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Variation of source distribution of total oxidants: Contributions of oxides of nitrogen, sulphur (IV) oxide emissions and background ozone from Lagos-Nigeria

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Air dispersion modeling system (ADMS)-urban was used as air dispersion tool to model the atmospheric pollutants composition over Lagos air shed. The model runs with single point source showing the variation of concentrations of air pollutants (NO_2, NO_x, O_3, and SO_2) with ambient air dispersion over the city of Lagos, Nigeria. This city is located in the coastal area, and is highly congested with a high intensity of marine, vehicular, and industrial activities. The model was run with input data collected during dry and wet seasons using ADMS-urban. The dispersion pattern of NO_x is during both seasons was significantly different. Whereas, a Gaussian type curve was observed during dry season, a Sigmoid curve was obtained during the wet season. It is noteworthy that the elevation was higher for the dry season than the wet season due to higher photochemical activities. The modelled results obtained in ppb are: $O_{3,}$: 6.13, 23.36; NOx: 2.02, 3.99; SO_2: 9.54, 6.01 during wet and dry seasons, respectively. These predicted concentration values from theoretical model compared fairly with the measured values.

Key words: Seasonal variation, air dispersion modeling system, air pollutants, theoretical and empirical models, photochemical activities.

INTRODUCTION

The temporal and spatial heterogeneity of emission patterns and microclimate combined with the complexity of the urban surface results in complex dispersion pathways at local scales within urban areas. This can lead to strong gradients in vertical and horizontal pollutant concentration (Vakeva et al., 1999). Important oxidants in polluted air are formed within the atmosphere by chemical reactions that occur among the primary pollutants. Among these are peroxy radicals, ozone, nitrogen dioxide and peroxyacetyl nitrate. These, in their gas phase, control the chemistry of the atmosphere and their resultant effects contribute to climate change. These chemical processes affect the current and future composition of the atmosphere while controlling the abundance of the rage of pollutants harmful to health, vegetation and materials (Bloss, 2009).

In order to achieve better understanding of biosphere – atmosphere interactions, climate change simulations and the study of chemistry–climate interactions both of the past and future atmospheres, there is the need for a tool to model the atmospheric composition. Among these models is the dispersion modeling, a typical example of theoretical model. If the physical, chemical and / or biological mechanisms underlying a process are well understood, a steady state or dynamic model can be developed. Steady – state models cannot be used for

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predicting system responses over time, and therefore, have limited management value. Time–variable models, on the other hand, can handle variable input loads, and can be useful for establishing cause effect relationships. When compared to empirical models, theoretical models are generally more complex. They require a longer period of observation for calibration and the number of variables and parameters to be measured are greater. They also require a significant amount of time for validation. Due to their complexity, and because the understanding of atmospheric systems is incomplete, these types of models are less frequently used than empirical models. Theoretical model also goes along with geographic information system (GIS) as well as geographic positioning system (GPS). The purpose of a dispersion model is to calculate air pollution concentrations according to the pollution emissions data and the nature of the atmosphere (Leksmono et al., 2006). Among many advanced dispersion models, Air dispersion modeling system (ADMS)-urban, AA Quire and Indic Air Viro are designed to model at an urban scale and include point, line and area sources (Chatterton, 2001). However, according to a survey carried out by Beattie (2000) and Woodfield et al. (2006), it was concluded that ADMS-urban is one of the most widely used advanced model tools, hence its attraction and choice for this study.

The ADMS-Urban model is a steady state new generation Gaussian type model which was originally developed (as UK - ADMS) for point source applications (Owen et al., 1999). The model has since been developed as a multi source dispersion modeling system for air quality management applications all over the world.

The behaviour of ADMS-urban has been studied extensively by several evaluations of long-term air pollution concentrations and comparisons with monitored data (Bennet and Hunter, 1997; Carruthers et al., 1996, 1999; Owen and Raper, 2001), while analyses of individual pollution episodes are more rare (Arciszewska and McClatchey, 2001). Local authorities should predict episodes in which pollutant concentrations overcome safety thresholds.

ADMS- urban is an improvement upon ADMS model (Carruthers et al., 1994, 1999) which includes a line source algorithm to enable the calculation of pollutant concentrations from road traffic and industrial sources. ADMS-urban is an urban scale, multi source model allowing up to 3000 grid sources, 1000 road sources and 100 industrial sources to be simultaneously modeled with complete terrain and street canyons. ADMS-urban is also called “new generation” dispersion model which means it uses an approach of boundary layer scaling based on the Monin – Obukhov length and boundary layer depth, rather than the Pasquill stability classes used by many earlier dispersion models (Leksmono et al., 2006). Another feature of ADMS-urban is that in convective conditions, the concentration profiles are assumed to be skewed Gaussian in order to bring material from elevated releases rapidly down to the surface (McHugh et al., 1997). The model is further integrated with a GIS, ArcView 3, and an emission database. This interface is an important visualization tool and also provides a means of manipulating the spatial element of the model input data (Owen et al., 1999).

METHODOLOGY

Study area

The study area for this work is Lagos, former capital of Nigeria. Four sites were used to represent different anthropogenic contributions and one used as control (high % of natural contribution). The coordinates and activities occurring within these sites have been described elsewhere (Abdul Raheem et al., 2009), while Lagos as a Nigeria conurbation and a commercial center have equally been described fully in FRNG (2009).

Emissions data for this study were the measured data generated between 2003 and 2006 (Abdul Raheem, 2007) and recently updated. The meteorological data were collected from Nigeria Meteorological Services (NIMET) Unit of Aviation Ministry, ARIAL, Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile – Ife as well as from global Baseline Surface Radiation Network (BSRN) of NASA located in Physics Department, University of Ilorin. The sources in the inventory are spatially described as point and area sources. The inventory is within a GIS allowing aggregation of emission from all sources, sectors up to a grid square basis. A constant value for surface roughness was used for the entire study area (z_o = 1.0 m). This is not representative of the whole study area and may result in inaccuracies in the modeling calculations (CERC, 2004). A surface roughness length of 1.0 m is representative of an urban area such as Lagos but some parts of the study area will be less built – up and a lower value for surface roughness would be more appropriate, this has been previously remarked by Owen et al. (1999) and they commented that such problem is likely to recur with the use of this type of model over a regional scale. The model allows two input values for the surface roughness; one at the source location and the other at the receptor location, but it does not allow for variation in surface roughness for different source locations. However, the algorithm for the evaluation of downwind concentration is displayed in Figure 1.

As shown in Figure 1, the system has a number of distinct features used to achieve the modeling of data (CERC, 2004). These include but not limited to input of meteorological ambient data, measured ambient data, traffic flow and downwind concentration. The modeled results show the concentration – distance line plot (Figures 4 to 11) that reflects the expected three ambient conditions that is, stable, neutral and convective.

RESULTS AND DISCUSSION

Typical examples of the input data used are the mean raw data showing time of the day, pollutants measured, their concentrations, meteorological data and seasonal variations as shown in Tables 1 and 2. The model tool as earlier described is a software (ADMS-urban) licensed to the researcher for a period of one year by Cambridge Environmental Research Consultants, Environmental Software and Services, United Kingdom.

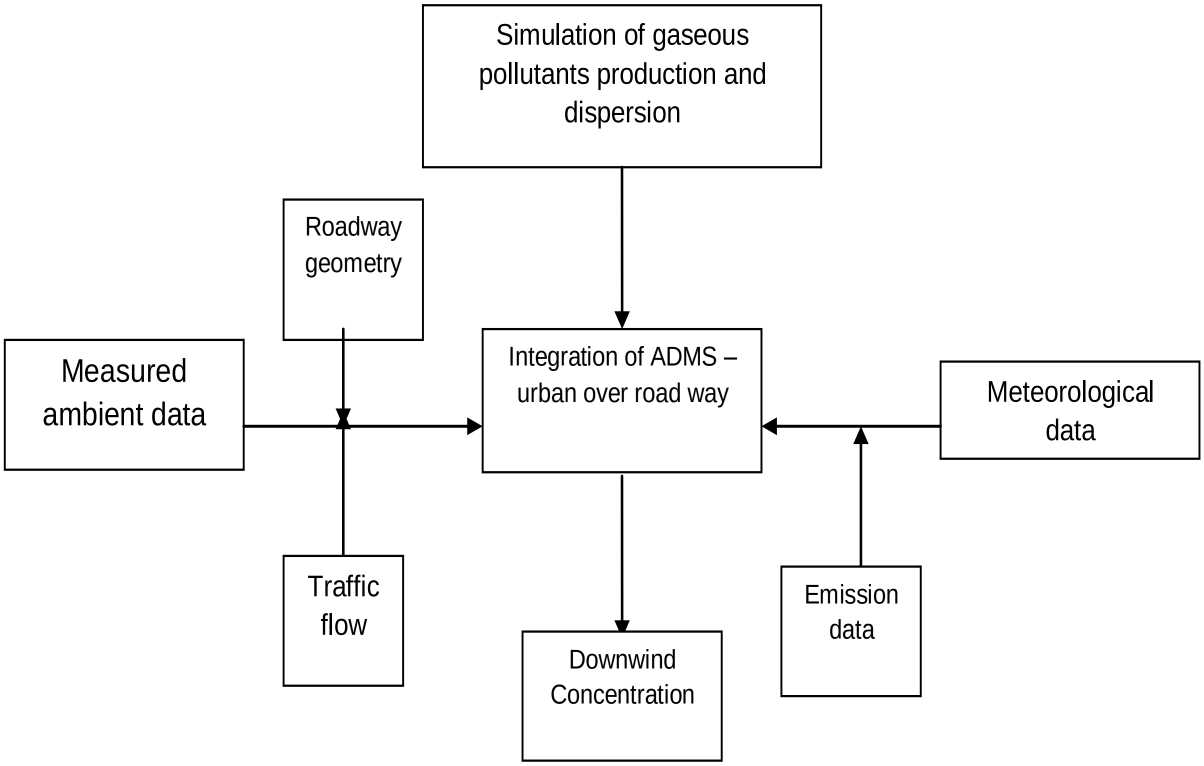

Figure 1. The algorithm for the evaluation of downwind concentration using the ADMS–urban model.

Table 1. Dry season environmental data for Lagos.

Start of sampling	End of sampling	OX (ppb)	NOx (ppb)	SO_2 (ppb)	RELHUM (%)	WND (ms^{-1})	DWND (°C)	AIR temp (°C)	Sun exp (Wm^{-2})
6.30 am	7.30 am	14.26	12.40	10.72	90.58	3.07	107.02	25.99	-1.65
7.45 am	8.45 am	22.92	5.89	7.20	87.58	4.67	156.38	26.38	2.80
9.00 am	10.0 am	28.95	5.39	11.15	73.75	7.09	189.02	29.05	8.90
10.15 am	10.0 am	46.86	5.66	14.82	67.92	7.35	182.63	30.25	11.00
11.30 am	12.30 pm	43.21	6.41	10.51	63.50	8.76	170.67	31.30	12.06
12.45 pm	1.45 pm	85.31	5.68	12.74	60.33	10.11	159.55	32.00	17.30
2.00 pm	3.00 pm	73.77	6.45	16.62	60.08	10.36	155.00	31.98	15.10
3.15 pm	4.15 pm	26.06	6.84	15.47	62.67	10.94	163.79	31.37	13.20
4.30 pm	5.30 pm	12.23	5.72	16.48	67.00	10.21	165.22	30.38	10.70
5.45 pm	6.45 pm	8.58	6.90	19.21	72.75	8.99	166.64	29.20	3.30

Adapted from Abdul Raheem et al. (2009).

After inputting data for dry and rainy seasons (Tables 1 and 2), and the mean traffic flow experienced during the two seasons throughout the sampling periods (Figures 2 and 3) into ADMS-urban as shown in Figure 1, new concentrations were calculated taking into consideration the values of surface roughness, the latitude of the site, Monin – Obukhov length, height of recorded wind, meteorological data, emissions, background concentrations, grid etc. The new concentration calculated is referred to as modeled concentration. Figures 4 to 11 show the dispersion of pollutants from single elevated point source during wet and dry seasons in Lagos. In other words, the concentration – distance line plots. The three ambient stability classes are represented. The deep blue colour represents the unstable condition of the atmosphere; green colour

Table 2. Rainy season environmental data for Lagos.

Start of sampling	End of sampling	OX (ppb)	NOx (ppb)	SO_2 (ppb)	RELHUM (%)	WND (ms^{-1})	DWND (°C)	Air temp (°C)	Sun exp (Wm^{-2})
6.30 am	7.30 am	9.25	3.16	2.30	95.75	4.05	128.38	24.84	-0.13
7.45 am	8.45 am	12.91	3.39	4.46	93.83	5.29	146.58	25.58	1.24
9.00 am	10.0 am	10.36	2.77	6.04	84.5	8.07	191.13	27.52	6.35
10.15 am	10.0 am	9.59	2.45	6.48	80.58	8.79	196.15	28.19	8.10
11.30 am	12.30 pm	9.00	2.25	3.74	78.25	9.72	203.63	28.74	9.25
12.45 pm	1.45 pm	15.03	1.77	4.39	77	10.32	205.68	29.03	14.42
2.00 pm	3.00 pm	16.72	2.87	5.68	76.67	11.45	210.44	28.96	15.74
3.15 pm	4.15 pm	10.78	3.54	7.05	77.58	11.54	213.56	28.58	11.56
4.30 pm	5.30 pm	3.57	3.89	8.13	79.67	11.06	213.20	27.94	7.81
5.45 pm	6.45 pm	1.45	3.89	9.00	83.08	10.05	209.95	27.13	1.65

Adapted from Abdul Raheem et al. (2009).

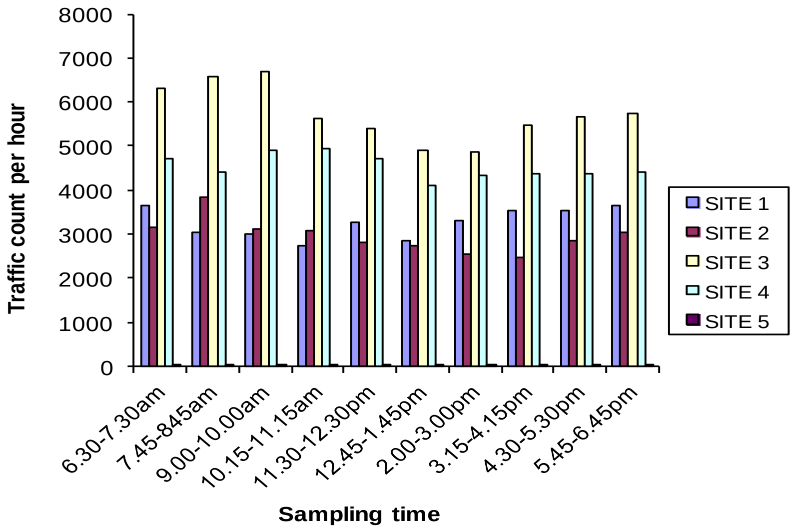

Figure 2. Variation of the average traffic count with the time of the day in Lagos during rainy season.

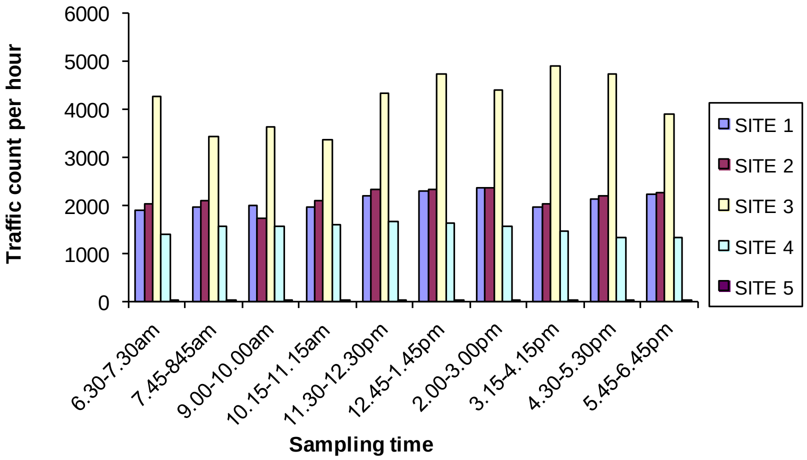

Figure 3. Variation of the average traffic count with the time of the day in Lagos during dry season.

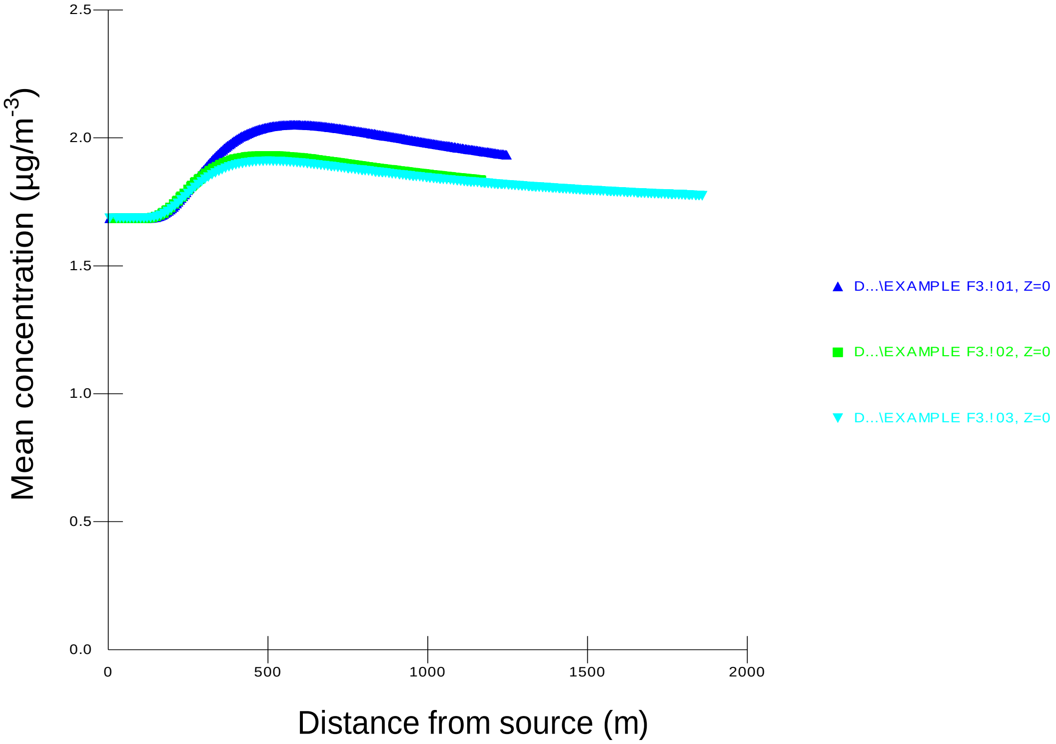

Figure 4. Concentration-distance line plot for no_2 in the rainy season for Lagos.

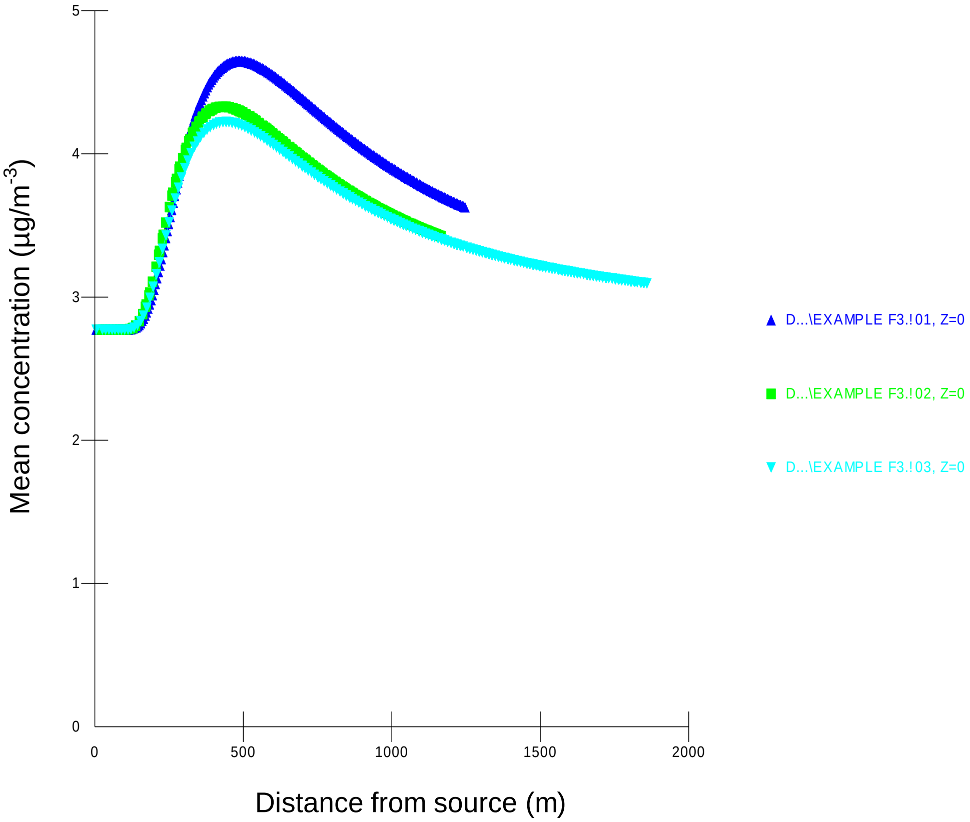

Figure 5. Concentration-distance line plot for no_x in the rainy season for Lagos.

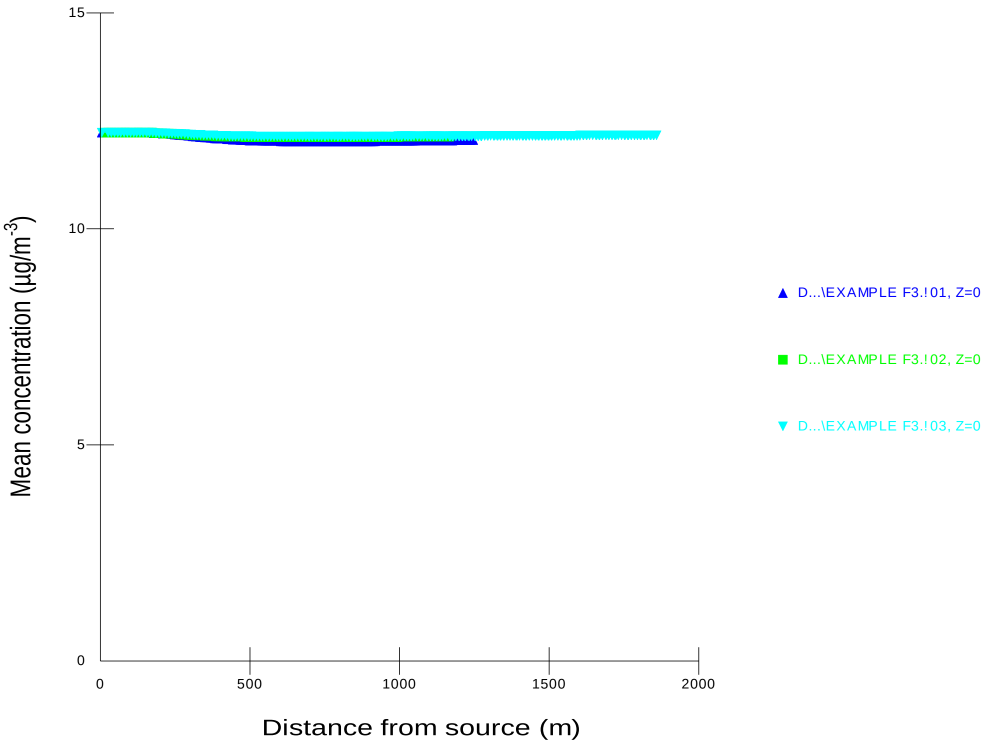

Figure 6. Concentration – distance line plot for o3 in the rainy season for Lagos.

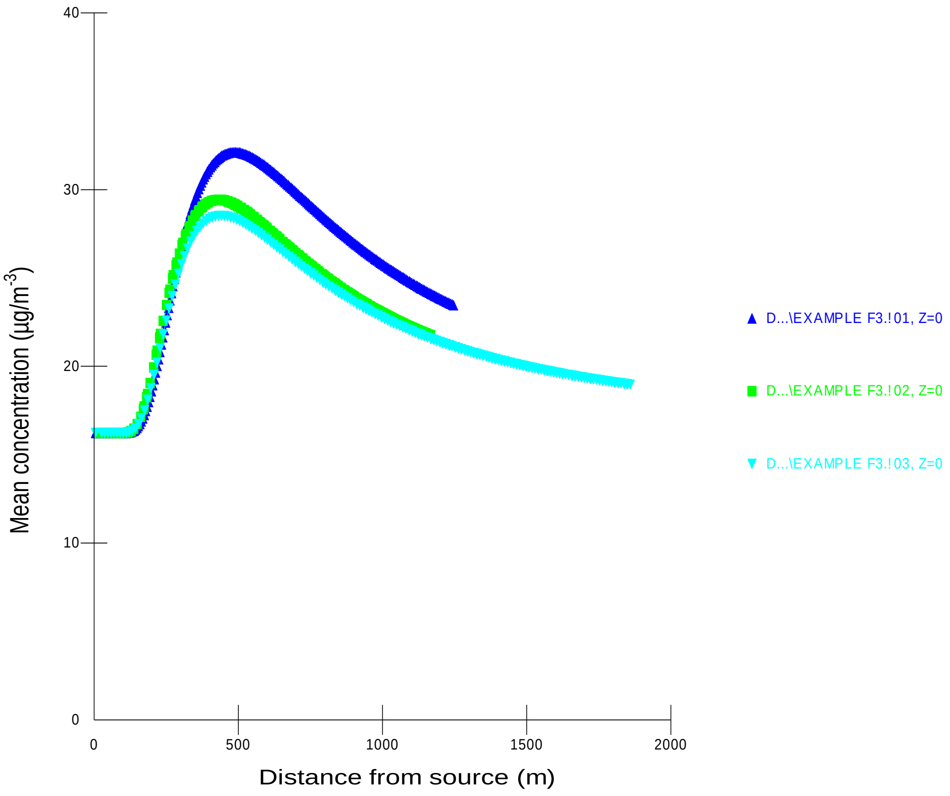

Figure 7. Concentration – distance line plot for so_2 in the rainy season for Lagos.

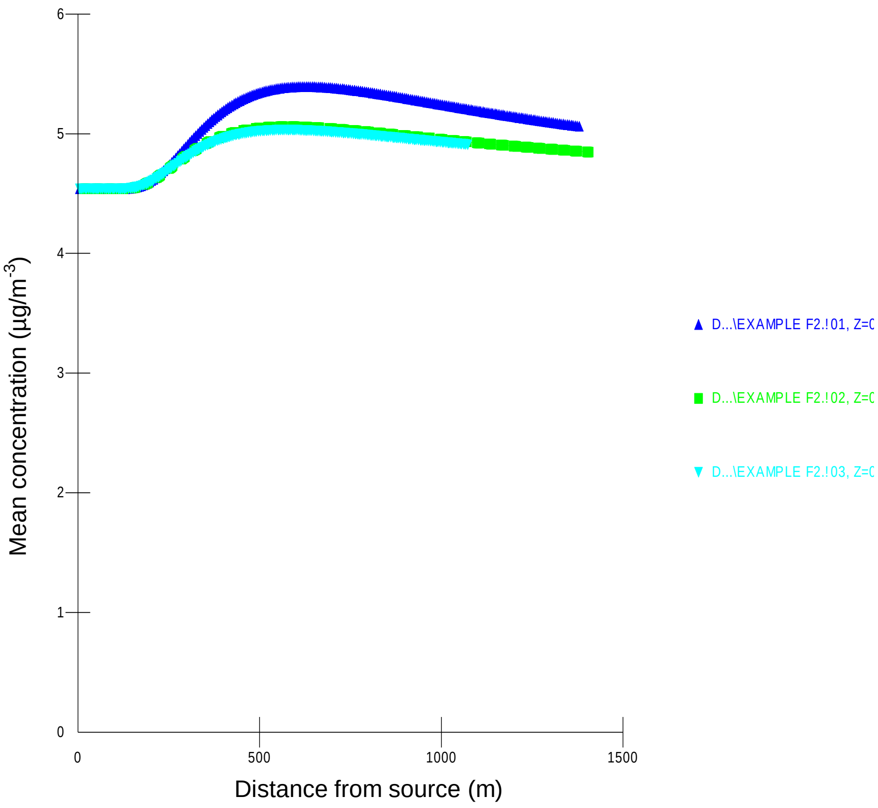

Figure 8. Concentration – distance line plot for no_2 in the dry season for Lagos.

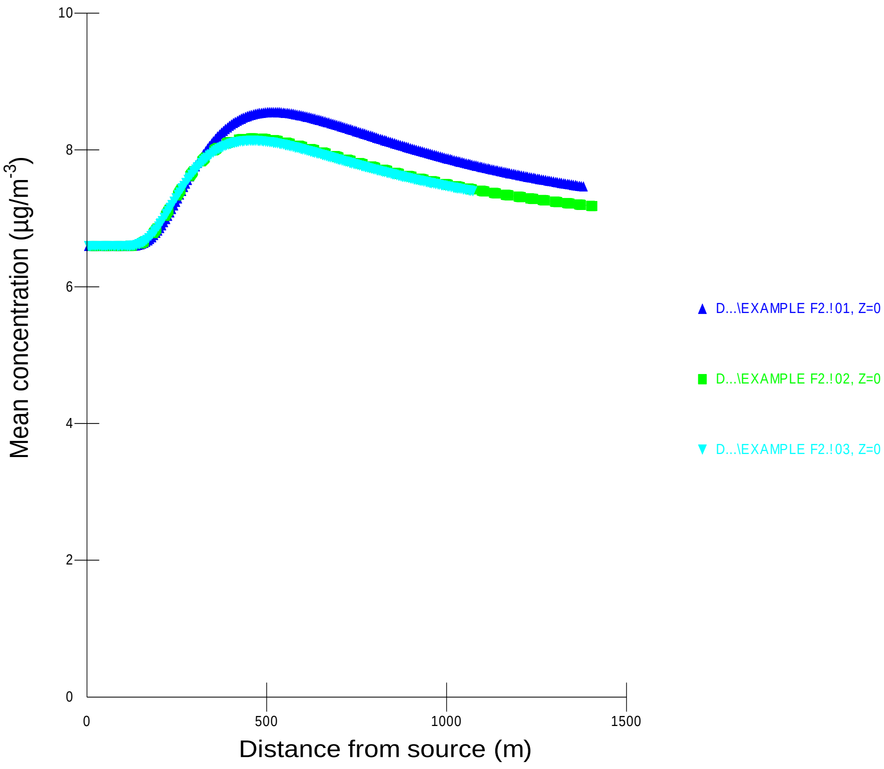

Figure 9. Concentration – distance line plot for no_x in the dry season for Lagos.

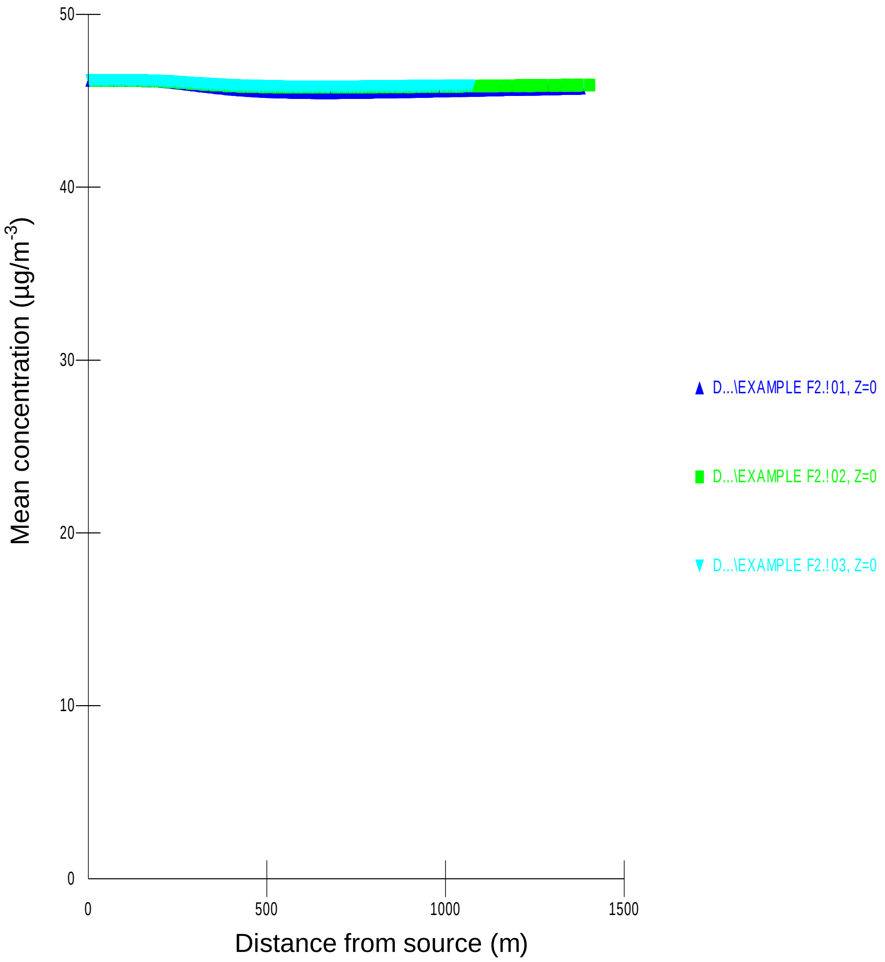

Figure 10. Concentration – distance line plot for o_3 in the dry season for Lagos.

represents the neutral atmospheric condition while the light blue colour represents the stable atmospheric condition as shown from the output of the model.

Figures 8 to 11 show the dispersion of pollutants from single elevated point source during dry season in Lagos. Figures 4 to 11 show the variation of concentrations of NO_2, NO_x, O_3 and SO_2 with distance in Lagos city during both rainy and dry seasons. Figures 6 and 10 show that the ozone concentration is nearly constant during both seasons with concentration range between 12 to 12.5 μgm^{-3} during rain and 47 to 48 μgm^{-3} during dry, from the unstable through neutral to stable conditions of the atmosphere. However, the concentration range shows a very slight decrease before attaining a constant value of 47 – 48 μgm^{-3} beyond a distance of about 500 m in the dry seasons. This may be attributable to its production as a secondary pollutant. The behaviour of NO_2 (1.7 to 2.2 μgm^{-3} in rain to 4.5 to 5.5 μgm^{-3} in dry) and NO_x (2.8 – 4.8 μgm^{-3} in rain and 6.5 to 8.5 μgm^{-3} in dry) are also different for the two seasons. A Gaussian type curve was produced for NO_x during the rainy season while an S – type curve was obtained during the dry season. This shows that the leighton ratio (NO_2) / (NO) which is a daylight factor that depends on ozone concentrations and the sunlight differ for the two seasons. For both seasons NO_2 has an S – type curve. The elevation is also higher for dry than rainy season. This could be attributed to a higher photochemical activity involving the complex chemistry of interconversion of NO_2 or NO_x into O_3 (Chou et al., 2006; Bloss, 2009) in the dry season. There is no visible change for the variation of SO_2 for both dry and rainy season, however, it is the only pollutant that have higher modeled concentration in the wet season compared to the dry season and showing a biogenic source different from the sources of the other two pollutants (Figures 7 and 11).

Comparison of monitored and modeled data

Table 3 shows that the modeled concentrations are generally higher in dry season and this follows a similar

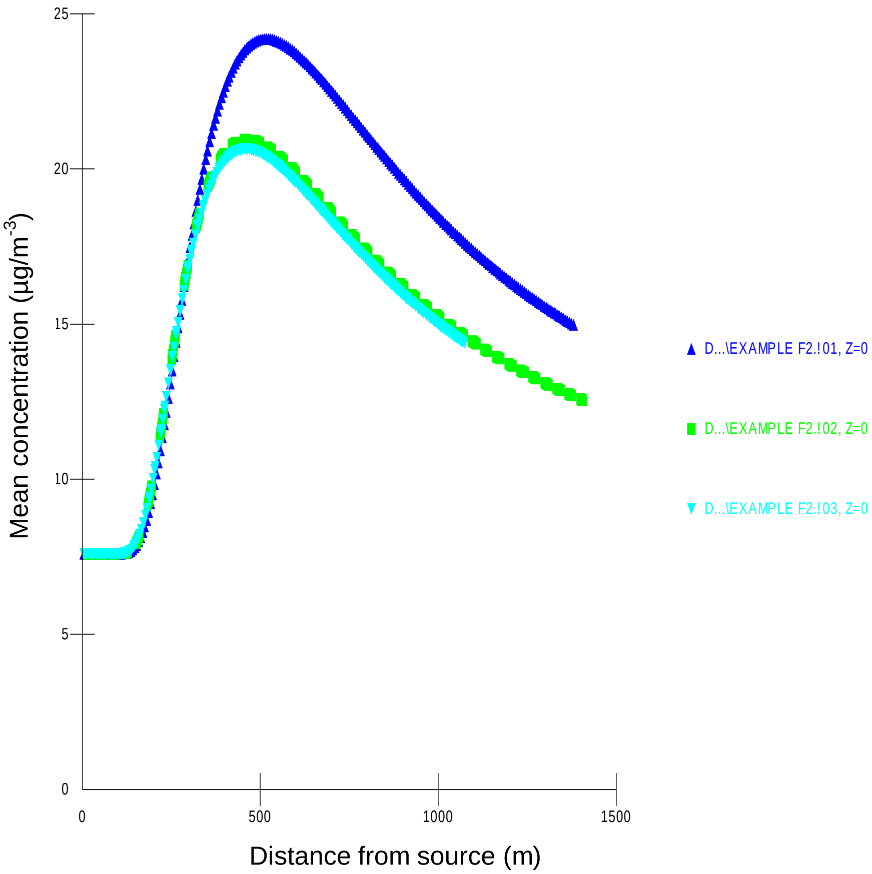

Figure 11. Concentration – distance line plot for so_2 in the dry season for Lagos.

Table 3. The measured and ADMS-urban modeled concentration values of O_3, NO_x and SO_2 in ppb during rainy and dry seasons in Lagos city.

Sites	Measured	O_3	Measured	NO_x	Measured	SO_2
		Modeled		Modeled		Modeled
Lagos rain	9.87 ± 1.61[a]	6.13	3.00 ± 0.24[a]	2.02	5.73 ± 0.51[b]	9.54
Lagos dry	36.22 ± 3.48[a]	23.36	6.73 ± 0.51 [a]	3.99	13.49 ± 1.72[b]	6.01

[a]Abdul Raheem et al. (2009) and [b]Abdul Raheem et al. (2012).

trend with field measurements. The relatively lower values during wet season have been attributed to the attenuation effect of rain. The modeled result for SO_2 in dry season is however lower by 37.0% than that of rainy season. For comparative purpose, the mean measured concentrations and predicted concentrations by ADMS-urban are summarized in Table 3. The predicted concentration for O_3 is lower than measured value while NO_x and SO_2 are higher during the wet season. This could be due to poor mixing of atmospheric air as a factor of wind speed downwind during the sampling period. The effect of ozone is more felt in rural than urban because of its being a secondary pollutant unlike the oxides of nitrogen and sulphur dioxide. Effect of rain attenuation is more on ozone than the other pollutants. However, in dry season all the modeled values are lower with ozone having the least 35.5% while the other pollutants are greater than 40% lowered than the measured values. Going by the complexity of the theoretical modeling, more information may be required for computation in other to have a good agreement between the predicted concentration and measured concentrations for NO_x, O_3; SO_2.

Though, it is outside the scope of this paper to compare the urban concentration measurement to that of rural concentration measurement of pollutants, it can be safely concluded that the chemical processes found in the atmosphere within and above cities (such as Lagos-Nigeria) differ from those of the more remote boundary layer as a consequence of the magnitude, diverse and complex nature of local anthropogenic emission sources, the higher concentrations of many trace species found as a result of this, and of the dynamic micro – and macro – environments in the urban landscape (Bloss, 2009).

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REFERENCES

Abdul Raheem AMO (2007). Measurement, modelling and analysis of ozone and ozone precursors in the ambient environment of Lagos and Ilorin cities, Nigeria. PhD Dissertation, University of Ilorin, Ilorin, Nigeria.

Abdul Raheem AMO, Adekola FA, Obioh IO (2009). The seasonal variation of the concentrations of ozone, sulphur dioxide and nitrogen oxides in two Nigerian cities. Environ. Model. Assess. 14(4):497-509.

Arciszewska C, McClatchey J (2001). The importance of meteorological data for modelling air pollution using ADMS-Urban. Meteorol. Appl. 8:345-350.

Beattie CI (2000). An Investigation into Urban Air Quality Management (AQM) Practices in England. Summary of Questionnaire Surveys Carried out in 2000, UWE, Bristol.

Bennet M, Hunter GC (1997). Some comparisons of lidar estimates of peak ground – level concentrations with the predictions of UK – ADMS. Atmos. Environ. 31(3):429-439.

Bloss WJ (2009). Atmospheric Chemical Processes of Importance in Cities. In Issues in Envoronmental Science and Technology, 28 Air Quality in Urban Environments. Edited by Hester RE and Harrison RM. Royal Soc. Chem. 2009.

Cambridge Environmental Research Consultants (CERC) (2004). ADMS – Urban Manual.

Carruthers DJ, Dixon P, McHugh CA, Nixon SG, Oates W (1999). Determination of compliance with UK and EU air quality objectives from high resolution pollutant concentration maps calculated using ADMS-Urban. Proc. 6th Int. Conf. Harm. Within Atm. Disp. Models for Regulatory Purposes, Rouen.

Carruthers DJ, Edmunds HA, Bennett M (1996). Validation of the UK – ADMS dispersion model and assessment of the performance relative to R91 and ISC using archive Lidar data. Report Ref. DoE/MW/RR/95/022 London. The UK Environmental Agency.

Carruthers DJ, Holroyd RL, Hunt JCR (1994). UK – ADMS – A new approach to modeling dispersion in the earth's boundary layer. J. Wind Eng. 52:139-153.

Chatterton TJ (2001). Regional and urban scale modeling of particulate matter: can PM_{10} be managed at a local level? PhD Thesis, University of East Anglia.

Chou CCK, Liu SC, Lin CY, Shiu CJ, Chang KH (2006). The trend of surface ozone in Taipei, Taiwan, and its causes: Implications for ozone control strategies. Atmos. Environ. 40:3898-3908.

Leksmono NS, Longhurst JWS, Ling KA, Chatterton TJ, Fisher BEA, Irwin JG (2006). Assessment of the relationship between industrial and traffic sources contributing to air quality objective exceedences: a theoretical modeling exercise. Environ. Model. Softw. 21:494-500.

McHugh CA, Carruthers DJ, Edmunds HA (1997). ADMS and ADMS – Urban. Int. J. Environ. Pollut. 8(3-6):438-440.

Owen B, Edmunds HA, Carruthers DJ, Raper DW (1999). Use of a new generation urban scale dispersion model to estimate the concentration of oxides of nitrogen and sulphur dioxide in a large urban area. Sci. Tot. Env. 235(1-3):277-291.

Vakeva M, Hameri K, Kulmala M, Lahdes R, Ruuskanen J, Laitinen T (1999). Street level versus rooftop concentrations of submicron aerosol particles and gaseous pollutants in an urban street canyon. Atmos. Environ. 33(9):1385-1397.

Woodfield NK, Longhurst JWS, Beattie CI, Chatterton T, Laxen DPH (2006). Regional collaborative urban air quality management: case studies across Great Britain. Environ. Model. Softw. 21(4):595-599.

Federal Republic of Nigeria Official Gazette (FRNG) (2 February 2009). "Legal Notice on Publication of the Details of the Breakdown of the National and State Official Totals 2006 Census" (PDF). Archived from the original on 2007-07-04, Retrieved 2007-06-29. www.population.gov.ng. 96:2.