SEASONAL VARIATIONS AND INFLUENCE OF TWO CLIMATIC PARAMETERS ON AMBIENT CONCENTRATIONS OF CARBON MONOXIDE AND PARTICULATE MATTER AT TIN CAN PORT, LAGOS, NIGERIA

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Abstract: Shipping activities are a major source of air pollution in port cities with the expected high population of port workers and related workforce being chronically exposed to air pollutants such as carbon monoxide (CO) and suspended particulate matters (SPM:PM_{10}). These two priority air pollutants in addition to relative humidity (RH) and wind speed were monitored every month over a period of four years at Tin Can, Apapa Lagos, being the location of the busiest port in Nigeria. Results indicate that the highest monthly mean concentrations recorded throughout the study were 3.31 ppm and 258.6 µg/m^3 for CO and PM_{10}, respectively. While the value of CO was within the recommended threshold limits by the World Health Organization (WHO) and the Federal Ministry of Environment (FMEnv), the PM_{10} exceeded the WHO specified limit of 50 µg/m^3 for a –24 h period of exposure. The ambient concentrations of the two air pollutants were higher in the dry season than their concentrations in rainy season. However, a significant seasonal variation was observed in the ambient concentrations of PM_{10}. Regression analysis shows that wind speed contributes significantly ($p<0.05$) to the detectable concentration of CO while RH had no significant influence on CO availability in the study area. Conversely, RH significantly influenced the concentration of PM_{10} with a direct positive correlation between the climatic index and particulate matter while wind speed had no significant influence on suspended particles. The study established that there is no risk of acute human exposure to the air pollutants in the ports area. In spite of the low ambient concentrations recorded during the study, chronic exposure of workers or residents in port areas has its long-term health implications. Further study is required to monitor the indoor concentrations of these pollutants, which were possibly dispersed by wind from the lagoon and the ocean.

Keywords: Lagos, seaport, air pollution, seasonal variation, climate

Introduction

Shipping and seaport activities have been observed as a major source of air emissions, which emanate from vessels, boats, ferries and several articulated vehicles hauling goods to and from seaport terminals. The high population of people working or living near busy seaports like the Lagos ports is inadvertently at risk of exposure to air pollution, which has been regarded as a major cause of morbidity and mortality globally – resulting largely from heart disease, stroke, chronic obstructive pulmonary disease and acute respiratory infections in children (WHO, 2016). Across the world, approximately 4.2 million deaths caused by outdoor air pollution in both cities and rural areas were recorded in 2016 as 91% of the world population breathes polluted air exceeding WHO air quality guidelines levels (WHO, 2018). Earlier report suggested that low-income and middle-income countries like Nigeria experience the highest burden of ambient air pollution (WHO, 2016). Lagos, being the location of the busiest seaports in Nigeria, is one of the fastest growing megacities in the world with many of its population breathing polluted air. Vehicular emission due to high traffic volume in Lagos has been the major source of air pollution while emissions from industries are the second most critical source, which has led to death of more than 11,000 people in the city in 2018 alone with children under the age of 5 being the most affected (Croitoru *et al*., 2019).

Carbon monoxide emissions from anthropogenic sources such as port activities and related sources account for 80% of carbon monoxide emissions to the atmosphere (Tellez *et al*., 2006). Acute exposure to CO emission is often fatal, accounting for thousands of reported death globally. In addition to harmful gases like carbon monoxide, air pollution contains tiny particles, generally referred to as suspended particulate matter (SPM). It comprises of many substances of diverse toxic chemical compositions, contaminated dust, suspended heavy metals, hydrocarbon materials, among other toxic chemical substances; identified as one of the criteria air pollutants with strongest evidence of public health concern (WHO, 2016). It is a common proxy indicator for air pollution; affecting more people than any other pollutant, and this air pollutant has been linked to certain health problems, including cardiovascular disease and asthma (American Chemical Society, 2020).

The availability of air pollutants, to a great extent, is influenced by climatic factors such as relative humidity, wind speed, among others. Outcomes of air quality monitoring, especially in high traffic density and shipping areas like Lagos port terminals have always helped in decision making process. This is for the purpose of reviewing emission laws and regulations aimed at protecting public health from the adverse effects of air pollution and human exposure to harmful air pollutants.

Materials and Methods

Study area

Tin Can Port in Apapa is one of the epicenters of port and terminal operations in Nigeria with a wide array of emission sources such as shipping activities, movement of haulage trucks and other vehicular activities. It is considered an air pollution hot spot; an area where the levels of one or more air pollutants are likely to be elevated (Smith *et al*., 2012). The study area is situated by the Lagos Lagoon at 6.4553° N, 3.3641° E (Fig. 1). There are many industries located in the study area. These include Dangote Sugar Refinery, TICT, JosepDam Port Services Ltd. (JPS), 5 Star Logistics, Port and Cargo Terminal, & PTML. Tin Can lies on 8 metre above sea level with an annual rainfall of 1665 mm. The average temperature is 26.9^{o}C.

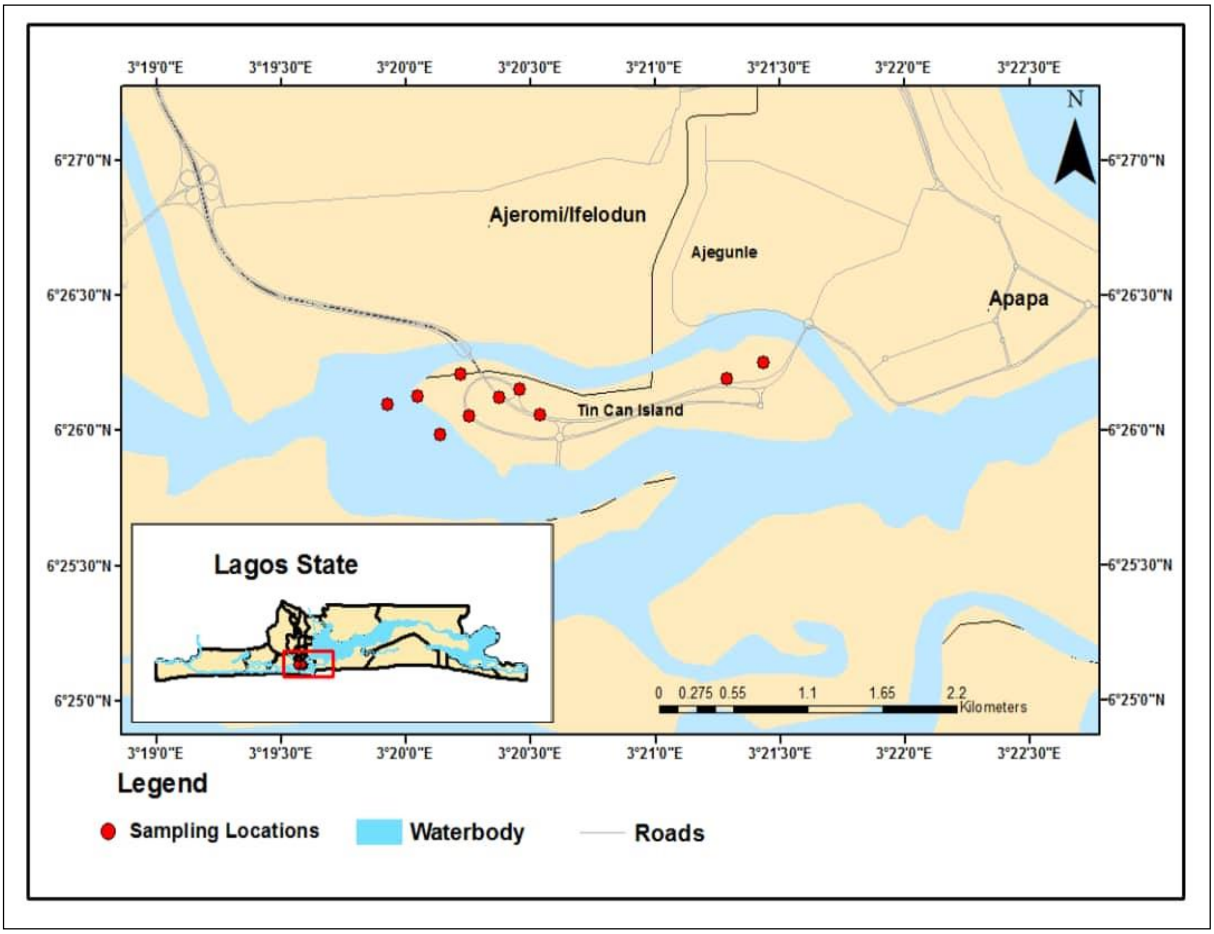

Fig. 1: Map of Lagos showing Tin Can Island and sampling locations

Air quality and meteorological data collection

Air quality monitoring was carried out for a period of 2 hours monthly between January 2016 and December 2019 at 10 different locations in Tin Can with two points on the Lagoon where high level of boat movements and shipping activities were observed. The study was carried out following the procedures of Obanya *et al*. (2018) with some modifications. Air pollutants were monitored *in-situ* at 10 points over a period of 2 h in the study area at an elevation of 2 metres using calibrated hand-held air quality monitors while Aeroqual aerocet 531 was used for Relative Humidity and wind speed. Concentration of the pollutants and the meteorological data were recorded twice at each of the sampling locations, which was geo-referenced using a handheld GARMIN 72H GPS device. The average values for each of the locations were computed. The data were collected during the morning peak period, covering both dry and wet seasons for 4 years. The study also included establishment of prediction models on the influence of meteorological parameters on the seasonal variation of concentration of gaseous pollutants.

Statistical analysis

The obtained readings were processed using SPSS Version 20 Software (IBM) and values were presented as means. The respective readings were also subjected to statistical analysis and significant means at $P<0.05$ were separated using independent samples T-Test. Apart from emission sources, the concentrations of ambient air pollutants depend on climatic factors and their influences such as dispersion (Tawari and Abowei, 2012).

Results and Discussion

Carbon monoxide: The monthly CO concentrations ranged from 0.01 to 4.50 ppm throughout the duration of the study (Table 1). In 2016, the highest annual mean concentration (3.31±0.291 ppm) of CO was recorded while the gas was least detected in 2019 with an annual mean concentration of 1.0±0.321 ppm. The monthly mean concentrations of CO ranged from 1.56 to 4.50 ppm in 2016; 0.01 to 2.50 ppm in 2017; 0.0 to 2.70 ppm in 2018 and 0.02 to 4.0 ppm in 2019. The annual mean values of CO for 2016, 2017, 2018 and 2019 are 3.31, 0.56, 1.05 and 1.00 ppm, respectively. The level of ambient CO in the study area was within the 8 h exposure limits recommended by the Federal Ministry of Environment (FMEnv) and the WHO.

Particulate matter: The monthly mean values of PM_{10} in 2016 ranged from 21.9 to 124.7 µg/m^3 with a mean value of 57.07 µg/m^3. In 2017, the monthly mean concentrations ranged from 51.4 to 258.6 µg/m^3 with a mean value of 85.30 µg/m^3. In 2018, the level of the particulate matter in the study area ranged from 48.5 to 185.1 µg/m^3 with a mean value of 88.41 µg/m^3 while the values ranged from 55.30 to 118.30 µg/m^3 with a mean value of 86.13 µg/m^3 in 2019. The maximum monthly mean value of PM_{10} recorded in 2017 exceeded the threshold limit of 250 µg/m^3 (Table 1). The WHO exposure limit recommended is the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure.

Table 1: Descriptive Statistics of Air Quality at Tin Can, Lagos, Nigeria

Parameters	Year	Range	Minimum	Maximum	Mean±SE	Exposure Limits	
						FMEnv	WHO
CO (ppm)	2016	2.94	1.56	4.50	3.31±0.291	10	9 for 8 h
	2017	2.49	.01	2.50	0.56±0.230		
	2018	2.70	.00	2.70	1.05±0.283		
	2019	3.98	.02	4.00	1.00±0.321		
PM_{10} (μg/m^3)	2016	102.80	21.90	124.70	57.07±8.477	250	50 for 24 h
	2017	207.20	51.40	258.60	85.30±16.296		
	2018	136.60	48.50	185.10	88.41±13.140		
	2019	63.00	55.30	118.30	86.13±5.696		

Relative humidity: The monthly mean values of RH for the year 2016 ranged from 62 to 86% with annual mean value of 74.67%. In 2017, the monthly mean RH values ranged from 52% to 85% with a mean value of 68.25%. The highest value of RH in the study area was recorded in the year 2018 with the annual mean value of 75.25% while the values ranged from 60.0 to 91.0% while the RH values ranged from 55.30 to 87.0% with a mean value of 73.75% in the year 2019 (Table 2).

Wind Speed: The monthly average wind speed for the year 2016 in the study area ranged from 3.90 to 8.70 m/s with annual average speed of 6.56 m/s. In 2017, the monthly average of wind speed recorded ranged from 4.10 m/s to 7.10 m/s with a mean value of 5.45 m/s while the wind speed ranged from 4.20 to 8.40 m/s in 2018 with the annual average wind speed of 6.05 m/s. In 2019, the wind speed ranged from 3.80 to 8.30 m/s over the course of 12 months while the annual average wind speed was 5.63 m/s. The highest monthly wind speed recorded during the study was 8.70 m/s in 2018 while the least wind speed was 3.80 m/s in 2019 (Table 2).

Table 2: Descriptive statistics of climatic indices at Tin Can, Lagos, Nigeria

Parameters	Year	Range	Minimum	Maximum	Mean±SE
Relative Humidity (%)	2016	24.00	62.00	86.00	74.67±2.423
	2017	33.00	52.00	85.00	68.25±2.742
	2018	31.00	60.00	91.00	75.25±2.703
	2019	32.00	55.00	87.00	73.75±2.728
Wind Speed (m/s)	2016	4.80	3.90	8.70	6.56±0.393
	2017	3.00	4.10	7.10	5.45±0.261
	2018	4.20	4.20	8.40	6.05±0.430
	2019	4.50	3.80	8.30	5.63±0.378

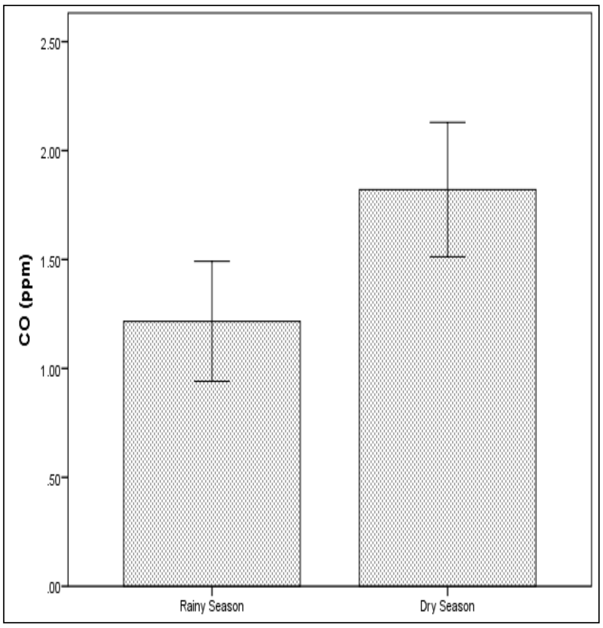

Fig. 2: Comparison of CO levels at Tin Can during rainy and dry season

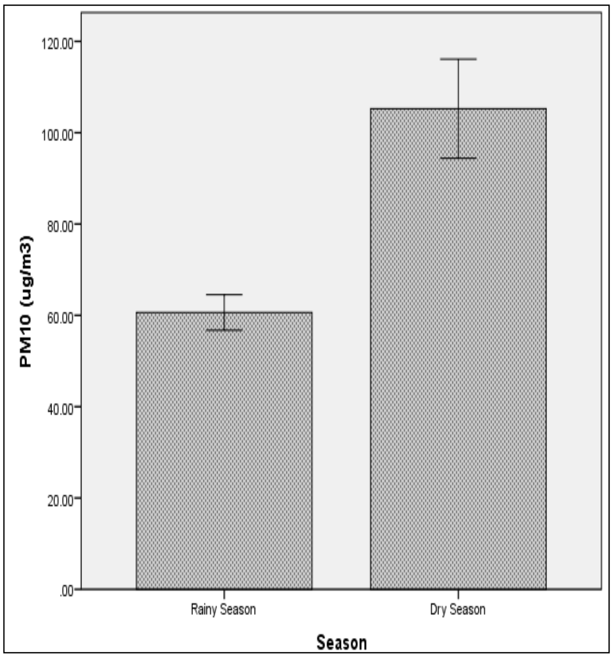

Fig. 3: Comparison of PM_{10} levels at Tin Can during rainy and dry season

Seasonal variation of air pollutants

The mean concentration of CO in dry season was higher than the mean concentration of the pollutant during the rainy season for the four-year period of study. However, the difference in the concentrations of CO between the rainy and dry seasons was not significant (Fig. 2). The mean concentration of particulate matter was much lower in the rainy season compared to the dry season throughout the study period, and seasonal variation was significant ($p<0.05$) in the levels of PM_{10} (Fig. 3). In addition, the t-test for equality of means shows PM_{10} has a significant difference ($p=0.01$) in concentrations both for equal variances assumed and not assumed between the rainy and dry seasons.

Meteorological influence on air pollutants

The correlation between wind speed and CO in this study is 0.71, which is high and 50.3% of the CO values obtained during the study could have been influenced by wind speed (Table 3). Regression analysis shows that wind speed contributes significantly ($p<0.05$) to the detectable concentration of CO in the study location (Table 4). The correlation between relative humidity and carbon monoxide was poor and 13.2% of CO data can be explained by this climatic index (Table 5). The statistical model poorly predicts the concentration of atmospheric CO due to relative humidity (Table 6). The ambient CO concentration in a highly industrialised area Tin Can was found to be lower than expected. This implies ambient CO was well-dispersed from the study area by wind action. The high wind speed in the study area is attributable to the proximity to the Lagos Lagoon and the Atlantic Ocean. However, there is a high possibility that indoor concentrations of air pollutants such as CO and PM_{10} in the study area could be high.

Table 3: Wind speed and CO model summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.709[a]	.503	.453	.43062	2.548

a. Predictors: (Constant), WS, b. Dependent Variable: CO

Table 4: Coefficients[a] for wind speed and CO model summary[b]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant: Wind Speed	6.318	1.529		4.132	0.002
Dependable variable: CO	-0.819	0.257	-0.709	-3.182	0.01

Table 5: RH and CO model summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.363[a]	.132	.045	.56930	1.359

[a]Predictors: (Constant), RH, b. Dependent Variable: CO

Table 6: Coefficients[a] for RH and CO Model Summary[b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.513	1.670		2.104	.062
	RH	-.028	.023	-.363	-1.231	.247

[a]Dependent Variable: CO

Table 7: Relative Humidity[a] and Particulate Matter Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.833[a]	.693	.663	15.685	1.412

[a]Predictors: (Constant), Relative Humidity; [b]Dependent Variable: Particulate Matter

Table 8: Coefficients[a] for Relative Humidity and Particulate Matter

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant: Relative Humidity	296.837	45.998		6.453	.000
Dependable variable: PM_{10}	-2.982	.627	-.833	-4.754	.001

Table 9: Wind speed[a] and particulate matter: model summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.557[a]	.311	.242	23.510	.895

[a]Predictors: (Constant), WS; [b]Dependent Variable: Particulate Matter

Table 10: Coefficients[a] for wind speed and particulate matter

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	255.924	83.487		3.065	.012
	WS	-29.844	14.054	-.557	-2.124	.060

[a]Dependent Variable: TSP; There is no significant relationship (p = 0.06) between Particulate Matter and WS

There is a high degree of correlation (0.83) between relative humidity and suspended particles, and 69.3% of the total variation in the PM_{10} values can be attributed to influence of RH (Table 7). Regression analysis (Table 8) indicates that RH contributes significantly to PM_{10} in the atmosphere ($p<0.05$). Conversely, the correlation between wind speed and PM_{10} was 0.56 (Table 9) and does not significantly contribute to the level of particulates in the atmosphere (Table 10).

Wind speed as a meteorological factor contributes in part to variations in concentrations of air pollutants (Chen *et al*., 2007); and there is a non-linear relationship between air pollutants and wind speed. Wind speed between 2 and 10 mph has little dilution effect while wind speed above 10 mph favours dilution and dispersal (Smith *et al*., 2012).

Through the years, assessments of human exposure to air pollution and epidemiological studies have been carried out through monitoring of gaseous and air-borne pollutants such as carbon monoxide (CO) and particulate matter. Air quality monitoring is often a result of the need to establish if threshold limits set by local regulators or standards set by international bodies such as WHO has been exceeded. In addition, air quality assessment provides the information needed to estimate population exposure to air pollution.

Long-term exposure to air pollution has been associated with a higher prevalence of obesity and cardiometabolic risk factors, especially hyperbetalipoproteinemia (Chen *et al*., 2019; Kim *et al*., 2019; Yang *et al*., 2019). Based on adequate scientific evidences, outdoor air pollution in general and particulate matter, in particular, has been classified as carcinogenic by the International Agency for Research on Cancer (Loomis *et al*., 2014). Specifically, cancer of the lungs, urinary tracts and bladder has been linked with chronic exposure to particulate matter (WHO, 2018). This study on the level of air pollution in Tin Can, Apapa shows a moderate level of air pollutants in the study area with some variations in the level of the CO and SPM across the two seasons throughout the period of study. The generally low concentrations of air pollutants during the rainy season compared to the values recorded in dry season have been attributed to rainfall which regularly clears the atmospheres thereby reducing the level of ambient air pollutants. This has been established by some studies (Fang *et al*., 2011; Kim *et al*., 2014; Zheng *et al*., 2019). Significantly low concentrations of CO, which were within the threshold limits recommended by FMEnv and WHO, were recorded during this study. Nonetheless, this does not rule out the health risk of chronic prolonged exposure for people in the study area. Non-fatal exposure may lead to neuropsychological changes such as parkinsonian syndrome and a spectrum of encephalopathy ranges from reversible dysfunction to severe irreversible dementia. Other effects of CO include cardiac damage such as high blood pressure, cardiac arrhythm and electrocardiograph signs of ischemia (Tellez *et al*., 2006; Schochat and Lucchesi, 2018).

The differential traffic density and proximity to sources of emissions in the urban centres create differential susceptibility of communities to illnesses resulting from air pollution, especially within vulnerable groups including children, the elderly and pregnant women (Olowoporoku *et al*., 2012). This suggests the vulnerability of pregnant women, child traders and elderly working or living around the port areas and adjoining communities. A significant numbers of people who are chronically exposed to low concentration of CO could develop some disease conditions such as headache, dizziness, fatigue, nausea and difficulty in concentrating while morbidity and mortality may increase in people with pre-existing disease conditions (Knobeloch and Jackson, 1999; Wright, 2002; Harvard Health Publishing, 2019). During the last few years, experimental research on animals and studies of human epidemiology have established the relationship between chronic exposure to low and middle levels of carbon monoxide in breathable air and adverse effects on human health, especially on organs consuming large amounts of oxygen such as the heart and brain. Harmful cardiovascular and neuropsychological effects have been documented in carbon monoxide concentration in air of less than 25 ppm and in carboxyhaemoglobin levels in blood of less than 10%. (Téllez *et al*, 2006)

Additionally, particulate matters, especially, PM_{10}, represents the particle mass that enters the respiratory tract, and, it includes both the coarse particle size and fine particles (measuring less than 2.5 µm, or $PM_{2.5}$), which adversely affect human health in urban centres (WHO, 2006). Long term exposure may lead to increased morbidity and mortality as it aggravates cardiorespiratory diseases and increased hospital admissions (Colucci *et al*., 2006) and diabetes with possibility of inflammation, metabolic syndrome and atherosclerosis (Brocato *et al*., 2014). Climatic factors such as wind speed have been found to influence availability of CO and SPM in ambient air (Cassidy *et al*., 2007; Fujita *et al*., 2014); and this has been further established by this study.

Conclusion

The ambient concentrations of CO and PM_{10} in the study area were mostly within the threshold limits recommended by the FMEnv, although the mean PM10 was slightly higher than recommended limits in 2017. The values of PM_{10} were all above the weighted 50 for 24 h stipulated by the WHO. Relative humidity and wind speed influenced the availability of the air pollutants and the level of suspended particulate matters varied significantly across rainy and dry seasons. The PM_{10} recorded was significantly lower during the rainy season, which is generally characterised by high precipitation in the study area. There is a possibility of pollutants dispersion to indoors and probably to other remote parts due to wind action and the prevailing wind condition in Apapa area while relative humidity equally influences availability of pollutants. Although the study indicates no risk of acute exposure to CO in particular, previous studies suggest long-term exposure to low concentration of these air pollutants still poses some risks to human health. Further studies, which focus on indoor concentration of air pollutants in Apapa, would be necessary to determine the actual level of air pollution and potential health risks workers and residents of the study area are exposed to.

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