Research Article

Diurnal and Spatial Variation of Ambient Carbon Monoxide Concentration from Vehicular Emissions in Port Harcourt Metropolis, Nigeria

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Abstract
Air pollution affects both the health and environment of living organisms. In large urban cities, the emission of carbon monoxide (CO) gas from the transport sector pose unprecedented risks being a silent and lethal killer. Consequently, deaths arising from suffocation by CO fumes have recently become a cause for concern in Nigeria. In this study, an attempt is made to evaluate the diurnal trend in CO generation and distribution at six major road junctions in Port Harcourt, Nigeria. CO concentration was measured using PCMM05 Pyle® Carbon Monoxide Meter. The generally observed trend in concentration in terms of diurnal variation was: morning > evening > afternoon while that of spatial variation was Rumuola Junction > Choba Junction > U.S.T. Roundabout > Sangana Street > Rumuokwuta Junction > Rumuokoro Roundabout. The maximum mean concentration of 150ppm was measured in the morning at Rumuola junction. The observed concentration was generally higher than the 10ppm limit for ambient air set by the Nigerian national regulatory body. Frequent traffic congestion from poorly maintained roads and/or inadequate roads, high vehicular traffic density, abundance of used vehicles with incomplete combustion and poorly maintained diesel engines among others were identified to be responsible for the high emissions, accumulation and dispersion of CO.

Plate 1 - Rumuola Junction ($4^{o}\ 49^{I}\ 58.03^{II}$ N, $7^{o}\ 00^{I}\ 17.28^{II}$ E)

Keywords: Traffic-related gases, CO emissions, Air Pollution, Vehicular emissions

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Introduction

Transportation activities have been identified as the single major source of air pollution in urban areas [1] with subsequent adverse human health effects [2], [3]. Vehicular emissions such as carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons, suspended particulate matter (SPM) and sulphur oxides (SOx) have been implicated as the major air pollutants in these areas, of which Port Harcourt is no exception. CO is dominant among vehicular emissions hence is the focus of this study.

Motor vehicles contribute over 90% of CO emissions in urban areas [4]. These emissions are most dense particularly near roadsides and intersections [5] making those points contamination hotspots. Air quality in these spots is also affected by a number of other factors, including traffic density with time, vehicle type, vehicle composition, terrain and local meteorological conditions. CO levels have always been the target of investigation in most monitoring and modelling studies on vehicular pollution near roadways and major intersections in many cities [6]; [7]; [2]; [8]; [9]; [10]. CO levels, as well as other traffic-related gases, have also received a great deal of interest due to their inherent toxicities and possible heterogeneous reactions with other components in the atmosphere [11]; [6]; [12]; [13].

According to Davis and Cornwell [14], CO is a colourless, odourless, tasteless and non-irritating gas that can be lethal to human beings within minutes at high concentrations exceeding 12,800 parts per million (ppm). In urban environments and especially in those areas where population and traffic density are relatively high, human exposure to the gas is expected to be significantly increased. CO results from incomplete fossil fuel combustion that characterizes mobile as opposed to stationary pollution sources and therefore it can be used as a marker for the contribution of traffic to air pollution [8]. The major source of CO in the atmosphere is largely due to anthropogenic influence. It exists in the environment in gaseous form and can be present in both outdoor and indoor environments. It is found in combustion fumes, such as those produced by cars and trucks, gasoline engines, camp stoves, lanterns, burning charcoal and wood, gas ranges, heating systems, generators, and poorly vented chimneys. It is produced by home appliances, such as gas or oil furnaces, gas refrigerators, gas clothes dryers, gas ranges, gas water heaters or space heaters, fireplaces, charcoal grills, and wood burning stoves. Fumes from automobiles and gas-powered lawn mowers may also contain CO and can enter a home through walls or doorways if an engine is left running in an attached garage. Also, it can intentionally enter the human body by way of cigarette smoke.

CO is regarded as one of the six criteria pollutants. Breathing it can poison people and animals. Under normal circumstances, oxygen is transported in the body after binding with haemoglobin to form oxyhaemoglobin (OHb). However, when CO is present in the blood, it will bind much more readily with haemoglobin by a factor of about 200:1, forming carboxyhaemoglobin (COHb) instead of oxyhaemoglobin (OHb). The formation of COHb reduces the blood's oxygen-carrying capacity, impairing tissue perfusion [15]; [16]; [17]; [18] as well as causing heart difficulties in people with chronic diseases, reduced lung capacity and impaired mental abilities. This situation is described as ***CO poisoning.*** All people and animals are at risk for CO poisoning. In addition, chronic exposure to relatively low levels of CO may cause persistent headaches, light headedness, depression, confusion, memory loss, nausea and vomiting [19]. It is unknown whether low-level chronic exposure may cause permanent neurological damage [20]. Typically, upon removal from exposure to CO, symptoms usually resolve themselves, unless there has been an episode of severe acute poisoning [19]. Chronic CO exposure might increase the risk of developing atherosclerosis [21]; [22]. Long-term exposures to CO present the greatest risk to persons with coronary heart disease and in females who are pregnant [23]. A study reported by Goldstein [24], shows that approximately 30% of people with severe CO poisoning will have a fatal effect. Exposures at 100 ppm or greater can be dangerous to human health [25]. It is known to be the most common cause of fatal poisoning in Britain today. It causes the accidental deaths of up to 500 people each year in the United States and a much larger number of sub-lethal poisonings [26]. CO also contributes to the formation of CO_2 and Ozone; green house gases that warm the atmosphere as reported by Our Nation's Air of US [27]

This study was carried out in Port Harcourt City, southern Nigeria. The City is the industrial nerve centre of Nigeria and host to a large number of multinational firms as well as other industrial concerns, particularly business related to the petroleum industry. Port Harcourt has an estimated population of 5.4 million people consisting of the Urban Area with an estimated population of 2.7 million people and the greater/rural area which has an estimated population of 3.7 million people [28]. Port Harcourt City is highly congested and populated as it is the only major City in Rivers State and it is also characterized by high commercial activities. Increasing automobiles traffic in the City, incessant use of generators, industrialization and use of agricultural land for building constructions have defaced the aesthetic beauty of the environment. Traffic volume is high in the town year round, because it is a highly populated and industrialized City. Emissions from heavily loaded transportation vehicles, poorly maintained diesel engines, local commuter buses running between city and suburbs, motor vehicles, generators, industrial enterprises situated within the city and thermal power station are largely responsible for the air pollution problems in Port Harcourt. This study, designed to acquire baseline CO data in a populated City, would ultimately assist in providing objective inputs for air quality management, traffic, and land-use planning and informing the public about air quality and the danger inherent in its deterioration.

Experimental

Materials and Reagents

This study was carried out in Port Harcourt, the capital City of Rivers State, Nigeria. The geographical coordinates of Port Harcourt are (Latitude 4.78ºN, Longitude 7.01ºE and Elevation 468m). It lies along the Bonny River (an eastern distributary of the Niger), 41 miles (66 km) upstream from the Gulf of Guinea.

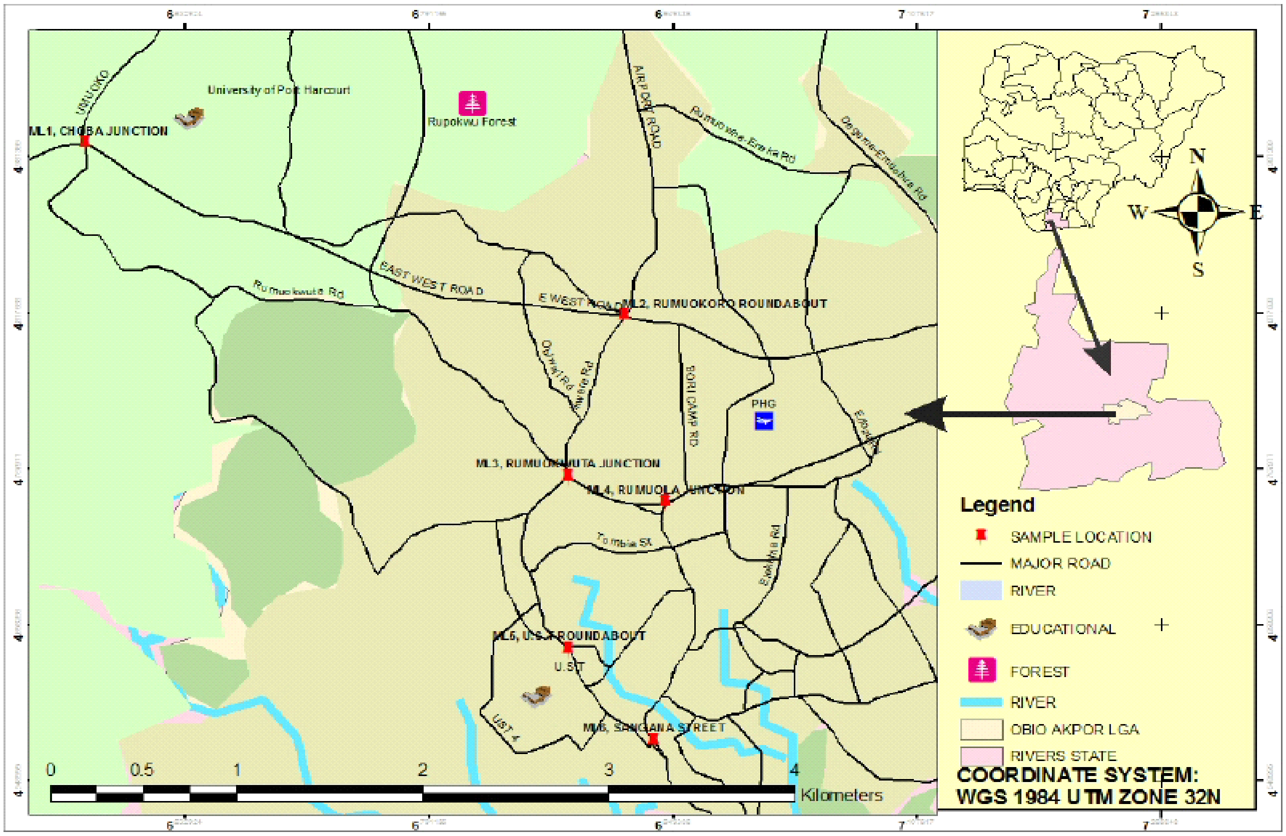

Figure 1 Map of Port Harcourt Showing Sampling Locations

Sample Locations

In order to acquire a comprehensive baseline distribution of this pollutant in the City, six sampling sites were carefully selected to represent all the quarters of the City with high levels of air pollution and a control station. The sites were created at contamination hotspots (roadside verges, junctions, roundabouts, and motor parks). Also, traffic census was conducted at each sample location during the two months campaign.

Table 1 Sample location, description and traffic volume

S. No.	Sample Location	Northing (N)	Easting (E)	Site Description/Traffic Volume
1.	Choba Junction	N 4º 53’ 55.39”	E 6º 54’ 24.19”	A major junction connecting University of Port Harcourt, East West Road and Choba Road
2.	Rumuokoro Roundabout	N 4º 52’ 01.38”	E 6º 59’ 52.06”	A roundabout that links the East West Road, Rumuagholu village, Rumuodomaya village, Ikwerre Road and the Airport Road. It is also a major junction with a regular congestion of people, hawkers and

				transporters
3.	Rumuokwuta Junction	N 4º 50’ 15.00”	E 6º 59’ 18.05”	This junction connects Mgbuoba/NTA road and Ikwerre road. There is a market with petty trading and numerous shops around the Rumuokwuta Junction.
4.	Rumuola Junction	N 4º49’58.03”	E 7º00’ 17.28”	This junction connects the Rumuola Road, Aba Road and Stadium Road. This junction is always associated with high traffic congestion even with the construction of flyover.
5.	U.S.T roundabout	N 4º 48’ 21.10”	E 6º 59’18.39”	This is a roundabout linking Mile 3 on Ikwerre Road and University of Science and Technology Main Gate. There is the Mile 3 Motor Park and Mile 3 Market around this roundabout.
6.	Sangana Street	N 4º 47’ 20.46”	E 7º 00’10.59”	This is a street in Mile 1 Diobu around the Mile 1 Park. Sangana Street has been turned from a residential to a very busy commercial area. The street is known for major commercial activities that people come from various parts of Port Harcourt City to buy and sell.
7.	Old G.R.A - Control Location	N 4º 46’53.00”	E 7º00’42.00”	This area is a Government Reserved Area (G.R.A.) where the Government House is located in Port Harcourt. It is the residence of top government officials and some of the richest people in the city. It is serene, quiet and void of high volume traffic all day long; characterized with less commercial activities as well as less CO-inducing activities, hence its choice as a control sampling location

Plate 2 Sangana Street (4º 47^{I} 20.46^{II} N, 7º 00^{I} 10.59^{II} E)

Description of Sampling and Measuring Techniques

Continuous CO measurements were carried out for a period of 30 minutes at an interval of 5 minutes (6 monitoring times) 3 times daily (morning, afternoon and evening) twice a week for a total of 8-weeks sampling period in the months of August and September 2014 at the six selected sampling locations and control location.

PCMM05 Pyle® Carbon Monoxide Meter was used for measuring CO concentration in the study area.

The PCMM05 Pyle® Carbon Monoxide Meter detects the presence of CO and measures concentrations between 1-1000 parts per million (PPM). The Meter indicates the presence of CO in two ways: by a reading on the LCD in PPM and by a beeper tone.

The Microsoft Office Excel 2010 and SPSS 20.0 were used in the compilation and analysis of the CO data collected while CO distribution in the City is presented in GIS based map. To test for significant differences in the levels of CO obtained for different periods at each location, the one-way ANOVA was used.

Results and Discussion

Results

The results showing the mean concentrations of CO and the single factor ANOVA for the two months campaign are presented in **Tables 2-8**. A bar chart of the mean CO concentration for all the sampling locations (plus control location) and a GIS based-map of Port Harcourt showing spatial distribution of CO are presented in **Fig. 2 and 3** respectively.

Table 2 Mean CO concentration (ppm) measured at CHOBA JUNCTION and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	121.0	143.0	132.8	7.9	2.8	126.1	139.4	0.664	10.00
AFTERNOON	16	85.8	114.0	99.9	11.3	4.0	90.5	109.3		
EVENING	16	99.4	141.0	119.0	12.2	4.3	108.8	129.1		
Total	48	85.8	143.0	117.2	17.1	3.5	110.0	124.4		

Table 3 Mean CO concentration (ppm) measured at RUMUOKORO JUNCTION and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	87.0	113.0	99.8	10.5	3.7	91.0	108.6	0.942	10.00
AFTERNOON	16	43.1	71.1	58.0	8.8	3.1	50.6	65.4		
EVENING	16	81.5	115.0	96.3	10.8	3.8	87.3	105.4		
Total	48	43.1	115.0	84.7	21.6	4.4	75.6	93.8		

Table 4 Mean CO concentration (ppm) measured at RUMUOKWUTA JUNCTION and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	71.8	94.0	87.0	7.3	2.6	80.8	93.1	0.998	10.00
AFTERNOON	16	61.0	84.2	73.9	8.4	3.0	66.8	80.9		
EVENING	16	91.8	118.0	102.3	9.7	3.4	94.2	110.4		
Total	48	61.0	118.0	87.7	14.4	2.9	81.6	93.8		

Table 5 Mean CO concentration (ppm) measured at RUMUOLA JUNCTION and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	135.0	164.8	150.0	9.7	3.4	141.9	158.1	0.685	10.00
AFTERNOON	16	91.8	102.6	95.9	3.3	1.2	93.1	98.7		
EVENING	16	105.0	126.7	115.7	7.1	2.5	109.8	121.6		
Total	48	91.8	164.8	120.6	23.9	4.9	110.5	130.6		

Table 6 Mean CO concentration (ppm) measured at U.S.T ROUNDABOUT and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	94.8	120.0	108.1	8.6	3.0	100.9	115.2	0.158	10.00
AFTERNOON	16	102.0	147.0	117.6	13.9	4.9	106.0	129.3		
EVENING	16	110.0	149.5	123.6	12.0	4.2	113.6	133.6		
Total	48	94.8	149.5	116.4	13.0	2.6	111.0	121.9		

Table 7 Mean CO concentration (ppm) measured at SANGANA STREET and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	42.5	61.5	53.0	6.4	2.3	47.6	58.3	0.992	10.00
AFTERNOON	16	109.9	134.0	118.5	7.0	2.5	112.7	124.3		
EVENING	16	81.6	103.2	91.9	6.5	2.3	86.5	97.3		
Total	48	42.5	134.0	87.8	28.2	5.8	75.9	99.7		

Table 8 Mean CO concentration (ppm) measured at CONTROL (OLD GRA) and its significance

Period of day	N	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Significance	FMENV Limit (ppm)
							Lower Bound	Upper Bound		
MORNING	16	9.33	10.1	9.73	0.258	0.091	9.52	9.95	0.163	10.00
AFTERNOON	16	7.97	9.4	8.68	0.481	0.170	8.27	9.08		
EVENING	16	8.70	9.9	9.32	0.459	0.459	8.94	9.70		
Total	48	7.97	10.1	9.24	0.594	0.594	8.99	9.49		

Tables 2-8 below show the mean CO concentrations in the morning, afternoon and evening of all the locations which ranged from 53.0ppm to 150.0ppm as compared to the control location (Old G.R.A.) which shows a mean CO concentration of range of 9.73ppm, 8.68ppm and 9.32ppm for morning, afternoon and evening respectively and the Federal Ministry of Environment Regulatory Standard of 10.0ppm. The mean concentrations of CO in the morning for eight weeks varied from 53.0ppm to 150.0ppm in the following order: Rumuola Junction (150ppm)> Choba Junction (132.8ppm)> U.S.T. Roundabout (108.1ppm) > Rumuokoro Roundabout (99.8ppm)> Rumuokwuta Junction (87.0ppm)> Sangana Street (53.0ppm) while that of afternoon ranged from 58.0ppm to 118.5ppm with the order: Sangana Street (118.5ppm) > U.S.T. Roundabout (117.6)> Choba Junction (99.9ppm)> Rumuola Junction

(95.9ppm)> Rumuokwuta Junction (73.9ppm)> Rumuokoro Roundabout (58.0ppm). In the evening, mean CO concentrations ranged from 91.9ppm to 123.6ppm with U.S.T. Roundabout (123.6ppm)> Choba Junction (119.0ppm)> Rumuola Junction (115.7ppm)> Rumuokwuta Junction (102.3ppm)> Rumuokoro Roundabout (96.3ppm)> Sangana Street (91.9ppm). The mean concentrations of CO of the control location which is Old G.R.A. ranged in the order of 8.68ppm, 9.32ppm and 9.73ppm for afternoon, evening and morning respectively.

Tables 2-8 also show that the diurnal variation in CO distribution has no significant variation in the morning, afternoon and evening in Choba Junction, Rumuokoro Roundabout, Rumuokwuta Junction, U.S.T. Roundabout and Sangana Street (P>0.05) while for Rumuola Junction the P-value in the morning was less than 0.05 significant value and therefore shows significant difference in CO distribution in the morning. Considering the diurnal variation in CO distribution among the morning, afternoon and evening at all the sampling locations, there was no significant difference as all the P-values were higher than 0.05 significant levels.

Discussion

Diurnal Variations and Ambient Levels of CO

The CO data obtained in this study are presented in Tables 2-8. The Nigeria Federal Ministry of Environment daily statutory limit for CO is 10.0ppm (11.4mgm^{-3}) [29]. The World Health Organization [30] and United States Environmental Protection Agency [31] regulatory limit per day for CO is 9.0ppm (10.04mgm^{-3}). The CO concentration at the control location at different times of the day falls within national and international limits but at all the sampling locations, these threshold limits were violated. The degree of deviations from these limits varied for the different periods of the day. In Nigeria, it is customary to classify the day into three time zones-morning (from dawn to noon), afternoon (noon to 4pm), and evening (4pm to 7pm). In this study, these classifications were upheld so as to identify the critical pollution period of the day and then prescribe possible mitigation measures.

The control location has its highest CO level in the morning which is 9.73ppm while for other locations, the highest CO concentration varied between morning and evening hours. Choba Junction, Rumuokoro Roundabout and Rumuola Junction sampling areas had their highest CO concentration in the morning hours while Rumuokwuta Junction and U.S.T Roundabout sampling areas had their highest CO concentrations in the evening hours. Sangana Street sampling area was an exception. It had its highest CO concentrations in the afternoon hours. At Choba Junction sampling area, the morning hours CO range was 121.0-143.0ppm (a mean of 132.8ppm), while the afternoon and evening ranges were 85.8-114.0ppm (a mean of 99.9ppm) and 99.4-141.0 (a mean of 119.0ppm) respectively. At the Rumuokoro Roundabout sampling station, the morning, afternoon and evening CO ranges were 87.0-113.0ppm, 43.1-71.1ppm and 81.5-115.0 ppm respectively. At the Rumuola Junction sampling area, the morning, afternoon and evening CO ranges were 135.0-164.8ppm, 91.8-102.6ppm and 105.0-126.7ppm respectively. At Rumuokwuta Junction sampling area, the morning, afternoon and evening CO ranges were 71.8-94.0ppm, 61.0-84.2ppm and 91.8-118.0ppm respectively while U.S.T Roundabout sampling station had morning, afternoon and evening CO ranges of 94.8-120.0ppm, 102.0-147.0ppm and 110.0-149.5ppm respectively. Sangana Street sampling area had ranges of 42.5-61.5ppm, 109.9-134.0ppm and 81.6-103.2ppm in the morning, afternoon and evening respectively. Quite worrisome is the observation that the mean CO load calculated for the different periods of the day and the different sampling locations exceeded the CO load of the control location, the Nigeria Federal Ministry of Environment daily statutory limit, the World Health Organization and United States Environmental Protection Agency regulatory limit. Similarly, results obtained in an earlier research carried out by Ukpebor *et al.* [32] at Benin City, Nigeria (measured mean values 15.0ppm, 20.3ppm, 18.7ppm, 14.8ppm, and 28.3ppm) also by far exceeded both international and national standards. The factors responsible for the observed diurnal variations in the CO distributions include: differences in local urban traffic volume at different times of the day, traffic flow, commercial activities, open garbage dumps and meteorological conditions.

Usually, over 90 percent of the CO in city centres comes from vehicle [33]. In Port Harcourt, the traffic volumes is at its maximum during the morning hours as a result of the rush to get to the offices, schools, and the city markets that are built around bus stops and road junctions while the use of below 2KV generating sets (also known as ‘I better pass my neighbour’) due to commercial activities is responsible for the elevated level measured during the afternoon hours in Sangana Street. These early morning rush hours are further complicated by frequent traffic jams resulting from the high traffic density, poorly maintained roads, unfavourable traffic handling, and inadequate traffic discipline.

The diurnal variation in CO distribution at all the sampling locations, was found to be insignificant (P>0.05) (Tables 2-8). This suggests uniformity in traffic volume and flow at the different periods of the day. Consequently the traffic volume and jam are high all day long at these locations. In a study in Lagos [34], higher CO levels were measured in the morning and this was attributed to increased traffic at that time of the day. Moreover, the study reported non-compliance of the obtained CO data with the statutory 10ppm regulatory limit. Just as observed in Port Harcourt, most of the identified CO pollution in Lagos was caused by traffic; high and unfavourable traffic handling and discipline.

Furthermore, similar studies in an Austrian Valley [35], and a residential area in Kuwait [33], observed the same diurnal trend in CO distribution, with the highest load measured during the morning rush hour. However, unlike this study and in Benin [32], relatively low CO concentrations were measured and reported in these cities. In Kuwait, the reported minimum and maximum CO values were 0.00ppm and 19.77ppm, respectively, with a mean of 1.93ppm. In the Austrian Valley, the mean CO range was 0.10-1.40ppm. In this study, the minimum and maximum CO values were 42.5ppm and 164.8ppm. Our reported values were several factors higher than the values obtained in Kuwait and Austria, which have more industries and higher traffic density. Ukpebor *et al.*, [32] reported minimum and maximum values of 1.0ppm and 84.0ppm, respectively which are still lower than our reported values but higher than the values obtained in Kuwait and Austria. However, the values of a similar study done in Lagos by Uhuegbu [36] with a mean range of 45-835ppm, exceeds the values of this study. The main factor probably responsible for lower CO levels in Kuwait and Austria than in Port Harcourt and Benin City is more efficient traffic handling and discipline. Traffic jams and chaos, which eventually lead to high accumulation of CO in the atmosphere, are better managed in the developed cities of Kuwait and Austria.

Second and more important, is the influence of wind speed in the dispersion and dilution of the emitted CO. Generally, serious air pollution episodes in an urban environment are directly caused by sudden increases in the emission of pollutants, and unfavourable meteorological conditions. Ogba and Utang [37] stated that 53 percent of the wind speeds in Port Harcourt is less than 3.1 m/s suggesting generally low pollutant dispersion. This unfavourable wind condition may have reduced the ability of the atmosphere to disperse the high dose of emitted CO. In Kuwait and Austria, wind speeds are higher; Abdul-wahab and Bouhamra [33] found a marked drop in the mean CO concentrations with stronger wind speeds. The inverse relation between wind speed and pollution levels resulting from traffic has been reported [38]; [39]. Tsai *et al.* [40] stated that in case of wind speed below 2m/s, the concentration of pollutants increase and becomes uniformly distributed around areas within the sources zones, while stagnant weather conditions with low wind speed contributes to accumulation of pollutants at the ground level [41]; [42].

Spatial Variations

The maximum, minimum and mean CO concentrations determined for the different sampling sites are as shown in Tables 2-8. Amongst all the sampling locations, Rumuola Junction, with a value of 120.6ppm, had the highest mean CO concentration. This is due to the fact that Rumuola Junction is a major interchange in Port Harcourt City, therefore making it a major daily route to many residents as it is a connecting junction to many parts of the City and major roads such as the Rumuola Road, Aba Road and Stadium Road etc. This junction is always associated with high traffic congestion even with the flyover. Rumuola junction is always busy as it is also a major Motor Park in Port Harcourt and a centre associated with commercial activities. The next highest mean CO levels was recorded at Choba Junction, with a value of 117.2ppm; closely followed by U.S.T Roundabout with a value of 116.4ppm. The least value was recorded at Rumuokoro Junction, with a mean concentration of 84.7ppm. The main factors probably responsible for these variations in urban air pollution which could be responsible for observed spatial distribution of CO levels are emission rate, emission strength, emission conditions and atmospheric dispersion [43]. According to Uhuegbu [36] the temperature of the environment is also a determining factor that affects the measurement of CO in an urban city. All the sampling locations had high ambient temperatures. In this study, vehicular exhaust is identified as the major source of CO in the atmosphere. Consequently, the identified significant spatial variations in the obtained CO data could be attributed to the differences in traffic frequency at the different sampling locations. The CO data obtained could also be attributed to meteorological conditions. This study was carried out in the wet season (August/September), CO will be higher in the dry season because rain dissolves CO to form carbonic acid.

Environmental and Health Implications of Measured CO Values

In Nigeria and the international community, there are air quality guidelines in force in order to control and reduce the impacts of air pollution on the human health as well as other negative consequences e.g. vegetation damage, climate change, etc. The national daily threshold limit for CO is 10.0ppm while the WHO regulatory limit is 9.0ppm as stated earlier. However, the measurement campaign presented herein as stated earlier clearly exceeded both national and international limits at all the sampling sites. This observation therefore calls for urgent precautionary measures. For instance, in Cairo, CO concentrations greater than the WHO guidelines for air quality values were recorded in streets having moderate-to-heavy traffic densities in residential areas and in the city center [44]. These concentrations resulted in high levels of carboxyhaemoglobin (COHb) in the blood of traffic policemen, sometimes reaching more than 10%. The Cairo study also found a significant direct relationship between ischemic heart disease and COHb levels in Cairo traffic policemen. Henry *et al.*, [45] reported that extended exposure to CO can lead to significant loss of lifespan due to heart damage. Nigeria has one of the lowest average life expectancies (44years) in the world. The idea that CO poisoning is a contributor to the abysmal low life expectancy in Nigeria can therefore not be completely jettisoned, especially when sites used for this study are heavily populated by petty traders, hawkers, policemen and transporters who daily spend several hours at these locations. Furthermore, CO is an indirect greenhouse gas that has the potential to increase the amount of other greenhouse gases such as methane, and eventually oxidizes into the main greenhouse, carbon dioxide, thus contributing indirectly to global climate change and its attendant consequences.

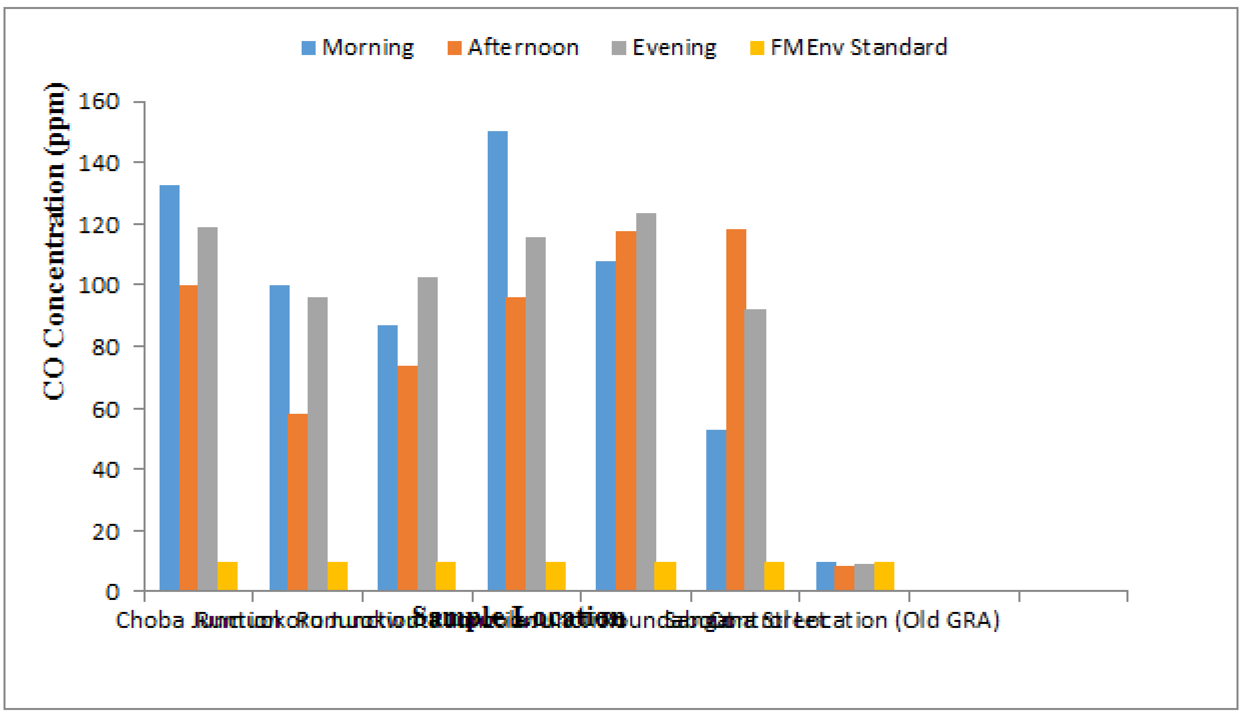

Figure 2 Mean CO Concentration at the Six Sampling Locations and the Control Location

Figure 3 below shows a GIS-based map of the percentage concentration at the various sampling locations in Port Harcourt. At each location, the height of the red bar depicts the percentage level of CO concentration out of the total CO level measured at all the sampling locations.

Rumuola Junction showed the highest in CO concentration as the CO data at this location is 20%, followed by Choba Junction and U.S.T. Roundabout which are 19% each. Rumuokoro Roundabout, Rumuokwuta Junction and Sangana Street measured 14% each.

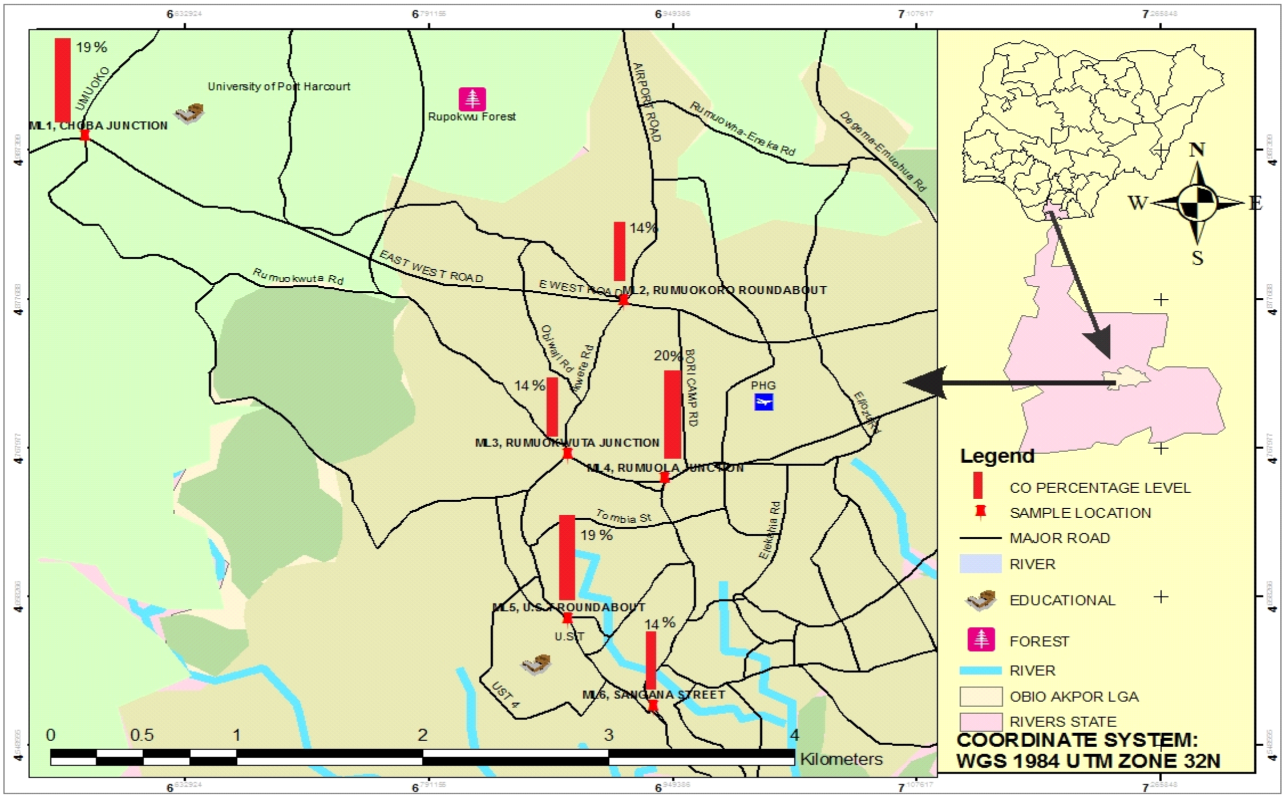

Figure 3 A GIS Base-Map Showing the Percentage CO Concentration at the various Sampling Locations in Port Harcourt

Conclusions

This study was conducted to assess Carbon Monoxide (CO) levels in Port Harcourt using PCMM05 Pyle® Carbon Monoxide Meter for measuring CO concentration. A total of seven locations were sampled one of which was a control location. It was observed that the baseline ambient level of CO in many parts of this city is quite high and exceeds the available national and international regulatory limits. This therefore calls for urgent precautionary measures, so as to protect the population against the adverse impacts of CO pollution. Diurnal variations were noticed in the data generated with the highest concentrations recorded in the morning and evening. Vehicular exhaust was identified as the main source of CO in the city. Frequent traffic jams resulting from high traffic density, poorly maintained roads, inefficient traffic handling, and inadequate traffic discipline were identified as being responsible for the high accumulation of CO in the locations selected. Consequently, the identified significant spatial variations in the obtained CO data could be attributed to the differences in traffic frequency and commercial activities at the different sampling locations. The prevalent low wind speed in the City was also observed to be responsible for the poor dilution and dispersion of the emitted CO. This work was limited by the inability to capture nighttime CO levels due to security risk.

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References

[1] Onursal, B. and Gautam, S., Vehicular air pollution: experiences from seven Latin American urban centers. World Bank Technical Paper No. 373. The International Bank of Reconstruction and Development, Washington DC, USA, **1997**.

[2] Chan, L. Y., Lau, W. L., Zou, S. C., Cao, Z. X., & Lai, S. C., Exposure level of carbon monoxide and respirable suspended particulate in public transportation modes while commuting in urban area of Guangzhou, China. *Atmospheric Environment*, **2002**, **36**: 5831– 5840.
[3] Colvile, R. N., Hutchinson, E. J., Mindel, J. S. & Warren, R. F., The transport sector as a source of air pollution. *Atmospheric Environment*, **2001**, 35: 1537–1565.
[4] Mukherjee, P. & Viswanathan, S., Carbon monoxide modeling from transportation sources. *Chemosphere*, **2001**, 45: 1071–1083.
[5] Sentian, J., 2003. Study of temporal and spatial variations of nitrogen dioxide (NO_2), ozone (O_3) and Carbon monoxide (CO_2) in Kota Kinabalu City. B-08-03-01-ER/U14, Universiti Malaysia Sabah.
[6] Bogo, H., Negri, R. M. & San Roman, E., Continuous measurement of gaseous pollutants in Buenos Aires city. *Atmospheric Environment*, **1999**, 33: 2587–2598
[7] Chan, L. Y. and Liu, Y. M., Carbon monoxide levels in popular passenger commuting modes traversing major commuting routes in Hong Kong. *Atmospheric Environment*, 2001, **35**: 2637–2646.
[8] Comrie, A. C. & Diem, J. E., Climatology and forecast modeling of ambient carbon monoxide in Phoenix Arizona. *Atmospheric Environment*, 1999, 33: 5023–5036.
[9] Sharma, P., Khare, M. & Chakrabarti, S. P., Application of extreme value theory for predicting violations of air quality standards for an urban road intersection. *Transportation Research Part D*, 1999, 4: 210-216.
[10] Sivacoumar, R. & Thanasekaran, K., Line source model for vehicular pollution prediction near roadways and model evaluation through statistical analysis. *Environmental Pollution*, **1999**, 104: 389–395.
[11] Saunders, S. M., Jenkin, M. E., Derwent, R. G. and Pilling, M. J., World Wide Web Site of a Master Chemical Mechanism (MCM) for Use in Tropospheric Chemistry Models. *Atmos. Environ.*, **1997**, 31: 1249.
[12] Kley, D., Kleinmann, M., Sanderman, H. and Krupa, S., Photochemical Oxidants: State of the Science. *Environ. Pollut.* **1999**, 100: 19–42.
[13] Ramon, M. M., Zabonetti, A. and Schwartz, J., The Effect of Ozone and PM10 on Hospital Admissions for Pneumonia and Chronic Obstructive Pulmonary Disease: A National Multicity Study. *Am. J. Epidemiol.* **2006**, 163: 579–588.
[14] Davis, M. L. and Cornwell, D. A., Introduction to Environmental Engineering, 3rd edition, **1998**, 471-475, WCB/McGraw-Hill, New York.
[15] World Health Organization, *Carbon Monoxide*; *Environmental Health Criteria 213*. Geneva: World Health Organization, **1999**.
[16] Varon J., Marik P. E., Fromm R. E., and Gueler A., Carbon Monoxide Poisoning: A Review for Clinicians. *The Journal of Emergency Med*, 1999, 17: 87-93.
[17] Maynard R. L. and Waller R., Carbon Monoxide. In: Holgate S. T., Samet J. M., Koren H. S. and Maynard R. L. (eds) “Air Pollution and Health.” Academis Press: Harcourt Brace & Company, Publishers, **1999**, pp. 749-796.
[18] Smith R. P., “Toxic Responses of the Blood”. In: Klaassen DD, Amadur MO and Doull J (eds) Casarett and Doulss's Toxicology, 3rd edn. New York: Mc Millan Publishing Company, **1986**, pp. 223-240.
[19] Fawcett, T. A., Moon, R. E., Fracica, P. J., Mebane, G. Y., Theil, D. R., Piantadosi, C. A., Warehouse workers' headache - Carbon monoxide poisoning from propane-fueled forklifts, *Journal of Occupational Medicine*, **1992**, Vol. 34, pp. 12–15.
[20] Lewis, G., Neal, F., Neal, L., Mary, A. H., Robert, H., and Lewis, N., Carbon Monoxide. *Goldfrank's toxicologic emergencies* (7th ed.), New York: McGraw-Hill. **2002**, pp. 1689–1704
[21] Davutoglu, V., Chronic carbon monoxide exposure is associated with the increases in carotid intima-media thickness and C-reactive protein level, *Tohoku Journal Exp. Med.*, **2009**, Vol. 219, pp. 201–6.
[22] Shephard, Roy, *Carbon Monoxide The Silent Killer*, Springfield Illinois: Charles C Thomas, **1983**, pp. 93–96.
[23] Allred, E. N., Bleecker, E. R., Chaitman, B. R., Dahms, T. E., Gottlieb, S. O., Hackney, J. D., Pagano, M., Selvester, R. H., Walden, S. M., and Warren, J., Short-term effects of carbon monoxide exposure on the exercise performance of subjects with coronary artery disease, *The New England Journal of Medicine*, **1989**, *Vol.* 321 (21), pp. 1426–1432
[24] Goldstein, M., Carbon Monoxide Poisoning. *Emergency Nursing*, **2008**, Vol. 34, No. 6, pp. 538-542.

[25] Chichkova, R. I. and Prockop, L. D., Carbon Monoxide Intoxication: An Updated Review. *Neurological Sciences*, **2007**, Vol. 262, No. 1-2, pp. 122-130.
[26] Walker, E. and Hay, A., Carbon Monoxide Poisoning. *BMJ*, **1999**, Vol. 319, No. 7217, pp. 1082-1083.
[27] Our Nation's Air of United States, **2008.** www.epa.gov/airpollution
[28] DipCreek Magazine, Port Harcourt, The Garden City, **2014**.
[29] Federal Ministry of Environment, Guidelines and Standards for Environmental Pollution Control in Nigeria, **2000**.
[30] World Health Organization, *Carbon Monoxide, in Air Quality Guidelines*, **2000**.
[31] U. S. Environmental Protection Agency (EPA), NAAQS United States Government Printing Office, **1993**.
[32] Ukpebor, E. U., Ukpebor, J. E., Eromomene, F., Odiase, J. I., and Okoro, D., Spatial and Diurnal Variations of Carbon Monoxide (CO) Pollution from Motor Vehicles in an Urban Centre. *Polish Journal of Environmental Studies*, **2009**, 19(4): 817-818.
[33] Abdul-Wahab, S. A. and Bouhamra, W. S., Diurnal Variations of Air Pollution from Motor vehicles in Residential area. *Intern. J. Environ. Studies*, **2004**, 61, 73.
[34] Baumbach, G., Vogt, U., Hein, K. R. G., Oluwole, A. F., Ogunsola, O. J., Olaniyi, H. B., and Akeredolu, F. A., Air pollution in a large tropical city with a high traffic density-results of measurements in Lagos, Nigeria. *The Science of the Total Environment*, **1995**, 169, 25.
[35] Schnitzhofer, R., Beauchamp, J., Dunkl, J., Wisthaler A., Weber A., and Hansel A., Long-term measurements of CO, NO, NO_2, benzene, toluene, and PM_{10} at a motor way location in an Austrian Valley. *Atmos. Environ.*, **2008**, 42, 1012.
[36] Uhuegbu, C. C., Measurement of Carbon Monoxide (CO) Emissions in Some Selected Area in Lagos State. *Journal of Scientific Research and Reports*, **2013**, 2(2): 536-543.
[37] Ogba, C. O. and Utang, P. B., Air Pollution Climatology in Spatial Planning for Sustainable Development in the Niger Delta, Nigeria. FIG Working Week 2009 Surveyor's Key Role in Accelerated Development, Eilat, Israel, 3-8 May **2009**.
[38] Adamopoulos, A. D., Kambezidis, H. D. and Sipsas, A. B., Meteorological factors that influence CO concentration in Athens basin. *Fresenius Environ. Bull.*, **1996**, 5, 351.
[39] Hickman, A. J., Atmospheric Pollution Measurements in West London. Lab Report 709, (Transport and Road Research Laboratory, TTRL, Crowthorne), **1976**.
[40] Tsai, C., Aggarwal, S. G., Chang, C. & Hung, I., Concentration profiles of acidic and basic air pollutants around an industrial part of Taiwan. *Water, Air and Soil Pollution*, **2004**, 151 (1-4): 287-304
[41] Jacobs, David E.; Clickner, Robert P.; Zhou, Joey Y.; Viet, Susan M.; Marker, David A.; Rogers, John W.; Zeldin, Darryl C.; Broene, Pamela *et al.*, "The prevalence of leadbased paint hazards in U.S. housing". *Environmental Health Perspectives*, **2002**, 110 (10): A599– 606.
[42] Hung, I., Deshpande, C. G., Tai, C. & Huang, S., Spatial and temporal distribution of volatile organic compounds around industrial park of Taiwan. *Aerosol and Air Quality Research*, **2005**, 5 (2): 141- 253.
[43] Baumbach, G., Air pollution caused by vehicular emissions in urban areas and highways. Staub-Reinhaultung derluft, **1993**, 53,267
[44] Ukpebor, E. E. and Ahonkhai, S. I., Spatial and Temporal Variation of Nitrogen dioxide concentration in Benin City using passive samplers. *Nig. J. Appl. Sci*,. **2000**, 18, 72.
[45] Henry, C. R., Satran, D., Lindgren, B., Adkinson, C., Nicholson, C. I., and Henry T. D., Myocardial injury and long-term mortality following moderate to severe CO poisoning. JAMA., **2006**, 295 - 398.

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