Seasonal Variation of $PH_{2.5}$ and PM_{10} Concentrations and Potential Human Health Risk in 5 Urban and 1 Rural Residential Communities of Rivers State

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Abstract: This study investigated the spatial and temporal variations and health risk associated with particulate matter (PM) (10μm and 2.5μm), total volatile organic compounds (TVOC), methanal (HCHO), relative humidity and temperature of six (6) communities (Mgbosimini, GRA Phase II, Rumueprikom, Ozuoba, Aluu and Isiokpo) of two (2) Local Government Areas in Rivers State during the months of November 2020 through April 2021. Air samples from the communities were measured for mass concentration for PM using a high-volume air sampler and weighing scale while a hand-held air quality device for TVOC, HCHO, relative humidity and temperature during the sampling period. Three (3) locations each in the sampling area where analysed and the average computed as the average for the month. Results obtained showed significant difference within the period of sampling (temporal) and across the communities (spatial) for PM, TVOC and HCHO. Also, the results showed a decrease in concentration for PM but an increase for TVCO and HCHO over the period of sampling except for Aluu that had a decrease in TVOC. Health risk assessment for adults revealed that except for Mgbosimini in November 2020, all other stations in November/December 2020 and January 2021 had health index greater than one (HI > 1) indicating risk to adults due to inhalation of $PM_{2.5}$ in the air. In the months of February, March and April 2021, Rumueprikom, Aluu and Isiokpo had HI >1, indicating health risk at these locations while Mgbosimini and GRA Phase II had HI <1 indicating no risk. Thus, the quality of air is not necessarily determined by urban-rural distribution but on the specific activities that may contribute to the quality of air and if the activities are persistent or consistent irrespective of the month, then there would be no significant reduction in air pollution.

Keywords: Particulate Matter, Spatial, Temporal, Health Risk, Rivers State

1. Introduction

1.1. Background

The increase in industrial and vehicular activities in major cities of Nigeria leading to the release of particulate into the atmosphere is a cause for serious concern for the health of its citizens. The composition of gases in the atmosphere is 78% of nitrogen (N_2) and 21% of oxygen (O_2), with some trace gases such as: argon (Ar) – 0.93%; carbon dioxide (CO_2) – 0.03%; neon (Ne) – 0.0018%; helium (He) – 0.0005%; methane (CH_4) – 0.04% and krypton (Kr) – 0.0001% [1]. These gaseous components in the atmosphere support the balance in existence between the abiotic and biotic components of the environment. V. Smil [2] defines air pollution as a matter of concentration rather than a mere presence in the atmosphere of particular elements or compounds. Therefore, for an element released in the environment to rise to the level of being considered a pollutant, the concentration at which it is released must cause environmental alteration. Therefore, air pollution is the release of gases into the atmosphere which will cause an imbalance in the natural air composition resulting in harm to the biotic or (and) abiotic components of the environment. Any substance released in the air which will, due to its concentration, cause harm to health, animals, properties of plants is termed a pollutant.

Due to anthropogenic activities in Nigeria, the most

common air pollutants released into the atmosphere are carbon monoxide, nitrogen dioxides, hydrocarbons, sulphur dioxide and solid particles such as dust and soot [3]. When some of these pollutants get into the food chain they could lead to the contamination of fish, fowl and other livestocks. The dissolution of some of these gases in the water could also lead to acidification of surface water bodies and hence increase the toxicity of metals such as lead, mercury, aluminium, cadmium and copper [4-6].

In this study, particulate matter (PM) is the air pollutant of focus due to its ability to be inhaled by residents of the city and cause detrimental health effects. Particulates are released into the air during the combustion of fossil fuels and biomass, both of these are done in the City of Port Harcourt; during the process, soot, ash and dust is ejected into the atmosphere [7]. PM pollution consists of solid particles and liquid droplets in air and may include mixtures of organics, acids, metals, minerals and elemental carbon. PM in the atmosphere, through chemical reactions, can be formed naturally from gases or are emitted through anthropogenic sources. Anthropogenic emission sources may include vehicle emissions, forest fires and industrial, domestic, and agricultural pollutants [8]. Windblown soil dust, marine and biogenic aerosols, road traffic and off-road vehicles, stationary combustion processes, industrial and construction processes, and combustion of agricultural waste are some natural and anthropogenic emission sources of PM. PM with diameter <10 mm (PM_{10}) or <2.5 m ($PM_{2.5}$) are particularly of public health concern; nano particulates are considered the most hazardous [9]. PM_{10} are inhaled by human beings and this may lead to serious health effects; $PM_{2.5}$ are usually referred to as fine particulates [10]. Fine particles are particularly of concern because they remain suspended in the air for longer periods of time because of their smaller diameters [11].

PM can be viewed either as: primary PM (those emitted directly into the atmosphere by the sources such as industry, electric power plants, diesel buses and automobiles) and secondary PM (those formed as a by-product of the primary PM such as sulphur dioxide and nitrogen oxide gases) [12]. Biomass burning leads to the release of black carbon (soot) particles into the atmosphere. These particles are made up of carbon, oxygen and hydrogen bound into layered, hexagonal structure similar to graphite [13]. Black carbon is particularly dangerous because it is a major constituent of $PM_{2.5}$ [14], hence it has the ability to linger in the atmosphere for a longer period of time and cause serious human health damage. Soot is a product of vaporized organic matter, usually polycyclic aromatic hydrocarbons. Formation of soot involves two steps: the production of benzene and acetylene and their transformation into phenyl [15]. According to CCAC [13], in the year 2015, household sources made up 58% of global emission of carbon black to the atmosphere, followed by transportation (24%). In Africa, Asia and the Pacific regions, biomass cookstoves, biomass heating stoves, coal stoves and other residential combustion including kerosene lamps contributed over 50% of black carbon to the atmosphere [13].

Exposure to acute concentrations of PM in the atmosphere leads to airway irritation and small reduction in lung volume [16]. Lung epithelial cells and alveolar macrophages have been affected by pro-inflammation; exposure to particulate pollution has been seen to cause localized (in lungs) and distant inflammatory responses [17, 18]. In addition to cardiovascular respiratory and respiratory diseases associated with chronic and acute exposure to PM [19], other health issues have also been document. K. Newell et al. [20] reviewed household air pollution and associated health effect in low- and middle-income countries. The study documented a link between PM exposure with alterations in both localized and systemic, immunologic and inflammatory responses. Exposure to smoke from wood burning has also been linked to epithelial inflammation with compromises in the integrity of epithelial barrier leading to increased risk of bacterial invasion; the release of the antioxidant Glutathione has also been associated with exposure to wood smoke [21]. The exposure of rats' eye lens to biomass smoke containing metal ions has revealed an association with protein aggregation and oxidative changes resulting in cataract [20]. WHO attributes and estimated 400- 610 death/million to indoor smoke from solid fuels in Sub-Saharan Africa [22].

I. F. Offor et al. [3] performed a review of particulate matter and elemental composition of aerosols at selected locations in Nigeria from 1985–2015. Results of the study revealed that $PM_{2.5}$ concentration ranged from 5–248 $\mu g/m^3$, while PM_{10} concentration ranged from 18–926 $\mu g/m^3$, revealing that about 50% of the particulate matter loads in Nigeria exceeded both the WHO (25 $\mu g/m^3$, 50 $\mu g/m^3$) and NAAQS (35 $\mu g/m^3$, 150 $\mu g/m^3$) guideline limits for $PM_{2.5}$ and PM_{10} respectively. The results also revealed seasonal variation in PM concentration; higher concentrations were recorded during the dry season than during the rainy season. In rural areas, PM was lower compared to urban areas.

A study aimed at exploring the influence of meteorological parameters such as wind direction, wind speed, rainfall, air temperature and relative humidity on $PM_{2.5}$ and PM_{10} concentration was also carried out in Woji town, Port Harcourt City, Nigeria. This study involved the measurement of $PM_{2.5}$ and PM_{10} for 236 days with the use of photo laser-based PM monitor while meteorological parameters were collected using Misol weather station. Results of this study revealed that PM concentrations were below USEPA 24-hr standard for all months studied except December with $PM_{2.5}$ = 58.8 $\mu g/m^3$ and PM_{10} = 164.5 $\mu g/m^3$. Concentration of PM_{10} also had a weak negative but significant correlation with rainfall and air temperature. $PM_{2.5}$ concentration showed a weak negative but not significant correlation with relative humidity measured. However, PM_{10} centration exhibited weak but significant correlation with relative humidity [23].

In Ibadan Metropolis, Nigeria, sixteen grain milling shops were randomly selected from two major markets and monitored for PM_{10} and $PM_{2.5}$. The $PM_{2.5}$ concentrations for both market locations ranged between 1,269.3 and 651.7 $\mu g/m^3$, while PM_{10} concentrations were between 1,048.2 and 818.1 $\mu g/m^3$. These concentrations far exceeded the World Health Organization guideline limit of 50 $\mu g/m^3$ and 25 $\mu g/m^3$ for $PM_{2.5}$ and PM_{10} respectively [24].

The increasing population in Rivers State, in addition to the anthropogenic activities taking place, will affect the air quality. This will also lead to health risks for those resident, students and workers. It is, therefore, necessary to monitor the air quality in the universities where students from around the country come together to study. There has been less study carried out in the City of Port Harcourt assessing the levels of PM in the atmosphere and particularly indoors air pollution. Although the industrial activities, increased population and other anthropogenic activities taking place therein is a cause for human health concern, there is little encouragement to the scientific community, in terms of research funding, to carry out these studies.

Therefore, this study aims to investigate the concentration of PM$_{2.5}$ and PM$_{10}$ in five urban communities (Mgbuosimini, GRA Phase 2, Rumueprikom, Ozuoba, Aluu) and one rural community (Isiokpo) as control. This study will also assess the Air Quality Index (AQI) in these communities. Objectives of the study are to identify three (3) stations in the six (6) communities, to collect air quality data from these sample stations, to sample these stations for six (6) months to cover three months each of the wet and dry seasons and to compare the differences in air quality parameters along different communities and across different seasons.

1.2. Aim of the Study

i. This study aims to investigate the concentration of PM2.5 and PM10 in five urban communities (Mgbuosimini, GRA Phase 2, Rumueprikom, Ozuoba, Aluu) and one rural community (Isiokpo) as control.
ii. This study will also assess the Air Quality Index (AQI) in these communities.

2. Material and Method

2.1. Study Area

The study area is the city of Port Harcourt in Rivers State, Nigeria (Figure 1). The city has a tropical climate with significant rainfall most months of the year and short dry season. Port Harcourt has an average total annual rainfall of 119.6 mm with most rainfall recorded in June, July, August, September and October and the least rainfalls in November, December, January and February [25].
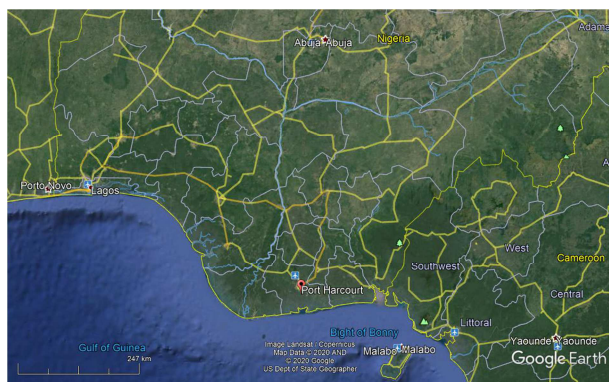
Figure 1. The city of Port Harcourt in Rivers State, Nigeria.

2.2. Sample Stations

Study locations, stations and coordinates are presented in Table 1 and figures 2–7 are the map of the locations of the sample stations.

Table 1. Study locations, stations and coordinate.

Location	Station	Coordinate
Mgbosimini	Station 1	4°48'47.03"N 6°58'15.80"E
	Station 2	4°48'29.46"N 6°58'22.51"E
	Station 3	4°48'22.88"N 6°58'27.11"E
GRA	Station 1	4°49'34.95"N 6°59'43.36"E
	Station 2	4°49'31.93"N 6°59'52.96"E
	Station 3	4°49'21.69"N 6°59'56.48"E
Rumueprikom	Station 1	4°49'45.80"N 6°58'35.15"E
	Station 2	4°49'49.90"N 6°58'54.98"E
	Station 3	4°50'1.94"N 6°59'10.66"E
Ozuoba	Station 1	4°52'14.89"N 6°55'45.24"E
	Station 2	4°52'5.87"N 6°55'37.46"E
	Station 3	4°51'54.92"N 6°55'36.89"E
Aluu	Station 1	4°56'1.77"N 6°56'37.44"E
	Station 2	4°56'1.16"N 6°56'52.26"E
	Station 3	4°56'2.88"N 6°57'1.00"E
Isiokpo	Station 1	4°58'42.56"N 6°52'45.49"E
	Station 2	4°58'0.50"N 6°52'42.11"E
	Station 3	4°57'12.62"N 6°52'48.07"E

Figure 2. The three stations of Mgbosimini.

Figure 3. The three stations of New GRA stations.

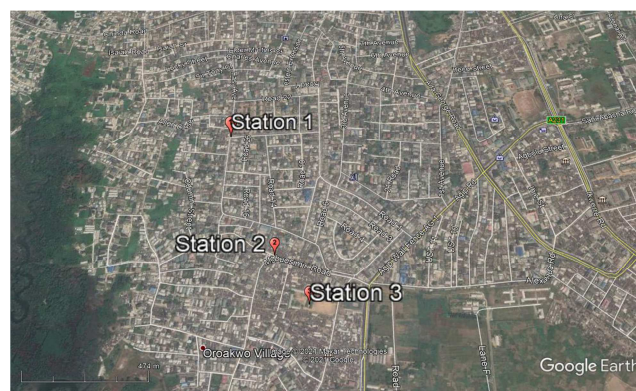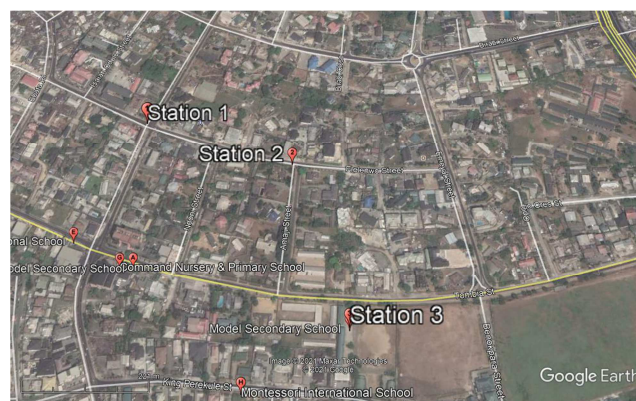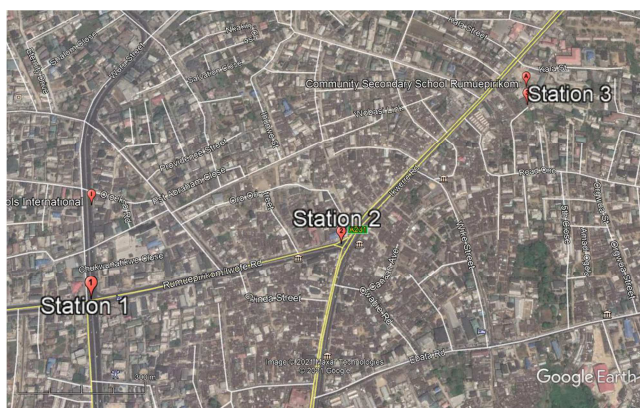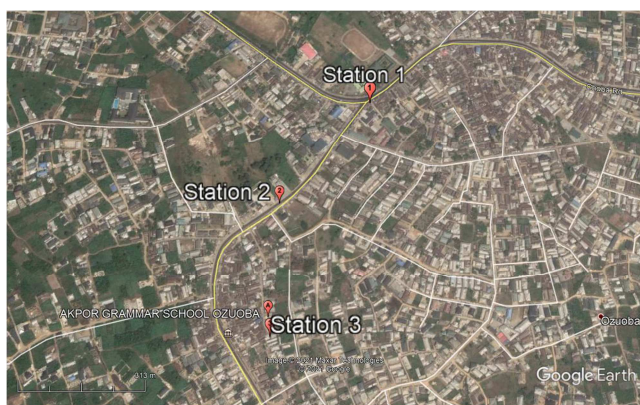*Figure 4. The three stations of Rumueprikom stations.*

Figure 5. The three stations of Ozuoba stations.

Figure 6. The three stations of Aluu stations.

Figure 7. The three stations of Isiokpo stations.

Details of equipment used are: model: HV-500RD, power supply: 100VAC, 10A, accuracy: +/- 5%, ambient temperature range: 0 - 40°C, maximum suction flow: 400L/min (when loading Φ110mm QR-100 1 sheet, 2 urethane forms), specification: Instantaneous flow rate, integrating flow is 25°C, automatically corrected to a value of 1atm. (20°C + 1 atm or you can also correct in the real flow rate) the temperature protection device is operated when the suction air temperature in the equipment becomes high and the blower motor is stopped, accessories.

TVOC, HCOH, temperature and percentage humidity were measured in-situ using a DI ZENE Air Quality Detector, Model: DZ8600. TVOC, HCHO, temperature and humidity measurement solution uses laser scattering particle acceleration, faster and more accurate 3D convection air holes.

2.3. Data Analysis

To test for statistically significant difference between PM concentration, Analysis of Variance (ANOVA) was employed using SigmaPlot for Windows [26].

To compare data from all stations, principal component analysis plot (PCA) and hierarchical clustering analysis using Euclidean distance were used to show similarity in data with PAST Statistics (PAST 4.06) [27].

2.4. Human Health Risk Assessment

Human health risk assessment was performed to examine to potential human health risk due to exposure to PM in the air.

Exposure assessment was done based on the lifetime average daily dose (LADD) and was calculated with the following equation:

$$LADD = \frac{(C \times IR \times ED \times EF)}{(BW \times AT)} \qquad (1)$$

where:

LADD = exposure dose (mg/kg/day).

C = contaminant concentration (mg/m^3).

IR = intake rate (m^3)/day) 10m^3/day for a child 6–8 years old, 15.2m^3/day male, 19–65 years old.

EF = exposure factor (250 days/year).

BW = body weight (kg) adult = 70 kg, child 1–6 years = 16 kg.

ED = exposure duration (25 years).

AT = averaging time (non- carcinogenic exposure: ED x 365 days/year) [28-30].

Risk characterisation was determined using the following equation.

Non- carcinogenic risk (Hazard Index: HI) = LAAD/ RfC.

The inhalation Reference Concentration (RfC) used was the RfC of diesel engine exhaust (5 µg/m^3) [31].

When HI < 1, it indicates a condition of no risk, however, when HI ≥ 1, it indicates risk.

2.5. Hypothesis

There is a statistically significant difference in air quality parameters between urban and rural communities.

2.6. Null Hypothesis

There is NO statistically significant difference in air quality parameters between urban and rural communities.

3. Results and Discussion

3.1. Spatial Variation of Air Quality Parameters

3.1.1. Particulate Matter

(i). PM$_{2.5}$ Concentration

Range of $PM_{2.5}$ concentration in the locations were as follows: Mgbosimini: $20 - 44$ µg/m^3, GRA: $18 - 51$ µg/m^3, Rumueprikom: $17 - 98$ µg/m^3, Ozuoba: $15 - 144$ µg/m^3, Aluu: $24 - 63$ µg/m^3, Isiokpo: $64 - 69$ µg/m^3. The highest mean concentration of PM2.5 concentration in the six locations were 32.28 ± 7.14 µg/m^3, 33.00 ± 7.54 µg/m^3, 40.94 ± 16.35 µg/m^3, 43.83 ± 26.75 µg/m^3, 44.78 ± 12.23 µg/m^3, 67.00 ± 1.61 µg/m^3 at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo respectively. Geometric means were 31.50 µg/m^3,

32.16 µg/m^3, 38.59 µg/m^3, 39.40 µg/m^3, 43.01 µg/m^3 and 66.98 µg/m^3 while coefficients of variance were 22.13, 22.84, 39.93, 61.03, 27.31 and 2.40 at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo respectively (Table 2). ANOVA revealed statistically significant difference at each station and among all stations (p <0.05) *(Table 2)*.

(ii). Concentration of PM$_{10}$

Mean concentration of PM_{10} across all communities were as follows: 34.83 ± 1.83 µg/m^3, 36.50 ± 1.80 µg/m^3, 44.11 ± 2.38 µg/m^3, 45.06 ± 4.60 µg/m^3, 51.11 ± 3.85 µg/m^3, 78.72 ± 0.69 µg/m^3 at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo respectively. Medians were 32 µg/m^3, 37 µg/m^3, 43 µg/m^3, 36 µg/m^3, 60 µg/m^3 and 78 µg/m^3 and variance were 60.26, 58.03, 101.99, 380.88, 267.16 and 8.57 at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo respectively. ANOVA for PM_{10} at each station revealed statistically significant difference (p < 0.05), ANOVA also revealed statistically significant difference when all stations were compared (p < 0.05) (Table 3).

Table 2. Statistical summary of PM$_{2.5}$ concentrations at all stations.

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
N	18	18	18	18	18	18	
Min	20	18	17	15	24	64	
Max	44	51	98	144	63	69	
Sum	581	594	737	789	806	1206	
Mean	32.28	33.00	40.94	43.83	44.78	67.00	
Std. error	1.68	1.78	3.85	6.31	2.88	0.38	
Variance	51.04	56.82	267.23	715.56	149.59	2.59	
Stand. dev	7.14	7.54	16.35	26.75	12.23	1.61	<0.05
Median	31	35	39	38.5	51	67	
25 prcntil	27.75	27.75	34.25	32	33.5	66	
75 prcntil	40	36.25	44.5	45.75	54	68.25	
Skewness	-0.02	0.26	2.52	3.35	-0.39	-0.48	
Kurtosis	-0.80	1.14	9.32	13.02	-1.29	-0.51	
Geom. mean	31.50	32.16	38.59	39.40	43.01	66.98	
Coeff. var	22.13	22.84	39.93	61.03	27.31	2.40	
p- value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

Table 3. Statistical summary of PM$_{10}$ concentrations at all stations.

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
N	18	18	18	18	18	18	
Min	27	23	30	29	30	76	
Max	55	48	59	111	70	89	
Sum	627	657	794	811	920	1417	
Mean	34.83	36.50	44.11	45.06	51.11	78.72	
Std. error	1.83	1.80	2.38	4.60	3.85	0.69	
Variance	60.26	58.03	101.99	380.88	267.16	8.57	
Stand. dev	7.76	7.62	10.10	19.52	16.35	2.93	<0.05
Median	32	37	43	36	60	78	
25 prcntil	30	31	3.70E+01	3.50E+01	3.50E+01	7.75E+01	
75 prcntil	37.75	42.25	52.75	52	65.75	79	
Skewness	1.49	-0.25	0.08	2.57	-0.20	2.68	
Kurtosis	1.65	-0.86	-1.16	7.70	-2.00	9.42	
Geom. mean	34.13	35.70	42.99	42.35	48.45	78.67	
Coeff. var	22.29	20.87	22.89	43.32	31.98	3.72	
p- value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

About 43% of the world's population relies on solid fuels for heating and cooking [32]. Use of improved biomass cookstoves (ICS) has the potential to reduce household air pollution (HAP). As part of an evaluation to

identify ICS for use in Kenya, a study carried out by F. Yip *et al.* [33] collected indoor air and personal air samples to assess differences between traditional cookstoves (TCS) and ICS. They conducted a cross-over

study in 2012 in two Kenyan villages; up to six different ICS were installed in 45 households during six two-weeks periods. Forty-eight-hour kitchen measurements of fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) were collected for the TCS and ICS. Concurrent personal CO measurements were conducted on a mother and one child in each household. They performed descriptive analysis and compared paired measurements between baseline (TCS only) and each ICS. Results from their study revealed that the geometric mean of 48-hour baseline $PM_{2.5}$ and CO concentrations in the kitchen was 586 µg/m^3 (95% CI: 460, 747) and 4.9 ppm (95% CI: 4.3, 5.5), respectively. For each ICS, the geometric mean kitchen air pollutant concentration was lower than the TCS: median reductions were 38.8% (95% CI: 29.5, 45.2) for $PM_{2.5}$ and 27.1% (95% CI: 17.4, 40.3) for CO, with statistically significant relationships for four ICS. A reduction in personal exposures to CO with ICS use was observed. They observed a reduction in mean 48-hour $PM_{2.5}$ and CO concentrations compared to the TCS; however, concentrations for both pollutants were still consistently higher than WHO air quality guidelines.

Many studies probing the link between air quality and health have pointed towards associations between particulate matter (PM) exposure and decreased lung function, aggravation of respiratory diseases like asthma, premature death and increased hospitalization admissions for the elderly and individuals with cardiopulmonary diseases. Of recent, it is believed that the chemical composition and physical properties of PM may contribute significantly to these adverse health effects. As part of a Belgian Science Policy project ("Health effects of particulate matter in relation to physical-chemical characteristics and meteorology"), the chemical composition (elemental and ionic compositions) and physical properties (PM mass concentrations) of PM were investigated, indoors and outdoors of old age homes in Antwerp, Belgium. The case reported here specifically relates to high versus normal/low pollution event periods. PM mass concentrations for PM_1 and $PM_{2.5}$ fractions were determined gravimetrically after collection via impaction. These same samples were hence analyzed by EDXRF spectrometry and IC for their elemental and ionic compositions, respectively. During high pollution event days, PM mass concentrations inside the old age home reached 53µgm^{-3} and 32µgm^{-3} whilst outside concentrations were 101µgm^{-3} and 46µgm^{-3} for $PM_{2.5}$ and PM_1, respectively. The sum of total sulphate, nitrate and ammonium, dominates the composition of PM, and contribute the most towards an increase in the PM during

the episode days constituting 64% of ambient $PM_{2.5}$ (52µgm^{-3}) compared to 39% on non-episode days (10µgm^{-3}). Other PM components, such as mineral dust, sea salt or heavy metals were found to be considerably higher during PM episodes but relatively less important. Amongst heavy metals, Zn and Pb were found at the highest concentrations in both $PM_{2.5}$ and PM_1. Acid-base ionic balance equations were calculated and point to acidic aerosols during event days and acidic to alkaline aerosols during non-event days. No significant sources of indoor pollutants could be identified inside the old-age home as high correlations were found between outdoor and indoor PM, confirming mainly the outdoor origin of indoor air [34].

Emissions of fine particulate matter ($PM_{2.5}$) from on-road traffic and their influence on air quality and human health are of major concern in urban areas. Exposure to traffic-related $PM_{2.5}$ indoors has received considerable attention as people spend about 80% of their time in indoor environments, but little information is currently available on the assessment and mitigation of this exposure. A systematic field study was conducted with the key objective to assess and mitigate indoor human exposure to traffic-related $PM_{2.5}$ in a typical naturally ventilated residential apartment. Results indicated that traffic-related $PM_{2.5}$ levels indoors exceeded the air quality guidelines (12 µg/m^3), and the $PM_{2.5}$ levels decreased significantly (74%) while using an indoor air cleaner. The human health risk assessment based on the bio-available fraction of toxic trace elements revealed a substantial reduction in potential health risk while using the air cleaner. Overall, the major outcomes of this study would help develop effective air pollution control strategies to reduce indoor human exposure to $PM_{2.5}$ and potential human health risk caused by vehicular pollution in urban areas in Singapore [35].

3.1.2. Spatial Variation of TVOC

TVOC was highest at Isiokpo (1.79 ± 1.66 mg/m^3), followed by Aluu (1.56 ± 1.28 mg/m^3), Rumueprikom (0.39 ± 0.56 mg/m^3), Ozuoba (0.33 ± 0.22 mg/m^3) and Mgbosimini (0.33 ± 0.35 mg/m^3) and the least concentration was measured at GRA (0.16 ± 0.13 mg/m^3). Median of TVOC at each community was 0.24 mg/m^3, 0.11 mg/m^3, 0.26 mg/m^3, 0.31 mg/m^3, 1.53 mg/m^3, 1.68 mg/m^3 at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo respectively. Geometric mean at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo were 0.094 mg/m^3, 0.055 mg/m^3, 0.082 mg/m^3, 0.111 mg/m^3, 0.301 mg/m^3 and 0.296 mg/m^3 respectively (Table 4).

***Table 4.** Statistical summary of TVOC across all stations.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
N	18	18	18	18	18	18	
Min	0.07	0.03	0.03	0.04	0.12	0.12	
Max	1.53	0.61	2.32	0.87	3.91	4.58	<0.05
Sum	5.88	2.79	6.97	5.86	28.12	32.22	
Mean	0.33	0.16	0.39	0.33	1.56	1.79	

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
Std. error	0.08	0.03	0.13	0.05	0.30	0.39	
Variance	0.12	0.02	0.31	0.05	1.63	2.74	
Stand. dev	0.35	0.13	0.56	0.22	1.28	1.66	
Median	0.24	0.11	0.26	0.31	1.53	1.68	
25 prcntil	0.15	0.07	0.07	0.13	0.26	0.22	
75 prcntil	0.32	0.21	0.34	0.47	2.14	3.13	
Skewness	2.94	2.57	2.79	0.94	0.65	0.19	
Kurtosis	9.38	8.44	8.56	0.79	-0.51	-1.83	
Geom. mean	0.24	0.12	0.19	0.25	0.95	0.83	
Coeff. var	105.59	84.53	144.42	66.61	81.75	92.46	
p- value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

3.1.3. Spatial Variation of HCHO

The highest concentration of formaldehyde was measured at Isiokpo (0.703 0.703 mg/m^3). Median and standard error at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo were median - 0.118 mg/m^3, 0.064 mg/m^3, 0.094 mg/m^3, 0.117 mg/m^3, 0.325 mg/m^3 and 0.297 mg/m^3, and standard error - 0.018, 0.009, 0.016, 0.020, 0.159 and 0.260 respectively. The statistical skewness at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo was 0.601, 1.141, 1.374, 1.076, 3.147 and 1.938 respectively, while the statistical kurtosis was -0.378, 1.788, 2.952, 1.124, 10.356 and 2.121 respectively (Table 5).

Table 5. *Statistical summary of formaldehyde (HCHO) concentration.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
N	18	18	18	18	18	18	
Min	0.005	0.008	0.02	0.024	0.068	0.049	
Max	0.268	0.173	0.293	0.352	2.885	3.345	
Sum	2.197	1.209	1.823	2.433	8.684	12.656	
Mean	0.122	0.067	0.101	0.135	0.482	0.703	
Std. error	0.018	0.009	0.016	0.020	0.159	0.260	
Variance	0.006	0.002	0.004	0.007	0.455	1.220	
Stand. dev	0.074	0.040	0.066	0.084	0.674	1.104	<0.05
Median	0.118	0.064	0.094	0.117	0.325	0.297	
25 prcntil	0.062	0.042	0.046	0.062	0.164	0.098	
75 prcntil	0.180	0.086	0.136	0.186	0.396	0.371	
Skewness	0.601	1.141	1.374	1.076	3.147	1.938	
Kurtosis	-0.378	1.788	2.952	1.124	10.356	2.121	
Geom. mean	0.094	0.055	0.082	0.111	0.301	0.296	
Coeff. var	60.835	59.833	65.375	62.307	139.755	157.073	
p- value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

3.1.4. Spatial Variation of Temperature and Relative Humidity

ANOVA of temperature across all stations revealed that there is no statistically significant difference (p > 0.05), however, temperature varied from sampling time to sampling time at each station significantly (p < 0.05). Minimum temperatures recorded at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo were 24°C, 24°C, 24°C, 25°C, 23°C and 23°C respectively, and maximum temperatures were 33°C, 35°C, 35°C, 36°C, 33°C and 33°C respectively. Variance at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo were 8.30, 9.24, 10.71, 8.96, 6.49 and 9.95 respectively, and median temperatures ranged from 31°C – 32°C (Table 6).

Table 6. *Statistical summary of atmospheric temperature across all communities.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
N	18	18	18	18	18	18	
Min	24	24	24	25	23	23	
Max	33	35	35	36	33	33	
Sum	536	544	552	569	547	536	
Mean	29.78	30.22	30.67	31.61	30.39	29.78	
Std. error	0.68	0.72	0.77	0.71	0.60	0.74	
Variance	8.30	9.24	10.71	8.96	6.49	9.95	> 0.05
Stand. dev	2.88	3.04	3.27	2.99	2.55	3.15	
Median	31	31	31.5	32	31	31	
25 prcntil	28	29	28.75	31.75	30	28	
75 prcntil	32	32.25	33	33	32	32	
Skewness	-1.11	-0.80	-1.00	-1.22	-1.93	-1.24	
Kurtosis	0.08	0.04	0.13	1.03	3.50	0.36	

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
Geom. mean	29.64	30.07	30.49	31.47	30.28	29.61	
Coeff. var	9.68	10.06	10.67	9.47	8.38	10.59	
p- value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

Percentage humidity ranged from 48 – 62%, 44 – 60%, 44 – 60%, 42 – 61%, 47 – 58% and 47 – 57% at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo respectively. Variances of percentage humidity at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo communities were 16.54, 28.61, 32.84, 34.62, 13.63 and 13.91 respectively. Highest percentage humidity was measured Mgbosimini – 55.78%, followed by Isiokpo – 55.17%. The lowest percentage humidity was measured at Ozuoba – 49.83%, the second lowest was measured at Rumueprikom – 50.61% (Table 7).

Table 7. Statistical summary of percentage humidity at each community.

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo	p-value
N	18	18	18	18	18	18	
Min	48	44	44	42	47	47	
Max	62	60	60	61	58	59	
Sum	1004	926	911	897	970	993	
Mean	55.78	51.44	50.61	49.83	53.89	55.17	
Std. error	0.96	1.26	1.35	1.39	0.87	0.88	
Variance	16.54	28.61	32.84	34.62	13.63	13.91	
Stand. dev	4.07	5.35	5.73	5.88	3.69	3.73	> 0.05
Median	55.5	51	48.5	48.5	55.5	56.5	
25 prcntil	52	46.75	45.75	45	51	53.75	
75 prcntil	59.25	57	57.25	54.25	57	58	
Skewness	-0.19	0.16	0.51	0.56	-0.66	-1.20	
Kurtosis	-1.04	-1.53	-1.44	-0.68	-0.91	0.41	
Geom. mean	55.64	51.18	50.31	49.51	53.77	55.04	
Coeff. var	7.29	10.40	11.32	11.81	6.85	6.76	
p- value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	

WHO guideline stipulates that $PM_{2.5}$ not exceed 10 µg/m^3 annual mean, or 25 µg/m^3 24-hour mean; and that PM_{10} not exceed 20 µg/m^3 annual mean, or 50 µg/m^3 24-hour mean [36]. In the present study, all stations had mean $PM_{2.5}$ concentrations that exceeded the annual mean and 24-hour mean. Although mean concentrations of PM_{10} exceeded the WHO 24-hour mean, only the mean concentrations at Aluu and Isiokpo exceeded WHO annual mean.

$PM_{2.5}$ and PM_{10} showed similar trend in concentration. Results showed a pattern of increasing particulate matter ($PM_{2.5}$ and PM_{10}) concentration moving from the more densely populated areas (Mgbosimini, GRA, Rumueprikom, Ozuoba) to the less populated area; this is contrary to expectations. The spatial trend observed is also contrary to those observed by X. Zhao *et al.* [37] who observed that population density and secondary industry held the keys to $PM_{2.5}$ pollution control. It was observed in a study carried out by X. Zhao *et al.* [37] that vegetation reduces particulate matter concentration in the air. This was contrary to results obtained in the present study; Aluu and Isiokpo had more surrounding vegetation but had higher concentrations of PM in the atmosphere. However, another study carried out by C. Lin *et al.* [38] to assess the difference in PM variations between urban and rural areas over eastern China from 2001 to 2015 showed that PM concentrations were higher in rural areas compared to the urban area. This study showed result with trends similar to those obtained in the present study.

C. A. Ku [39] carried out a study which revealed that land use has a significant effect on particulate concentration in the atmosphere. This was also observed in an earlier study carried out by S. Superczynski and S. Christopher [40]. This could account for the variation observed moving from the urban areas into the rural area. The rural settlements are usually predominantly farming settlements; these processes may involve burning of woods and forest wastes. A. N. Dibofori-Orji and O. S. Edori [41] also revealed that burning contributes to PM in the atmosphere, this, therefore, could explain the results obtained in the present study. Paved roads also help to reduce suspended particle released from the loose soil; there are more paved roads in the urban roads compared to the rural area and this could also account for the higher PM in the urban areas when compared to the rural areas. This is supported by a study carried out by G. Kalaiarasan *et al.* [42].

TVOC level less than 0.3 mg/m^3 is considered to be a low level of concern, when concentration is between 0.3 – 0.5 mg/m^3 it is acceptable. A range concentration of 0.5 – 1 mg/m^3 is considered marginal while a range concentration of 1 – 3 mg/m^3 is considered as high [43]. In the present study, Mgbosimini, GRA, Rumueprikom and Ozuoba had TVOC levels which fell within the marginal range, while Aluu and Isiokpo can be considered high.

Mean TVOC measured at all stations in the present study was lower than those measured outdoor of retail stores in the Greater Memphis Area, Tennessee, U.S.A., in summer 2019 [44]. Outdoor VOC sources may include: gasoline, diesel emissions, wood burning, oil and gas extraction and processing and industrial emissions [45].

Although HCHO is a VOC, it is particularly important

because it is a carcinogen; formaldehyde (HCHO) is the most important carcinogen in outdoor air among the 187 hazardous air pollutants (HAPs) identified by the U.S. Environmental Protection Agency (EPA), not including ozone and particulate matter [46]. Hence, due to possible burning from farm activities at Aluu and Isiokpo, higher concentrations of HCHO may be to related to burning when compared to the urban areas.

3.2. Temporal variation of Air Quality Parameters

3.2.1. Particulate Matter

Across all communities, $PM_{2.5}$ concentration was higher than in the dry season when compared to the wet season. Geometric mean of $PM_{2.5}$ concentrations at Mgbosimini,

GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo in the dry season were 37.24 µg/m³, 36.48 µg/m³, 41.23 µg/m³, 49.12 µg/m³, 49.83 µg/m³ and 68.22 µg/m³ respectively, and 26.64 µg/m³, 28.34 µg/m³, 36.12 µg/m³, 31.61 µg/m³, 37.13 µg/m³ and 65.77 µg/m³ respectively in the wet season (Table 8).

PM_{10} concentrations were alsohigher in the dry season (mean ± standard deviation: Mgbosimini – 39.0 ± 9.18, GRA – 40.78 ± 7.48, Rumueprikom – 48.67 ± 8.25, Ozuoba – 53.22 ± 24.61, Aluu – 56.89 ± 15.07 and Isiokpo – 80.00 ± 3.64) when compared to the wet season (mean ± standard deviation: Mgbosimini – 30.67 ± 2.18, GRA – 32.22 ± 5.12, Rumueprikom – 39.56 ± 10.09, Ozuoba – 36.89 ± 7.35, Aluu – 45.33 ± 16.29 and Isiokpo – 77.44 ± 1.13) (Table 9).

***Table 8.** Statistical summary of seasonsonal variation for $PM_{2.5}$ concentrations.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Dry season						
N	9	9	9	9	9	9
Min	29	35	36	32	40	67
Max	44	43	50	144	55	69
Sum	338	329	373	492	451	614
Mean	37.56	36.56	41.44	54.67	50.11	68.22
Std. error	1.68	0.85	1.51	11.41	1.79	0.28
Variance	25.53	6.53	20.53	1170.75	28.86	0.69
Stand. dev	5.05	2.55	4.53	34.22	5.37	0.83
Median	40	36	40	44	52	68
25 prcntil	32.5	35	38	38.5	46.5	67.5
75 prcntil	41	37	45	53	54	69
Skewness	-0.61	2.43	0.95	2.76	-1.37	-0.50
Kurtosis	-0.89	6.42	0.19	7.96	0.52	-1.28
Geom. mean	37.24	36.48	41.23	49.12	49.83	68.22
Coeff. var	13.45	6.99	10.93	62.59	10.72	1.22
Wet season						
N	9	9	9	9	9	9
Min	20	18	17	15	24	64
Max	34	51	98	48	63	67
Sum	243	265	364	297	355	592
Mean	27.00	29.44	40.44	33.00	39.44	65.78
Std. error	1.50	3.09	7.79	3.09	5.00	0.40
Variance	20.25	85.78	546.78	85.75	225.03	1.44
Stand. dev	4.50	9.26	23.38	9.26	15.00	1.20
Median	28	28	35	32	35	66
25 prcntil	23.5	24	27	28.5	28	64.5
75 prcntil	29.5	32.5	45	38.5	56.5	67
Skewness	-0.54	1.66	2.17	-0.53	0.74	-0.57
Kurtosis	0.20	4.00	5.60	1.32	-1.37	-1.10
Geom. mean	26.64	28.34	36.12	31.61	37.13	65.77
Coeff. var	16.67	31.45	57.82	28.06	38.03	1.83

***Table 9.** Statistical summary of seasonsonal variation for PM_{10} concentrations.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Dry season						
N	9	9	9	9	9	9
Min	27	23	39	34	30	76
Max	55	48	59	111	70	89
Sum	351	367	438	479	512	720
Mean	39.00	40.78	48.67	53.22	56.89	80.00
Std. error	3.06	2.49	2.75	8.20	5.02	1.21
Variance	84.25	55.94	68.25	605.44	227.11	13.25
Stand. dev	9.18	7.48	8.26	24.61	15.07	3.64
Median	37	42	48	45	62	79
25 prcntil	31.5	38.5	40	35	45.5	78.5
75 prcntil	47	46	58	61.5	66.5	80.5
Skewness	0.53	-1.91	0.12	1.92	-1.41	2.18

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Kurtosis	-0.58	4.39	-1.83	3.91	0.42	5.86
Geom. mean	38.07	40.00	48.04	49.42	54.59	79.93
Coeff. var	23.54	18.34	16.98	46.23	26.49	4.55
Wet season						
N	9	9	9	9	9	9
Min	27	23	30	29	30	76
Max	35	42	58	52	69	79
Sum	276	290	356	332	408	697
Mean	30.67	32.22	39.56	36.89	45.33	77.44
Std. error	0.73	1.71	3.36	2.45	5.43	0.38
Variance	4.75	26.19	101.78	53.86	265.50	1.28
Stand. dev	2.18	5.12	10.09	7.34	16.29	1.13
Median	30	31	39	35	37	78
25 prcntil	30	31	30.5	32	34	76
75 prcntil	32	34.5	48	40.5	65.5	78
Skewness	0.55	0.30	0.70	1.21	0.83	-0.49
Kurtosis	1.85	2.03	-0.61	1.36	-1.47	-1.39
Geom. mean	30.60	31.86	38.48	36.30	43.00	77.44
Coeff. var	7.11	15.88	25.50	19.89	35.94	1.46

3.2.2. Temporal Variation TVOC

Concentration of total volatile organic carbons measured at Mgbosimini, GRA, Rumueprikom and Ozuoba were higher in the wet season (mean standard deviation: 0.46 ± 0.44 mg/m^3, 0.23 ± 0.15 mg/m^3, 0.67 ± 0.69 mg/m^3, 0.46 ± 0.21 mg/m^3 respectively) compared to dry season (mean standard deviation: 0.19 ± 0.12 mg/m^3, 0.08 ± 0.04 mg/m^3, 0.11 ± 0.10 mg/m^3, 0.19 ± 0.12 mg/m^3 respectively). However, Ozuoba and Aluu showed a reverse in trend, i.e., TVOC concentrations were higher in the dry season (Ozuoba $- 1.82 \pm 0.81$ mg/m^3, Aluu $- 3.35 \pm 0.56$ mg/m^3) and lower in the wet season (Ozuoba $- 1.30 \pm 1.63$ mg/m^3, Aluu $- 0.23 \pm 0.09$ mg/m^3) (Table 10).

Table 10. Statistical summary of seasonsonal variation for TVOC concentrations.

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Dry season						
N	9	9	9	9	9	9
Min	0.069	0.032	0.033	0.04	0.629	2.984
Max	0.455	0.155	0.341	0.402	3.607	4.584
Sum	1.733	0.741	0.975	1.706	16.401	30.185
Mean	0.19	0.08	0.11	0.19	1.82	3.35
Std. error	0.04	0.01	0.03	0.04	0.27	0.19
Variance	0.01	0.00	0.01	0.01	0.65	0.31
Stand. dev	0.12	0.04	0.10	0.12	0.81	0.56
Median	0.155	0.074	0.084	0.142	1.825	3.112
25 prcntil	0.112	0.0525	0.036	0.109	1.3275	2.9905
75 prcntil	0.2555	0.111	0.1535	0.3085	2.014	3.667
Skewness	1.52	0.87	1.77	0.72	1.15	1.74
Kurtosis	2.06	0.20	2.79	-0.76	3.21	2.37
Geom. mean	0.17	0.07	0.08	0.15	1.67	3.32
Coeff. var	62.81	47.59	95.40	63.96	44.26	16.59
Wet season						
N	9	9	9	9	9	9
Min	0.228	0.093	0.255	0.22	0.118	0.115
Max	1.534	0.607	2.315	0.871	3.914	0.369
Sum	4.149	2.05	5.991	4.153	11.719	2.036
Mean	0.46	0.23	0.67	0.46	1.30	0.23
Std. error	0.15	0.05	0.23	0.07	0.54	0.03
Variance	0.20	0.02	0.48	0.04	2.66	0.01
Stand. dev	0.44	0.15	0.69	0.21	1.63	0.09
Median	0.255	0.209	0.301	0.461	0.271	0.223
25 prcntil	0.237	0.13	0.263	0.2845	0.1665	0.152
75 prcntil	0.5785	0.2245	0.994	0.601	3.1095	0.3005
Skewness	2.22	2.27	2.05	0.76	1.09	0.62
Kurtosis	4.71	6.17	4.28	0.50	-0.72	-0.30
Geom. mean	0.35	0.20	0.47	0.42	0.54	0.21
Coeff. var	96.48	66.69	103.90	45.26	125.33	40.63

3.2.3. Temporal Variation HCHO

Formaldehyde in the atmosphere was higher in the rainy season compared to the dry season. Geometric mean at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo in the dry season were 0.06 mg/m^3, 0.05 mg/m^3, 0.05 mg/m^3, 0.07 mg/m^3, 0.34 mg/m^3 and 0.32 mg/m^3 respectively, while in wet season HCHO concentrations were 0.158 mg/m^3, 0.061 mg/m^3, 0.140 mg/m^3, 0.173 mg/m^3, 0.263 mg/m^3 and 0.275 mg/m^3 respectively (Table 11).

Table 11. *Statistical summary of seasonsonal variation for formaldehyde (HCHO)(mg/m^3) concentrations.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Dry season						
N	9	9	9	9	9	9
Min	0.005	0.019	0.02	0.024	0.288	0.288
Max	0.123	0.134	0.096	0.143	0.471	0.385
Sum	0.647	0.519	0.487	0.737	3.137	2.885
Mean	0.07	0.06	0.05	0.08	0.35	0.32
Std. error	0.01	0.01	0.01	0.01	0.02	0.01
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Stand. dev	0.04	0.03	0.03	0.04	0.06	0.04
Median	0.069	0.048	0.046	0.063	0.339	0.301
25 prcntil	0.048	0.036	0.0345	0.0505	0.3045	0.2945
75 prcntil	0.1035	0.069	0.08	0.119	0.3765	0.3575
Skewness	-0.40	1.58	0.52	0.17	1.37	1.00
Kurtosis	-0.04	3.47	-0.72	-1.57	2.17	-0.72
Geom. mean	0.06	0.05	0.05	0.07	0.34	0.32
Coeff. var	51.31	57.74	48.93	50.30	16.15	11.29
Wet season						
N	9	9	9	9	9	9
Min	0.060	0.008	0.091	0.096	0.068	0.049
Max	0.268	0.173	0.293	0.352	2.885	3.345
Sum	1.550	0.690	1.336	1.696	5.547	9.771
Mean	0.172	0.077	0.148	0.188	0.616	1.086
Std. error	0.023	0.015	0.020	0.028	0.320	0.501
Variance	0.005	0.002	0.004	0.007	0.923	2.261
Stand. dev	0.069	0.046	0.060	0.084	0.960	1.504
Median	0.177	0.073	0.131	0.173	0.168	0.099
25 prcntil	0.126	0.047	0.109	0.110	0.107	0.074
75 prcntil	0.239	0.098	0.162	0.241	0.941	2.953
Skewness	-0.083	0.864	1.983	0.791	2.108	0.883
Kurtosis	-0.868	2.035	4.792	0.278	4.057	-1.592
Geom. mean	0.158	0.061	0.140	0.173	0.263	0.275
Coeff. var	39.777	60.060	40.470	44.363	155.838	138.509

3.2.4. Temporal Variation of Temperature and Relative Humidity

Atmospheric temperature was higher in the dry season (Mgbosimini – 30.67 ± 1.87°C, GRA – 31.00 ± 1.66°C, Rumueprikom – 31.00 ± 1.87°C, Ozuoba – 32.78 ± 1.48°C, Aluu – 31.78 ± 0.67°C, Isiokpo – 31.56 ± 0.73°C) compared to the wet season Mgbosimini – 28.89 ± 3.52°C, GRA – 29.44 ± 3.94°C, Rumueprikom – 30.33 ± 4.36°C, Ozuoba 30.44 ± 3.71°C, Aluu – 29.00 ± 1.00°C, Isiokpo – 28.00 ± 3.67°C (Table 12).

Percentage humidity was higher in the dry season compared to the wet season. In the dry season, the lowest percentage humidity measured at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo was 56%, 47%, 47%, 46% 56% and 55% respectively, and the highest at these locations were 62%, 60%, 60%, 61% 58% and 59% respectively. Variance of percentage humidity at Mgbosimini, GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo was 3.44, 22.44, 23.61, 26.50, 0.86 and 1.50 respectively in the dry season, and 5.00, 13.36, 5.00, 8.00, 7.86 and 20.50 respectively in the wet season (Table 13).

Table 12. *Statistical summary of seasonal variation for atmospheric temperature (°C) concentrations.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Dry season						
N	9	9	9	9	9	9
Min	28	29	28	31	31	31
Max	33	33	34	36	33	33
Sum	276	279	279	295	286	284
Mean	30.67	31.00	31.00	32.78	31.78	31.56
Std. error	0.62	0.55	0.62	0.49	0.22	0.24

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Variance	3.50	2.75	3.50	2.19	0.44	0.53
Stand. dev	1.87	1.66	1.87	1.48	0.67	0.73
Median	31	31	31	32	32	31
25 prcntil	28.5	29	29.5	32	31	31
75 prcntil	32	32.5	32.5	33.5	32	32
Skewness	-0.56	-0.21	0.00	1.37	0.25	1.01
Kurtosis	-1.34	-1.67	-0.29	2.19	-0.04	0.19
Geom. mean	30.61	30.96	30.95	32.75	31.77	31.55
Coeff. var	6.10	5.35	6.03	4.52	2.10	2.30
Wet season						
N	9	9	9	9	9	9
Min	24	24	24	25	23	23
Max	32	35	35	35	32	33
Sum	260	265	273	274	261	252
Mean	28.89	29.44	30.33	30.44	29.00	28.00
Std. error	1.17	1.31	1.45	1.24	1.00	1.22
Variance	12.36	15.53	19.00	13.78	9.00	13.50
Stand. dev	3.52	3.94	4.36	3.71	3.00	3.67
Median	30	31	33	32	30	28
25 prcntil	24.5	25	25	26	26.5	24
75 prcntil	32	32.5	33	33	31	31.5
Skewness	-0.70	-0.25	-0.79	-0.62	-1.18	-0.12
Kurtosis	-1.63	-1.43	-1.41	-1.48	0.47	-1.49
Geom. mean	28.69	29.20	30.04	30.23	28.85	27.78
Coeff. var	12.17	13.38	14.37	12.19	10.34	13.12

Table 13. *Statistical summary of seasonal variation for atmospheric humidity concentrations.*

Statistics	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Dry season						
N	9	9	9	9	9	9
Min	56	47	47	46	56	55
Max	62	60	60	61	58	59
Sum	533	493	494	486	512	513
Mean	59.22	54.78	54.89	54.00	56.89	57.00
Std. error	0.62	1.58	1.62	1.72	0.31	0.41
Variance	3.44	22.44	23.61	26.50	0.86	1.50
Stand. dev	1.86	4.74	4.86	5.15	0.93	1.22
Median	59	57	57	54	57	57
25 prcntil	58	49.5	49.5	49.5	56	56
75 prcntil	60.5	58	58.5	59	58	58
Skewness	-0.41	-0.80	-0.75	-0.16	0.26	0.00
Kurtosis	0.00	-1.21	-1.29	-0.98	-2.02	-0.29
Geom. mean	59.20	54.59	54.69	53.78	56.88	56.99
Coeff. var	3.13	8.65	8.85	9.53	1.63	2.15
Wet season						
N	9	9	9	9	9	9
Min	48	44	44	42	47	47
Max	55	54	51	50	55	59
Sum	471	433	417	411	458	480
Mean	52.33	48.11	46.33	45.67	50.89	53.33
Std. error	0.75	1.22	0.75	0.94	0.93	1.51
Variance	5.00	13.36	5.00	8.00	7.86	20.50
Stand. dev	2.24	3.66	2.24	2.83	2.80	4.53
Median	52	47	46	45	51	54
25 prcntil	51	45	44.5	43	48	48.5
75 prcntil	54.5	52	47.5	48	53.5	58
Skewness	-0.62	0.60	1.10	0.14	0.01	-0.18
Kurtosis	0.44	-1.34	1.30	-1.01	-1.25	-1.54
Geom. mean	52.29	47.99	46.29	45.59	50.82	53.16
Coeff. var	4.27	7.60	4.83	6.19	5.51	8.49

PM in the present study showed seasonal variation, this was similar to a study designed to assess seasonal variation of fine particulate matter in residential micro–environments of Lahore, Pakistan [47]. In the wet season, there is an increase in precipitation and wind speed. Studies have shown that wind speed has a negative correlation with PM concentration in atmosphere [48, 49]. This may account for the lower PM concentrations observed in all locations in the

wet season when compared to the dry season. Similar to PM in the atmosphere, TVOC also showed seasonal variation. Indoor/outdoor ratios of $PM_{2.5}$, PM_{10}, and TVOC increased during the warm season in a study carried out by A. Chamseddine et al. [50]; these results were similar to those observed in the present study.

As earlier stated, PM have the ability to linger in the atmosphere for long periods of time and the ability to diffuse. This is due to their small diameter and hence very light weight compared to larger particles in the atmosphere. The characteristics and source of PM, therefore, plays a major role in its concentrations. This is because, the characteristics and source determine the diameter of PM in the atmosphere and how long it will linger in the atmosphere. Whereas coarse particles (2.5 and 10 µm diameter) are typically deposited to the Earth within a short period of time (minutes to hours) and travel within short distances (tens of kilometres), fine particles (2.5 µm in diameter) on the other hand remain in the atmosphere for longer periods of time (days to weeks) and can travel much longer distances (thousands of kilometres) [12].

The concentration of particles in the air varies across space and time and is related to the source of the particles and the pollutant transformations that occur in the atmosphere. Also, as mentioned earlier, anthropogenic activities play a major role in the concentration of PM in the atmosphere. Activities that see to the continuous release of atmospheric contaminants, such as gas flaring, have shown to have a positive correlation to PM concentration in the atmosphere [51, 52].

The concentration of PM in the atmosphere, as other atmospheric pollutants, is dependent on the meteorological conditions; meteorology affects dispersion, transformation and removal, hence spatial and temporal characteristics of atmospheric pollutants [53, 54]. In the study area, is a tropical rain forest with a mean annual rainfall of 11.9.6 [25]. Wind speed and direction, humidity, rainfall, ambient temperature, surface pressure and sunlight are metrological factors [55-57]. S. E. Bauer et al. [58] found a positive correlation between $PM_{2.5}$ concentration in the atmosphere with desert dust, industrialization and agricultural fires in Africa.

3.2.5. Human Health Risk Assessment

Fine particles are about 30 times smaller than human hair.

Although there are not present records in the study area, they have been identified to be of greatest risk to human health if inhaled and have been associated to increased risk of cardiovascular disease in human beings [59-61]. When PM enters into the body, it could also lead to immune system damage and compromise the immune capacity of the human body increases the risk of a range of diseases [62]. The immune-compromising ability of PM involves the oxidative damage mechanism, apoptosis mechanism and calcium homeostasis disequilibrium mechanism. The health effects of PM can also be related to the particle makeup; PM mainly comprises of ions, reactive gases, organic compounds, metals, and particle carbon core [19]. Thus, when fine particles of this makeup make their way into the human body, they can cause early death patients suffering from cardiovascular diseases [19, 59].

Assessment of human health risk related to $PM_{2.5}$ due to the inhalation of air revealed hazard for children in the dry season (November, December and January) at all locations (HI > 1). In March, except for Mgbosimini, HI was greater than 1 at GRA, Rumueprikom, Ozuoba, Aluu and Isiokpo. In February and April, HI < 1 at Mgbosimini and GRA, and HI > 1 at all other locations (Table 14).

Human health risk assessment for adults revealed that except for Mgbosimini in November, all stations in dry season (November, December and January) had HI > 1 indicating risk to adults due to inhalation of $PM_{2.5}$ in air. In wet season (February, march and April), Rumueprikom, Aluu and Isiokpo all has HI > 1 indication health risk at these locations, however, Mgbosimini and GRA indicated no risks in the wet season (Table 14).

Vehicular activities can lead to a corresponding increase in PM concentrations [63-66]. However, it can be observed that the PM concentrations in the areas with higher vehicles had lower PM when compared to Aluu and Isiokpo with less vehicles. The mean HQ related to $PM_{2.5}$ estimated for Tehran, the most populous city in Iran and Western Asia and the capital of Iran, was 6.1 and 6.4 in 2016 and 2017 respectively [67]; these values are higher than those measured in at all stations. I. D. Sulaymon et al. [68] identified human health risk hazard due to exposure of metals bound to $PM_{2.5}$ to adults and children in transport pathways of Abuja, Nigeria, similar to some stations sampled in the present study.

Table 14. Hazard index (HI) for human health risk assessment for the inhalation of $PM_{2.5}$.

Month	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
Children						
November	1.0	1.2	1.3	1.2	1.4	2.2
December	1.3	1.2	1.4	2.6	1.7	2.2
January	1.3	1.1	1.3	1.5	1.7	2.2
February	0.9	0.9	1.2	1.2	1.1	2.2
March	0.8	1.0	1.6	1.0	1.3	2.1
April	0.9	0.9	1.1	1.0	1.4	2.1
Adult						
November	0.9	1.1	1.2	1.1	1.3	2.0
December	1.2	1.1	1.3	2.4	1.6	2.0
January	1.2	1.0	1.2	1.4	1.6	2.0
February	0.8	0.9	1.1	1.2	1.0	2.0

Month	Mgbosimini	GRA	Rumueprikom	Ozuoba	Aluu	Isiokpo
March	0.7	0.9	1.5	0.9	1.2	1.9
April	0.8	0.8	1.0	0.9	1.3	2.0

PM is composed of inorganic materials such as: calcium, potassium, silica, sodium, aluminium, iron and magnesium, unconverted char and bed material (in case of fluidized bed gasifier) [69]. Arsenic, selenium, zinc and lead also make up minor constituent of PM. J. N. Galloway *et al.* [70] predicted that based on the rate of emission, atmospheric concentration and trends in deposition, Ag, Cd, Cu, Pb, Sb, Se and Zn can be expected to show great increases in the atmosphere as a result of anthropogenic activities; they found that Hg and Pb were being deposited in some areas at levels toxic to humans and Cd, Cu, Hg, Pb and Zn at levels toxic to other organisms. Although trace metals are released into the atmosphere by natural processes such as volcanic eruption, seas-salt spray, forest fires, rock weathering, biogenic sources and wind-borne soil particles [71], anthropogenic activities have caused an increase in their concentration in the atmosphere [72]. Anthropogenic sources such as: industries, agriculture, wastewater, mining and metallurgical processes have been noted to cause an exceedance of the natural of metals in the atmosphere [71, 73]. Metals such as Cu, Cd and Pb are commonly associated with industrial areas, Cr, Mn, Ni, V and Zn are associated with traffic, while No, K, Ca, Ti, Mg and Fe are associated with natural sources [74-76].

The life expectancy in Africa is lowest compared to other regions of the world; Africa´s life expectancy is 61.2 years while global life expectancy is 72.0 years [77]. However, the life expectancy in Nigeria, 55.2, is lower than the mean life expectancy of the continent of African [77]. Several factors have been attributed to the low life expectancy in Nigeria, one of which is poor air quality which has been attributed to several premature deaths in the country [78].

In Nigeria, air pollution is estimated to contribute to the risk of a death rate of 55.37 deaths per 100, 000; respiratory infections cause an estimated 119.97 deaths per 100, 000 [79]. In 2013, ambient PM pollution in Nigeria caused an estimated 39, 825 deaths and household air pollution caused an estimated 67, 148 deaths [78]. These deaths were estimated to cost the country a staggering 41, 796 and 70, 471 million USD for ambient PM pollution and household air pollution respectively [78]. Hence, managing air pollution is not only a health benefit but also an economic benefit.

Electricity generation through thermal (oil and gas) power plants in most of southern Nigeria which generates massive gaseous emissions are a contributor to PM in the environment [80]. Petroleum exploration in the Niger Delta region of Nigeria over the years has led to the release of gases in the atmosphere through gas flaring; gas flaring, consequently, increases the input of PM into the atmosphere [51]. For a period of 49 years (1965 – 2013), 55% of gases explored in the Niger Delta regions was being flared an enormous amount of 4.56×10^5 tons (4.11×10^8 tons CO_2 equivalent) of black carbon into the environment [81].

4. Conclusion

Therefore, this study realized that the quality of air is not necessarily dictated by urban-rural distribution, but on the specific activities that may contribute to the quality of air. Also, if the activities that contribute to the availability of contaminants in the atmosphere are consistent, there would be no significant reduction or change. Therefore, we should be more concerned about the nature of the natural or anthropogenic activities of wherever we find ourselves and Attention should be placed on the air quality in rural settlement and not only urban areas.

Acknowledgements

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