RESEARCH ARTICLE OPEN ACCESS

Prediction of Carbon Monoxide Concentration in the Vicinity of Inderprashta Marg, near ITO, Delhi, India

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ABSTRACT
High concentration of CO may persist in the micro-environment of urban roadways due to the closely spaced high-rise buildings on either side of the roadways causing built up of pollutant. In order to achieve estimates of air quality on both spatial and temporal scales, the use of air quality dispersion modeling becomes more significant. Keeping these in view, the prediction of CO concentration in the Vicinity of Indraprashta Marg, near ITO, Delhi, India using Caline – 4 model for local meteorological and traffic conditions has been carried out. Furthermore, the statistical analysis of predicted CO concentration with monitored data has been performed. The procedure includes site selection, description of sampling (receptor) locations, primary and secondary data collection prediction of CO prediction for the real type parameters using Caline – 4, and statistical analysis of monitored and predicted CO concentration. The hourly concentration of predicted CO clearly shows two peaks (morning and evening) of CO during the day in all the months of the prediction. The morning peak has more predicted CO concentration values than that of evening peak hours. The predicted values of average hourly concentration CO have been observed to be very close irrespective of location.
Keywords: CO Prediction, Caline 4 Model, Urban Road, Statistical Analysis

I. INTRODUCTION

In air quality management, monitoring provides a basis for assessing urban air quality, but it is not possible practically or economically to monitor at every location of interest or predict future levels using this approach alone. Therefore, in order to achieve estimates of air quality on both spatial and temporal scales, the use of air quality dispersion modeling becomes more significant. Several line source models are available to predict pollutant concentrations in the field of urban roadways and intersections. But, researchers have used their own countries developed air quality models. However, in India, CLAINE – 4 has been recommended to predict CO concentration in the proximity of urban roads and traffic intersections. The rapid increase in road traffic volume and induction of high speed vehicles without modification of the road conditions, especially, poorly ventilated urban roadways causing built-up of CO in the micro environment. The challenge is compounded by the complexity of kinematics of dilution process along with the difficulty in making CO concentration measurements due to its spatial variability. In recent past, significant efforts have been made to improve the scientific understanding of exhaust dispersion phenomenon in the close vicinity of urban roadways. However, very little attention has been paid to the problem of CO concentrations and its variability at urban roadways surrounded by closely spaced, irregular high-rise building either one side or both side of the road. In view of this, the present study provides linear regression model for evaluation of CO in the micro environment for planners and decision makers responsible for urban air quality management. Several air quality models exist for evaluating roadside air quality (Gokhale and Khare, 2004). However, many of the models are too complex to be operated routinely given the simplicity of the available meteorological and traffic data (Dirks et al., 2003). A few models widely used for evaluating the dispersions at roadside, are for example, the GM (Chock, 1978), the GFLSM (Luhar and Patil, 1989), the CALINE-4 (Benson, 1992), the CAR-FMI (Harkonen et al., 1996), and at street canyons, the OSPM (Berkowicz, 2000; Palmgren et al., 1999) model. Anjaneyulu et al. (2006) predicted the CO for 15 links in Calicut city by using CALINE4 and IITLS and Linear regression models. Keeping these in view, the prediction of CO concentration in the Vicinity of Indraprashta Marg, near ITO, Delhi, India using Caline – 4 model for local meteorological and traffic conditions has been carried out. Furthermore, the statistical analysis of predicted CO concentration with monitored data has been performed.

II. METHODOLOGY

2.1 Site Selection

The Indraprashta Marg, near ITO, Delhi, India is one of the congested roads with either side high rise buildings. The study points are described in Fig. 1 below:

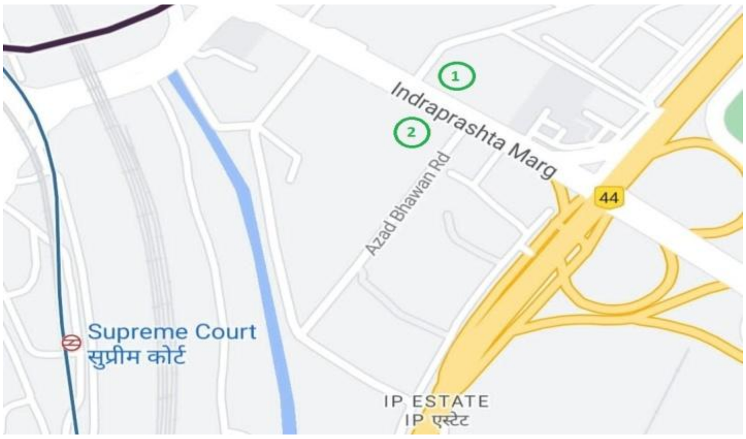

Fig. 1: Locations of study area, i.e., Indraprashta Marg, near ITO, Delhi, India

2.2 Collection and Analysis of Traffic Parameters

The traffic volume in terms of vehicles/hour and traffic composition has been collected in the month of March, April and May 2011. The traffic volume comprised of Bus and Trucks (HVs), Light Carriage Vehicles (LCVs), Cars, Three Wheelers (M3W) and Two Wheelers (M2W). The numbers of vehicles have been counted manually at an hourly basis for all the categories. The traffic counts have been performed from 8:00AM to 8:00 PM continuously. The vintage of vehicles and their corresponding emission factors for different categories of vehicles have been collected published report of CRRI (Central Road Research Institute). The traffic data have been analyzed using MS Excel spread sheet and composite emission factor has been evaluated. The hourly traffic volume (vehicles/hr) for different categories of vehicles approaching to Indraprashta Marg has been counted on March 2, 3 and 4, 2011.

Table 1: Average hourly traffic volume, vehicles/hour for different categories of vehicles approaching to Indraprashta Marg

Time Period, hrs	HVs	LCVs	CARS	M3W	M2W
8:00 to 9:00	155	6	1146	383	529
9:00 to 10:00	161	7	2219	804	1588
10:00 to 11:00	131	10	1965	1342	2249
11:00 to 12:00	126	7	1629	859	1863
12:00 to 13:00	125	6	1507	1018	1968
13:00 to 14:00	150	11	1748	1248	1450
14:00 to 15:00	155	14	1814	1247	2157
15:00 to 16:00	170	9	1696	1040	1916
16:00 to 17:00	178	10	1771	947	1518
17:00 to 18:00	169	9	1885	1281	1879
18:00 to 19:00	160	12	2022	1172	2048
19:00 to 20:00	143	8	1950	1026	1919

The three days hourly traffic volume has been averaged and given in Table 3.7. The average traffic volume varied at different hours of the day along with various categories of vehicles. The average traffic volume varied at different hours of the day along with various categories of vehicles. Fig. 3.14 shows the average traffic volume for the month of March at different hours of the day along with various categories of vehicles.. The heavy vehicles have their maximum numbers (178) at 4:00 PM to 5:00 PM, however, minimum (125) at 12:00 to 1:00 PM. The light carriage vehicles have their maximum numbers (14) at 2:00 PM to 3:00 PM, however, minimum (6) at 8:00 to 9:00 AM. The cars have their maximum numbers (2219) at 9:00 AM to 10:00 AM, however, minimum (1146) at 8:00 to 9:00 AM. The Three Wheelers (M3W) have their maximum numbers (1342) at 10:00 AM to 11:00 AM, however, minimum (383) at 8:00 to 9:00 AM. The Two Wheelers (M2W) have their maximum numbers (2249) at 10:00 AM to 11:00 AM, however, minimum (529) at 8:00 to 9:00 AM. The Fig. 3 shows the average composition of heavy vehicles (3%), cars (38%), three wheelers (22%) and two wheelers (37%).

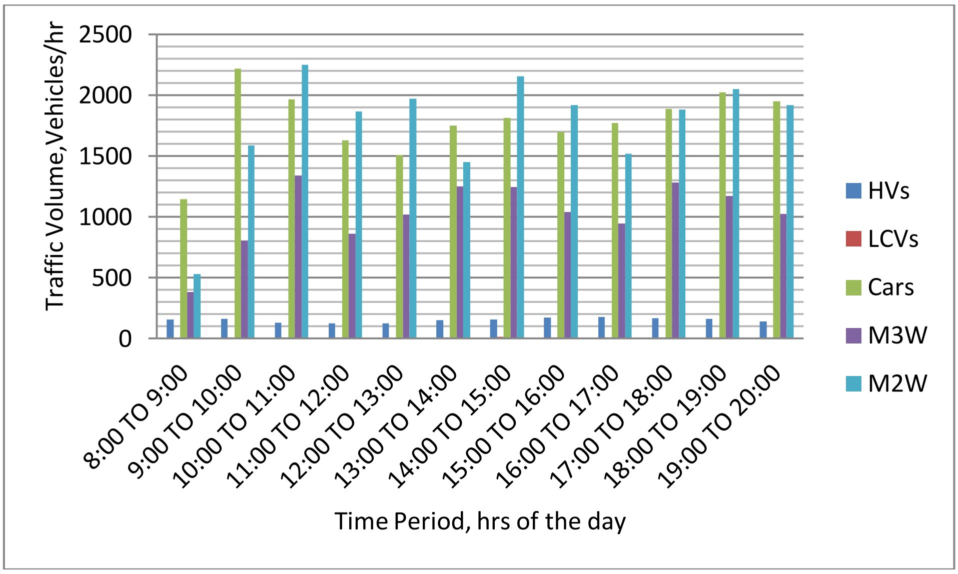

Fig. 2: Hourly variation of traffic volume at Indraprashta Marg on March, 2011

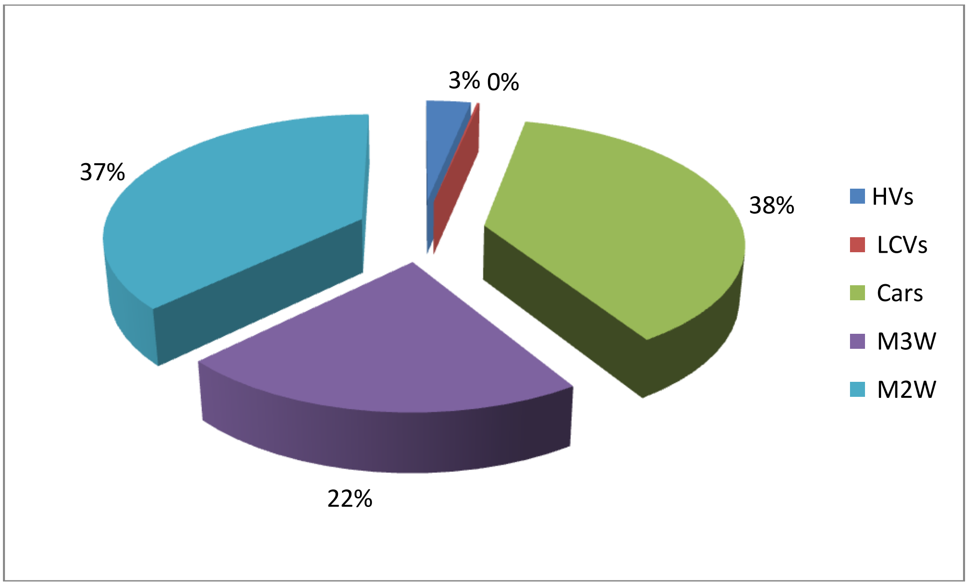

Fig. 3: Average traffic composition at Indraprashta Marg on March, 2011

2.3 Traffic Vintage and Emission Factors

A study carried out by central Road Research Institute, New Delhi in July, 2002 reveals that the fleet of vehicles in Delhi is young and consists of a large number of new technology vehicles. Many of the old vehicles have either been scrapped or transferred to another place in the country. The data relating to the vintage of the vehicles have been obtained by:

(i) Fuel station surveys
(ii) Outer cordon surveys
(iii) Fuel filling, Garaging and Registration pattern

(iv) Vehicles in use
To ensure that the sample represents the currently plying vehicle population, the survey stations have been spatially spread out in the cities and adequate numbers of vehicles have been interviewed in each category. The estimated average age of the vehicles has been shown in Table 2.

Table 2: Estimated average age of different categories of vehicles

Average Age of Vehicles, yrs	Percentage Share of Vehicles on Road				
	HVs	LCVs	Cars	M2W	M3W
15 – 20	Nil	Nil	5	Nil	Nil
15 – 15	20	20	10	20	Nil
05 – 10	30	40	35	30	50
00 – 05	50	40	50	50	50

It may be seen that the currently operating vehicles are much younger in age and use new technology. Thus, pollutants emitted by the vehicles mix actually plying are much lower. To estimate the air pollution loads from different vehicle types the emission factors with appropriate deterioration factors as employed by the CPCB in their report have been employed (Table 3).

Table 3: Emission Factors of CO for Different Categories of Vehicles with Age

Average Age of Veh., Yrs	HVs		LCVs		Cars		M3W		M2W	
	DF	EF	DF	EF	DF	EF	DF	EF	DF	EF
00 to 05	1.17	3.2	1.19	0.7	1.09	1.39	1.47	0.1	1.2	1.4
05 to 10	1.33	3.6	1.25	5.1	1.28	1.98	1.7	0.1	1.3	2.2
10 to 15	1.47	4.5	1.27	6.9	1.17	3.9	-	-	1.4	4
15 to 20	-	-	-	-	1.35	9.8	-	-	-	-

2.4 Estimation of Composite Emission Factor

The pollutant CO emitted from the tail pipe of the automobiles has been estimated on the basis of vehicle – kms travelled by different age group and categories of vehicles. The average emission factor for CO for different categories of vehicles has been calculated by using the emission factors and corresponding deterioration factors (Equation below).

$$Average\ Emission\ Factor = \frac{N_1\ x\ DF\ x\ EF +\ N_2\ x\ DF\ x\ EF + N_3\ x\ DF\ x\ EF +\ N_4\ x\ DF\ x\ EF}{Total\ No.of\ Vehicles}$$

Where, N_1 – No. of vehicles of 15 – 20 yrs of age
N_2 – No. of vehicles of 10 – 15 yrs of age
N_3 – No. of vehicles of 5 – 10 yrs of age
N_4 – No. of vehicles of 0 – 5 yrs of age
DF – Deteriorating Factor with age
EF – Emission Factor

Thereafter, the composite emission factor has been estimated considering vintage of vehicles plying on the road. Initially, average emission factor has been evaluated for different categories of vehicles including appropriate deterioration factor as mentioned in "transport fuel quality for the year 2006 to 2010 (CRRI)". The composite emission factor as been evaluated using following equation:

$$Composite\ Emission\ Factor = \frac{M_1\ x\ EF_1 + M_2\ x\ EF_2 + M_3\ x\ EF_3 + M_4\ x\ EF_4 + M_5\ x\ EF_5}{Total\ No.of\ Vehicles}$$

Where,
M_1 – No. of heavy vehicles (HVs)
EF_1 – Average emission factor
M_2 – No. of light carriage vehicles (LCVs)
EF_2 – Average emission factor
M_3 – No. of cars
EF_3 – Average emission factor
M_4 – No. of three wheelers (M3Ws)
EF_4 – Average emission factor

M_5 – No. of two wheelers (M2Ws)
EF_5 – Average emission factor
The evaluated average and composite emission factors, of different categories of vehicles, using above equations for CO has been given in Table 4.

Table 4: Evaluated average and composite emission factors, of different categories of vehicles

S. No.	Categories of Vehicles	Emission Factors, gm/km	
		Average	Composite
1	HVs	4.64	**2.3**
2	LCVs	4.11	
3	Cars	2.77	
4	M3W	0.16	
5	M2W	2.82	

The computed composite emission factor in gm/km has been converted into gm/mile and used in Caline – 4 model for predictions.

2.5 CO Prediction Procedure

Prediction of CO concentration at various receptor locations of intersection has been carried out using CALINE-4 model. Initially, relevant information necessary for model run such as traffic volume, composite emission factor and meteorological parameters as well as train conditions have been collected. Thereafter, input files as per model requirement have been prepared and the model run has been performed. The average hourly CO concentration has been obtained at pre-defined receptor locations of the intersection as an output. The CO concentration predictions have been carried out for the months of March, April and May, 2011.

2.6 Statistical Analysis Procedure for Predicted CO Data

The statistical analysis has been performed for measured and predicted values of CO data considering relevant statistical parameters such as mean, Index of Agreement (IA), Normalized Mean Square Error (NMSE), Pearson's Correlation Coefficient (COR), the Fractional Bias and the Factor-of-Two (F2). The statistical analysis has been done at 95 % confidence level for all the independent parameters. The MS excel spread sheet has been developed for the following standard statistical equations and used for the evaluation of these parameters.

$$IA = 1 - \frac{\overline{(C_{PRED}-C_{OBS})^2}}{\overline{\left(|C_{PRED}-\overline{C_{OBS}}|+|C_{OBS}-\overline{C_{OBS}}|\right)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

$$NMSE = \frac{\overline{(C_{OBS}-C_{PRED})^2}}{\overline{C_{OBS}}\,\overline{C_{PRED}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(ii)}$$

$$R = \frac{\overline{(C_{OBS}-\overline{C_{OBS}})(C_{PRED}-\overline{C_{PRED}})}}{\sigma_{OBS}\sigma_{PRED}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}$$

$$FB = \frac{2(\overline{C_{PRED}}-\overline{C_{OBS}})}{\overline{C_{PRED}}+\overline{C_{OBS}}|} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iv)}$$

Where, IA is the Index of Agreement, NMSE, the Normalized Mean Square Error, R the Pearson's Correlation Coefficient, FB the Fractional Bias and F2, the Factor-of-Two, C_{PRED}, the predicted CO concentration and C_{OBS}, observed CO concentration and σ_{PRED}, standard deviation of predicted concentration and σ_{OBS}, standard deviation of observed CO concentration.

III. RESULTS AND DISCUSSION

3.1 Predicted CO Concentration at Indraprashta Marg

The predicted hourly concentration of CO at location 1 using Caline – 4 for the month of March shows similar trends of CO concentration variation as discussed in the case of monitored CO concentration (Fig. 4). The values of predicted CO concentrations by Caline – 4 have been observed to be (5539 µg/m^3) in morning (peak value) followed by evening peak (5077 μg/m^3). It is evident that Caline 4 model have under predicted in comparison of monitored values of CO in the month of March.

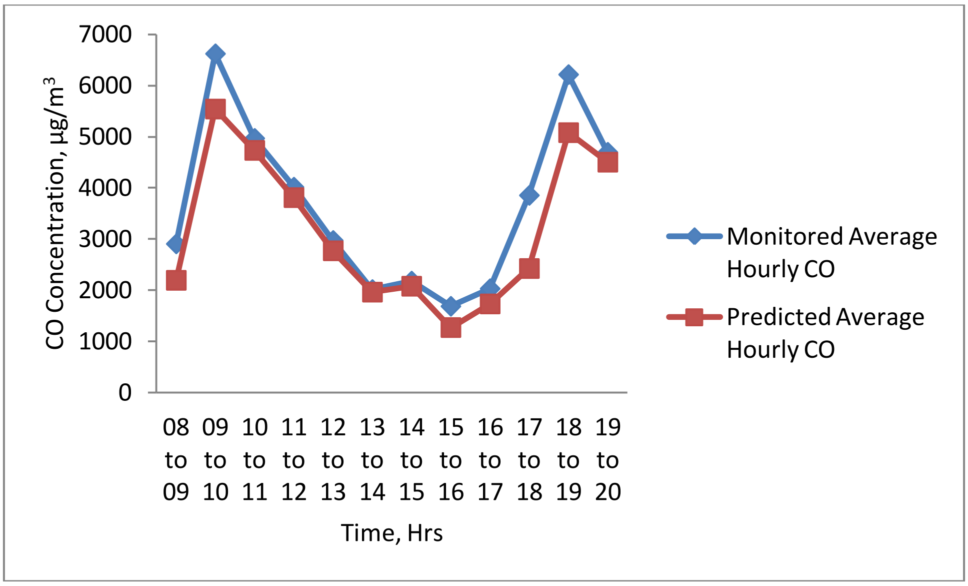

Fig. 4: Comparative monitored and predicted average hourly CO concentration at location 1

The predicted hourly concentration of CO at location 2 using Caline – 4 for the month of March shows similar trends of CO concentration variation as discussed in the case of monitored CO concentration (Fig. 5). The values of predicted CO concentrations by Caline – 4 have been observed to be (1500 μg/m^3) in morning (peak value) followed by evening peak (3000 μg/m^3). It is evident that Caline 4 model have under predicted in comparison of monitored values of CO in the month of March.

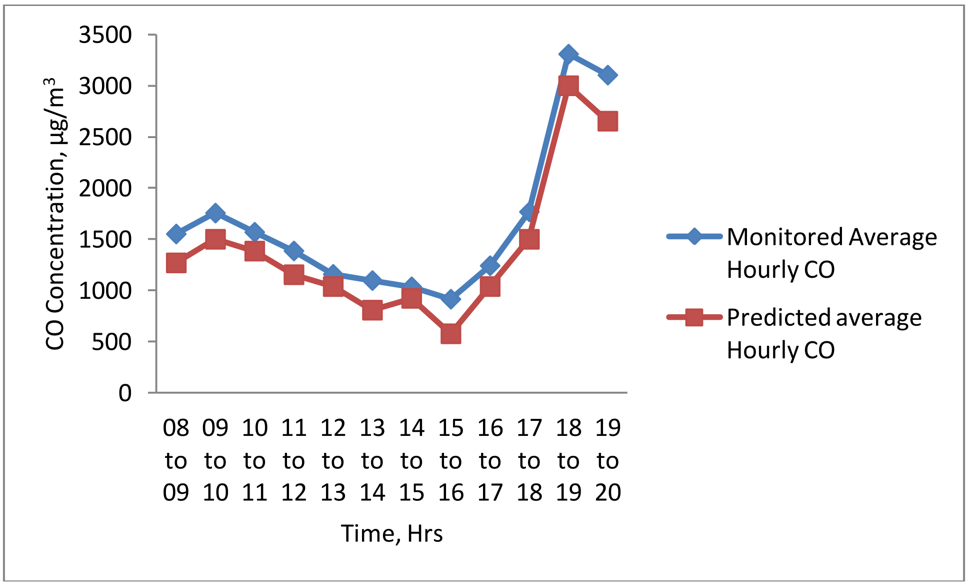

Fig. 5: Comparative monitored and predicted average hourly CO concentration at location 2

3.2 Statistical Analysis Results

The values of mean, IA, NMSE, R, FB and the F2 for monitored and predicted CO concentration at Indraprashta Marg (location 1) have been given in Table 5 and Fig. 6. The value of IA has been found to be 0.95, which is very close to 1.0. This shows perfect agreement between monitored and predicted concentrations of CO. The value of NMSE has been evaluated to be 0.03, which denotes better model performance. The value of Correlation Coefficient, R gives quantitative relation between monitored and predicted results. It has been has been found to be (0.88), close to unity, which implies good model performance. The value of fractional bias (FB) ranges from + 2 to – 2 and has ideal value zero for an ideal model. The value of FB been evaluated to be – 0.04, which is very close to zero, indicates better performance of model. The ideal value for the Factor-of-Two (F2) should be 1 (100%). The calculated value of F2 has been found to be 86.28%, shows good correlation among monitored and predicted values.

Table 5: Values of statistical parameters for monitored and predicted concentrations of CO

Parameters	Monitored CO	Predicted CO	Range
Mean	3678	3173	–
Index of Agreement (IA)	1.00	0.95	0.0 – 1.0
NMSE	0.00	0.03	0.0 – 1.0
Pearson's Correlation (R)	1.00	0.88	+ 1 to – 1.0
Fractional Bias (FB)	0.00	-0.04	+ 2 to – 2
F2	100%	86.28	100%

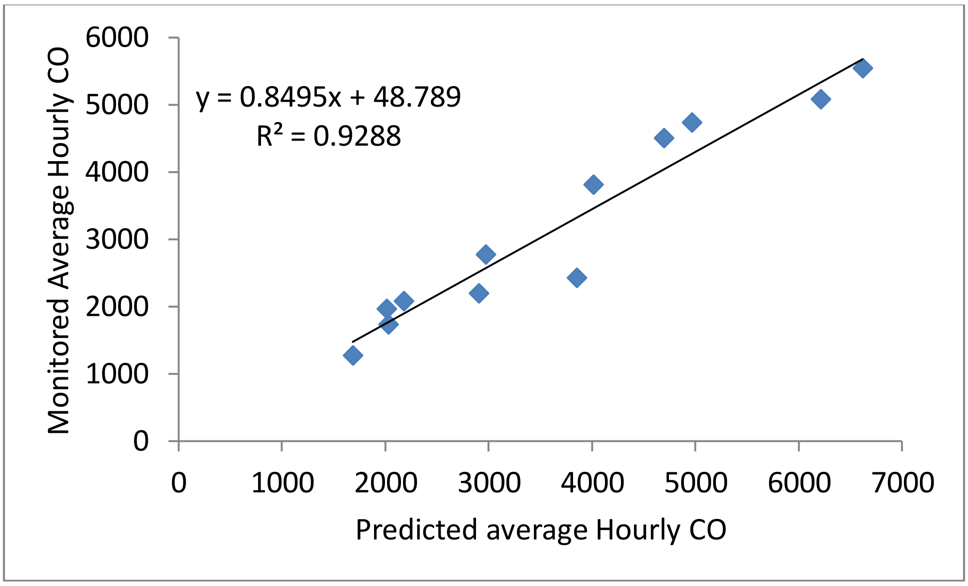

Fig. 6: Correlation between monitored and predicted average hourly CO concentration at location 1

The values of mean, IA, NMSE, R, FB and the F2 for monitored and predicted CO concentration at Indraprashta Marg (location 2) have been given in Table 6 and Fig. 7. The value of IA has been found to be 0.96, which is very close to 1.0. This shows perfect agreement between monitored and predicted concentrations of CO. The value of NMSE has been evaluated to be 0.02, which denotes better model performance. The value of Correlation Coefficient, R gives quantitative relation between monitored and predicted results. It has been has been found to be (0.91), close to unity, which implies good model performance.

Table 6: Values of statistical parameters for monitored and predicted concentrations of CO

Parameters	Monitored CO	Predicted CO	Range
Mean	1657	1404	–
Index of Agreement (IA)	1.00	0.96	0.0 – 1.0
NMSE	0.00	0.02	0.0 – 1.0
Pearson's Correlation (R)	1.00	0.91	+ 1 to – 1.0
Fractional Bias (FB)	0.00	-0.16	+ 2 to – 2
F2	100%	84.69	100%

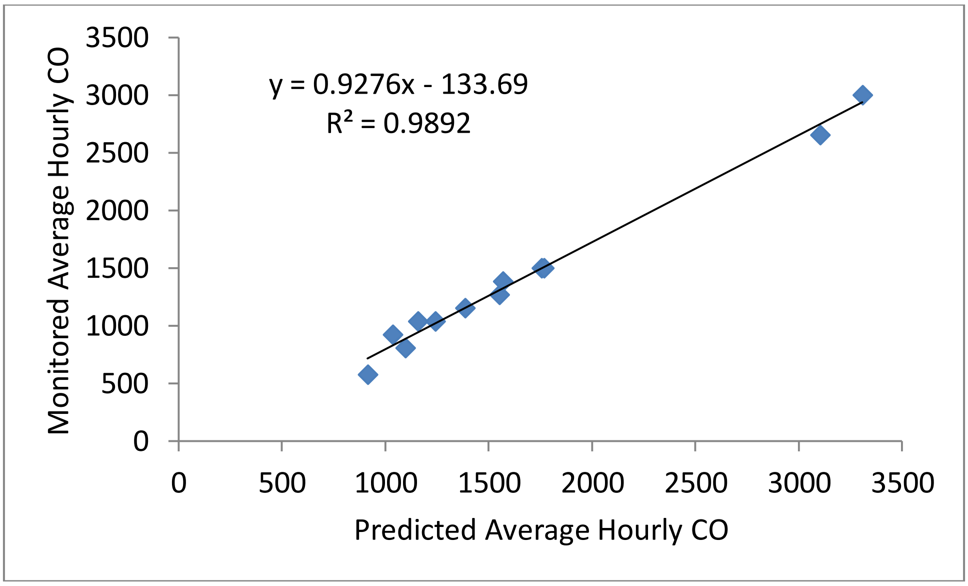

Fig. 7: Correlation between monitored and predicted average hourly CO concentration at location 2

The value of fractional bias (FB) ranges from + 2 to – 2 and has ideal value zero for an ideal model. The value of FB been evaluated to be –0.16, which is very close to zero, indicates better performance of model. The ideal value for the Factor-of-Two (F2) should be 1 (100%). The calculated value of F2 has been found to be 84.69%, shows good correlation among monitored and predicted values.

IV. CONCLUSIONS

The hourly concentration of predicted CO clearly shows two peaks (morning and evening) of CO during the day in all the months of the prediction. The morning peak has more predicted CO concentration values than that of evening peak hours. The predicted values of average hourly concentration CO have been observed to be very close irrespective of location. The values of statistical parameters in terms of mean, Index of Agreement (IA), Normalized Mean Square Error (NMSE), Pearson's correlation coefficient (COR), the Fractional Bias and the Factor-of-Two (F2) have been found to be very close to ideal model performance. The values of statistical parameters chosen for the model predicted results showed good correlation between monitored and predicted values of 1 hourly average CO at both locations, either side of the road.

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