongly influenced by both climatic and meteorological conditions [7,9,10]. Indoor air quality (IAQ) is a continuing concern for students, parents, teachers, and school staff, leading to many complaints regarding poor IAQ in many developed countries around the world [11]. Over the years, several research work has been published with respect to IAQ in schools in both developed and developing countries around the world [11-23]. Some of the human health implications associated with PM pollutions in schools are as follows: higher susceptibility of children to environmental pollutants [24,25,26], higher inhalation rates per body mass [27,28], and longer time spent in schools [26,28]. Findings from several studies have identified different pollutant parameters that contribute to IAQ problems in some schools around the world. For example, high PM₁₀ and CO₂ levels in Porto, Portugal [12], Hong Kong [13] and Munich, Germany [14], Kosice, Slovakia [15], Qatari [26]; high mean concentrations of both PM₁₀ and PM_{2.5} in Lahore, Pakistan [16]; higher mean indoor CO₂ concentration than the ASHRAE standards-62 [17] of 1000 ppm in Athens, Greece [18,19], and Serbia [20], or the CO₂ value established by Portuguese legislation [21]; high CH₂O concentration emitted by building materials or furnishings in South Korea [22] and France [23]; and high average SO₂ concentrations in French schools [29].

Human health effects associated with both indoor and outdoor environmental air pollutants have been of great concern due to the high exposure risk even at relatively low concentrations of the air pollutants [30]. Evidence continues to emerge showing that exposure to airborne

pollutants and/or poor IAQ can cause adverse human health complications requiring absence from schools, and can cause acute health symptoms that decrease students' performance [21]. Over the past decades, several epidemiological studies and the adverse human health effects associated with PM pollution have been documented across the world [30-45]. According to Brunekreef & Holgate [45], these effects have been reported in short-term studies, which relate day-to-day variations in air pollution and health, and long-term studies, which have followed cohorts of exposed individuals over time. Therefore, good indoor air quality in classrooms provides healthy learning environment to children, promotes learning ability and also helps to make teachers as well as staff to be more productive [46]. Some of the main factors affecting indoor environment include temperature, humidity, air exchange rate, air movement, ventilation, particle pollutants, biological pollutants, and gaseous pollutants [47]. Although PM-related air pollution affects cardiorespiratory health, it is unclear which particle size fractions and sources of particles are responsible for the human health effects [38,40,44].

The exposure to ambient PM pollution is a major threat to public health and poor indoor air quality can cause a wide range of health-related symptoms that may lead to a significant reduction in human productivity as well as increased mortality. However, information about indoor conditions of school classrooms in Akwa Ibom State are limited and availability of IAQ data is important as children are vulnerable to health hazards and spend long times in classrooms. Therefore, the present study investigates indoor air quality in schools in urban and industrial (Oil & Gas) zones in Akwa Ibom State of Nigeria during the rainy (June – July) and dry (November – December) seasons of 2018.

2. Materials and Methods

2.1. School Selection and Sampling Sites

This study was carried out in naturally ventilated classroom in Urban Zone (Uyo Local Government Area) and in Industrial Zone (Ikot Abasi Local Government Area) in Akwa Ibom State of Nigeria (Figure 1). Akwa Ibom State, which is currently the largest oil-producing state in the Nigeria's Niger Delta region, is located in the coastal southern part of the country (i.e. South-South geopolitical zone). Akwa Ibom State covers a total land area of 8412 km² and lies between latitudes 4°32'N and 5°33'N, and longitudes 7°25'E and 8°25'E. The state is bordered on the east by Cross River State, on the west by Rivers State and Abia State, and on the south by the Atlantic Ocean and the southernmost tip of Cross River State.

Uyo, which is the capital of Akwa Ibom State, is situated between latitude 5° 01' North of Equator and longitude 7° 56' East of the Meridian. It is bounded in the west by Abak, east by Uruan, north by Ikono, Ibiono Ibom and Itu and in the south by Etinan, Ibesikpo/Asutan and Nsit Ibom Local Government Areas.

Ikot Abasi is a local government area in Akwa Ibom State with an area of approximately 451.73 km². Ikot

Abasi is located in the south west corner of Akwa Ibom State, Nigeria. It is bounded by Oruk Anam Local Government Area in the north, Mkpatt Enin and Eastern Obolo Local Government Areas in the east and the Atlantic Ocean in the south. The Imo River forms the natural boundary in the west separating it from Rivers State. Ikot Abasi is a home to Aluminium Company of Nigeria (ALSCON) – the biggest aluminium smelter plant in Africa and Ikom Power Company (IPC) – the first independent power plants in Nigeria.

Figure 1 shows location maps for the two selected school zones in the study. Indoor air quality parameters were measured in one school randomly selected from two different zones in Akwa Ibom State; zone 1 is State Capital (Uyo Metropolis) which represents the urban sector, and zone 2 is located further south in close proximity to the oil and gas industrial region which represents the industrial sector. The present research was carried out in naturally ventilated classroom in industrial and in urban zones located within Akwa Ibom State of Nigeria. The windows in the classrooms were kept opened during the assessment period. The characteristics of the classrooms selected for the study are presented in Table 1.

Table 1. Overview of office characteristics

	SCHOOL A (Urban)	SCHOOL B (Industrial)
Number of occupants	35	34
Floor area (m ²)	1400	1450
Number of Doors	1	2
Number of windows	4	4
Number of Fans	NIL	NIL
Cleaning Frequency	Once daily	Once daily

2.2. Monitoring Protocol

IAQ parameters measurements were carried out for 14 days in two campaigns performed in June – July (rainy season) and November – December (dry season) of 2018. The indoor PM₁, PM₂, PM₅, and PM₁₀ mass concentrations were monitored simultaneously using Fluke 985 Particle Counter with six channels and particle size range of 0.3 – 10.0 µm (Fluke Corporation, United Kingdom) [7]. In addition, the Fluke 975 AirMeter manufactured by Fluke Corporation (United Kingdom) was used to simultaneously measure, logs, and display temperature, relative humidity, CO₂, and CO concentrations. The Fluke 975 AirMeter automatically compensates for barometric pressure changes and has an extensive discrete or continuous data logging capacity. In this present study, the measuring instruments were located approximately 1 m away from walls and mounted on a flat surface with a height of 1.5 m in order to simulate school children breathing zone [48,49,50].

2.3. Statistical Analysis

Multiple statistically analysis techniques were used to compare IAQ parameters and test for significant differences between the zones (urban vs. industrial) and annual seasonal variations. Descriptive statistics were used to characterize the measured IAQ parameters and *T*-test was conducted to compare differences between the

two zones (urban vs. industrial) and annual seasons for particulate matter (PM₁, PM₂, PM₅, and PM₁₀), carbon monoxide (CO), carbon dioxide (CO₂) levels, temperature and relative humidity. One-way ANOVA was used to make comparisons by seasons and locations for particulate matter (PM₁, PM₂, PM₅, and PM₁₀), carbon monoxide (CO), and carbon dioxide (CO₂) levels. Statistical analyses were conducted to determine and evaluate the impact of relevant parameters on the particle concentrations and students' exposure in the naturally ventilated classroom. A value of $p < 0.05$ was considered statistically significant. All data analyses were carried out and the airborne PM distribution profiles are presented using a scientific data analysis and graphing software package – SigmaPlot[®], Version 14 (Systat Software Inc., USA).

3. Results and Discussion

Among the indoor air quality parameters monitored, PM concentrations were found to be significantly higher in the naturally ventilated classroom in industrial zone compared to urban zone. The low CO and CO₂ levels measured indicate adequate ventilation in the naturally ventilated classroom in industrial and urban zones during the assessment period. Table 2 presents the descriptive statistics of daily average IAQ parameters and other measured comfort parameters during the assessment period. Correlation matrix among PM₁, PM₂, PM₅, PM₁₀ concentrations and other indoor air quality parameters in a naturally ventilated classroom in industrial and urban zones are presented in Table 3 – Table 6. The data were grouped into two periods: the rainy season (June – July) and dry season (November – December) of 2018. The seasonal variations of PM (PM₁, PM₂, PM₅, and PM₁₀) concentrations in both naturally ventilated classroom in industrial and urban zones during rainy and dry seasons are graphical shown in Figure 2 – Figure 5.

The concentrations of particulate matter (PM) in the naturally ventilated classroom in industrial zone during the rainy season ranged from 5152 – 5984 µg/m³ for PM₁; 2744 – 3207 µg/m³ for PM₂; 137 – 149 µg/m³ for PM₅; 38 – 46 µg/m³ for PM₁₀ and in urban zone, the concentrations of PM ranged from 1978 – 2491 µg/m³ for PM₁; 1010 – 1311 µg/m³ for PM₂; 38 – 56 µg/m³ for PM₅; 15 – 24 µg/m³ for PM₁₀. During the dry season, the concentrations of PM in the naturally ventilated classroom in industrial zone ranged from 6138 – 6999 µg/m³ for PM₁; 2984 – 3980 µg/m³ for PM₂; 146 – 159 µg/m³ for PM₅; 47 – 59 µg/m³ for PM₁₀ and in urban zone, the concentrations of PM ranged from 2556 – 3972 µg/m³ for PM₁; 1911 – 2311 µg/m³ for PM₂; 51 – 66 µg/m³ for PM₅; 18 – 34 µg/m³ for PM₁₀. Results of this study has revealed that the concentrations of PM₁, PM₂, PM₅, and PM₁₀ measured in the naturally ventilated classroom in industrial zone were significantly ($p < 0.001$) higher than those measured in urban zone during both rainy and dry seasons. Based on the results of correlation analysis, for the pairs with negative correlation coefficients and *P* values below 0.050, one variable tends to decrease while the other increases. For pairs with *P* values greater than 0.050, there were no significant relationship between the two variables. In this present study, the concentrations of

PM₁₀ measured were found to be much lower than the ambient maximum contaminant level for airborne PM₁₀ standard promulgated by the United States Environmental Protection Agency (US-EPA) (150 µg/m³ daily average and 50 µg/m³ annual average) and World Health Organization (WHO) PM₁₀ guidelines values (50 µg/m³ daily average and 20 µg/m³ annual average). The WHO suggest Global Air-Quality Guideline values as follows 10 µg/m³ annual mean, 25 µg/m³ 24-hour mean for PM_{2.5} and 20 µg/m³ annual mean, 50 µg/m³ 24-hour mean for PM₁₀ [51]. Findings from related studies have shown that human activities may act as an important indoor source for PM in classrooms considering that the occupant density in the schools was several times higher than those measured in the other buildings [14,52,53]. In the present study, it was found that indoor PM₁₀ concentrations varied significantly with occupant's activities and higher PM₁₀ concentrations were observed in naturally ventilated classroom in industrial zone. The high PM₁₀ concentrations measured in this study could be attributed to resuspension of previously deposited airborne particles and their delayed deposition associated with physical activity of the students [7,21,54-56]. In a classroom environment, there are several important sources of particles and these include mineral dust, building materials and chalk [21]. It has been reported that even low activity can have a significant impact on the concentration of airborne particles with diameters greater than 5 µm [55].

Over the years, several studies have been conducted with the aim of understanding indoor air quality of school environment across the world [11-23,26,52-54,56-63]. In a study, Tippayawong et al. [62] found that the highest concentrations were measured for particles in the 0.3 – 0.5 µm size range with an average value of 180 cm⁻³ while the lowest concentrations were measured in the 2.5 – 5 µm size range with an average of 0.05 cm⁻³. In a related study, Parker et al. [63] reported that while the smallest particle (0.3 – 0.4 µm) concentrations remained relatively constant over a day between about 4 and 8 cm⁻³, coarse particles

(7.5 – 10 µm) rose with occupancy from zero to about 0.025 cm⁻³ during typical days. The building studied by Tippayawong et al. [62] was naturally ventilated and had higher concentrations than those measured in this study, while Parker et al. [63] studied a mechanically ventilated building which had lower concentrations. In a related study, Lee and Chang [13] investigated IAQ of five classrooms in Hong Kong and reported that the average respirable suspended particulate matter (RSPM) concentrations were higher than the Hong Kong air quality objective and the maximum indoor PM₁₀ level which exceeded 1000 µg/m³. In the present study, the investigation of IAQ was carried out in a naturally ventilated classrooms and the windows were kept opened at all times during the school hours. It has been observed that the IAQ of the school building could be influenced by outdoor pollutant sources [64] and the PM concentrations measured in the present might have been affected by anthropogenic activities (e.g. industrial activities associated with petroleum industry, fossil fuel combustion and traffic-related emissions) within the surrounding environment. Review of findings from various studies investigating particulate matter in ambient air at selected locations in Nigeria from 1985 – 2015 showed that PM_{2.5} concentration ranged from 5 – 248 µg/m³ and PM₁₀ concentration ranged from 18 – 926 µg/m³ [65]. According to Offor et al. [65], about 50% of the outdoor PM concentrations in Nigeria exceeded both the WHO (25 µg/m³, 50 µg/m³) and National Ambient Air Quality Standards (NAAQS) (35 µg/m³, 150 µg/m³) guideline limits for PM_{2.5} and PM₁₀, respectively. Based on the PM_{2.5}/PM₁₀ ratios (which fall below the WHO guideline, 0.5 – 0.8) for the selected outdoor studies, it has been observed that the aerosols in Nigerian environment are mainly made up of more coarse particles and less fraction of fine particles. In a study, it has been observed that built-up areas of Nigerian cities are characterised with high levels of annual mean ambient airborne PM₁₀ concentration of > 120 µg/m³ while rural areas had annual mean ambient PM₁₀ values of 57.4 µg/m³ [66].

Table 2. Descriptive statistics of daily average Indoor Air Quality (IAQ) parameters

Season	Period		Pollutants				Comfort parameters			
			PM ₁ (µg/m ³)	PM ₂ (µg/m ³)	PM ₅ (µg/m ³)	PM ₁₀ (µg/m ³)	CO (ppm)	CO ₂ (ppm)	T (°C)	RH (%)
Rainy	Naturally Ventilated Classroom in Industrial Zone	Mean	5537.58	2922.08	141.43	42.93	1.59	264.65	25.16	79.51
		Min	5152.00	2744.00	137.00	38.00	1.41	241.00	24.60	78.60
		Max	5984.02	3207.00	149.00	46.00	1.77	392.00	25.70	79.90
		Median	5373.01	2946.01	140.50	43.02	1.61	250.31	25.20	79.90
	Naturally Ventilated Classroom in Urban Zone	SD	332.05	123.35	3.72	2.30	0.11	39.90	0.38	0.60
		Mean	2158.43	1139.72	45.86	20.14	1.18	223.21	24.89	79.41
		Min	1978.00	1010.02	38.00	15.00	1.12	220.11	23.70	78.60
		Max	2491.00	1311.00	56.00	24.00	1.25	228.22	25.60	79.90
	Naturally Ventilated Classroom in Industrial Zone	Median	213.00	1082.50	44.00	20.01	1.16	222.16	25.15	79.90
		SD	159.31	123.05	6.23	2.92	0.05	3.38	0.67	0.60
		Mean	6466.86	3496.72	151.57	53.01	2.09	364.72	25.75	79.51
		Min	6138.00	2984.02	146.00	47.00	1.78	355.33	24.60	78.60
Dry	Naturally Ventilated Classroom in Industrial Zone	Max	6999.00	3980.00	159.00	59.02	2.45	388.45	26.80	79.90
		Median	6270.50	3536.02	15.50	53.00	2.12	358.45	25.55	79.90
		SD	353.42	264.09	4.34	3.90	0.19	10.56	0.77	0.60
		Mean	3196.29	2131.15	61.08	26.71	1.31	266.70	25.79	79.51
	Naturally Ventilated Classroom in Urban Zone	Min	2556.02	1911.00	51.00	18.00	1.12	260.21	24.60	78.60
		Max	3972.02	2311.02	66.02	34.00	1.68	280.21	26.80	79.90
		Median	3149.51	2164.50	61.50	27.00	1.23	264.74	25.56	79.90
		SD	364.94	129.97	4.38	3.52	0.22	6.80	0.77	0.60

NOTES: CO = Carbon monoxide, CO₂ = Carbon dioxide, T = Temperature, RH = Relative humidity.

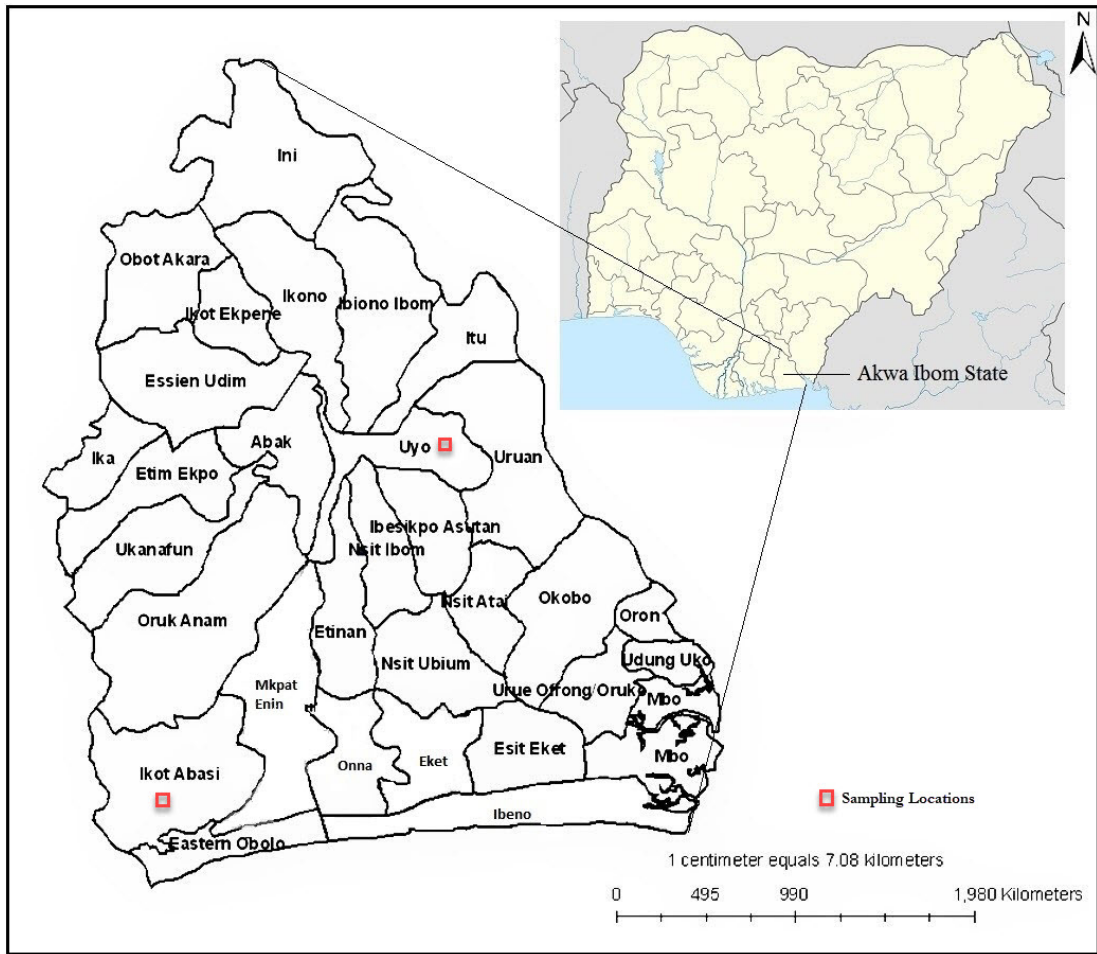


Figure 1. Map of Nigeria Showing the Location of Akwa Ibom State (Study Area: Zone 1 – Urban [Uyo Local Government Area] & Zone 2 – Industrial [Esit Eket Local Government Area]).

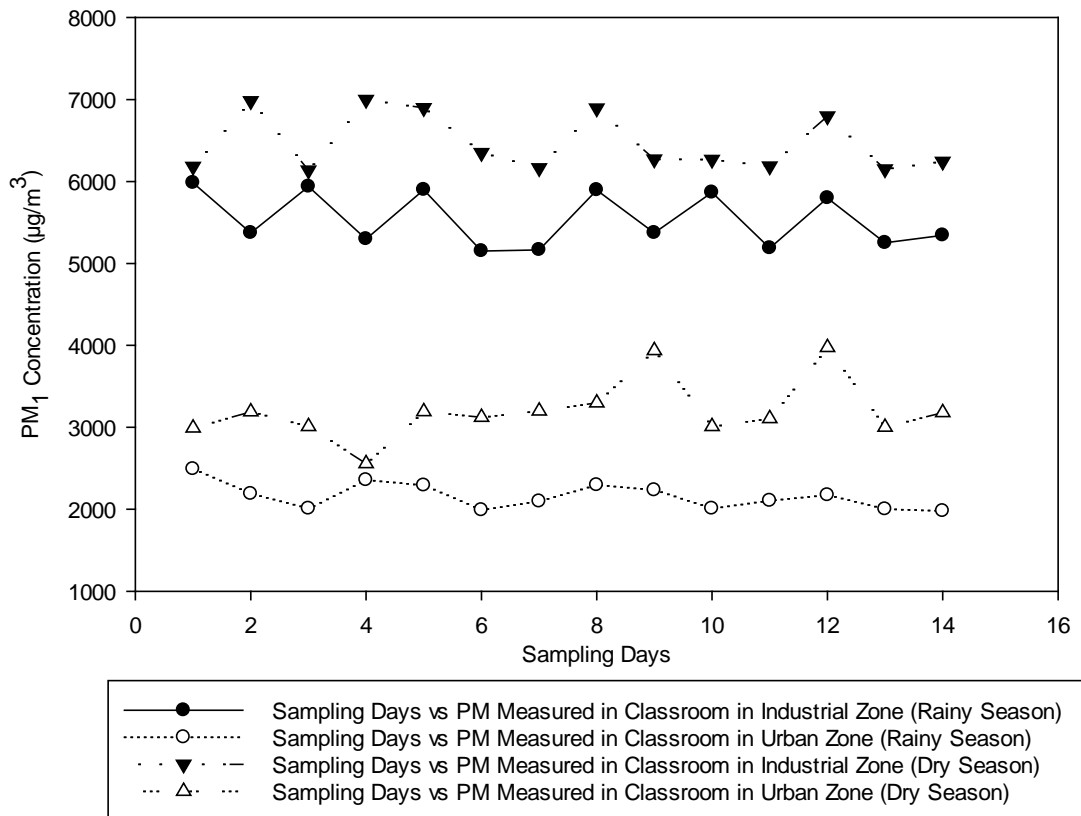


Figure 2. Seasonal Variations of PM₁ Concentrations in a Naturally Ventilated Classroom during Rainy and Dry Seasons

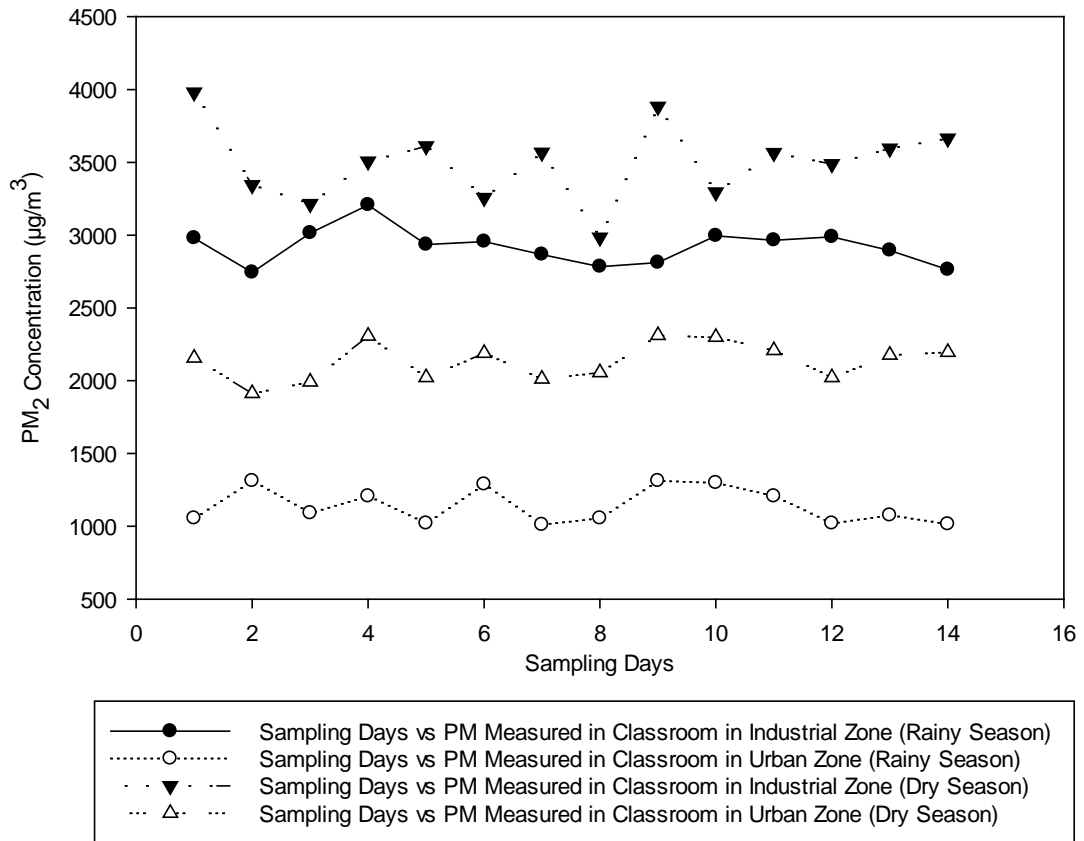


Figure 3. Seasonal Variations of PM_{2.5} Concentrations in Naturally Ventilated Classroom during Rainy and Dry Seasons

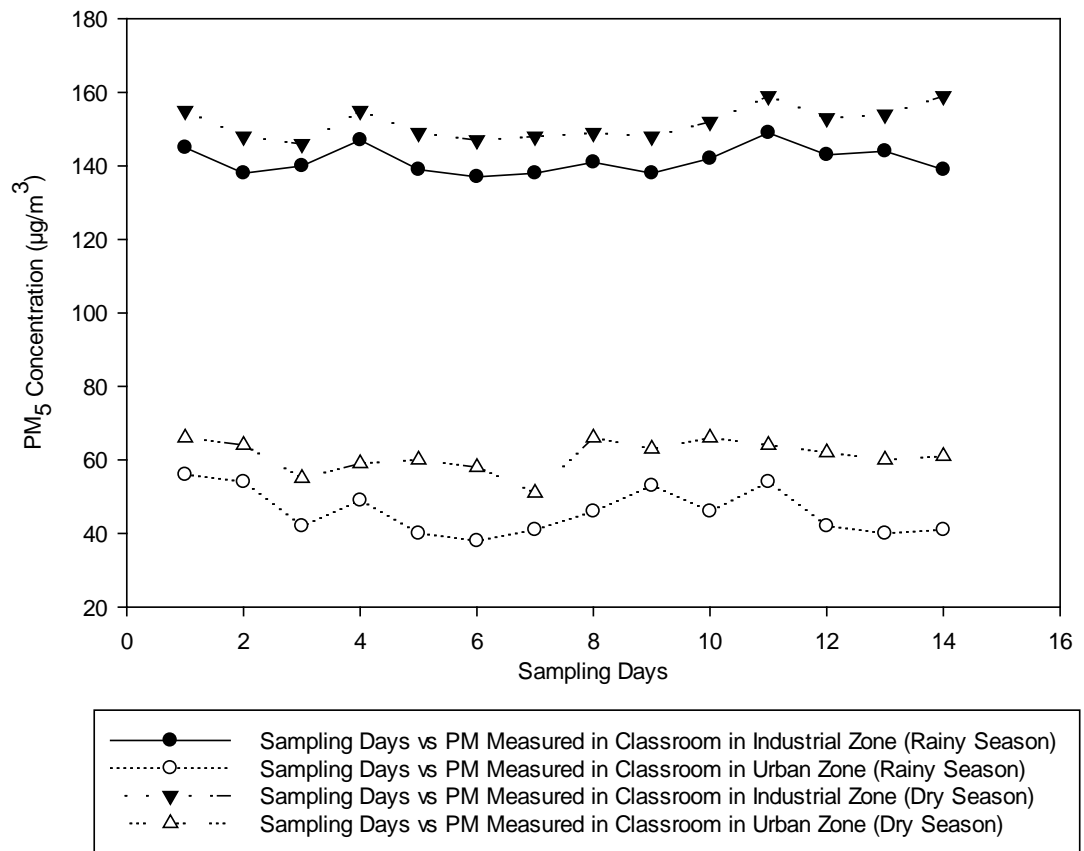


Figure 4. Seasonal Variations of PM₅ Concentrations in Naturally Ventilated Classroom during Rainy and Dry Seasons

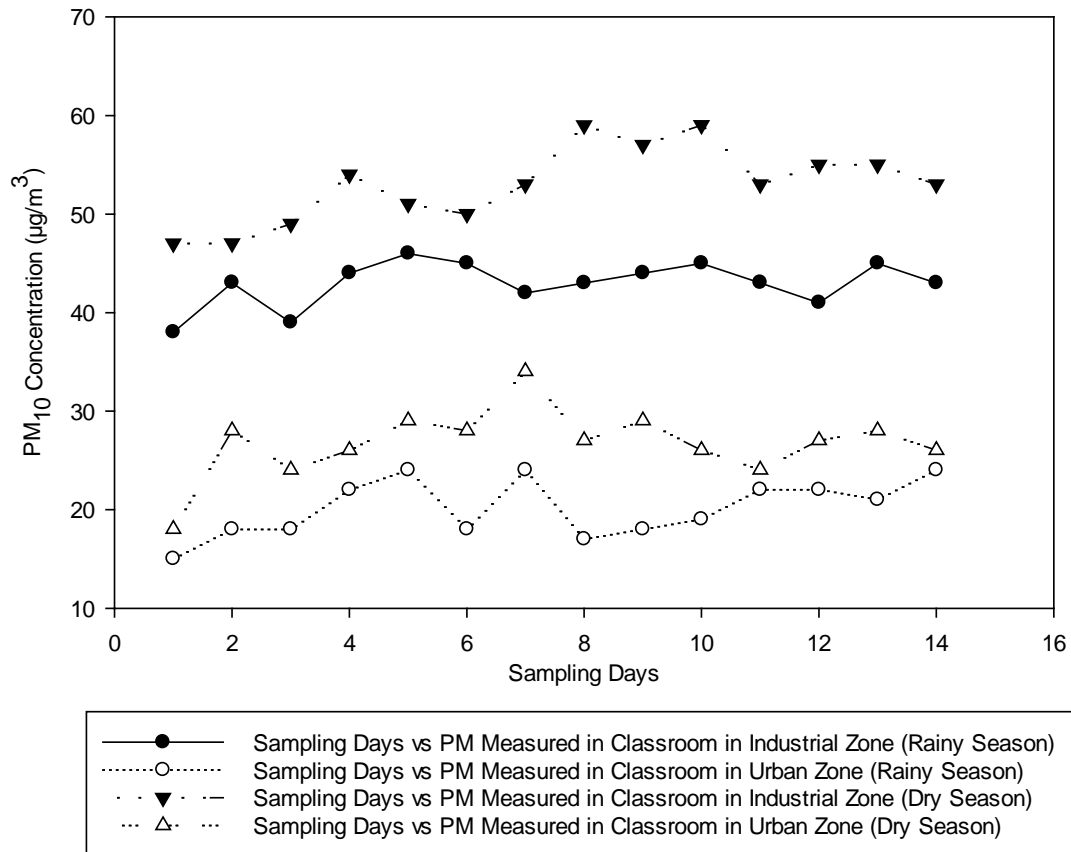


Figure 5. Seasonal Variations of PM₁₀ Concentrations in Naturally Ventilated Classroom during Rainy and Dry Seasons

In this present study, the mean daily indoor concentrations of CO measured in naturally ventilated classrooms in industrial and in urban zones during the assessment period were less than the 1- and 8-h standards set by the US-EPA of 35 and 9 ppm, respectively [67]. Similarly, the mean daily indoor concentrations of CO in all naturally ventilated classrooms in industrial and in urban zones during the assessment period were also less than the 1- and 8-h WHO guidelines of 30.60 and 8.60 ppm, respectively [68]. CO, toxic air pollutant, is produced in the incomplete combustion of carbon-containing fuels, such as gasoline, natural gas, oil, coal, and wood. The largest anthropogenic source of CO in the developed and developing countries is traffic related air pollutants in urban areas and other industrial emissions associated with incomplete combustion of fossil fuels (e.g. gas flaring and venting). CO occurs indoors either directly as a result of emissions from various indoor sources or indirectly as a result of infiltration of CO from outdoor air into the indoor environment (e.g. from vehicles in major roads nearby, wastes burning) [68-70]. In this study, there were no significant indoor sources of CO observed in naturally ventilated classrooms under investigation during the monitoring campaign.

In this study, the slight elevated concentration of the indoor CO₂ concentrations was likely from traffic emissions and /or other sources. However, there were no significant correlation between indoor CO and CO₂ concentrations suggesting that both have different sources of emissions. However, other researchers have attributed high CO₂ levels in classrooms to indoor sources associated with a result of high occupancy combined with inadequate

ventilation [22,26,71]. Therefore, high number of students combined with small classroom volumes and poor ventilation could considerably increase indoor CO₂ concentrations over a long period of time. Apart from emissions in the industrial and urban zones in Akwa Ibom State, the findings reveal that a large fraction of students might have been exposed to poor IAQ and traffic-related pollutants over a long period of time. Therefore, there is a need for exposure measures that account for both the composition and volume of traffic in some part of the Nigeria's Niger Delta region.

The ANSI/ASHRAE Standard 55-2013 [72] specifies the combination of indoor environmental and personal factors that produce acceptable thermal conditions to a majority of occupants within a space. According to the US-EPA recommendations, maintaining indoor RH between 30% and 50% (< 60%) is ideal in order to control mould growth [67]. In this present study, indoor temperature and RH were not entirely in accordance with international standards. Therefore, policies should be put in place to regulate and maintain effective control of temperature and RH in classrooms in order to comply with ANSI/ASHRAE Standard 55-2013. Generally, there is scarcity of information about indoor conditions of classrooms in Akwa Ibom State schools and availability of IAQ data is important as children are vulnerable to health hazards and spend long times in classrooms. Although air pollution has mainly been associated with pulmonary diseases and cardiorespiratory disorders [45], limited experimental and epidemiological data suggest that air pollutants may also exert deleterious gastrointestinal effects [73]. Potential mechanisms by which air pollutants

may cause intestinal injury are thought to include direct adverse effects on epithelial cells, alterations in immune responses, or modulation of the gut microbiota [73-76]. Air pollution exposure has also been shown to impair lung function development in children [77]. Based on the findings of a study by Salim et al. [76], it has been suggested that early exposure to particulate matter pollution can result in an earlier onset of intestinal disease in genetically susceptible hosts and can alter responses to gut injury in later life. In addition, air pollution has also been associated with a variety of non-pulmonary diseases including myocardial infarction [78], appendicitis [79], and rheumatoid arthritis [80]. Air pollution-mediated inflammation has been implicated as the cause of several adverse health effects [81]. Over the past years, scientific evidences from several epidemiological and experimental studies have demonstrated that short-term and long-term exposure to particulate matter is often associated with cardiopulmonary injury and systemic diffusion [82].

4. Conclusions

The PM concentrations were significantly higher in naturally ventilated classroom in industrial zone compared to those in urban zone. The higher PM concentration in the naturally ventilated classroom in industrial zone could be attributed to various anthropogenic activities, industrial emissions associated with petroleum industry, power generation as well as re-suspension of dust. In addition, the long distant transport of pollutants into industrial zone atmosphere from the neighbouring state (Rivers State) might have accounted for a significant portion of the regional PM pollution. Findings from this study have shown significant seasonal variations of PM distributions and naturally ventilated classroom in industrial zone had the highest concentration of PM compared to the naturally ventilated classroom in urban zone. Generally, the PM fractions decreased in the rainy season and increased in the dry season. Since there is no evidence of a safe level of PM exposure, high concentrations of respirable particles in classroom can adversely affect human health, students' performance and productivity. The results obtained from this study suggest the need for effective management of indoor air quality in schools and there is an urgent need for routine air monitoring data on components of the PM mass. Availability of IAQ data are essential to enable epidemiological studies that can define the roles of PM chemical components in causing adverse human health implications in order to guide more targeted emission controls for the most hazardous components. The results obtained reveal important contributions towards understanding of airborne PM distribution patterns and the available data that can be used for making public health policies. However, more comprehensive studies are required with more regional attributions and continuous measurements to fully evaluate the air quality of most part of the Nigeria's Niger Delta region. In addition, it is necessary to take other gaseous pollutants into consideration to determine the general air quality in various school environment in Akwa Ibom State.

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