

Spatio-temporal variations in urban vehicular emission in Port Harcourt city, Nigeria

*Utang, P. B. and Peterside, K. S.

<http://dx.doi.org/10.4314/ejesm.v4i2.5>

Abstract

The increasing high volume of road traffic and congestion is a fundamental issue in Port Harcourt metropolis. The degradation of air quality arising from these is another serious dimension of the problem. This study estimated the emissions of pollutants from vehicles during traffic peak periods within parts of the city of Port Harcourt in Nigeria. It estimated air pollutants, Carbon Monoxide, Nitrogen Oxides, Sulphur Oxides and Hydrocarbons in four sampling points. The level of variation in concentration of emissions between peak and off peak periods of traffic, and between locations was determined. Only traces of SO_x were detected at all times and locations, while the concentration of CO detected was higher than the Federal Environmental Protection Agency limits and the recommended municipal (local) standard. This was predominantly in location A. Levels of Hydrocarbon (C_xH_y) detected varied in space and time, while. NO_x was generally above the local and international standards in all the locations during peak traffic period. Though this study did not cover the whole city of Port Harcourt, findings from the four sampling points suggest that the city is under the threat of traffic related pollution and is possibly more susceptible given increasing population influx and vehicular traffic. Improved road network and construction of modern roundabouts could help reduce peak period traffic in the nearest future.

Key Words: Air pollution, Road intersection, Peak and off peak, traffic congestion, Vehicular emission

Introduction

The urban milieu is an obvious setting where the functionality of the system depends largely on automobile transportation. Automobile transport emissions have been identified as key factors in the deterioration of the urban air environment, constituting up to 90% of urban air pollution (USEPA, 1994). Pollution due to traffic constitute up to 90 – 95% of the ambient CO levels, 80 – 90% of NO_x, and high levels of hydrocarbon and particulate matter in the world, posing a serious threat to human health (Savile, 1993).

Transportation sources account for 77% of CO levels, 80-90% of NO_x, 36% of volatile organic compounds and 22% of particulate matter and the average concentration of NO₂ found to increase by 35% due to increase in vehicular emission (USEP, 1993;

CEC, 1992). At local scales, such as city centre and congested streets, traffic can be responsible for 80-90 % of pollution and this situation is particularly severe in cities in developing countries (Odhiambo, et al, 2010). Cities have higher values of CO₂ concentration in heavily congested traffic areas (Akpan and Ndoke, 1999).

Although studies such as that of Akpan and Ndoke, (1999) have been conducted for traffic congestion points within an urban milieu, peak and off peak periods have not been taken into account. Generally, exhaust gas emission concentrations vary, depending on the engine operating mode (idling, accelerating, cruising and decelerating) (Colls, 2002). Deceleration and idle are characteristics of peak traffic at road intersections,

*Department of Geography and Environmental Management,
University of Port Harcourt, Nigeria*

**Corresponding author's e-mail: betenutang@yahoo.com*

while high acceleration and cruise are common at off peaks. Thus a spatio-temporal variation in rate and type of air pollutant exists between and within peak and off peak periods of urban traffic.

With the emission concentration in traffic being some $10^4 - 10^5$ times typical ambient background and, released only a few tens of centimeters above ground level, excellent dispersion is essential (Colls, 2002; Abhishek and colls, 2010). Thus the meteorological conditions, in addition to concentration of activities, which generates emission, account for the spatial and temporal variations. The emission of vehicle pollutants into the atmosphere is an increasingly important health issue that affects nearly everyone (Rouphail, et al, 2001). The health challenges faced by road users, passers-by, residents and business operators in traffic flash points, having high concentration of vehicular traffic during some periods of the day are worrisome issues. A comparison of the monitored and inventory emissions with acceptable standards (threshold) is useful in determining the extent of safety of road side business operators and hawkers in traffic intersection congested traffic points.

This study estimates emission levels at road intersections experiencing recurrent traffic congestion at certain periods, identified as peaks, and comparing the values with less congested periods known as off peak periods. In addition, a comparison of the different points is made in relation to the atmospheric (surface layer meteorological) conditions. This study is based on the hypotheses that: vehicular emissions during peak and off peak periods are the different; while the concentration of each pollutant is influenced by weather conditions; and that these conditions are different in space and time.

Materials and Methods

The study was conducted in Port Harcourt metropolis located in Rivers state, Nigeria. It was conducted over a period of 15 days between the 1st and 19th of November, 2010.

The sample frame consisted of the 10 highly notorious high traffic density junctions in Port Harcourt Metropolis. Four nodes were selected by simple random sampling. The sampled nodes include:

Nwaja Bridge Junction along Trans-Amadi Industrial Layout, (location A), Artillery Junction along Aba Road Express Way (location B), Rumuokoro Round About, (Location C) and Railway junction Woji road in Woji town (Location D) (See Fig 1).

Collection of data from the selected sites was carried out in three (3) time periods for duration of four working days of the week. These times are as follows:

- 7.30 am – 9.00 am Morning peak hours
- 1.00 pm – 3.00 pm Off peak period
- 5.00 pm – 8.00 pm Evening peak hours

This research involved the collection of data on the following air quality parameters: Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x), and Hydrocarbons (C_xH_y). The climatic elements sampled were the ambient temperature (°C), relative humidity (%), and wind velocity (ms⁻¹). Air quality parameters were measured using the Testo 350XL Emission Analyzer, which is an automatic instrument that measures O₃, CO, NO (option) NO₂, SO₂, C_xH_y and H₂S (options), temperature and differential pressure as well as the wind velocity and direction. The relative humidity value was obtained using the Kestrel 4000 weather tracker.

Data were presented graphically and in tables, while further analysis was based on descriptive and explanatory (inferential) statistics. The descriptive statistics included measures of central tendency and variation (dispersion). The inferential statistical tool used to test the hypotheses was the Analysis of Variance (ANOVA).

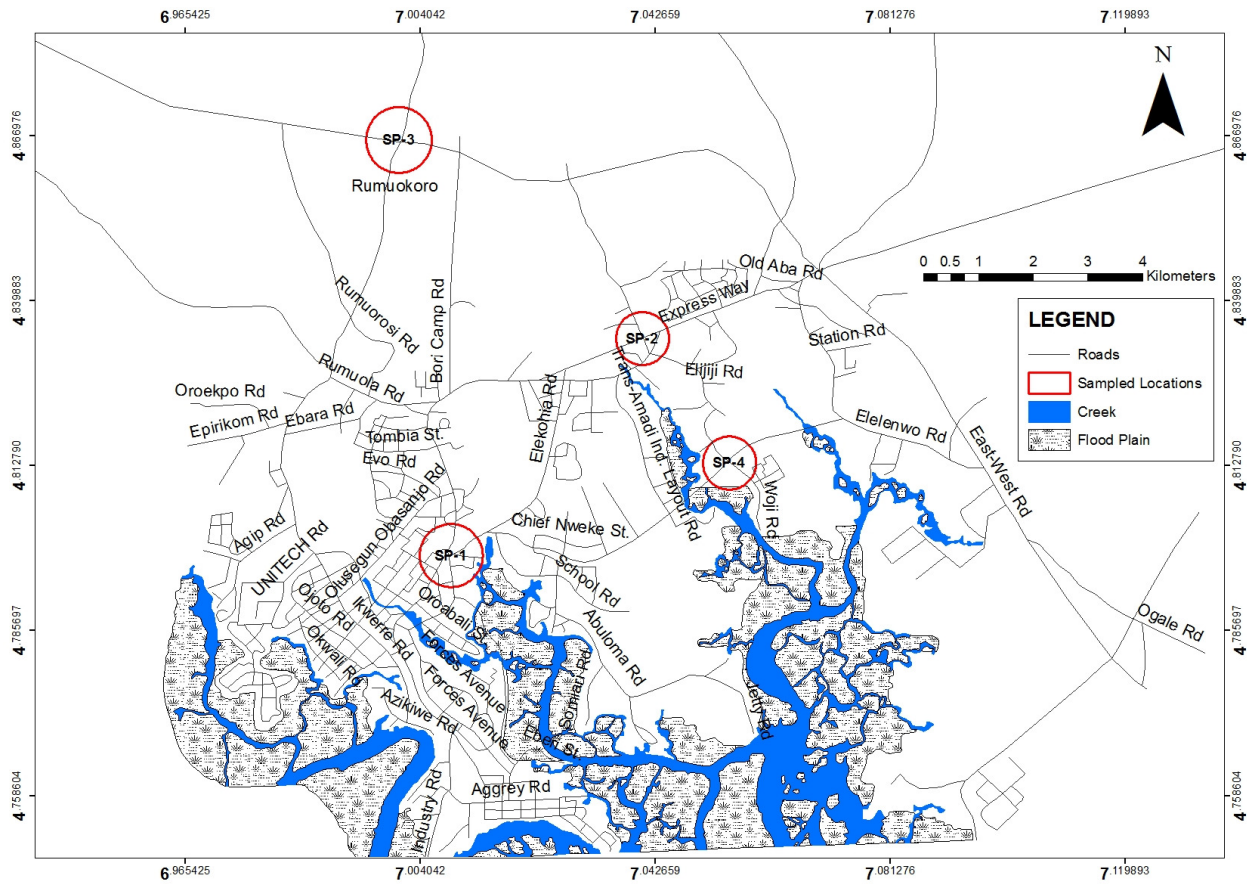


FIG 1 Map of Port Harcourt Metropolis Showing the Sampled Areas

Results and Discussion

Mean daily air quality levels during peak and off peak periods of traffic in four days at the four locations

The results as presented in table 1 show that SO_x was not generally detected, whereas low concentration of NO_x was detected. CO and C_xH_y were detected, with CO mostly during the evening peaks and C_xH_y during morning peak period. Off peak concentration of CO was experienced higher than morning peak in sample area A (Nwaja junction), while off peak C_xH_y concentration was higher than evening peak at location B (Artillery junction).

Generally, variation existed in air quality between the locations and period of data collection. Highest variation between locations was in the evening peaks, for CO and C_xH_y. Both of these accounted for the highest variation during all periods.

Sulphur oxides were generally not detected in the area, so consideration was not of this air quality parameter. CO and C_xH_y were detected highly during the evening peak period while NO_x was highest during the morning peak period and lowest or not detected during the off peak period.

The level of each pollutant in each of the four sampling points during the morning, evening and off peak periods of traffic is represented graphically in figs 1-4.

The Figs confirm that CO on the average was concentrated more during evening peak during the four day of investigation, while NO_x was concentrated more during morning peaks. C_xH_y was more concentrated in location B and during evening peak.

Table 1: Average emission estimates at peak and off peaks at four locations

LOCATION	AIR QUALITY PARAMETERS				METEOROLOGY		
	Morning Peak				Wind speed (m/s)	Air temp (°C)	R/H (%)
	Sox (ppm)	CO (ppm)	NO _x (ppm)	C _x H _y (5)			
A	.0003	6.8	0.33	264.7	1.08	32.3	52
B	.0003	7.3	0.5	3.7	1.14	31.6	45
C	.0004	1.0	0.6	3.4	1.65	31.5	44
D	.0005	7.0	0.3	50.3	1.12	32.1	50
Mean	.0004	5.5	0.43	80.53	1.24	31.9	47.8
Std dev		3.02	0.14	124.75	0-269	0.386	3.862
Evening Peak							
A	0.0005	24.8	0.6	10.8	1.17	35.2	48
B	0.0003	14.7	1.2	731	1.13	35.1	43
C	0.0005	16.2	1.1	0.5	1.44	30.3	28.7
D	0.0008	8.6	0.9	70.7	1.25	33.7	31
Mean		16.07	0.95	203.25	1.25	33.58	37.67
Std Dev		6.81	0.26	353.19	0.138	2.29	9.31
Off Peak							
A	0.00008	9.7	0.08	40.3	1.1	35.6	72
B	0	2.5	0	0.2	1.2	36.6	68
C	0.00003	2.8	0.1	0	1.14	34.8	61
D	0.0002	3.9	0.0003	3.7	1.12	35.8	64
Mean		4.73		11.05	1.14	35.45	66.25
Std Dev		3.37		19.57	0.043	0.443	4.787
Grand Mean		8.78	0.48	98.28	1.21	36.64	50.7
Std Dev		6.85	0.42	212.74	0.230	1.04	5.99

Source; Authors' Fieldwork, 2010

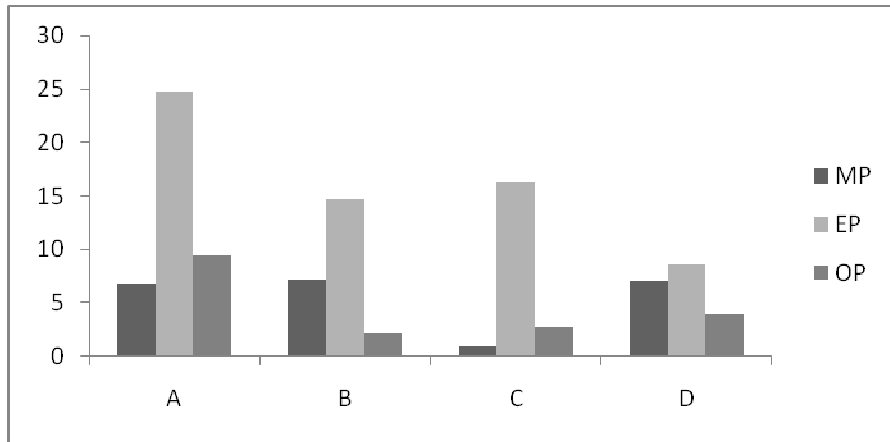


Fig 2: Average CO concentration at different locations and periods

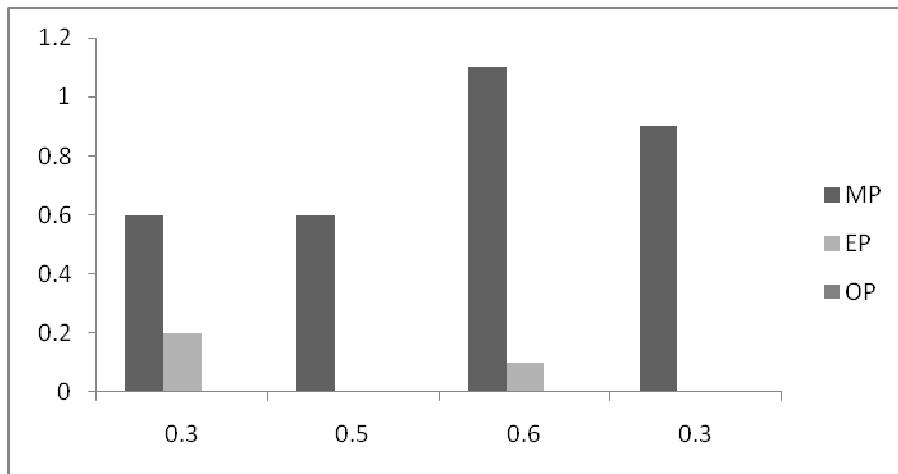


Fig 3: Estimated average NOx concentration at different locations and periods

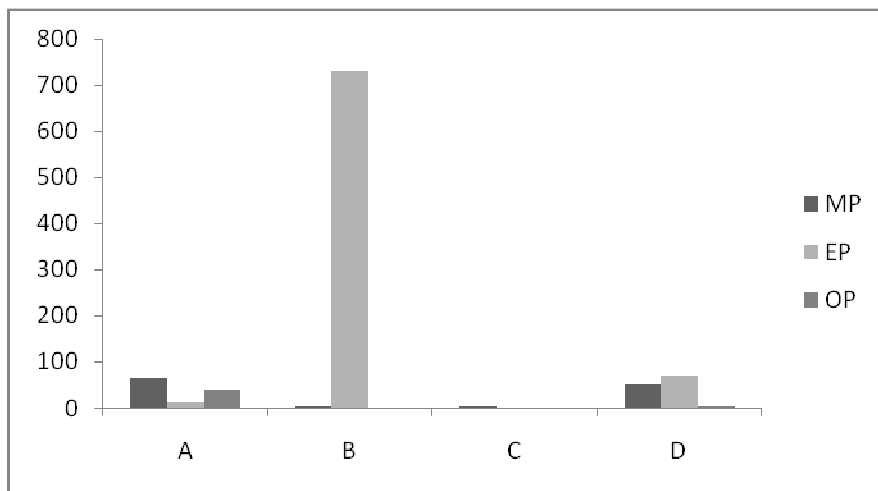


Fig 4: Estimated average CxHy concentration at different locations and periods

Several mutually inclusive factors could account for the variation. Among these are variations in prevailing meteorological conditions and traffic flow (mode of operation), quality of vehicles, including age, maintenance and fuel type vehicle (i.e. diesel or petrol) (Faiz *et al.*, 1996; Sharma and Roychowdhury (1996 in Roupail, et al, 2001).

Because areas of concern are associated with intersections, traffic lights, queues and cars parking due to engine being temporarily switched off, driving involves repeated acceleration, idling and decelerating cycles. The low concentration on CO and CxHy during off peak could be attributed to the rate of acceleration. During this period, the combustion is efficient and there is excess air. However because combustion chambers are high during this period, NOx could be high, as indicated from the result. At peak period, characterized by deceleration, there is excess fuel, so CxHy are increased (Colls, 2002; Abhisheek and Colls, 2010).

Hydrocarbon (HC) emissions can be influenced by ambient temperature. Very low ambient temperatures (e.g., below 20 °F) can influence emissions at ignition and cause the catalytic converters, in vehicles that have it, to cool during short stops.

Very high ambient temperatures can also have a secondary influence on exhaust emissions because engine load is increased by air conditioner use. Effects can include higher Nitrogen oxides. The amount of water vapour in the air can affect nitrogen oxide gaseous emissions in older and malfunctioning vehicles. Concentrations of all pollutants are lower at higher wind speeds (Levy, 2003). Although CO air concentrations are generally high in areas with heavy traffic congestion, the emissions are substantially greater in cold weather because cars need more fuel to start at cold temperatures and some emission control devices such as oxygen sensors and catalytic converters operate less efficiently when they are cold (Tubal et al, 2002)

Operating characteristics involves the consideration of the, temperature, humidity, wind speed, and the degree of traffic congestion. Ambient temperature has a large direct effect on evaporative hydrocarbon emissions.

The high hydrocarbon concentration during peak periods in the four locations could be attributed to the constantly high temperature

One of the hypotheses is that concentration at peak periods is significantly influenced by weather conditions. The test results as shown in table 2 and equations 1-3 indicate a corroborated this hypothesis particularly as the parameters, are significantly correlated and influenced by temperature and relative humidity, except for Hydrocarbon.

Of the weather elements temperature does not have significant influence on all the pollutants as in equations 1 and 2 hydrocarbon concentration was not correlated with temperature and relative humidity.

$$CO = -33.59 - 0.193X_1 + 0.514X_2 - 0.342X_3 \dots\dots\dots (1)$$

$$t = -0.484 \quad -0.405 \quad 1.147 \quad -0.771$$

$$Sig \ t \ (0.654) \quad (0.706) \ (0.315) \ (0.484)$$

$$NO_x = -0.934X + 0.098X_1 + 0.446X_2 - 0.810X_3 \dots\dots\dots (2)$$

$$t \quad -0.404 \quad 0.305 \quad 1.528 \quad -2.798$$

$$Sig \ t \ (0.707) \ (0.776) \ (0.201) \ (0.049)$$

$$C_xH_y = -1622.96 - 0.192X_1 + 0.452X_2 - 0.039X_3 \dots\dots\dots (3)$$

$$t \quad -0.579 \quad -0.372 \quad 0.959 \quad -0.083$$

$$Sig \ t \ (0.593) \quad (0.729) \ (0.392) \ (0.938)$$

Where X_1 = air temperature; X_2 = Relative humidity; X_3 = wind speed

Utang and Ogba (2009) have already reported that the synoptic wind system in Port Harcourt is characteristically calm to very gentle during most time of year as to have little influence on pollutant dispersion. This confirms the insignificant relationship and influence of wind speed as indicated in the results obtained from this study.

Another null hypothesis (Ho) states that the concentration of each pollutant during the days of air quality inventory is significantly the same between the locations and peaks periods.

The results as presented in table 3a and b shows that the test statistics for carbon monoxide was F value of 58.10 and 24.24 respectively, while critical or table values were 8.74. Based on the statistical decision rule, we rejected the H_0 , implying a significant difference in concentration of CO between the four locations over the days.

For Nitrogen Oxides, the test statistics gives a value of 1.08 and 2.87 while critical value is 8.74. The null hypothesis was not hence the concentration of in NOx between the four locations in the five days of inventory was significantly the same.

Result of the test statistics for hydrocarbon follows the pattern of carbon monoxide.

Temporal Variation in Air Quality in the Four Locations

The results as shown in table 4 indicate that the mean hourly concentration for CO and NOx did not vary much from the mean daily in all the periods. Hydrocarbon concentration however highly deviated from the mean daily, mostly during the evening peaks and off peak.

On the null hypothesis that air quality is the same in the four days and at morning and evening peak periods, the test results are presented in table 5.

Table 2: Correlation coefficients for relationship between air quality parameters and weather variables

Coefficients	Parameters		
	CO	NOx	CxHy
R	0.613	0.857	0.556
R ² (%)	37.6	73.4	31.0
F	0.803	3.683	0.598
Sig F	0.554	0.120	0.649

Source: Analysis of fieldwork data, 2010

Table 3: ANOVA Table of variation in air quality between location and peak traffic

a. Peak morning

Comparison of Carbon monoxide values					
Source of variations	Sum of squares	Degree of freedom	Mean sum of squares	F Cal	Critical F
Between Sum of Squares	111.56	3	37.19	58.10	8.74
Within Sum of Squares	7.66	12	0.64		
Total Sum of Squares	119.22	15	7.95		
Comparison of Nitrogen Oxides					
	0.1925	3	0.064	1.08	
	0.03	12	0.069		
	1.02	15	0.068		
Comparison of hydrocarbon					
	186727.97	3	62242.66	562.42	
	1328.03	12	110.67		
	1880556	15	12537.07		

Source: Analysis result, 2010

b. Evening Peak

Comparison of Carbon monoxide values					
Source of variations	Sum of squares	Degree of freedom	Mean sum of squares	F Cal	Critical F
Between Sum of Squares	534.38	3	178.13	24.235	8.74
Within Sum of Squares	88.21	12	7.35		
Total Sum of Squares	622.28	15	41.49		
Comparison of Nitrogen Oxides					
	0.94	3	0.31	2.87	
	10.74	12	0.89		
	11.65	15	0.78		
Comparison of hydrocarbon					
	1497099.18	3	499033.06	309.23	
	19365.19	12	1613.77		
	1516464.37	15	101097.62		

Source: Analysis result, 2010

Table 4: Daily average emission (for the four locations at peak and off peaks)

DAY	PARAMETERS			
	Morning Peak			
	SOx (ppm)	CO (ppm)	NOx (ppm)	CxHy (5)
1	0.0003	5.23	0.38	83.5
2	0.0004	5.9	0.35	82.8
3	0.0004	5.53	0.48	74.7
4	0.0003	5.35	0.48	81
Mean		5.50	0.42	80.5
Std dev		0.29	0.07	4.00
Evening Peak				
1	0.0002	15.9	1.03	210.7
2	0.0007	16.2	1.03	174.6
3	0.0006	16.8	1.01	207.7
4	0.0007	15.5	0.87	219.9
Mean		16.1	0.99	203.2
Std Dev		0.55	0.077	19.78
Off Peak				
1	0	5.6	0.05	0
2	0.0002	4.0	0.03	6.3
3	0.00005	4.4	0.05	26.9
4	0.00003	4.7	0.06	10.98
Mean		4.7	0.05	11.05
Std Dev		0.68	0.01	11.49
Grand Mean				98.26
Std Dev				83.7

Source; Analysis result, 2010

Table 5: ANOVA Table of variation in air quality between days and peak traffic

Comparison of Carbon monoxide values					
Source of variations	Sum of squares	Degree of freedom	Mean sum of squares	F Cal	Critical F
Between Sum of Squares	360.19	2	180.10	47.9	19.4
	33.84	9	3.37		
	394.03	11	35.8		
Within Sum of Squares	Comparison of Nitrogen Oxides				
	1.78	2	0.89	296.6	
	0.03	9	0.003		
1.89	11	0.17			
Total Sum of Squares	Comparison of hydrocarbon				
	75758.69	2	57879.05	174.4	
	1952.39	9	216.93		
77710.49	11	7064.6			

Source; Analysis result, 2010

Table 6: Space-time comparison of inventory data with standards

Pollutants	LOCATION				STANDARDS	
	Morning Peak					
	A	B	C	D	LOCAL	INTL
CO (ppm)	6.8	7.2	0.95	7.0	10-20	35
NOx(ppm)	0.3	0.5	0.6	0.3	0.04-0.06	0.053
SOx(ppm)	0	0	0.0006	0.0004	0.01	0.03
CxHy(%)	280.3	3.7	3.4	50.3	N/A	N/A
Evening Peak						
CO (ppm)	25	14.7	16.2	8.9	10-20	35
NOx(ppm)	0.6	2.3	1.1	0.9	0.04-0.06	0.053
SOx(ppm)	0	0	0	0.0006	0.01	0.03
CxHy(%)	10.8	786.7	0.5	70.7	N/A	N/A

Source; Analysis result, 2010

The result indicates that for all the parameters, a significant variation existed in their concentration during the days of emission inventory. The reasons for the variations could be attributed to variation in operation modes, local meteorology (atmospheric boundary layer conditions), traffic count and variations in vehicle characteristics.

Comparing the levels of concentration of air quality parameters with international and National/Local standards

From table 6, the CO concentration in all the locations during the morning peak periods were within both local and international standards. The value of NOx at 0.2ppm at location 3 is above both local and

international standards while the value of SOx is within the local and international standards. From table 6, the value of CO 25ppm in location A is above local standards but within international standards at all locations. NOx is generally above the local and international standards in all the locations while the value of SOx is within local and international standards.

The health challenges associated with high concentration of these pollutants are enormous. For example NO₂ is responsible for immune system impairment, exacerbation of asthma and chronic respiratory diseases: reduced lung function and cardiovascular disease (Schwela, 2000).

The implication of the inventory data is that if this is the usual scenario, then most hawkers, road side itinerant and semi permanent business operators are at risk of the health challenges associated with these vehicular traffic based pollution. A prevalence of chronic bronchitis and asthma in street cleaners exposed to vehicle pollutants in concentrations higher than WHO recommended guidelines, thus leading to significant increase in respiratory problems (Rachou, 1995).

Recommendations

In light of the above research project, the following recommendations have been made:

- Improvement in the condition of inner roads to reduce the number of vehicles at major intersections will help reduce the concentration of pollutants if there is no serious traffic situation in a particular area at every point in time.
- Technology changes and development in the transport sector should be carried out by the Government. The actualization of the implementation of the Monorail System proposed by the Rivers State government is a case to be reckoned with. Monorail transportation technology is unique and faster in getting the people to their destinations This will help reduce the use of private cars plying the roads, since the advancement in. The reduction in the number of vehicles plying the roads will drastically reduce traffic jam, hence vehicular emission.
- Vehicle Emission Control Technologies have been useful in reducing emission of pollutants. The city government could encourage this. There are several types of emission control technologies in use now. In developing countries especially, only catalytic converters and fuel injection systems are common.
- The construction of modern roundabouts and overhead bridges can be valuable. These improve traffic flow as well as cut down vehicular emissions and fuel consumption by reducing the vehicle idle time at intersections and thereby creating a positive impact on the environment.

Conclusion

That pollution at traffic intersection is usually high, particularly during traffic peaks and that motor vehicle remains the dominant source of urban air pollution has been confirmed. Addressing this situation requires an understanding of causal factors related to emissions. This study created the awareness that vehicular traffic at peak periods has the potential to cause pollution especially depending on the operation characteristics, meteorology, age of the vehicle and the type of fuel used in the vehicle. This research, although confined to nodal traffic points suggest that Port Harcourt is not safe from traffic related air pollution threats. Thus there is need for concerted efforts at reducing the threat in order to stem possible air pollution episodes at road intersections. This can be achieved through legislative, economic and civil engineering measures.

References

- Abhishek, T. and Colls, J. (2010), Air pollution Measurement, modeling and mitigation, London, Routledge
- Akpan, U.G., Ndoke, P. N. (1999), Contribution of vehicular traffic emission to CO₂ emission in Kaduna and Abuja. Federal University of Technology Minna Nigeria.
- CEC, (1992), The state of the environment in the European Community. Overview, Vol. 3. Commission of the Communities, Brussels and Belgium.
- Colls, J. (2002), Air pollution; London, Spon Press
- Koku, C.A., Osuntogun, B.A. (2007), Environmental-Impacts of Road Transportation in Southwestern States of Nigeria. *Journal of Applied Sciences*, 7(16), 2536-2360.
- Levy, J. I., Bennett, D. H., Melly, S. J. and Spengler, J. D. (2003), Influence of traffic patterns on particulate matter and polycyclic aromatic hydrocarbon concentrations in Roxbury, Massachusetts; *Journal of Exposure Analysis and Environmental Epidemiology*, 13, 364–371. doi:10.1038/sj.jea.7500289

- Odhiambo, G.O. Kinyua,, A.M. Gatebe, C.K.and Awange, J. (2010), Motor Vehicles Air Pollution in Nairobi, Kenya. *Research Journal of Environmental and Earth Sciences*, 2(4), 178-187.
- Rouphail, N, M., Frey, H. C., Colyar, J. D. and Unal, A. (2001), Vehicle emissions and traffic measures: Exploratory analysis of field observations at signalized arterials. Paper presented at the 80th Annual Meeting of the Transportation Research Board.
- Saville, S. B. (1993), Automotive options and quality Management in developing Countries. *Industrial Environment*, 16(1-2), 20-32.
- Schwela, D. (2000), Air pollution and health in urban areas. *Reviews on Environmental Health*, 15(12), 13-24.
- Tubal, G., Estoque, M. Holdsworth, J. and Villarin, J.S.J. (2002), Effect of the Diurnal of the Convective Boundary Layer Height over Metro Manila on Pollutant Science Diliman, Vol 14, No 1
- USEPA. (1994), Guide to Environmental Issues, Doc. No 520/B-94-01. United States Environmental Protection Agency, Washington, DC, USA.
- Utang, P. B. and Ogba, C. O. (2009), Climatological imperatives for air quality management within the coastal milieu of the Niger Delta, Nigeria; *Journal of the Nigerian Environmental Society (JNES)*, 5(2), 1-14.