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# Mathematical Modeling of Road Traffic Carbon Monoxide Pollutant: a Case Study of Minna Metropolis, Nigeria

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**Abstract** – *Motor vehicle emission is a major source of air pollution in urban areas with carbon monoxide being one of the major pollutants; yet hardly any locally developed modeling tools are available for environmental protection agencies in Nigeria. A Gaussian based mathematical model for road traffic carbon monoxide pollutant in Minna metropolis was formulated. A temperature velocity relation for carbon monoxide was introduced into the model using the Michael Boltzmann equation. Field measurement of carbon monoxide concentration was carried out using the Non Dispersive Infrared Analyzer. The model was simulated using quick basic programming language. The results obtained showed that the trend in modeled concentrations was similar to that of the measured concentrations except for stability class D range. The average value of index of agreement d, between the measured concentrations and the modeled concentrations was 0.89. The highest value of index of agreement obtained was 0.98 while the lowest value obtained was 0.77. The model can be effectively used for predicting the concentration of carbon monoxide pollutant in the atmosphere in Minna metropolis. It can also be used as a tool for carbon monoxide pollution monitoring and control.* 

***Keywords**: Pollutants, Road Traffic Pollution, Carbon Monoxide and Line Source Model*

## Nomenclature

| | |
|---|---|
| $C$ | Concentration of Pollutant (g/m$^3$) |
| $Q$ | Total emission rate of vehicles (g/s) |
| $Z$ | Distance relative to source (m) |
| $H$ | Emission height (m) |
| $U$ | Mean wind speed (m/s) |
| $\sigma z$ | Vertical dispersion parameter |
| $RC$ | Possible road capacity in stability time of CO (km/s) |
| $qc$ | CO emission rate per vehicle or emission factor (g/m) |
| $W$ | Width of the road (m) |
| $Lr$ | Length of the road (m) |
| $c_m$ | Average space time usage per vehicle (m$^2$) |
| $Vt$ | Velocity of the vehicle depending on the type of road (m/s) |
| $hs$ | Vehicle exhaust height (m) |
| $\Delta h$ | Plume rise (m) |
| $F_0$ | Buoyancy factor (m$^4$/s$^3$) |
| $g$ | Gravitational constant (9.81m/s$^2$) |
| $v_s$ | Exit velocity of carbon monoxide(m/s) |
| $r_s$ | Exit radius of vehicle exhaust pipe(m) |
| $Ta$ | Ambient temperature (K) |
| $Ts$ | Exit temperature of vehicle exhaust pipe (K) |
| $U$ | Wind velocity (m/s) |
| $t$ | Stability time of CO (s) |
| $\sigma$ | Rural dispersion coefficient |
| $x$ | Downwind distance (m) |
| $i, j$, and $k$ | Constants |
| $R$ | Ideal gas constant (8.314J/mol K) |
| $m$ | molecular mass of the gas (kg) |
| $T$ | Temperature (K) |

## I. Introduction

Air pollution refers to the presence of undesirable materials in air, in quantities large enough to produce harmful effects [1]. The problem of air pollution is tightly connected with the development of industry, transport and energetic. Continuous process of coal, natural gas and organic fuel burning aimed at obtaining energy and heat, wide spread of automobile transport, waste of chemical plants, and metallurgical works all lead to accumulation of different chemical compounds in the atmosphere. Air pollution is a major environmental health problem affecting both developed and developing countries in the world [2]. Atmospheric pollutants are responsible for both acute and chronic effects on human health [3]. Increasing amounts of potentially harmful gases and particles are being emitted into the atmosphere at a global scale, damaging human health and the environment [4]. Local and regional pollution take place in the lowest layer of the atmosphere, the troposphere, which at its widest, extends from earth's surface to about 16 km (about 10 mi) [5]. In the weather phenomenon known as thermal inversion, a layer of cooler air is trapped near the ground by a layer of warmer air above. When this occurs, normal air mixing almost ceases and pollutants are trapped in the lower layer [5]. Extending beyond a regional scale, air pollution results in global warming and also depletion of the ozone layer. Scientists predict that the temperature increase referred to as global warming will affect world food supply, alter sea levels, make weather more extreme, and increase the spread of tropical diseases [5]. It is worth of mentioning that in most of commercial cities of Nigeria, emissions from vehicles constitute the major sources of air pollution.

Motor vehicle emission has been recognized as one of the major sources of air pollution particularly in highly urbanized areas [4]. There has been a substantial increase of air pollution caused by vehicular exhaust emissions (VEEs) due to addition of more and more vehicles on roadways to meet increase in transportation demand [6]. The major pollutants associated with road traffic are carbon monoxide (CO), hydrocarbons, sulphur dioxide, nitrogen oxides (NOx), and particulate matters which include lead from gasoline additives. Carbon monoxide from motor vehicles results from incomplete combustion. When fuels are incompletely burned, various chemicals called volatile organic compounds (VOCs) also enter the air [2]. Carbon monoxide is a colorless, odorless, tasteless and non-irritating gas but can be lethal to human beings within minutes at high concentrations exceeding 12,800 parts per million [7]. It is a chemical compound of carbon and oxygen with the formula CO. It is colourless, odourless, about three percent lighter than air, melts at -205° C (-337° F) and boils at -191.5° C (-312.7° F), and is poisonous to all warm-blooded animals and many other forms of life. When inhaled, it combines with haemoglobin in the blood, preventing absorption of oxygen and resulting in asphyxiation. Therefore, short-term exposure to high CO concentrations might cause an acute health impact [8]. Minna is predominantly residential with very few cottage industries, densely populated at the central area popularly called Mobil with low density at the outskirts [9]. Due to increasing economic activities, relatively peaceful environment and proximity to the Federal Capital Territory, there is a remarkable influx of people into the city and thus increased number of cars [9]. Some road junctions in Minna metropolis that are usually congested with traffic include Mobil roundabout, Tunga market roundabout and Kpakungu roundabout which connects the road leading to Bida and has within the last three years experienced rapid increase in human activities. The major sources of carbon monoxide pollution include cars and other internal combustion engines or generally fossil fuel driven vehicles [9].

The main aim of this project is to provide an air quality assessment tool for traffic related carbon monoxide pollutant in Minna metropolis. This will be achieved by proposing a dispersion model for carbon monoxide pollutant. The objectives are to:

1. Obtain data on carbon monoxide concentration along a selected traffic junction.
2. Develop a mathematical model expressing the concentration of carbon monoxide pollutant in the atmosphere.
3. Compare the measured ground level data and the model prediction by simulation.

## II. Experimental

In the experimental method, measurements and simulation of the mathematical model was carried out for carbon monoxide concentration at the selected traffic junction as well as observing and measuring prevailing meteorological conditions such as atmospheric temperature, wind speed, rainfall and insolation. Other parameters and constants needed for the model simulation were also estimated for example dispersion parameters, atmospheric stability class, length of the road way and other vehicle parameters. Table I shows the measured and estimated parameters. Data on wind speed, ambient temperature, rainfall and insolation were obtained from the Nigeria Meteorological Agency (NIMET) station located at the Minna National Airport in Niger state. The meteorological data corresponding to each measurement as well as the stability class specified using wind speed and solar insolation relation. The selected traffic junction in Minna used for this study is Kpakungu Roundabout which connects the road leading to Bida. The non-dispersive infrared analyzer was used to measure the concentration of carbon monoxide in the atmosphere. The instrument measures real time concentration of carbon monoxide in the atmosphere. Measurement was carried out for a period of ten days in the months.

### *II.1. Formulation of Mathematical Model*

Most discharges to the atmosphere are from car exhaust and these emissions of pollutants then blow upwards and disperse horizontally and vertically. These take the form of Gaussian distribution equation and are functions of wind speed and atmospheric stability [10]. This model is based on the maximum ground level concentration of carbon monoxide, considering the spread of a plume in vertical and horizontal directions, which is assumed to occur by Gaussian diffusion along the direction of the mean wind. Vehicular emission is generally considered as a line source in air dispersion models [11]. The Gaussian line source model is based on the superposition principle namely; concentration at a receptor is the sum of contributions from all of the infinitesimal point sources making up the line source [12]. The mechanism of diffusion from each point source is assumed to be independent of the presence of other sources. According to Chock (1978), the validity of this assumption becomes questionable when the line source has an accompanying self-generated turbulence such as the case of a roadway with traffic. In addition, the superposition approximation becomes worse as the angle of wind direction becomes small relative to the road axis. To alleviate these problems, it would be useful to avoid the initial point source assumption so the model can take the form of the equation below. This is known as the

Gaussian dispersion line source equation as shown in Equation (1) [12]:

$$C = \frac{Q}{(2\pi U\sigma_z)^{1/2}} \left\{ exp\left[-\frac{1}{2}\left(\frac{Z-H}{\sigma_z}\right)^2\right] + exp\left[-\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2\right]\right\} \quad (1)$$

The following assumptions were made in order to develop a Gaussian line source dispersion equation for carbon monoxide:

1. Diffusion of pollutant occurs according to Gaussian equation.
2. The emission is a line source emission.
3. Atmospheric stability depends on wind speed and insolation.
4. An ideal gas behavior is assumed for carbon monoxide.
5. There is no chemical transformation of the pollutant.
6. Rural terrain is assumed.
7. The pollutant's exit velocity is assumed to be equal to the velocity of the vehicle.
8. Concentration of pollutant is proportional to temperature change between the ambient temperature and a reference temperature corresponding to temperature at the start of the day.
9. A maximum possible emission rate of pollutant is assumed.

CO pollution is very sensitive and traffic volume changes over times are considerably unpredictable [13]. Let CO emission rate of vehicles $Q$, be expressed in terms of road capacity (maximum possible traffic volume):

$$Q = (RC)q_C \quad (2)$$

RC is calculated using Li's (1998)[14] equation:

$$RC = \left(\frac{(WL_r)/V_t}{C_m}\right) \quad (3)$$

$H$ known as the emission height in Equation (1) can be obtained using the formula below [10]:

$$H = hs + \Delta h \quad (4)$$

Wayson (2000) [15] developed an equation for Δh of emitted carbon monoxide by vehicle transportation as follows:

$$\Delta h = 1.6\left(\frac{F_0 t^2}{U}\right)^{1/3} \quad (5)$$

But:

$$F_0 = g v_s r_s^2 \left[1-\left(\frac{T_a}{T_s}\right)\right] \quad (6)$$

Since rural terrain is assumed, Turner's version of the rural Pasquill dispersion coefficient is used. As mentioned in chapter two, the most faithful representation by far of Turner's version of the rural Pasquill dispersion coefficients is published by McMullen which is given below:

$$\sigma = exp[i + j(lnx) + k(lnx)^2] \quad (7)$$

In the Gaussian dispersion equation, the most important parameters considered for model development are prevailing meteorological conditions viz wind speed, solar radiation and atmospheric temperature which in turn define the stability class. Let the wind velocity define the atmospheric stability while the actual velocity of carbon monoxide relative to that of the wind be substituted in place of $U$ in Equation (1). From the kinetic theory of gases, the root mean square velocity of a gas is related to temperature by Maxwell Boltzmann's equation written as:

$$U = \left(\frac{3RT}{m}\right)^{1/2} \quad (8)$$

Substituting Equations (2), (3) and (8) into Equation (1) and putting $R$ = 8.314 and $m$= 28 which is the molecular weight for carbon monoxide gives:

$$C = \frac{\left(\frac{WL_r/V_t}{C_m}\right)(q_c)}{(2\pi\sigma_z(\frac{3\times 8.314\times T}{28})^{0.5})^{1/2}} \times \left\{exp\left[-\frac{1}{2}\left(\frac{Z-H}{\sigma_z}\right)^2\right] + exp\left[-\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2\right]\right\} \quad (9)$$

Assuming concentration of carbon monoxide pollutant is proportional to temperature change between the ambient temperature $T_a$ and a reference temperature $T_r$ corresponding to temperature at the start of the day that is at 7.00am, preliminary investigation of measured concentration and temperature change gives an approximate value of constant of proportionality of 0.25. Substituting this value in Equation (9), simplifying, and replacing $T$ with $T_a$ gives the final model equation as:

$$C = \frac{\left(\frac{WL_r}{V_t}\right)\times\left(\frac{q_c}{C_m}\right)(T_a - T_r)}{4\times(2\pi\sigma_z(0.9T_a)^{0.5})^{1/2}} \times \left\{exp\left[-\frac{1}{2}\left(\frac{Z-H}{\sigma_z}\right)^2\right] + exp\left[-\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2\right]\right\} \quad (10)$$

### *II.2. Simulation of Mathematical Model*

Parameters needed for model simulation among others include vehicle parameters, road parameters and receptor location. Physical dimensions of the vehicles and road were obtained using a tape rule. CO like other pollutants accumulates based on stability time independently or in conjunction with atmospheric temperature, pressure, wind speed and curb length or area [13]. The concentration of CO pollutant reaches a peak within five minutes of pollutant injection [13]. Therefore let the stability time of CO be taken as five minutes. The space time was taken as the length and width measurement of a typical vehicle which was 1.66m by 4.71m. A vehicular speed of 60km/hr was used which is the speed limit commonly specified for vehicles moving within cities. It was assumed that the pollutant is being emitted with the same speed as that of the vehicle and so 60km/hr was also used as the exhaust exit velocity. The road length was selected as 200m which is the selected grid size to investigate. A downwind distance of 30m was used which should be less than the road length. A CO emission factor of 0.036 was used based on work done by Ndoke (2010) [16]. The simulation of the model was done using quick basic programming language. The index of agreement between the measured concentration and the modeled concentration was calculated using the equation proposed by Willmott (1982) [17] and is shown in Table I.

TABLE I
MEASURED AND ESTIMATED PARAMETERS NEEDED FOR MODEL SIMULATION

| Parameter | Value |
|---|---|
| **Measured** | |
| Receptor height (z) | 1.5m |
| Downwind distance from source (x) | 30m |
| Vehicle exhaust height (hs) | 0.3m |
| Vehicle exhaust radius (rs) | 0.025m |
| Average space time of one vehicle (cm) | 7.82m$^2$ |
| Road width (w) | 6.4m |
| Road length (Lr) | 200m |
| **Estimated** | |
| Vehicle exhaust exit velocity (vs) | 1.67m/s |
| Vehicle exhaust exit temperature (Ts) | 473K |
| Vehicle average speed (vt) | 1.67m/s |
| Stability time of CO (t) | 300s |

## III. Results and Discussion

Potential air pollution impact is usually estimated through the use of air quality simulation models [18]. An urban air quality simulation model is a tool that uses physical principle for estimating pollutant concentration in space and time as a function of the emission distribution and meteorological condition. There are a wide variety of air pollution models. The models require two types of data inputs: information on the sources including pollutant emission rate, and meteorological data such as wind velocity and turbulence [18]. The model then simulates mathematically the pollutant's transport and dispersion, and perhaps its chemical and physical transformations and removal processes [18] Due to the very short distances between sources and receptors, only very fast chemical reactions have a significant influence on the measured concentrations within street canyons [18]. For this reason, most traffic-related pollutants such as CO and hydrocarbons can be considered as practically inert species within these distances. The model output is air pollution concentration for a particular time period, usually at specific receptor location [19].

A dispersion model is a mathematical description of the meteorological, transport and dispersion processes, using source and meteorological parameters, for a specific period in time. The model calculations result in estimates of pollutant concentration for specific locations and times [20]. The movement of pollutants in the atmosphere occurs by transport, dispersion and deposition. Transport is movement caused by time-average wind flow. Dispersion results from local turbulence that is, motion that lasts less than time used to average transport.

Deposition processes include precipitation and sedimentation, causing downward movement of pollutant in the atmosphere. Due to the very short distances between sources and receptors, only very fast chemical reactions have a significant influence on the measured concentrations within street canyons [19]. For this reason, most traffic-related pollutants for example CO and hydrocarbons can be considered as practically inert species within these distances [8]. Emission and vaporization of atmospheric pollutants are followed by dispersion of vapour to form a vapour cloud [21]. The dispersion factor is very important in studying the distribution of pollutants into the atmosphere. The basic concept of the roadway air dispersion model is to calculate air pollutant levels in the vicinity of a highway or arterial roadway by considering them as line sources. The model takes into account source characteristics as well as roadway geometry, surrounding terrain and local meteorology. The acquisition and pre-processing of these data is an important part of any modeling study, since the performance of a model greatly depends on the quality of the inputs [8].

The amount of turbulence in the ambient air has a major effect upon the rise and subsequent dispersion of air pollutant plumes. Atmospheric turbulence is created by many factors such as wind, flow over rough terrain, trees or buildings, and thermal turbulence from rising air. Any factor which enhances the vertical motion of air either rising or sinking will increase the degree of turbulence [10]. The Pasquill stability classes used with the Gaussian based models classified stability into six categories with A being the most turbulent and F the least turbulent. Data on wind speed and insolation was used to classify the stability classes and it was observed that they fell within the three classes B, C, and D with C occurring the most and D occurring the least

The measured values of carbon monoxide concentration showed a general trend for all the days with little variations. As shown in Figures 1 to 10, concentration was found to increase from 8pm at the start of experiment to between 1.00pm and 3.00pm after which the increase starts occurring at a slower rate. It can easily be concluded that as the number of vehicles plying the road increases, the concentration of carbon monoxide in the atmosphere also increases and reaches an almost steady state in which the rate of input is approximately equal to the rate of removal. Although this general trend is occasionally interrupted by the sudden changes in atmospheric stability induced by wind, rain and insolation. As shown in Figures 1 to 10, the simulated carbon monoxide concentrations showed similar trend with the measured concentrations. The graphs of modeled and measured concentration indicated that at the start of experiment when carbon monoxide concentration was still low, the simulated concentration values agreed very closely with the measured concentration with little or no errors but as the concentration of carbon monoxide increases, the deviation between the measured and simulated value also increases. This probably could be due to factors whose effect become prominent with time and which have not been dealt with in the model. i.e increase in human activity with time, presence of other gases and background concentrations, evaporation and heat exchange. The simulated results indicate that wind speed and isolation, atmospheric temperature, wind speed and stability influence the pollutants dispersion from the source.

Wind speed and insolation was found to play a major role in the dispersion of pollutants. As shown in Figures 1 to 10, increase in wind speed resulted in increase in measured concentration while increase in insolation had the effect of reducing measured concentration. This trend was also reflected in the model. This can be explained by the fact that high wind speed hinders the vertical motion of air thereby reducing atmospheric turbulence. This hinders the pollutants from dispersing easily hence the high concentration. On the other hand, high insolation enhances vertical motion of air thereby making pollutants to disperse faster resulting in reduced measured concentration. The DFLSM of Khare and Sharma (1999) [6] calculated atmospheric dispersion coefficient based on wind speed and temperature data without taking into account sunlight and cloud cover and the model was found to over predict CO concentration during day time peak hours. Categorizing atmospheric stability using wind speed and insolation only takes care of the dispersion aspect of the pollutant and this dispersion in real sense is an indication of the ability of the pollutant to rise (disperse) vertically. Relating temperature to velocity of gas as was done in the model therefore had a contributing effect to the overall concentration by taking care of the horizontal movement of the pollutant. From the result of the measured concentrations as shown in Figures 1 to 10 and the corresponding ambient temperature, it can be observed that concentration of carbon monoxide increases with increase in atmospheric temperature. This can be explained by the fact that as temperature increases, the velocity of the molecules increase and the pollutants reach and accumulate at the receptor faster thereby increasing concentration.

Certain points of high error between measured and modeled concentrations were also observed and most of these points corresponded to stability class D range.

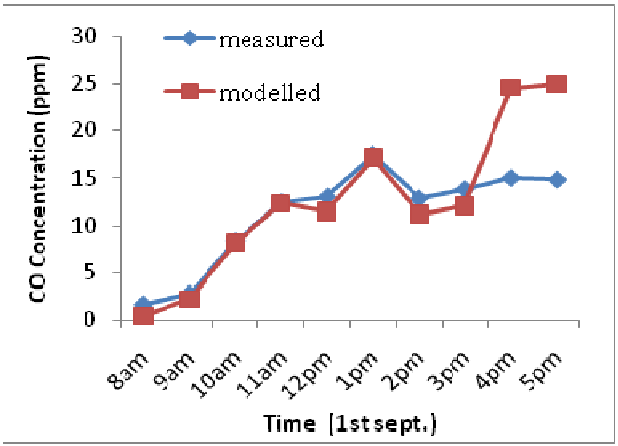


Fig. 1. Measured and Modeled CO Concentration for 1st September

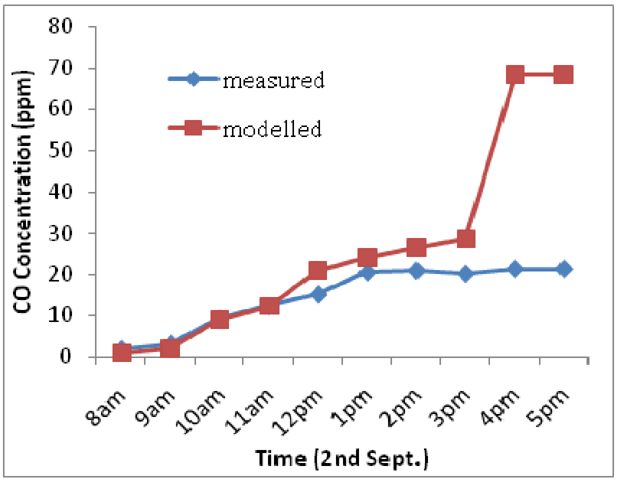


Fig. 2. Measured and Modeled CO Concentration for 2nd September, 2011

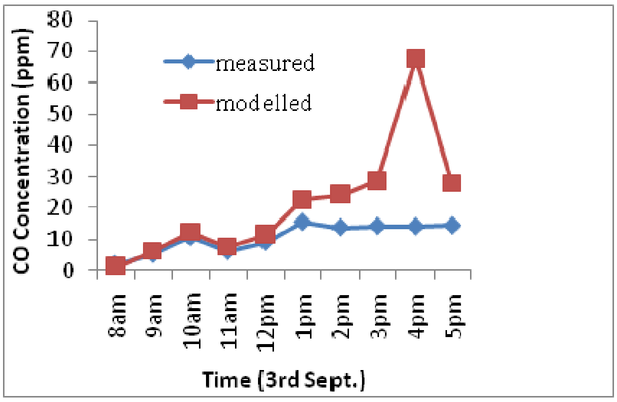


Fig. 3. Measured and Modeled CO Concentration for 3rd September

For example 4pm and 5pm in Figure 2, 4pm in Figure 3 11am in Figure 4, 5pm in Figure 6, 1pm and 4pm in Figure 8, and 3pm and 4pm in Figure 10. The stability class was specified based on the wind velocity and insolation but the modeled concentration at the points of high wind velocity corresponding to stability class D showed high deviation from the measured concentrations.

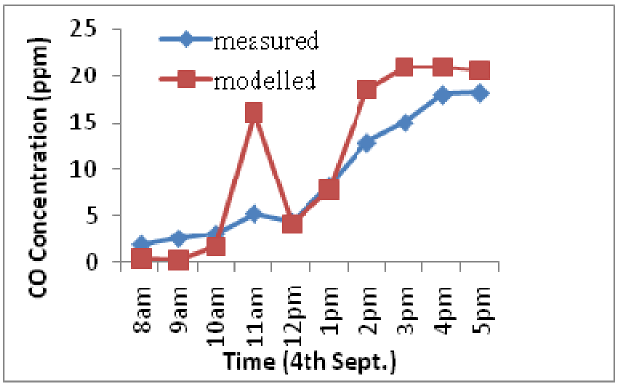


Fig. 4. Measured and Modeled CO Concentration for 4th September

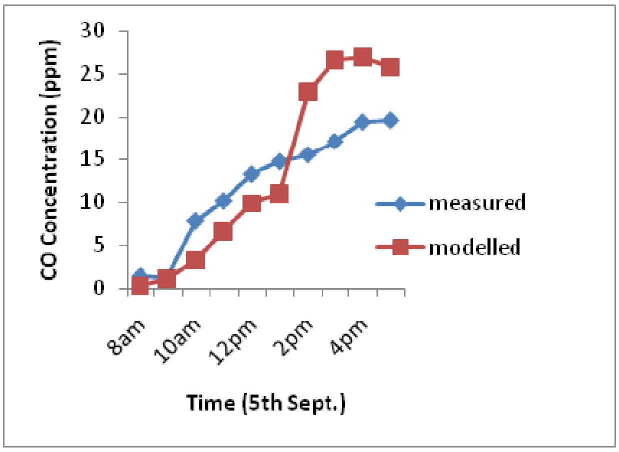


Fig. 5. Measured and Modeled CO Concentration for 5th September

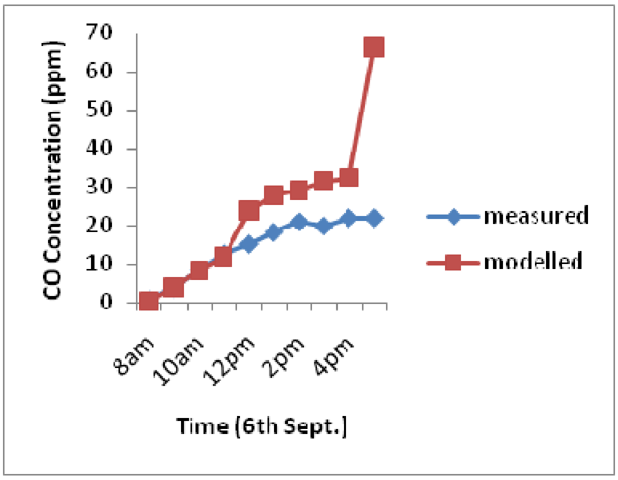


Fig. 6. Measured and Modeled CO Concentration for 6th September

This indicates that increasing wind velocity introduces uncertainties in atmospheric turbulence and specifying the stability class when the wind velocity is high could be misleading. The Gaussian plume model as would be seen in the works of Pasquill (1962) [23] and Sutton (1947) [24] was originally applied to stack gas dispersion in which a distinct plume of pollutant gas can be observed. The dispersion coefficient calculated by defining the Pasquill stability classes was done based on point source emission and thus the concentrations corresponding to each of the stability classes are significantly different from each other. Even though road way dispersion is assumed to be a line source and treated as such, the resultant effect of roadway pollutants in the atmosphere is a scatter of gases in the atmosphere and thus a response to a change in stability class might not produce a corresponding magnitude of change in concentration as that observed in a point source dispersion. Meanwhile, change in weather condition particularly from a calm but sunny weather to a stormy rainy weather will automatically change the stability class to be used in the model hence the exaggerated modeled concentration for stability class D. The Indian Institute of Technology Line Source Model attempted to solve this problem by proposing new formulas for calculation of dispersion coefficients but the Pasquill stability classes were still used.

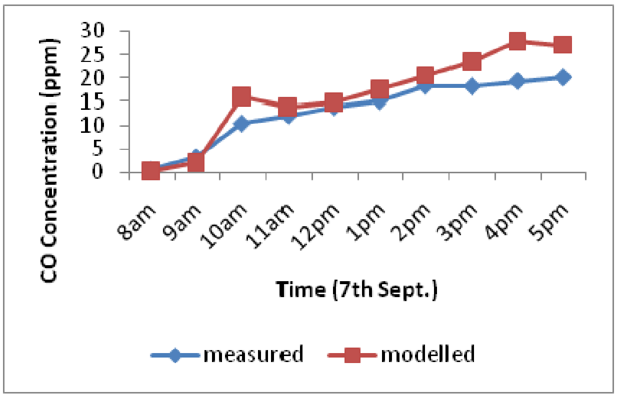


Fig. 7. Measured and Modeled CO Concentration for 7th September

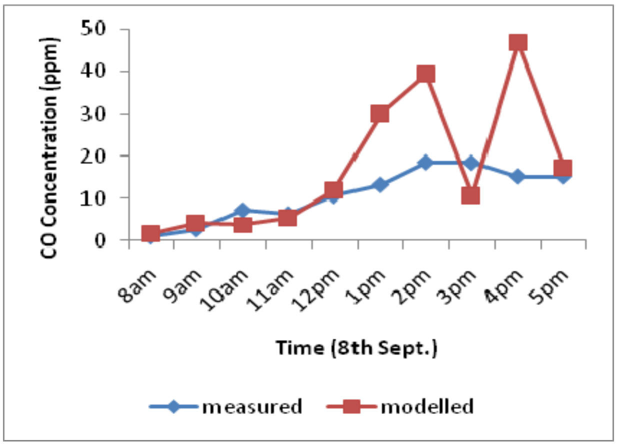


Fig. 8. Measured and Modeled CO Concentration for 8th September

In day 1, light rainfall and low insolation was experienced. This probably accounts for the sudden decrease in concentration after 1.00pm as shown in Figure 1. Day 2 was characterized by no rainfall and stable weather condition hence the uniform increase in concentration but stability class D produced large modeled concentration at 4.00pm and 5.00pm as shown in Figure 2.

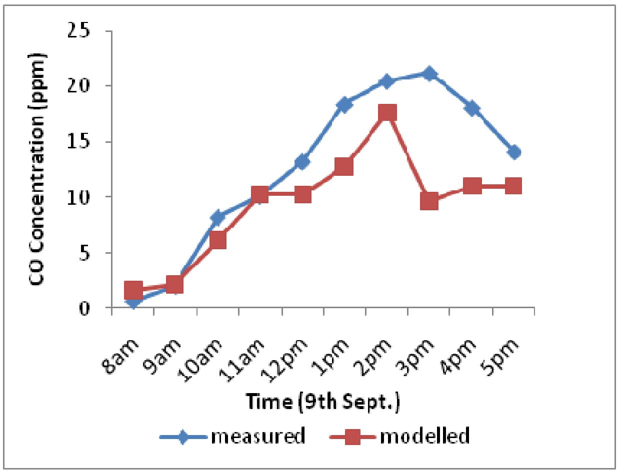


Fig. 9. Measured and Modeled CO Concentration for 9th September

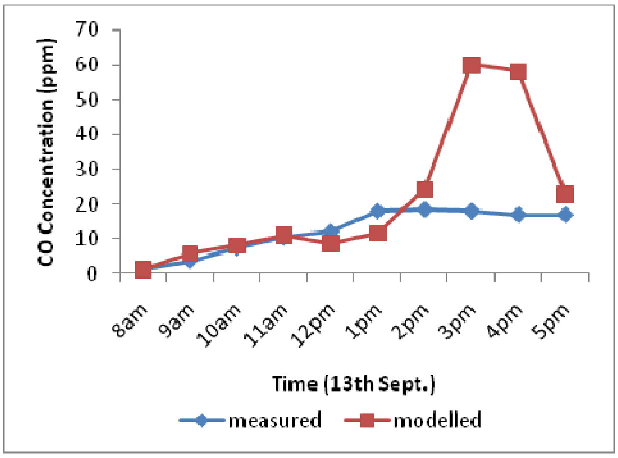


Fig. 10. Measured and Modeled CO Concentration for 13th September

Day 3 as shown in Figure 3 was characterized by high insolation and heavy rainfall. This day measured lower concentrations than other days. It could be assumed that the effect of rainfall could have contributed to the high insolation to give rise to low concentration of measured CO. But since rainfall was not included as a variable in the model equation, no conclusion can be drawn on that assumption. However, the modeled CO concentration agreed very closely with the measured CO concentration with index of agreement of 0.97. This indicates that insolation data on its own was adequate irrespective of rainfall. As shown in Figure 4, the unstable weather condition resulted in varying stability classes hence the un-uniform trend in both measured and modeled concentration. In Day 5, the weather condition was relatively stable though the winds became more prominent later on in the day. Day 6 and 7 were characterized by very light rainfall. As shown in Figures 6 and 7 respectively, the measured and modeled concentrations followed a similar trend with little variations. Still the error noticed corresponded to a stability class of D i.e. at 5pm Figure 6. Day 8 was characterized by light rainfall with high wind velocity. No rain was experienced on Day 9 while there was light rainfall with high insolation on Day 10. As shown in Figure 9 and 10 respectively, the measured and modeled concentration were high and showed similar trend with high error points corresponding to a stability class of D. The points of stability class D to a large extent affected the accuracy of the model but notwithstanding, the index of agreement between measured and modeled concentration indicates good result.

From the index of agreement between the measured and modeled concentration for each day measurement was carried out as shown in Table I, it can be seen that the values range between 0.77 and 0.98 while the average value is 0.89. These values indicate good index. The index are also better than that of other line source models such as the DFLSM and the GFLSM which for example showed index of agreement of 0.77 and 0.45 respectively in work done by Khare and Sharma (1999) in Le Meridian city.

TABLE II
INDEX OF AGREEMENT d, FOR EACH DAY

| Day | Index of agreement |
|---|---|
| 1 | 0.87 |
| 2 | 0.81 |
| 3 | 0.77 |
| 4 | 0.97 |
| 5 | 0.88 |
| 6 | 0.98 |
| 7 | 0.98 |
| 8 | 0.86 |
| 9 | 0.96 |
| 10 | 0.79 |

## IV. Conclusion

The following conclusion can be drawn based on the analysis conducted in this study:

1. A carbon monoxide predictive model

$$C = \frac{\left(\frac{WL_r}{V_t}\right) \times \left(\frac{q_c}{C_m}\right) (T_a - T_r)}{4 \times (2\pi\sigma_z(0.9T_a)^{0.5})^{1/2}} \times$$
$$\times \left\{exp\left[-\frac{1}{2}\left(\frac{Z-H}{\sigma_z}\right)^2\right] + exp\left[-\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2\right]\right\}$$

   which is based on Gaussian equation has been proposed.
2. Data on insolation was found to be adequate in categorizing atmospheric stability.
3. Increasing wind speed was found to pose uncertainties in defining stability class.
4. Concentration of pollutant was found to reduce with increased insolation.
5. Concentration of pollutant was found to increase with high wind velocity.
6. Concentration of pollutant at the receptor was found to increase with increase in atmospheric temperature.
7. The average index of agreement between the measured and modelled concentration was 0.89.
8. The model is adequate for predicting the concentration of carbon monoxide in the atmosphere

and can be effectively used as a tool for pollution monitoring and control.

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