International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 6 Issue 3|| March 2017 || PP. 104-108

Evaluation and Validation of the CALINE-4 Model near Bahadur Shah Zafar Marg, New Delhi, India

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Abstract: *The rapid increase in vehicular population and traffic activity has led to serious air quality concerns in urban areas of developing countries. Among traffic-related pollutants, carbon monoxide (CO) constitutes a major share due to incomplete fuel combustion in automobiles and may account for nearly 70% of total urban air pollution, particularly in the vicinity of busy roads and intersections. In this study, the CALINE-4 line source dispersion model was evaluated by comparing predicted CO concentrations with field measurements. Bahadur Shah Zafar Marg, a major urban roadway in New Delhi characterized by high traffic density and heterogeneous vehicle composition, was selected for model validation. Ambient CO concentrations were monitored and simulated following standard protocols. The predicted hourly average CO levels closely matched the observed concentrations across all monitoring locations. Statistical performance indicators such as mean concentration, Index of Agreement (IA), Normalized Mean Square Error (NMSE), Pearson's correlation coefficient (R), Fractional Bias (FB), and Factor-of-Two (F2) indicated strong agreement between measured and modeled values. The results confirm that CALINE-4 slightly underestimates CO levels but performs reliably under Indian urban traffic conditions. The findings provide useful inputs for urban air quality management, planning, and policy formulation.*
Keywords: *Carbon Monoxide, CALINE-4, Traffic Pollution, Model Validation, Statistical Performance*

I. Introduction

Carbon monoxide (CO) is a localized air pollutant with elevated concentrations occurring primarily near emission sources, especially roadways. In urban environments, vehicular traffic represents the dominant source of CO emissions. Several studies have identified CO as one of the most prevalent traffic-related pollutants in cities, particularly in developing nations experiencing rapid motorization (Mukherjee and Viswanathan, 2001; Riley, 2002; Schipper et al., 2009). High traffic volumes combined with poor dispersion conditions, such as closely spaced high-rise buildings, contribute to pollutant accumulation along urban roads and intersections.

Exposure to elevated CO levels poses significant health risks to residents, commuters, and pedestrians living or traveling near major roadways. Numerous monitoring and modeling studies have investigated vehicular CO concentrations near roads and intersections worldwide (Bogo et al., 1999; Moseholm, 1996). While several dispersion models are available for roadside air quality assessment, many require detailed input data that are often unavailable in developing countries (Dirks et al., 2003).

Among the commonly applied models for near-road pollution assessment are the GM model (Chock, 1978), GFLSM (Luhar and Patil, 1989), CALINE-4 (Benson, 1992), CAR-FMI (Harkonen et al., 1996), and OSPM for street canyons (Berkowicz, 2000). However, model performance depends strongly on local traffic and meteorological conditions. Therefore, site-specific validation is essential prior to application. This study aims to validate the CALINE-4 model for predicting CO concentrations under typical urban traffic conditions in Delhi by comparing modeled results with observed field data.

II. Materials and Methods

2.1 Study Area

Bahadur Shah Zafar Marg, a major arterial road in New Delhi, was selected as the study corridor due to its high traffic intensity, diverse vehicle mix, and representative urban flow conditions. The site lies at latitude 28°38′55″ N and longitude 77°21′32″ E. The roadway is flanked by buildings of varying height and geometry, resulting in moderate ventilation conditions. Four monitoring locations were selected along the road, two toward the Delhi Gate side and two toward the India Gate side.

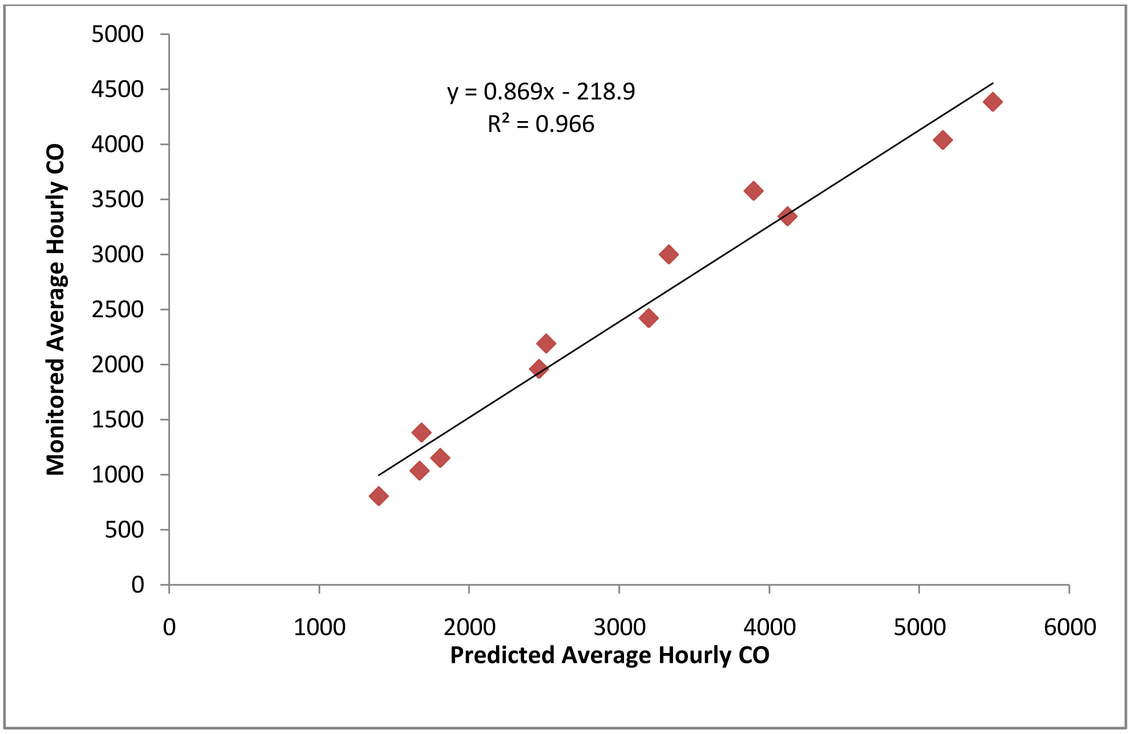

Fig.: Correlation between monitored and predicted average hourly CO concentration at location 1

2.2 Carbon Monoxide Monitoring

Ambient CO concentrations were measured using a portable electrochemical CO monitor (Model CO-84), capable of detecting concentrations from 0.1 to 99 ppm. The instrument was pre-calibrated before deployment. Monitoring was conducted between 8:00 AM and 8:00 PM at each location. Since the instrument lacked an internal data logger, readings were manually recorded at three-minute intervals and averaged to obtain hourly and eight-hour mean concentrations.

Monitoring on the Delhi Gate side (Locations 1 and 2) was carried out from March 18 to April 2, 2011, while measurements on the India Gate side (Locations 3 and 4) were conducted from April 20 to May 4, 2011. A total of 242 samples were collected at each site.

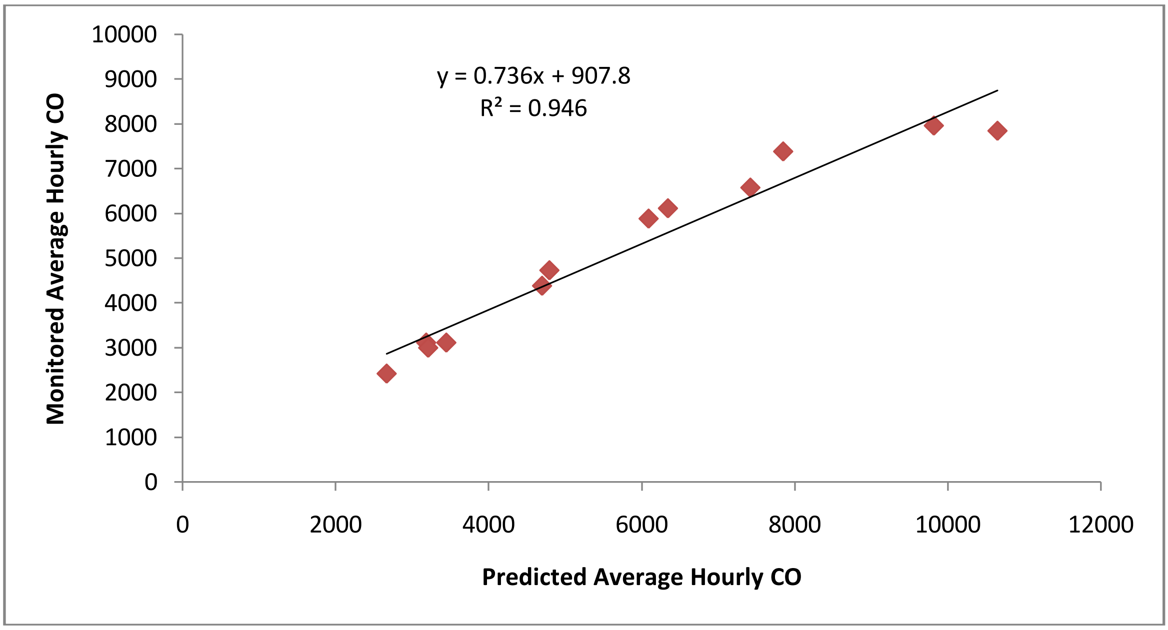

Fig.: Correlation between monitored and predicted average hourly CO concentration at location 2

2.3 Meteorological Data

Meteorological parameters including wind speed, wind direction, ambient temperature, atmospheric stability, and mixing height were obtained from the India Meteorological Department, Mausam Bhawan, and the Central Road Research Institute (CRRI). Monthly datasets were processed to derive representative daily average values, which were subsequently used as input for the dispersion model.

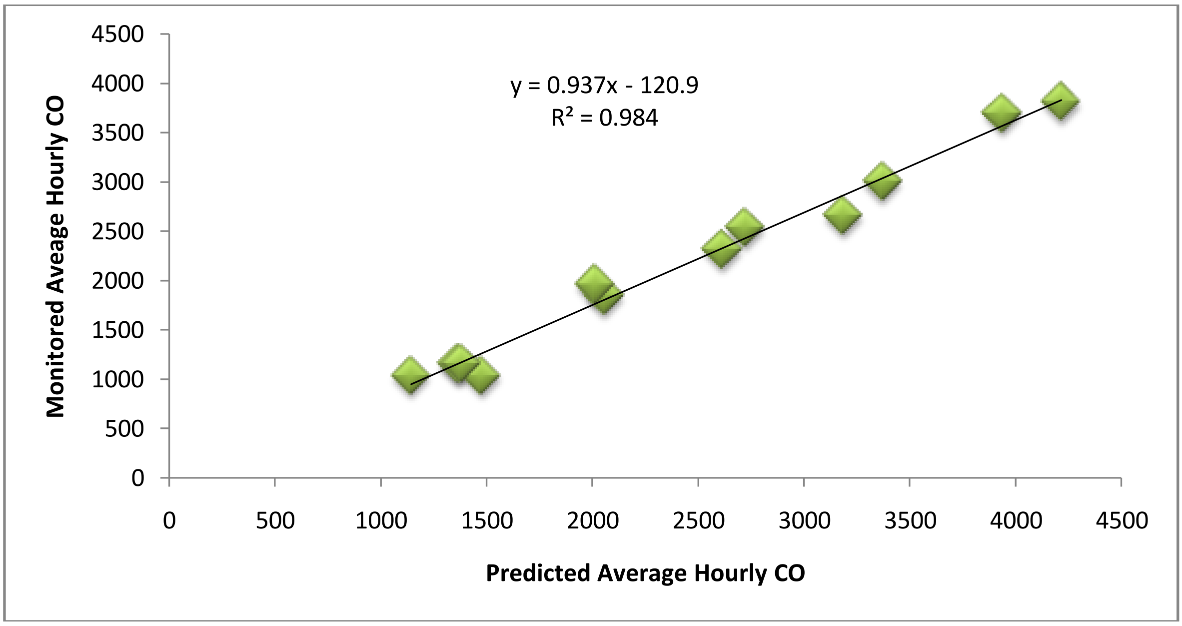

Fig.: Correlation between monitored and predicted average hourly CO concentration at location 3

2.4 Traffic Data Collection

Traffic volume and vehicle composition data were collected manually during April 2011 from 8:00 AM to 8:00 PM. Vehicles were classified into heavy vehicles (buses and trucks), light commercial vehicles, cars, three-wheelers, and two-wheelers. Hourly traffic counts were recorded for each category. Vehicle age distribution and emission factors were obtained from published CRRI reports. Data analysis was performed using spreadsheet tools to estimate composite emission factors.

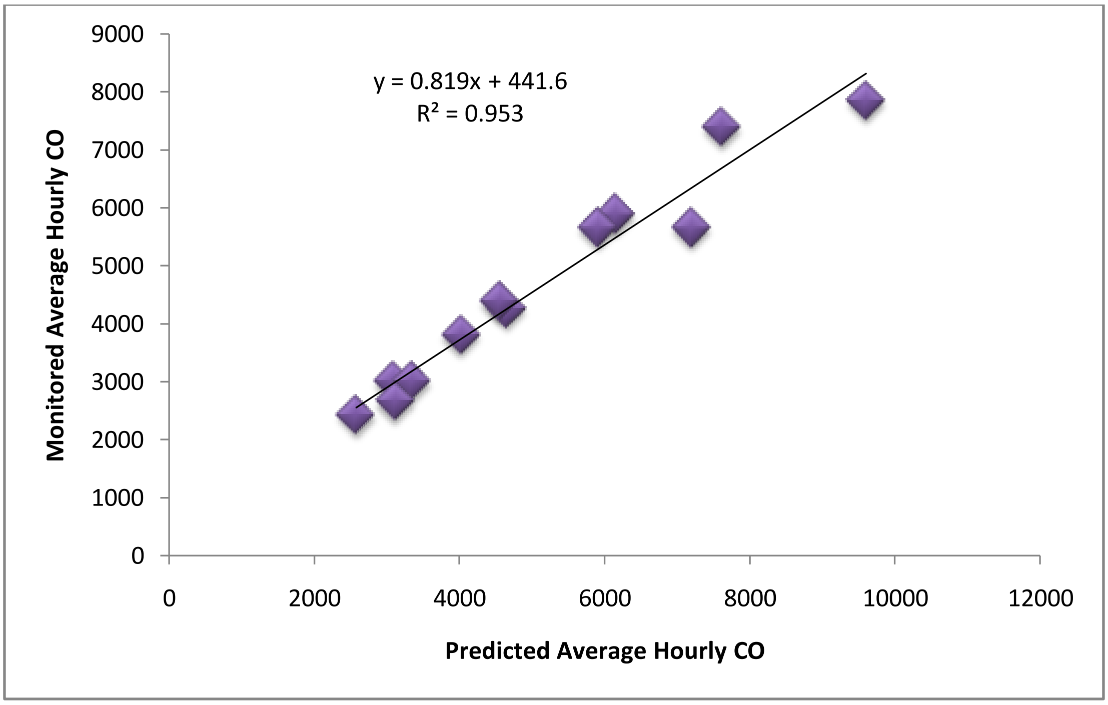

Fig.: Correlation between monitored and predicted average hourly CO concentration at location 4

2.5 Emission Factor Estimation

Average CO emission factors were calculated for each vehicle category by accounting for vehicle age and deterioration factors as specified in CRRI guidelines for the period 2006–2010. Composite emission factors were then derived by weighting category-specific emission factors according to observed traffic composition. These composite values were used as emission inputs in the CALINE-4 model.

2.6 CO Prediction Using CALINE-4

The CALINE-4 model was applied to predict hourly average CO concentrations at the selected receptor locations. Input parameters included traffic volume, composite emission factors, roadway geometry, and meteorological conditions. Model simulations were conducted for the monitoring periods corresponding to March and April 2011.

III. Results and Discussion

3.1 Model Performance at Delhi Gate Side

At monitoring Locations 1 and 2, the predicted CO concentrations showed strong agreement with observed values. The Index of Agreement ranged from 0.93 to 0.94, indicating excellent model performance. NMSE values were below 0.05, while Pearson's correlation coefficients were close to unity. Fractional Bias values were slightly negative, confirming a tendency toward under-prediction. The Factor-of-Two values exceeded 79%, demonstrating reliable model accuracy.

3.2 Model Performance at India Gate Side

For Locations 3 and 4, the model exhibited even better agreement, with IA values between 0.96 and 0.97 and NMSE values as low as 0.02. Correlation coefficients ranged from 0.89 to 0.91. Although the model continued to slightly under-predict CO concentrations, the overall statistical indicators confirmed strong predictive capability.

3.3 Comparative Assessment

The predicted CO concentrations followed similar diurnal patterns to the observed data, with peak levels occurring during morning and evening traffic hours. Consistent with previous studies (Ganguli et al., 2006), CALINE-4 demonstrated a minor under-prediction tendency. Nevertheless, its performance was superior to alternative models such as CAL3QHCR under comparable conditions.

IV. Conclusions

The study confirms that CALINE-4 performs effectively in predicting hourly CO concentrations under heterogeneous urban traffic conditions in Delhi. Predicted concentrations closely matched monitored values across all locations, although slight under-estimation was observed. Statistical evaluation using IA, NMSE, R, FB, and F2 demonstrated near-ideal model performance. Higher CO concentrations were observed on the Delhi Gate side due to comparatively poorer ventilation, while the India Gate side exhibited lower levels. Overall, CALINE-4 is a reliable tool for roadside air quality assessment and can support urban transport planning, environmental management, and policy development.

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