Original Research

Spatial and Diurnal Variations of Carbon Monoxide (CO) Pollution from Motor Vehicles in an Urban Centre

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Abstract

In the months of May and June, 2008, about 20 deaths from CO poisoning were reported in Nigeria. Ignorance along with lack of information and data about this toxic substance can be blamed for these deaths. In this study, a preliminary attempt is made to evaluate the diurnal trend in CO generation and distribution at several road junctions and motor parks in Benin City. A dosimeter (*in situ* method) that uses an electrochemical sensor to measure ambient levels of CO was used. At the 5 sampling locations selected, very high CO concentrations were measured with a mean range of 14.8-28.3 ppm. The 10.0 ppm statutory limit set by the Federal Ministry of the Environment, Housing and Urban Development (FMEH&UD) was clearly exceeded.

Diurnal variations in the data were statistically significant ($P < 0.05$), with the highest CO concentrations recorded in the morning hours. Spatial variations were also statistically significant, with the highest mean CO load of 28.3 ppm measured at Sokponba road junction. Vehicular exhaust was identified as the main CO source in the city. Frequent traffic jams resulting from poorly maintained roads, high traffic density, unfavourable traffic handling, inadequate traffic discipline and very low wind speed are identified as the main factors responsible for the high emissions, accumulation, and low dilution and dispersion of the generated CO.

Keywords: carbon monoxide, *in situ*, electrochemical, dosimeter

Introduction

In the months of May and June 2008, about 22 deaths from CO poisoning were reported by the Nigerian media. The cause of death was suffocation by CO fumes from power generators. In Nigeria, the electricity supply is highly erratic, with a resulting increase in the use of generators as the main source of electricity and, consequently, a higher probability of CO poisoning.

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Mortality and morbidity rates in Nigeria rank among the highest in the world, with the average life expectancy currently at 44 years. Before now, most of the deaths in the country had been traceable to malaria fever and complications from HIV/AIDS. However, if new statistics for deaths from CO poisoning are computed and evaluated alongside deaths from other causes, then urgent precautionary measures would have to be put in place to stem this new trend. Intervention programmes and policies for CO control and abatement are difficult to formulate, because available information on atmospheric (outdoor and indoor) levels of

Table 1. CO Sampling sites, descriptions and coordinates.

S/N	Site Code	Coordinates	Site description
1.	AQ AP	N 06º 21.003’ E 005º 39.643’	4 m from Agbor motor park. A busy park with daily traffic volume of about 2,200 cars/hour
2.	AQ RR	N 06º 20.440’ E 005º 37.339’	4 m from ring road with a traffic volume of about 3,200 cars/hour.
3.	AQ NB	N 06º 20.939’ E 005º 37.925’	3 m from New Benin road junction; about 3,500 cars/hour
4.	AQ EC	N 06º 20.631’ E 005º 38.237’	3 m from a busy road junction - 2nd East Circular road junction with traffic volume of about 2,000 cars/hour
5.	AQ SR	N 06º 19.243’ E 005º 38.240’	3 m from Sokponba road junction by Ekiosa Market with Traffic volume of about 4,200 cars/hour.

CO are rather very scanty. Furthermore, educational programmes are also difficult to design and implement because the population is largely illiterate. The dearth of information on CO status in our atmosphere is attributable to the following factors:

(a) The high cost of the non dispersion infrared (NDIR) continuous monitor for CO, recommended by the World Health Organization (WHO) [1] and the Nigerian Federal Ministry of the Environment (FMEH&UD) [2].
(b) Erratic power supply that makes the use of the NDIR nearly impossible.
(c) Non-availability of diffusion tubes for CO as a result of its low solubility, and
(d) Lack of trained personnel in the area in air pollution studies.

However, quite fortunately and timely, the CO dosimeter (BK precision CO monitor) is one piece of air quality monitoring equipment supplied through the assistance of the World Bank to the Edo State Ministry of the Environment in Nigeria in 2004. The sampler has a detection range of 0-1,000 ppm, an accuracy of ±5%, a response time of < 70 sec and a resolution of 1 ppm.

Carbon monoxide is considered a silent killer because it is odourless and colourless, making it virtually undetectable. Carbon monoxide binds reversibly with haemoglobin and inhibits oxygen uptake. Long-term (chronic) exposure to low levels of CO may produce heart disease and damage to the nervous system. Exposure of pregnant women to CO may cause low birth weight and nervous system damage to the offspring [3]. Apart from its lethality, CO is an indirect greenhouse gas that increases the amount of other greenhouse gases and eventually oxidizes into the main greenhouse gas, CO_2.

Industrial plant exhaust, incomplete combustion of carbon-containing fuels, smoking of cigarettes, burning of waste, defective heaters, defective stoves, ovens and especially vehicular exhaust are the main anthropogenic source group of CO in the environment [3]. As a result of the health and environmental significance of CO, this study is therefore designed, among other things, to:

(i) provide baseline levels of this pollutant in the atmosphere of Benin City,
(ii) evaluate the diurnal trend of this pollutant,
(iii) acquire data for comparison to regulatory standards,
(iv) provide data for health practitioners that would engender epidemiological studies, and
(v) generate data that would assist in policy formulation for the control and amelioration of CO poisoning.

Data Collection and Analysis

Sampling Area/Sites

This study was carried out in Benin City, the capital of Edo State, which is located at 6.5ºN and 5.8ºE. The city is ancient, with a population of about 1,137,770 (census of 1991). The climate of Benin City is tropical with two major seasons, wet (April-October) and dry (November-March). Rainfall is bimodal, peaking usually in July and September, with a brief drop in August. The mean annual rainfall is 2,300 mm, while the average temperature is 32ºC. The mean relative humidity is about 70%. Benin City is a commercial city with few petroleum and allied industries. Traffic volume is high in the city year round, because the city is a gateway to the other parts of the county. Emissions from heavily loaded transportation vehicles, badly maintained automobiles that run on diesel and leaded fuel, industrial emissions and open burning of refuse waste are largely responsible for the air pollution problems in the city. Previous air quality and noise assessment of the city revealed excessive levels of suspended particulate matter [4] and noise burden [5].

In order to acquire a comprehensive baseline distribution of this pollutant in the city, five sampling sites were carefully selected to represent all the quarters of the City with high levels of air pollution. The sites were created at roadside verges, junctions and motor parks (Table 1). The monitoring sites were geo-referenced using a GARMIN GPS MAP 765 chart plotting receiver.

CO Sampler and Sampling Procedure

CO concentrations were measured using a CO dosimeter (model 627, BK Precision USA). This sampler has a range from 0 to 1,000 ppm, with a sensitivity of 1 ppm, an accuracy of ±5%, operating temperature from 0 to 40ºC and operating relative humidity from 15 to 90%. It is equipped with a sensor that has an electrochemical sensing electrode and a counter electrode. The sensor has a permanent irreplaceable filter built inside the sensor to filter out trace concentrations of SO_2, NO_2, and most hydrocarbons. The CO being diffused into the sensor reacts with the special catalyzed sensing electrode to produce electrons. A built-in circuit amplifies the signal into a millivolt output that is displayed on a liquid crystal display (LCD) panel as CO concentration in ppm. The CO monitor was calibrated before deployment and during the monitoring campaign by ensuring that the zero and span of the dosimeter were checked at regular intervals using zero air and a standard CO concentration.

This sampling approach has been used by several authors [6, 7] because of the following positive attributes: low cost, high accuracy and sensitivity, no special training before usage, direct readout, wide spatial coverage and no dependence on electricity.

Sampling Routine

Continuous CO measurements were carried out in the dry season months of November 2006 – February 2007. The CO concentrations were determined on a half-hourly basis from 8 a.m. to 7 p.m., four times a week for a total of a 16-week sampling period at the five selected monitoring sites at a height of ~1.5-2.0 m from ground level.

Air temperatures and humidity were measured simultaneously before and after the CO measurements using a humidity/temperature meter, with resolutions of 0.1% RH and 0.1ºC (model RS 1364, RS components Ltd, UK). At the same time, wind speeds were measured using an LM -8000 anemometer with a resolution of 0.1 ms^{-1} (Heatmiser UK Ltd).

Statistical Analysis: Microsoft Office Excel 2007 & SPSS/6.0

The "Analysis ToolPak" available in Microsoft Office Excel 2007 provides data analysis tools for statistical and engineering analysis. It was used in the analysis of the CO data collected. To test for significant differences in the levels of CO obtained for different periods at each location, the one-way ANOVA was conducted. In order to test the significance of the interaction between period and location a two-way ANOVA was also conducted.

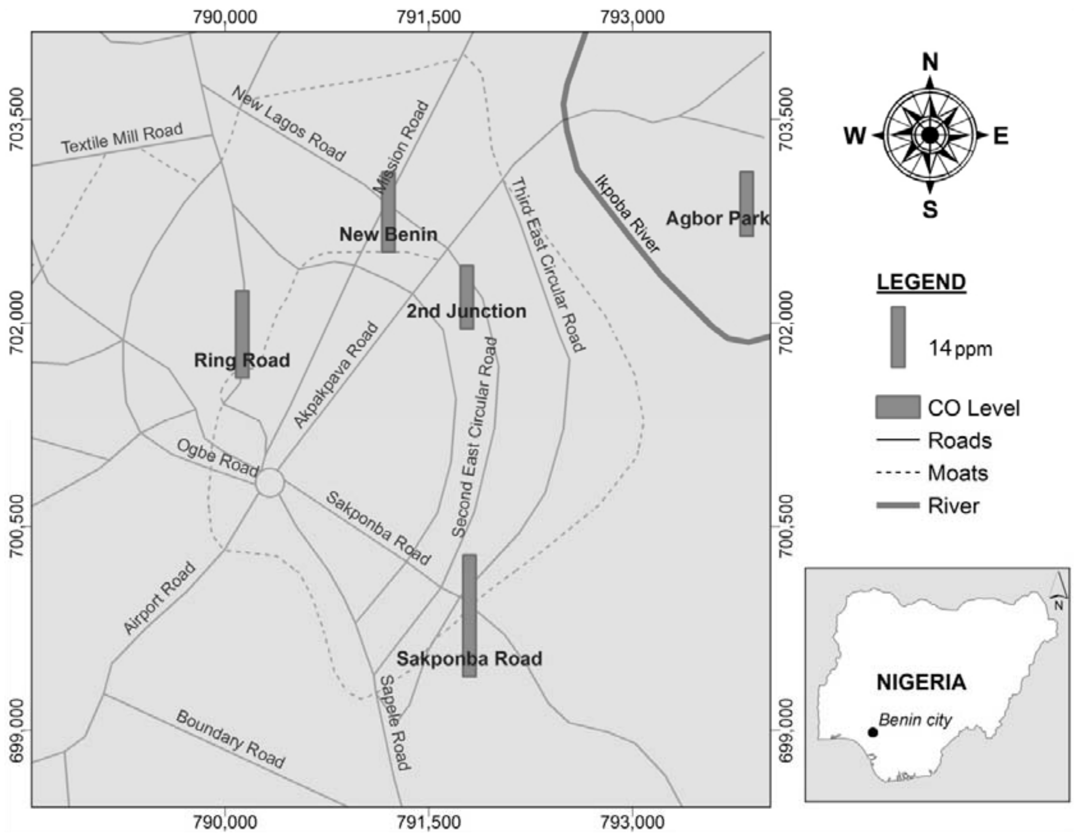

Fig. 1. GIS base-map of Benin City showing spatial distribution of CO.

Table 2. Single factor ANOVA for diurnal distributions of CO levels.

Source of variation	SS	df	MS	F	P-value	F-crit
Agbor Park						
Between Groups	1,281.333	2	640.6667	9.905253	0.00033219	3.2381
Within Groups	2,522.5	39	64.67949			
Total	3,803.833	41				
Ring Road						
Between Groups	188.9048	2	94.45238	2.901649	0.06686754	3.2381
Within Groups	1269.5	39	32.55128			
Total	1,458.405	41				
New Benin						
Between Groups	2,813.19	2	1,406.595	28.49408	0.00000002	3.2381
Within Groups	1,925.214	39	49.36447			
Total	4,738.405	41				
2nd Junction						
Between Groups	579.4762	2	289.7381	7.533908	0.00171180	3.2381
Within Groups	1,499.857	39	38.45788			
Total	2,079.333	41				
Sokponba Road						
Between Groups	7,192.333	2	3596.167	21.95604	0.00000041	3.2381
Within Groups	6,387.786	39	163.7894			
Total	13,580.12	41				

Results and Discussion

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. The CO data obtained in this study are presented in Figs. 1 (a GIS map of the city showing spatial CO distribution) and 2, and Table 2. The measured meteorological data are shown in Table 3.

Diurnal Variations and Ambient Levels of CO

The Nigeria Federal Ministry of Environment Statutory limit for CO is 10.0 ppm (11.4 mgm^{-3}) [2]. The World health Organization [1] and United States Environmental Protection Agency [8] regulatory limit for the same pollutant is 9.0 ppm (10.0 mgm^{-3}). At all the sampling stations and at different times of the day, these threshold limits were violated. However, 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 4 p.m.) and evening (4 p.m. to 7 p.m.). In this study, these classifications were upheld so as to identity the critical pollution period of the day and then prescribe possible mitigation measures. For almost all the sites, the highest CO concentration was measured in the morning hours. For example, at the Agbor Park sampling area, the morning hours CO range was 9.0-45.3 ppm, while the afternoon and evening ranges were 5.5- 8.3 ppm and 6.0-18.3 ppm, respectively. At the ring road sampling station, the morning, afternoon and evening CO ranges were 18.3-35.5 ppm, 10.8-21.5 ppm and 11.9-21.5 ppm, respectively. Similar trends were observed for the other three sampling locations. Quite worrisome is the observation that the mean CO load calculated for the different periods of the day and the different sampling sites exceeded all national and international CO statutory limits.

The results of the single factor ANOVA analysis (Table 2) of the CO data generated at different times of the day revealed significant statistical differences ($P < 0.05$) for Agbor park, New Benin, 2nd junction and Sokponba road sampling sites. The factors responsible for the observed diurnal variations in the CO distributions include:

(i) differences in local urban traffic volume at different times of the day,
(ii) traffic flow, and
(iii) meteorological conditions.

Table 3. Meteorological data during the sampling period.

Sampling Site	Ambient Temp. (ºC)		Relative Humidity (%)		Wind Speed (ms^{-1})	
	Range	Mean	Range	Mean	Range	Mean
Agbor Park	29.1-31.3	30.3	68.2-82.3	77.9	0.0-0.7	0.3
Ring Road	28.0-32.2	30.1	68.4-80.4	76.6	0.0-0.9	0.4
New Benin	27.9-32.2	31.0	67.3-73.7	72.3	0.0-1.2	0.6
2nd Junction	28.3-33.4	30.9	68.4-78.0	69.4	0.1-1.5	0.5
Sokponba Road	27.2-36.3	32.4	63.9-74.4	65.8	0.0-0.8	0.4

Usually, over 90 percent of the CO in city centres comes from vehicles [9]; in Benin City, the traffic volume 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.

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.

At the ring road sampling location, the diurnal variation in CO distribution was found to be insignificant ($P > 0.05$), (Table 2). This suggests uniformity in traffic volume and flow at the different periods of the day. This assumption is valid, because both local and transit traffic pass through this part of the city. Consequently, the traffic volume and jam are high all day long at this location. The observed excessive enrichment in CO levels and the differences in its diurnal cycle by 80% at the sampling sites is consistent with previous findings [10] in Lagos, the formal capital of Nigeria. In that study, 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 the non-compliance of the obtained CO data with the statutory 10 ppm regulatory limit. Just as observed in Benin, 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 [11] and a residential area in Kuwait [9], observed the same diurnal trend in CO distribution, with the highest load measured during the morning rush hour. However, unlike in our study, relatively low CO concentrations were measured and reported in these cities. In Kuwait the reported minimum and maximum CO values were 0.0 ppm and 19.77 ppm, respectively, with a mean of 1.93 ppm. In the Austrian Valley, the mean CO range was 0.10-1.40 ppm. In our study, the minimum and maximum CO values were 1.0 ppm and 84.0 ppm, respectively. Our reported CO values are several factors higher than the values obtained in Kuwait and Austria, which have more industries and higher traffic density. The main factor probably responsible for lower CO levels in Kuwait and Austria than in 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. In Benin City, the wind speed is generally low all year round. For most of the day the wind is still. In this study, wind speed of 0.0-1.5 ms^{-1} was recorded at all sampling sites (Table 3). 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 [9] found a marked drop in the mean CO concentrations with stronger winds. The inverse relation between wind speed and pollution levels resulting from traffic has been reported [12, 13].

Spatial Variations

The maximum, minimum, and mean CO concentrations determined for the different sampling sites are shown in Table 4. Spatial variations in the CO data were significant ($P < 0.05$) (Table 5), with the highest mean concentrations of 28.3 ppm reported for Sokponba Road sampling station, the next highest mean CO load at Ring Road with a mean value of 20.3 ppm, and the least mean concentration of 14.8 ppm at the 2nd Junction sampling site (Table 4). Factors responsible for the spatial variations in urban air pollution, which could also be responsible for the observed spatial distribution in the CO levels, are emission rate, emission strength, emission conditions and atmospheric dispersion conditions [14]. All the sampling sites had identical dispersion conditions characterized by low wind speeds, high ambient temperatures and humidity (Table 3). The very low wind speed of between 0.0-1.5 ms^{-1} has already been explained as being responsible for the poor dispersion and dilution of CO at the sampling sites.

In our 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 sites. Traffic census conducted in this study showed differences in traffic density at the different sites. For instance, Sokponba Road monitoring site with the

Table 4. Mean CO levels measured at the sampling sites.

Site	Code	CO concentration in ppm				No. of samples
		Max.	Min.	Mean	SD	
Agbor Park	AQ AP	56.0	4.0	15.0	13.4	1,024
Ring Road	AQ RR	52.0	9.0	20.3	3.6	1,024
New Benin	AQ NB	43.0	1.0	18.7	1.8	1,024
2nd Junction	AQ EC	45.0	7.0	14.8	5.5	1,024
Sokponba Road	AQ SR	84.0	9.0	28.3	21.1	1,024

Table 5. Two-Factor ANOVA with replication for spatial variations in CO levels.

Source of Variation	SS	df	MS	F	P-value	F-crit
Location	2,961.8	4	740.46	4.9638	0.0009	2.4363
Period	389.39	13	29.953	0.2008	0.9988	1.7907
Interaction	4,386.7	52	84.36	0.5655	0.99	1.4353
Within All	20,884	140	149.17			
Total	28,622	209				

highest traffic census of about 4,200 cars/hour (Table 1), also recorded the highest mean CO concentration. This trend was observed for the other sampling locations. This positive correlation between traffic density and an air pollutant had earlier been reported [15] for the city of Benin.

Mean CO Values and Guideline Limits

In Nigeria, there are air quality guidelines in force in order to control and reduce the impacts of air pollution on human health as well as other negative consequences e.g. vegetation damage, climate change, etc. The national daily threshold for CO is 10.0 ppm (11.4 mgm^{-3}) [2]. The WHO regulatory limit for the same pollutant is 9.0 ppm (10.0 mgm^{-3}) [1]. The measurement campaign presented herein shows that these limits were clearly exceeded 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 centre [16]. 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 [17]. A recent report concludes that extended exposure to CO can lead to significant loss of lifespan due to heart damage [3]. As already indicated, Nigeria has one of the lowest average life expectancies (44 years) 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, 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 (methane), and eventually oxidizes into the main greenhouse gas, CO_2, thus contributing indirectly to global climate change and its attendant consequences.

Conclusions

This study evaluated the diurnal variation of CO, a critical pollutant in a large tropical city. It was observed that the baseline ambient level of CO in this city exceeds the

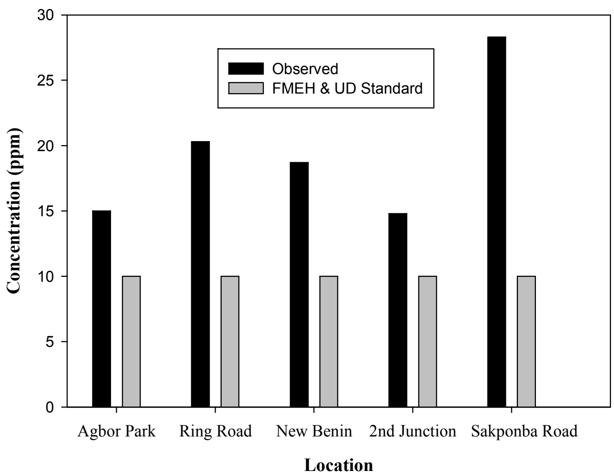

Fig. 2. Mean daily CO concentration versus regulatory standard.

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 during morning hours. Vehicular exhaust was identified as the main source of CO in the city. Frequent traffic jams resulting from high traffic density, unfavourable traffic handling, and inadequate traffic discipline were identified as being responsible for the high accumulation of CO in the sites selected. 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 as a result of security risks, and also the inability to extend this study to other cities in Nigeria because of financial and logistical handicaps.

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