Measurement and Modelling of Vehicular Emissions in Some Selected Towns in Nasarawa State, Nigeria

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ABSTRACT: This work focused on the measurement and modeling of vehicular emissions (CO, NO_2, SO_2 and PM_{10}) in some selected towns of Nasarawa State, Nigeria using appropriate standard method for six months and the data modeled by Standard Research Institute model. The measured and modeled results of the pollutants concentrations in all the selected towns ranged as follows; CO, 6.52-17.93 µg/m³ and 1.63-2.70 µg/m³, NO_2, 0.14-0.23 µg/m³ and 0.04-0.18 µg/m³, SO_2, 0.18-0.28 µg/m³ and 0.09-0.20 µg/m³ and PM_{10} 9.92-33.37 µg/m³ and 4.53-17.23 µg/m³ respectively. Comparison of these results with the National Ambient Air Quality Standard (NAAQS) set limits for these pollutants in the ambient air showed that CO concentration exceeded the limit of 11.40 µg/m³ in all the selected towns except for Akwanga town, while the concentration levels of NO_2, SO_2, and PM_{10} in the ambient air of the selected towns were within the permissible limit and pose no threats. Vehicular density was also determined by counting for the same period. The mean vehicular density decreases across the selected towns, with Karu having 3982, Lafia 2768, Keffi 2171 and Akwanga 1719. The mean concentration of each pollutant also showed the same trend with a significant correlation of about 99% between vehicular density and pollutant concentration for all the pollutants except NO_2. From these results, it is worth recommending that government should enforce the control of vehicles that emit much fumes and sponsor the fabrication of electric or fuelless vehicles.

Cite this paper as: ASHESHI, O. O; ACHIDE, A. S. (2024). Measurement and Modelling of Vehicular Emissions in Some Selected Towns in Nasarawa State, Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (1) 113-121

Transportation industry is vital to any modern society. It offers freedom to travel short and long distances thereby enhancing personal development and professional activities. Largely the economic development of the world today is facilitated by contemporary transport technology. Due to its accessibility and commonness, road transport is mostly used in Nigeria. However, the quest for transportation has inevitably posed some hazards to human health and the general environment, especially road transport (Zagha and Nwaogazie, 2015). Many vehicles today are designed such that they use an internal combustion engine that burns gasoline and other fossil fuels. In this process of combustion, a number of gaseous pollutants and particulate matter are generated and emitted into the environment through the exhaust of the engines as a result of incomplete combustion (Kumar, 2016). Out of these pollutants, nitrogen oxides, carbon monoxides, sulphur dioxide, lead and particulate matter, are the dominance. Exposure to these traffic related air pollutants have been shown to cause a number of adverse human health effects ranging from chronic conditions such as systemic inflammation to acute conditions such as alteration in heart rate variability and myocardial infarction (Pope *et al*., 2015).Other human health effects of air pollution due to vehicular emissions include; carcinogenicity, pulmonary tuberculosis, cerebrospinal meningitis, pneumonia, whooping cough and measles (Nwachukwu, 2012). Depending upon the chemical nature of the pollutants, some may be harmful when present in the air in small concentrations and others only if they are present in high concentrations. The adverse effects of vehicular emissions on humans as mentioned are quite pervasive. Specifically, the pollutants have known adverse effect on human health especially children, who are the most susceptible age group due to their

peculiarities (Nwaerema *et al.,* 2020). Although air quality in the urban centers all over the world are distinguished from those of the less build up areas by differences in carbon monoxide, volatile organic compounds, oxides of sulphur, nitrogen oxide and particulate matter, these differences are attributed on a large scale to anthropogenic interference of nature (Tawari and Abowel, 2012). It has been affirmed that, in developing countries of the world, vehicular increase has been largely unchecked by environmental regulating bodies creating high levels of pollution (Komolafe *et al*, 2014). In Nigeria, it is reported that vehicular emissions contribute to about 50 - 80% of the total air pollutants (Briant *et al*., 2013; Okunola *et al*., 2012).Air quality standards are legal limits placed on levels of air pollutants in the ambient air during a given period of time, they characterize the allowable level of a pollutant in the atmosphere and thus define the amount of exposure permitted to the population and or to ecological systems (Krzyzanowski and Cohen, 2008). Air quality standards vary from country to country depending on exposure conditions, the socio-political situation and importance of other health related problems. Hence, the objective of the paper is the measurement and modeling of vehicular emissions in some selected towns in Nasarawa State, Nigeria.

MATERIALS AND METHODS

*Description of Study Area:*Nasarawa State (Figure 1) is located in the North-Central (Middle Belt) Nigeria, on a landmass of 27,116.8 sq kilometers and between latitude 7^0 90' N and longitude 7^0 10' and 10^0 00' E (See Figure1). The State has common boundaries with Abuja, the Federal Capital Territory to the North-West and Kogi State to the South-West; Kaduna State to the North, Plateau to the North-East; Taraba State to the South-East and Benue State to the South. The state is made up of 13 Local Government Areas, (Akwanga, Awe, Doma, Karu, Keana, Keffi, Kokona, Lafia, Nasarawa, Nasarawa-Eggon, Obi,Toto and Wamba). It has a major road network that links the eastern and the northern parts of Nigeria. This road traverses six local government area headquarters (Lafia, Nasarawa-Eggon, Akwanga, Kokona, Keffi, and Karu) out of 13 local government areas in the state. Nasarawa state because of its proximity to the Federal Capital Territory (FCT) Abuja, greater percentage of workers in Abuja reside in Karu/Mararaba and Keffi areas of the State. UNDPI (2008) survey indicates that the Karu/Mararaba area has the highest population growth rate in Northern Nigeria. The 2006 National Population Census (NPC 2006) put the population of Nasarawa State at 1,863,275. The weather is generally hot between the months of February to April before the rains set in. From November to January, however, when the hermattan season sets in, the weather becomes relatively cool and dry. Consequently, the mean monthly temperature is between 28.9 ^{0}C and 24.9 ^{0}C.The climatic condition is tropical, characterized by raining and dry seasons. The raining season is from April - October while the dry season is from November - March.

Fig. 1: Map of Nasarawa State showing the study towns

Materials: Materials used in the field work study include portable gasman monitors to assess the gaseous pollutants (CO, NO_2 and SO_2) concentrations while digital hand held Haz-Dust particulate monitor (TM_{10}) was used to measure the Particulate Matter (PM_{10}) concentration. Portable Gasman monitors measure concentrations in part per million (ppm) and

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all the readings were converted to μg/m³ using equation1.

$$Conc.\ in\ \frac{\mu g}{m^3} = \frac{conc.\ in\ ppm \times Rmm \times 10^3}{24.45} \quad (1)$$

Where Rmm is relative molecular mass of gas considered (Tyovenda *et al.*, 2016).

Sampling Site Selection: Three sites were selected for each of the four towns (Lafia, Akwanga, Keffi and Karu) for study as presented in Table 1 and fig. 1 is Map of Nasarawa state showing the study towns in white. The sites were chosen in the selected towns based on human activities, as observed by the researchers.

Table 1: Sampling Towns and Sites

S/N	TOWN	SITE	Coordinates	
			Lat	Long.
1	Lafia	Doma Road Roundabout, Police Barracks junction and Akuruba Motor Park.	8.3 N	8.31E
2	Akwanga	Central Roundabout, C.O E Akwanga road and Dantsoho Filling station.	8.55 N	8.21 E
3	Keffi	Total, Mobil and High court.	8.51 N	7.52 E
4	Karu	First Flyover, Masaka bridge and Mararaba Bus stop.	9.03 N	7.60 E

where, Lat. and Long. Denote latitudes and longitudes respectively.

Sampling Procedures: The instruments were placed at an elevated height of 1.5m above the ground level to reflect human breathing zone, and readings were taken every 5 seconds at 20.0 m interval up to 100.0 m away from the centre of the road in the downwind direction.

Monitoring was carried out three times viz-a-viz morning peak – hours (8:00am – 9:00am), afternoon off – peak hours, (12:00noon – 1:00pm) and evening peak – hours (4:00pm – 5:00pm) respectively, for three days, in a month in each of the selected towns for a period of six months and the averages were calculated. Traffic density was determined by counting of various categories of vehicles during the same period.

Model Procedure: From our local meteorology, neither leeward nor a windward case was observed, and so we computed average concentration C_A as follows;

$$C_A = \frac{C_L + C_W}{2} \quad (2)$$

$$C_A = \frac{Dq}{2}\left[\frac{1}{(s_w + 0.5)\left[(x^2 + z^2)^{\frac{1}{2}} + 2\right]} + \frac{1}{W(s_w + 0.5)}\right] \quad (3)$$

From literature, the eddy diffusivity coefficient D, can be computed from Equation 4,

$$D = \frac{L_B^{\frac{4}{3}}(b\varepsilon)^{\frac{1}{3}}}{2^{\frac{4}{3}}(8\pi)^{\frac{2}{3}}} \quad (4)$$

Where L_B is the separation constant in meter, b is a constant and is equal to 0.8 for open country, ε is the energy dissipation rate and is given by 4.74×10^3 x with x denoting the downwind distance. In practice, the value of ε ranged from 0.1 – 2.0 w kg^{-1}.

For simplicity, we let D =1, and multiply Equation 3 by an arbitrary constant Ω, known as the correction factor of the ith pollutant (s) then Equation 3 reduces to Equation 5. Equation 5 was applied in this study.

$$C_A = \frac{\Omega q}{2(s_w + 0.5)}\left[\frac{1}{W} + \frac{1}{\left[(x^2 + z^2)^{\frac{1}{2}} + 2\right]}\right] \quad (5)$$

Model Parameters Estimation: The wind speed data was collected during the research period, road traffic lane width w, x and z, the coordinates along the wind and vertical direction respectively were measured. However, the emission factors of vehicles was difficult to determine, since it depends on vehicle age, model of vehicle, type of fuel/diesel used by the engine and above all, the type of vehicle, i.e. either light, medium or heavy duty trucks; for this study approximate values were adopted from various sources of published literature such as that of Guttikunda (2008) and presented in Table 2, while Table 3 shows the measuring parameters.

Table 2: Approximate vehicular emission factor, q (g/km/h) of some pollutants

Pollutant	Vehicle type Contribution %			q (g/km/h)
	Light	Medium	Heavy Duty Trucks	
PM_{10}	32 (**2.18**)	18 (**1.22**)	50 (**3.4**)	**6.8**
$PM_{2.5}$	32 (**1.02**)	18 (**0.58**)	50 (**1.6**)	**3.2**
SO_2	32 (**0.90**)	18 (**0.51**)	50 (**1.26**)	**2.81**
NO_X	32 (**1.93**)	18 (**1.09**)	50 (**3.02**)	**6.03**
CO	32 (**12.32**)	18 (**6.93**)	50 (**19.25**)	**38.5**
CO_2	32 (**1228.8**)	18 (**691.2**)	50 (**1920**)	**3840.0**
HC	32 (**3.36**)	18 (**1.89**)	50 (**5.25**)	**10.5**

Source: Guttikunda, 2008

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Table 3: Modeling Parameters

X (m)	Z (m)	$(X^2 + Z^2)^{\frac{1}{2}} + 2$	Town /Road Width (W) in meters
20.0	1.5	22.0562	
40.0	1.5	42.0281	Karu / 11.8
60.0	1.5	62.0187	Lafia / 11.8
80.0	1.5	82.0141	Keffi / 10.3
100.0	1.5	102.0112	Akwanga/10.3

Model validation: In order to authenticate our prediction, we used the Normalized Mean Square Error (NMSE) and Correlation Coefficient R, defined in Equations 6 and 7.

$$N_{MSE} = \frac{\overline{(C_P - C_M)^2}}{\overline{C_P} \times \overline{C_M}} \quad (6)$$

$$R = \frac{\overline{(C_M - \overline{C_M})(C_P - \overline{C_P})}}{\sigma_M \times \sigma_P} \quad (7)$$

Where C_p and C_M are the predicted and measured concentrations, $\sigma_{m \ and \ \sigma_p}$ are the Standard deviations of the measured and the predicted values respectively (Guttikunda, 2008).

Table 4: Model Validation

Town	Normalized Mean Square Error (N_{MSE})	Correlation Coefficient (R)
Karu	0.25	0.89
Lafia	0.17	0.92
Keffi	0.31	0.65
Akwanga	2.36	0.72

RESULTS AND DISCUSSION

The data obtained were analyzed using statistical tools of mean and bar charts to compare the measured concentrations with the model results and the recommended standards by NAAQS. The Stanford Research Institute (SRI) model was used to model the concentrations of the criteria pollutants (CO, NO_2, SO_2, and PM_{10}). In order to evaluate the efficiency of the applied model, statistical tools of Normalized Mean Square Error and Correlation coefficient were used.

Fig. (2-17) are plots and comparison of mean concentrations of pollutants measured and modeled against the downwind distance x (m). The monthly mean concentration of CO measured was highest (17.93) $\mu g/m^3$ in Karu in the month of January, followed by Lafia (17.34) $\mu g/m^3$ in the month of December while least values (7.72) $\mu g/m^3$ and (6.52) $\mu g/m^3$ of CO concentration were measured in Keffi and Akwanga respectively in August. These peak values in Karu and Lafia may be attributed to high traffic

volume and the presence of many local industries sited in these towns. In addition, because of the high population density in Karu and Lafia, many products of incomplete combustion of carbon containing fuels such as coal, wood, oil and natural gas can also aid elevated levels of CO in the ambient air of these towns. For highest values being captured in December, for both Karu and Lafia, it can be as a result of festive (Christmas and New Year) periods and meteorological factors such as wind speed and direction, reduction of temperature, washout and rainfall as recorded in the study area.

The CO concentration in the selected towns as measured and modeled were in the range of 6.52 - 17.93 and 1.63 - 2.70 $\mu g/m^3$ respectively.
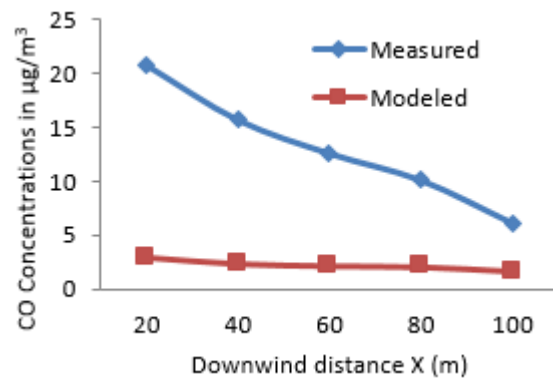

Fig. 2: Comparison of mean of CO Measured and Modeled in Karu town
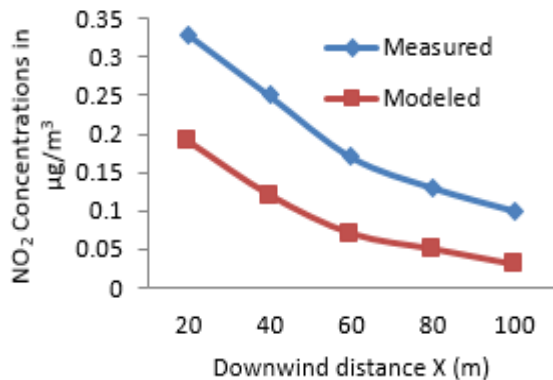

Fig. 3: Comparison of mean of NO_2 Measured and Modeled in Karu town

These shows that the results exceeded the limits of 11.4 $\mu g/m^3$ as set by the National Ambient Air Quality Standard (NAAQS) in all the selected towns, except Akwanga Town. The inhabitants of Karu, Lafia and Keffi are susceptible to cardiovascular diseases, impairment of lungs and reduction in the ability of the circulatory system to transport oxygen because of the

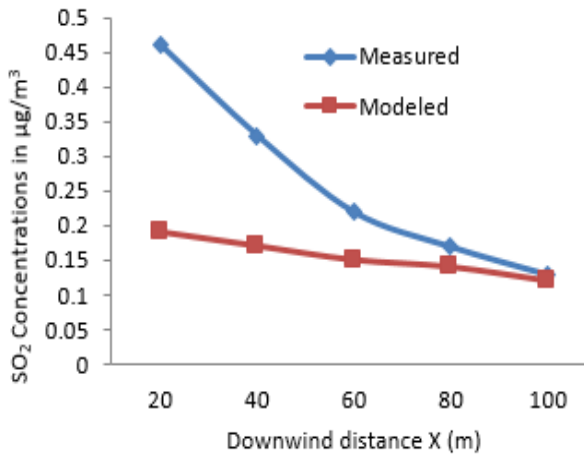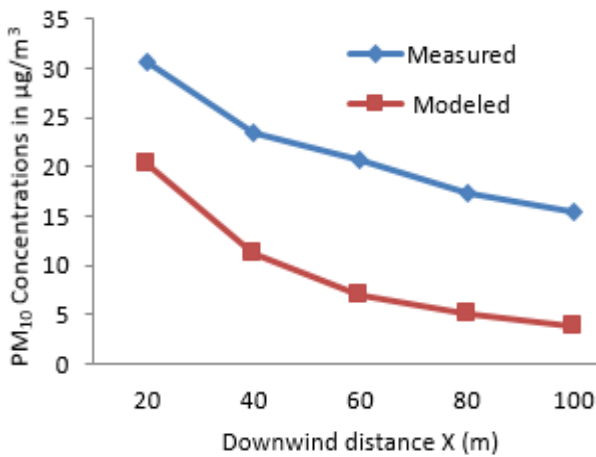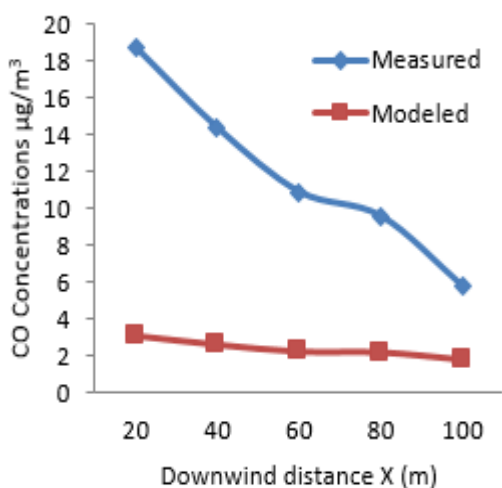inhalation of air containing elevated levels of CO (Nwachukwu, 2012).

The results depicted in the study area showed that measured values of NO_2 concentrations are highest, (0.23) $\mu g/m^3$ in Karu in the month of January, followed by Lafia having the value (0.20) $\mu g/m^3$ in the month of December. As stated earlier for the case of CO, high value of NO_2 in air of these towns can be attributed to road traffic and other fossil fuel combustion processes
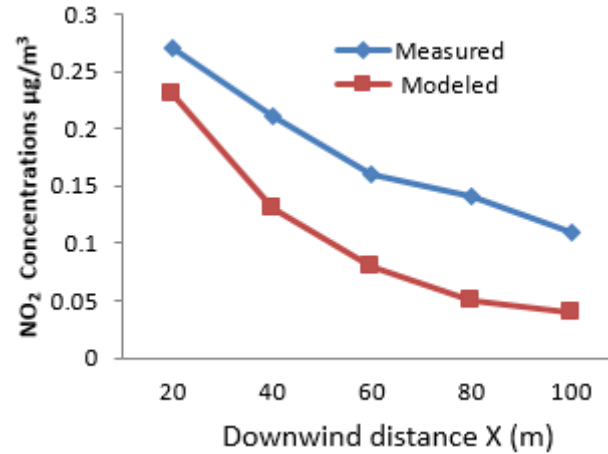

Fig. 4: Comparison of mean of SO_2 Measured and Modeled in Karu town

Fig. 5: Comparison of mean of PM_{10} Measured and Modeled in Karu town

Fig. 6: Comparison of mean of CO Measured and Modeled in Lafia town

Fig. 7: Comparison of mean of NO_2 Measured and Modeled in Lafia town
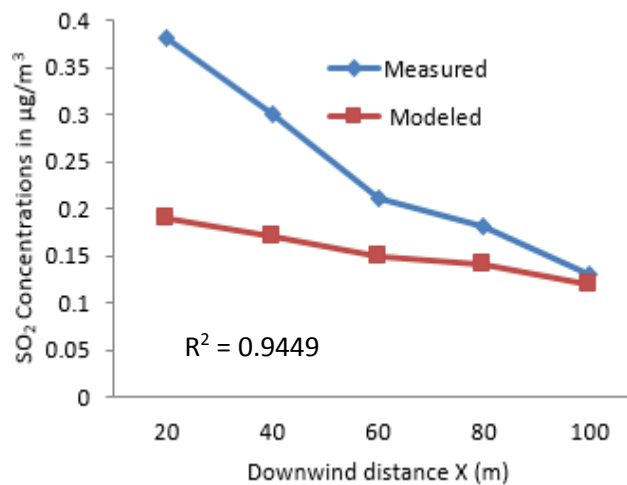
Fig. 8: Comparison of mean of SO_2 Measured and Modeled in Lafia town

The measured and modeled concentrations of NO_2 over the selected towns were in the range, 0.14-0.23 and 0.04-0.18 $\mu g/m^3$ respectively. This result is within the permissible level of 0.60$\mu g/m^3$ stipulated by NAAQS and poses no potential threats on the inhabitants. The monthly mean concentration of SO_2 measured was highest 0.29$\mu g/m^3$ in Keffi in the month of December followed by Lafia (0.28) $\mu g/m^3$ and Karu (0.28) $\mu g/m^3$ in the month of January and February respectively.
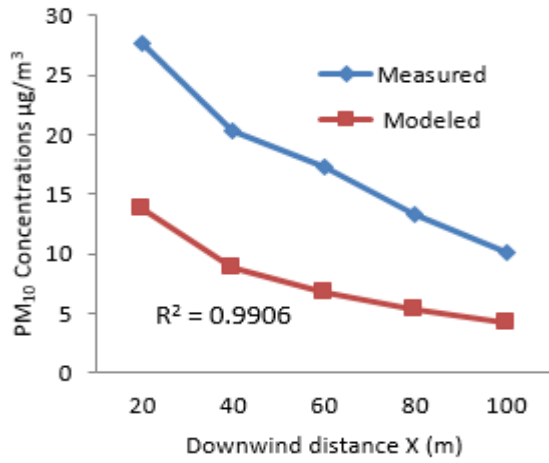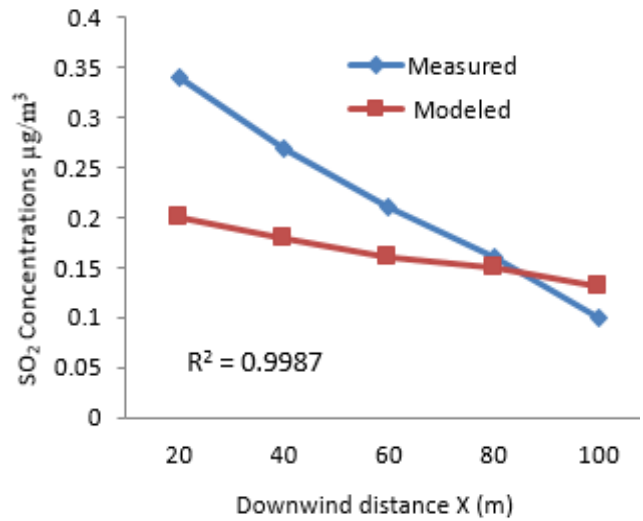
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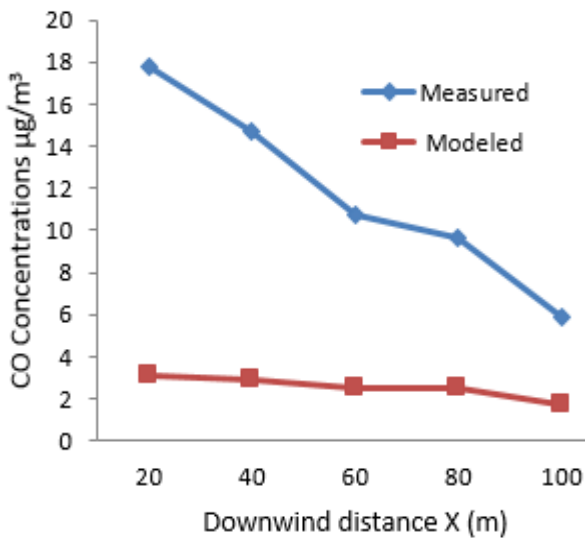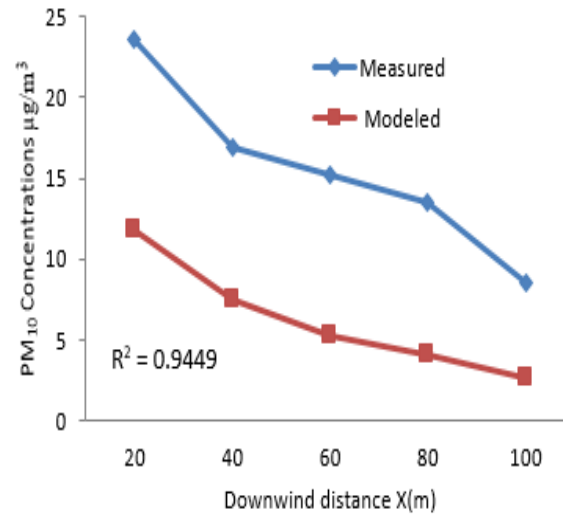**Fig. 9:** Comparison of mean of PM$_{10}$ Measured and Modeled in Lafia town

Fig. 10: *Comparison of mean of CO Measured and Modeled in Keffi town*

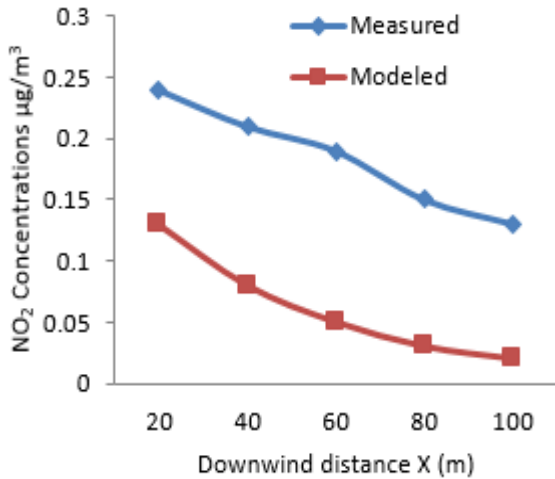**Fig. 11:** Comparison of mean of NO$_2$ Measured and Modeled in Keffi town

Fig. 12: Comparison of mean of SO$_2$ Measured and Modeled in Keffi town

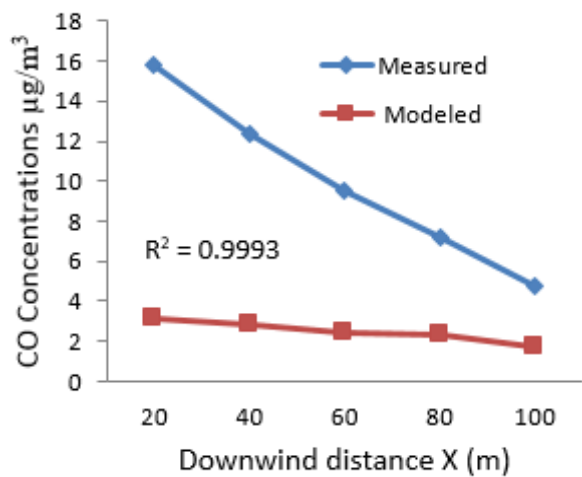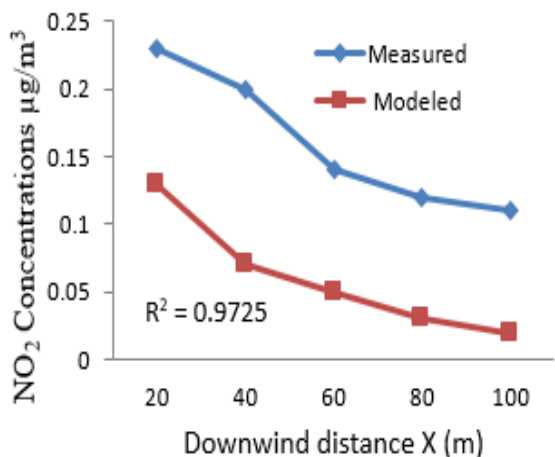**Fig.13:** Comparison of mean of PM$_{10}$ Measured and Modeled in Keffi town

Fig. 14: Comparison of mean of CO Measured and Modeled in Akwanga town

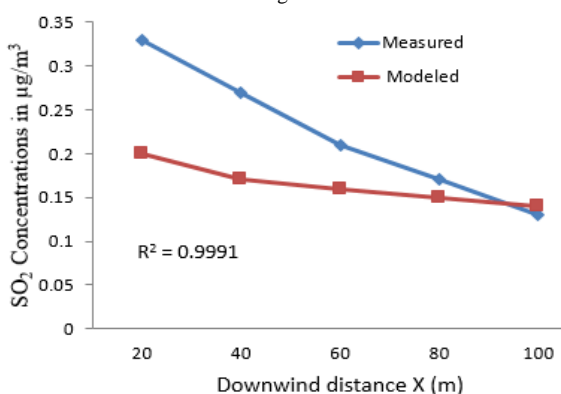**Fig. 15:** Comparison of mean of NO$_2$ Measured and Modeled in Akwanga town

Fig. 16: Comparison of mean of SO$_2$ Measured and Modeled in Akwanga town

and 0.09 - 2.0 µg/m^3 respectively. The enhanced values of SO$_2$ measured and modeled in these towns may be due to abundance of fossil fuel burning sources in these towns. For the highest value of monthly mean concentration of SO$_2$, to be released in ambient air in Keffi, Lafia and Karu it may not be unconnected with the meteorological influences arising from wind speed, rainfall, temperature as well as the geographical terrain of these towns
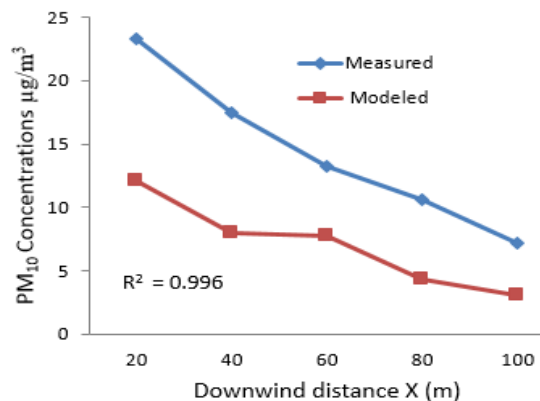

Fig. 17: Comparison of mean of PM$_{10}$ Measured and Modeled in Akwanga town

. These areas are likely to record more cases of chronic respiratory and risk of acute respiratory diseases like benign (Abam and Nwachukwu, 2009). The results showed that peak value, 33.37µg/m^3 of particulate matter concentration was observed in Karu in the month of December followed by Lafia, 24.25µg/m^3 in the same month of December. These results agreed with the published literature of (Ugwuanyi *et al*., 2016).
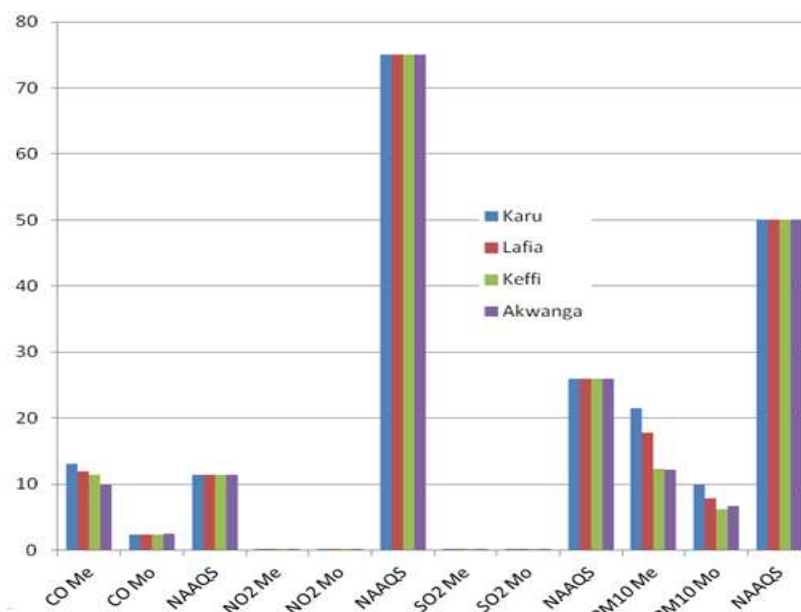
The mean concentrations of SO$_2$ measured and modeled in the selected towns ranged from 0.18 - 0.28

Fig. 18: Measured and Modeled Results compared with NAAQS

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The occurrence of highest concentration of particulate matter in Karu and Lafia can be attributed to high traffic congestion, as well as massive ongoing road construction works in these towns. The result of PM_{10} concentration ranged from 9.92 - 33.37 and 4.53 - 17.23 $\mu g/m^3$ respectively, in the selected towns. Though this was within the NAAQS, the inhabitants of Karu and Lafia are prone to likely cases of asthma, coughing, painful breathing and chronic bronchitis. These particulates also have impacts on plant lives as they can settle on plants leaves and block the stomata thus preventing carbon dioxide and sunlight that are needed for photosynthesis (Jimoda, 2012). The SRI model (equation 7), might have been seen to depart significantly from the measured data Fig. (2-17). This result shows that the modeled data were less than the measured results in all the cases. This, one can say that the present model under-estimated the pollutants concentrations. The reason for this might be attributed to some secondary data (wind speed s_w, diffusivity constant D, source emission rate q) used in the SRI model, which may not have matched the real time situation at the time of data collection. This was observed as a major setback in the use of SRI model. Although, the SRI model applied, under-estimated the particulates and gaseous concentrations, the results of the Normalized Mean Square Error and Correlation Coefficient presented in Table 5 suggested that the applied model performed better in Karu, Lafia and Keffi towns but performed poorly in Akwanga town. In order to gauge the health impacts of all the vehicular emissions studied, the six months mean concentrations of all the pollutants studied were compared with the National Ambient Air Quality Standards (Allowable limits values) as presented in Fig. 18. The CO concentration as measured exceeded the NAAQS limit of 11.4 $\mu g/m^3$ in all the selected towns except Akwanga town. All the other pollutants concentration levels in all the selected towns were below NAAQS limit.

Conclusion: The results of this research show that the mean vehicular density is proportional to the mean pollutant concentrations in the study area. Vehicular emissions contribute to the degradation of air quality of Nasarawa state towns particularly in Lafia, Keffi, and Karu LGAs. The study has shown also that the use of modified Stanford Research Institute (SRI) model can be used to determine vehicular emissions especially with good control measures.

REFERENCES

Abam, FI; and Unachukwu, GO (2009). Vehicular Emission and Air Quality Standards in Nigeria. *European. J. Sci. Res.* 34(4). 550-560.

Briant, R; Korsakissor, I; Seigneur, C (2013). An improved line source model air pollutant dispersion from roadway traffic. *Atm. Environ.* 45, 4099-4107.

Guttikunda, S (2008). Simple Interactive Model for Better Air Quality. *www.sim-air.org*

Jimoda, LA (2012). Effects of Particulate Matter on Human Health, the Ecosystem, Climate and Materials. *Working. Living Environ. Protect.* 9(1):27-44.

Komolafe, AA; Adegboyega, SA; Anifowose, AYB; Akinluyi, FO; Awonira, DR (2014). Air Pollution and Climate Change in Lagos, Nigeria: Needs for Proactive Approaches to Risk Management and Adaptation. *Am. J. Environ. Sci.* 10(4): 412-423.

Krzyzanowski, M; Cohen, A (2008). Update of WHO Air Quality Guidelines. Air Qual. Atmos. Health 1:7-13

Kumar, A (2016). Modeling for vehicular pollution in urban region. A review. *Pollution,* 2(4): 449-460, autumn.

NPC, (2006). National Population Commission Census Report. Nigerian Statistics Annual Report. Pp.14 Retrieved May 22, 2012, from: http://www.nigerianstat.gov.ng/nbsapps /annual reports/CHAPTER%202.pdf/

Nwachukwu, AN; Chukwuocha, EO; Igbodu, O (2012). A Survey on the Effects of Air Pollution on Diseases of the People of Rivers state, Nigeria. *Afr. J. Environ. Sci. Technol.* 6(10):371-379.

Nwaerema, P; Jiya, SN; Fred-Nwagwu, FW (2020). Characterization of Air Quality Index (AQI) of Port Harcourt Tropical Littoral City, Nigeria. *Inter. J. Health. Safe. Environ.* 6(7):627-637.

Okunola, OJ; Uzairu, A; Gimba, CE; Ndukwe, GI (2012). Assessment of Gaseous Pollutants along High Traffic Roads in Kano, Nigeria. *Inter. J. Environ. Sustainability*, 1(1): 1-15.

Pope 3rd, CA; Turner, MC; Burnett, RT; Jerrett, M; Gapstur, SM; Diver, WR; Krewski, D; Brook, RD (2015). Relationship between Fine Particulate Air Pollution, Cardiometabolic Disorders and Cardiovascular Mortality. *Circulation Res.* 122(12): 1645-1647.

Sombo, T; Achem, UC; Hemba, EC (2014). Pollution Standard Index (PSI) of Air Pollutants in Makurdi Metropolis, Nigeria. *Nig. J. Phy.* 25: (1): 161-162.

Tawari, CC; Abowei, JFN (2012). Air Pollution in the Niger Delta area of Nigeria.*Intern. J. Fisheries. Aquatic Sci. 94-117.*

Ugwuanyi, JU; Tyovenda, AA; Ayua, TJ (2016). Fine Particulate Distribution and Assessment in Nasarawa State, Nigeria. *IOSR- J. Appl. Phys.* 8 (2):32-38.

UNDPI, (2008). United Nation Department of Public Information: Achieving the Millennium Development Goals in Africa-Recommendations of the MDG Steering Group.

Zagha, O; Nwaogazie, IL (2015). Road Air Pollution Assessment in Port-Harcourt, Nigeria. *Standard Sci. Res. Essays.* 3(3): 066-074.