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# Diurnal variations of carbon monoxide (CO) pollution from motor vehicles in an urban centre in Nigeria using a CO dosimeter

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## ABSTRACT

In the months of May and June, 2008, about 20 deaths from CO poisoning were reported in Nigeria national dailies. Ignorance and dearth of information and data about this toxic substance have been suggested for this ugly trend. In this study, a preliminary attempt was 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) which uses an electrochemical sensor to measure ambient levels of CO was used. At the 5 sampling locations created, 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 Environment, Housing and Urban Development (FMEH&UD) was clearly exceeded.

Diurnal variations in the data were significant ($P < 0.05$) with the highest CO concentrations recorded in the morning hours. Spatial Variations were also 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 were identified as largely 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 was reported in the Nigerian national dailies[15,16,19,23,24]. The cause of death was as a result of suffocation by CO fumes from power generating sets. In Nigeria, electricity supply is highly erratic and epileptic with a resulting increase in the use of generating sets as the main source of electricity and consequently a higher probability of CO poisoning.

Mortality and Morbidity rates in Nigeria rank amongst the highest in the World, with the average life expectancy currently put at 44 years[18]. Before now, most of the deaths in the country had been attributed mainly to malaria and complications from HIV/AIDS. However, if the new statistics for deaths from CO poisoning is computed and evaluated along side deaths from other causative factors, 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 CO are rather very scanty. Enlightenment programmes are also difficult to design and implement, because the population is largely illiterate. The lack of information on CO status in Nigeria 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)[26] and Nigeria Federal Ministry of Environment (FMEH&UD)[6].
(b) erratic and epileptic power supply, which renders the use of the NDIR near 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 of air pollution studies.

However, quite fortunately and timely, CO Dosimeter (BK precision CO monitor) was one of the air quality monitoring equipment supplied through the assistance of the World Bank to the Edo State Ministry of Environment in Nigeria in 2004. The sampler has a range of detection of 0 to 1000 ppm, accuracy of ± 5%, response time of < 70 sec and resolution of 1ppm.

Carbon monoxide is considered a silent killer because it is odourless and colourless making it virtually undetectable. Carbon monoxide binds reversibly with haemoglobin and inhibit 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[7]. 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[7]. As a result of the health and environmental significance of CO, this study is therefore designed to:

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

## METHODOLOGY

### Sampling area/sites

This study was carried out in Benin City, the capital of Edo State and lies within latitude 6.5°N and longitude 5.8°E. The city is ancient with a population of about 1,137,770[10]. 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 2300mm, while the average temperature is 32°C. 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 all year round, because the city is a gateway to the other parts of the county. Emissions from heavily loaded transport vehicles, badly maintained automobiles that run on diesel and leaded fuel, industrial emissions and open burning of refuse are responsible largely for air pollution problems in the city. Previous air quality and noise assessment of the city revealed excessive levels of suspended particulate matter[22] and noise burden[11].

In order to acquire a comprehensive baseline distribution of this pollutant in the city, five sampling sites were carefully created to represent all the quarters of the City with high air pollution sources. The sites were created at roadside verge, junctions and motor parks. TABLE 1 represents the monitoring sites, description and their coordinates. The monitoring sites were Georeferenced by using GARMIN GPS MAP 765 Chart plotting Receiver.

**TABLE 1 : Sampling sites, description and their coordinates**

| Site Code | Co-ordinates | Site Description |
|---|---|---|
| AQ AP | N 06° 21.003′ E 005° 39.643′ | Site created 4m from Agbor motor park. A busy park with high traffic volume per day of about 2200 cars/hour. |
| AQ RR | N 06° 20.440′ E 005° 37.339′ | Sampling site created 4m from Ring road with a traffic Census of about 3,200cars/hour. |
| AQ NB | N 06° 20.939′ E 005° 37.925′ | This sampling station was created 3m from New Benin road junction with very high and chaotic traffic jam almost all day long of about 3500 cars/hour. |
| AQ EC | N 06° 20.631′ E 005° 38.237′ | Site created 3m from the very busy road junction -2nd East Circular road junction with traffic volume of about 2,000 cars/hour. |
| AQ SR | N 06° 19.243′ E 005° 38.240′ | Sampling location created 3m from Sokponba road junction by Ekiosa Market with Traffic volume of about 4,200 cars/hour. |

## CO Sampler and the sampling procedure

The CO concentrations were measured using a CO dosimeter (model 627, BK Precision USA). This sampler has a range of 0 to 1000 ppm, with a sensitivity of 1 ppm, an accuracy of ± 5%, operating temperature of 0 to 40°C and operating relative humidity of 15 to 90%. It is equipped with a sensor which 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. CO gas diffusing into the sensor reacts with the special catalyzed sensing electrode to produce electrons. A built-in circuit, amplifies the signal into a millivolt output which is displayed on a liquid crystal display (LCD) Panel, front of the instrument as CO concentration in ppm. The CO monitor was calibrated before deployment and during the monitoring exercise 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[5,12,25] because of the following positive attributes: low cost, high accuracy and sensitivity, no special training before usage, direct readout, wide spatial coverage and its independent on electricity.

## Sampling routine

Continuous CO measurements were carried out in the dry season months of November 2006 - February 2007. CO concentrations were determined half hourly from the hours of 8.00 am. - 7.00pm, four times a week for a total of 16 weeks sampling period at the five created monitoring sites at a height of ~1.5 – 2.0m.

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

## Statistical analysis: Microsoft office excel 2007 & SPSS/6.0

The "Analysis ToolPak" available in Microsoft Office Excel 2007 provided data analysis tools for statistical and engineering analysis. It is the Excel 2007 "Analysis ToolPak that was used in the analysis of the CO data collected. To test for significant differences in the levels of CO obtained for different periods in 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 (TABLE 4).

# RESULTS AND DISCUSSION

This study, designed to acquire baseline CO data in a populated city, would ultimately assist in providing objective inputs to air quality management, traffic and land-use planning and informing the public about air quality and the danger inherent in its deterioration. Carbon monoxide data obtained in this exercise are presented in Figures 1 and 2 and TABLE 3. The measured meteorological data are shown in TABLE 5.

## Diurnal variations and ambient levels of CO

The Nigeria Federal Ministry of Environment Statutory limit for CO is 10.0 ppm (11.4 mgm$^{-3}$)[6]. The World health Organization[26] and United States Environmental Protection Agency[20] regulatory limits for the same pollutant is 9.0 ppm (10.0 mgm$^{-3}$). At all the sampling stations created and at the different times of the day, these threshold limits were exceeded. 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 12.00 noon), afternoon (12.00 noon to 4.00p.m) and evening (4.00p.m. to 7.00p.m). In this study, these classifications were upheld, so as to identity critical pollution period of the day and then prescribe possible mitigation measures. For almost all the sites created, the highest CO concentration, were measured in the morning hours (Figure 1). For example, at

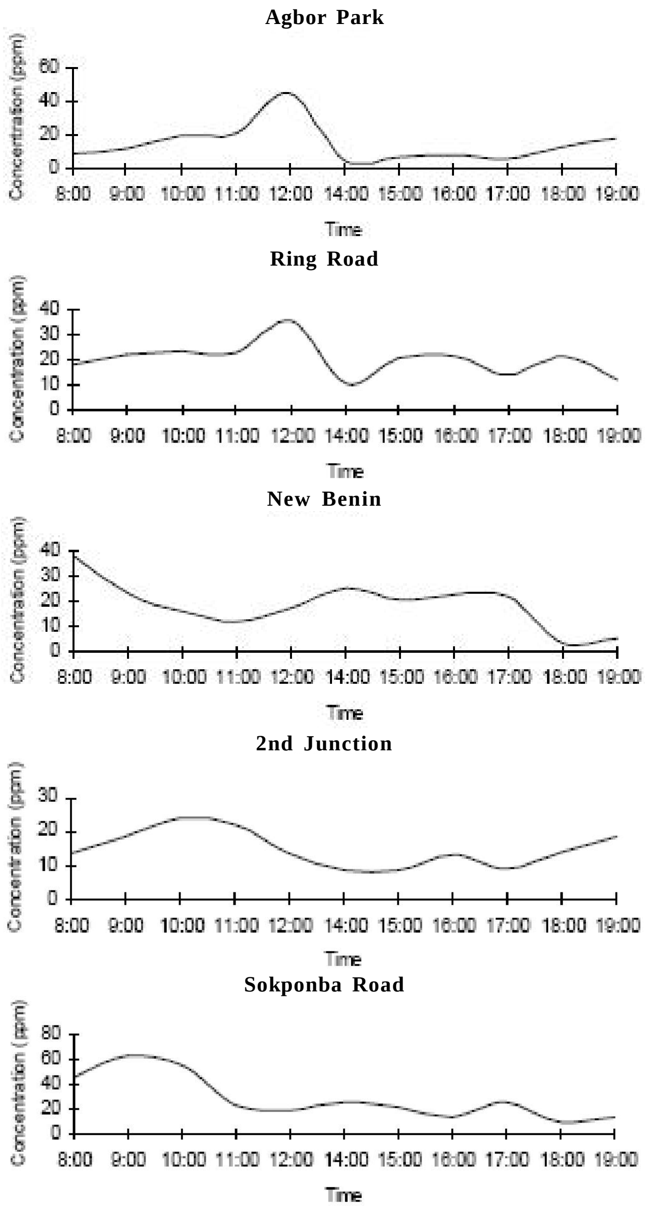


**Figure 1 : Diurnal distributions of CO levels**

Agbor Park sampling area, the morning hours CO range was 9.0 – 45.3 ppm, while the afternoon and evening ranges were 5.5 to 8.3 ppm and 6.0 – 18.3 ppm respectively. At 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 the available national and international CO statutory limits.

The results of the single factor ANOVA analysis (TABLE 2) of the CO data generated at the different times of the day, revealed significant statistical differences ($P < 0.05$) for Agbor park, New Benin, 2nd junction and Sokponba road sampling sites. Factors responsible for the observed diurnal variations in the CO distributions include: (i) differences in local urban traffic volume at the different times of the day, (ii) traffic flow and (iii) meteorological condition.

Usually, over 90 percent of the CO in city centres comes from vehicles[1] and in Benin City, traffic volume are 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 mornings rush, are further complicated by frequent traffic jams resulting from the high traffic density, poorly maintained roads, unfavourable

**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 | 1281.333 | 2 | 640.6667 | 9.905253 | 0.0003322 | 3.2381 |
| Within Groups | 2522.5 | 39 | 64.67949 | | | |
| Total | 3803.833 | 41 | | | | |
| **Ring road** | | | | | | |
| **Source of Variation** | **SS** | **df** | **MS** | **F** | **P-value** | **F-crit** |
| Between Groups | 188.9048 | 2 | 94.45238 | 2.901649 | 0.0668675 | 3.2381 |
| Within Groups | 1269.5 | 39 | 32.55128 | | | |
| Total | 1458.405 | 41 | | | | |
| **New Benin** | | | | | | |
| **Source of Variation** | **SS** | **df** | **MS** | **F** | **P-value** | **F-crit** |
| Between Groups | 2813.19 | 2 | 1406.595 | 28.49408 | 0.00000002 | 3.2381 |
| Within Groups | 1925.214 | 39 | 49.36447 | | | |
| Total | 4738.405 | 41 | | | | |
| **2nd Junction** | | | | | | |
| **Source of Variation** | **SS** | **df** | **MS** | **F** | **P-value** | **F- crit** |
| Between Groups | 579.4762 | 2 | 289.7381 | 7.533908 | 0.0017118 | 3.2381 |
| Within Groups | 1499.857 | 39 | 38.45788 | | | |
| Total | 2079.333 | 41 | | | | |
| **Sokponba road** | | | | | | |
| **Source of Variation** | **SS** | **df** | **MS** | **F** | **P-value** | **F-crit** |
| Between Groups | 7192.333 | 2 | 3596.167 | 21.95604 | 0.00000041 | 3.2381 |
| Within Groups | 6387.786 | 39 | 163.7894 | | | |
| Total | 13580.12 | 41 | | | | |

traffic handling and inadequate traffic discipline.

At 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 period of the day. This assumption is valid, because local and transit traffic, pass through this part of the city. Consequently, traffic volume and jam is high all day long at this location. The observed excessive enrichment in CO levels and the differences in its diurnal cycle in 80% of the sampling sites is consistent with previous findings[2] in Lagos, the formal capital of Nigeria. In their study, higher CO levels were measured in the morning hours and this they attributed to increased traffic at that time of the day. Similarly, they observed and 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[17] and a residential area in Kuwait[1], observed the same diurnal trend in CO distribution, with the highest load measured during the rush morning hours. 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 0.0ppm and 19.77 ppm respectively, with a mean of 1.93 ppm. In 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 that the values obtained in Kuwait and Austria that are more (urban) developed with more industries and higher traffic density and frequency. The first factor which is probably responsible for lower CO levels in Kuwait and Austria than in Benin City, is better traffic handling and discipline. Traffic jams and chaos which eventually lead to the high accumulation of CO in the atmosphere are better managed in the developed cities of Kuwait and Austria.

Secondly and more importantly, is the influence of wind speed in the dispersion and dilution of the emitted CO. Generally, serious air pollution episodes in the urban environment are not directly caused by sudden increases in the emission of pollutants, but result from unfavourable meteorological conditions. In Benin City, wind speed is generally low all year round. For most time of the day the wind is still. In this study, a wind speed range of 0.0 – 1.5 $ms^{-1}$ was recorded at all the created sampling sites (TABLE 5). This unfavourable wind condition may have reduced the ability of the atmosphere to disperse the high dose of emitted CO. At Kuwait and Austria, wind speeds are higher and Abdulwahab and Bouhamra[1] found in their study, a marked drop in the mean CO concentrations with stronger winds. The inverse relation between wind speed and pollution levels resulting from traffic have been reported[4,8,13].

## Spatial variations

The maximum, minimum and mean CO concentrations obtained for the different sampling sites are shown in TABLE 3.

**TABLE 3 : 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 | 4 | 15 | 13.4 | 1,024 |
| Ring Road | AQ RR | 52 | 9 | 20.3 | 3.6 | 1,024 |
| New Benin | AQ NB | 43 | 1 | 18.7 | 1.8 | 1,024 |
| 2nd Junction | AQ EC | 45 | 7 | 14.8 | 5.5 | 1,024 |
| Sokponba Road | AQ SR | 84 | 9 | 28.3 | 21.1 | 1,024 |

Spatial variations in the CO data were significant (P < 0.05) (TABLE 4), with the highest mean concentration of 28.3 ppm reported for Sokponba Road sampling station. The next site with the highest mean CO load was Ring Road with a mean value of 20.3 ppm. The least mean concentration of 14.8 ppm was calculated for 2nd Junction sampling site. Factors responsible for 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[3].

**TABLE 4 : Two-Factor ANOVA With Replication for Spatial variations in CO levels**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Location | 2961.8 | 4 | 740.46 | 4.9638 | 0.0009 | 2.4363 |
| Period | 389.39 | 13 | 29.953 | 0.2008 | 0.9988 | 1.7907 |
| Interaction | 4386.7 | 52 | 84.36 | 0.5655 | 0.99 | 1.4353 |
| Within | 20884 | 140 | 149.17 | | | |
| Total | 28622 | 209 | | | | |

All the sampling sites had identical dispersion conditions, characterized by low wind speed, high ambient temperature and humidity (TABLE 5). The very low wind speed of between 0.0 – 1.5 $ms^{-1}$ has already been explained as been responsible for the poor dispersion and dilution of CO at the sampling sites.

**TABLE 5 : Meteorological Data Captured during the sampling exercise**

| Sampling Site | Ambient Temp. (°C) | | Relative Humidity (%) | | Wind Speed (m/s) | |
|---|---|---|---|---|---|---|
| | 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 | 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 |

In our study, vehicular exhaust was 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 exercise, showed differences in traffic density at the different sites. For instance, Sokponba Road monitoring site with the highest traffic census of about 4,200 cars/hour (TABLE 1), equally 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[21] for the city under assessment.

## Mean CO values and guideline limits

In Nigeria, there are air quality guidelines put in place 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 $mgm^{-3}$)[6]. The WHO regulatory limit for the same pollutant is 9.0 ppm (10.0 $mgm^{-3}$)[26]. The measurement campaign

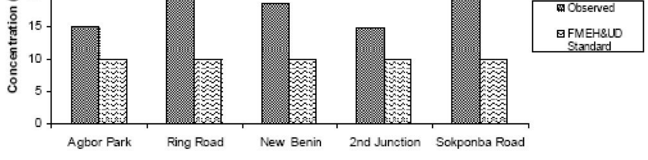


**Figure 4 : Observed CO concentration versus regulatory standard**

presented herein, shows that these limits were clearly exceeded at all the sampling sites. This observation therefore solicits 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[9]. 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 level in Cairo traffic policemen[14]. A recent report concludes that CO exposure can lead to significant loss of lifespan after exposure due to damage to the heart muscle[7]. As already indicated Nigeria has one of the lowest average life expectancy (44 years) in the world. The idea that CO poisoning is a contributor to the abysmal low life expectancy in this country, can therefore not be completely jettisoned, especially when sites used for this study are heavily populated by petty traders, hawkers and transporters, who spend several hours daily 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 the Global climate change and its attendant consequences.

## CONCLUSION

This study evaluated the diurnal variation of CO, a criteria pollutant in a large tropical city. It was observed that the baseline ambient level of CO in this city exceeded the available national and international regulatory limits. This therefore calls for urgent precautionary measures, so as to protect the populace against the adverse impacts of CO pollution. Diurnal variations were noticed in the data generated, with the highest concentrations recorded during the 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 created. 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 the night time CO levels as a result of security risks and also the inability to extend this study to other cities in Nigeria attributed to financial and logistics handicaps.

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