Emission Load Distribution and Prediction of NO_2 and PM_{10} using ISCST3 and CALINE4 Line Source Modeling

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Abstract - *Mysore district is one of the tourist destinations, in Karnataka, India, with a population of about 10.25 lakhs. 2-wheelers (2W) constitute more than 75 % of total vehicular population. Based on the vehicle growth during the last few years, it is observed that, the vehicle growth in Mysore city is about 8 to 9 % per annum. Industrial source complex short term model 3 (ISCST3) and California line source model 4 (CALINE4) were used to predict NO_2 and PM_{10} concentrations emitted from line/mobile sources. $PM_{2.5}$ and SO_2 emission factors were found to be very less (0.04 and 0.002 g/km) compared to CO and NO_2 emission factors (1.4 and 1.7 g/km). Emission loads for CO and NO_2 pollutants were found to be high at link 1, 2, 5, 6, 12 and 13 due to heavy traffic densities. During winter season ISCST3 and CALINE4 model predicted NO_2 concentrations were found to be ranging from 9–25 $\mu g/m^3$ and 10–40 $\mu g/m^3$, respectively. However, PM_{10} concentrations were found to be 18–43 $\mu g/m^3$. Maximum concentration was found near to Receptors (R1-3), which may be due to maximum vehicular density and downwind to the pollution sources. Pollutant concentrations were found to be maximum during winter season (calm condition) followed by summer and monsoon seasons (unstable condition). NO_2 and PM_{10} predictions made by ISCST3 and CALINE4 model showed a significant variation. Though, NO_2 and PM_{10} concentrations were found to be within National Ambient Air Quality Standards (NAAQS) of 80 $\mu g/m^3$ and 100 $\mu g/m^3$, respectively. It was also observed that, CALINE4 model was not applicable to predict pollutant with lower concentrations.)*

***Key Words*: ISCST3, CALINE4, PM_{10}, NO_2, Emission Load.**

1. INTRODUCTION

Due to urbanization and rapid growth of motor vehicles, Indian cities are experiencing deteriorated air quality which is responsible for serious health, environmental and socio-economic impacts [1]. The motor vehicle population in India has increased from ~0.3 million (in 1951) to 115 million (in 2009), of which 2W accounted for approximately 70 % of the total vehicles [2]. Line source dispersion models such as, ISCST3 and CALINE4 models can provide current and future air quality levels at any given point in the impact zone, which can be used to facilitate control and manage the vehicular/urban air pollution [3,4]. Faulkner et al. (2008) stated ISCST3 model was sensitive towards the changes in wind speed, temperature, solar radiation, mixing heights and surface roughness for predicting downwind PM_{10} concentrations [5]. Bhanarkar et al. (2005) indicated that, industrial sources account for 77% and 68% of the total emissions of SO_2 and NO_2, respectively, whereas vehicular emissions contributed to about 28% of the total NO_2 emissions, in Jamshedpur, India [3]. Further, Kansal et al. (2011) informed that, in Delhi city vehicles contribute 58% of the total ambient air pollution, followed by Thermal Power Plants (TPPs) 30% by using ISCST3 model [6]. However, CALINE 4 model is the latest version in CALINE series and most widely used to predict air pollutant concentrations (CO, NOx and PM) emitted from mobile sources along the highway under urban and sub-urban conditions [7]. Ganguly et al. (2009) have showed that, GFLSM model prediction decreases with the increase in downwind distances as compared with CALINE4 model [8]. Dhyani et al. (2013) have used CALINE4 model on two road corridors, Kiratput (flat terrain) and Darlaghat (hilly terrain) in Himachal Pradesh to predict CO concentration from traffic emission [9]. Further, Dhyani et al. (2014) have carried out environmental impact assessment (EIA) for a highway corridor in Delhi city, India and used CALINE 4 model for the prediction of CO concentration [10]. Most of the traffic count studies revealed that, maximum traffic densities were found between 08:00 – 11:00 hours and 17:00 – 21:00 hours [4,9,11,12]. However, air pollutant concentrations near road intersections have observed to be varied in minutes due to the influence of traffic signals [13,14,15], which can inevitably increase the complexity of prediction of pollutants by any model. Mysore is the most popular tourist place in Karnataka. The total number of vehicles which was about 6000 in 1970 increased to 1.45 lakhs in 1996, 3.55 lakhs in 2005 and the current vehicle population is 6.5 lakhs in 2014 [16]. Hence, the aim of the present study is to collect meteorological data, prepare emission inventory and conduct traffic count studies along with segregation of category of vehicle passing and to predict NO_2 and PM_{10} concentrations emitted from line/mobile sources using ISCST3 and CALINE4 models.

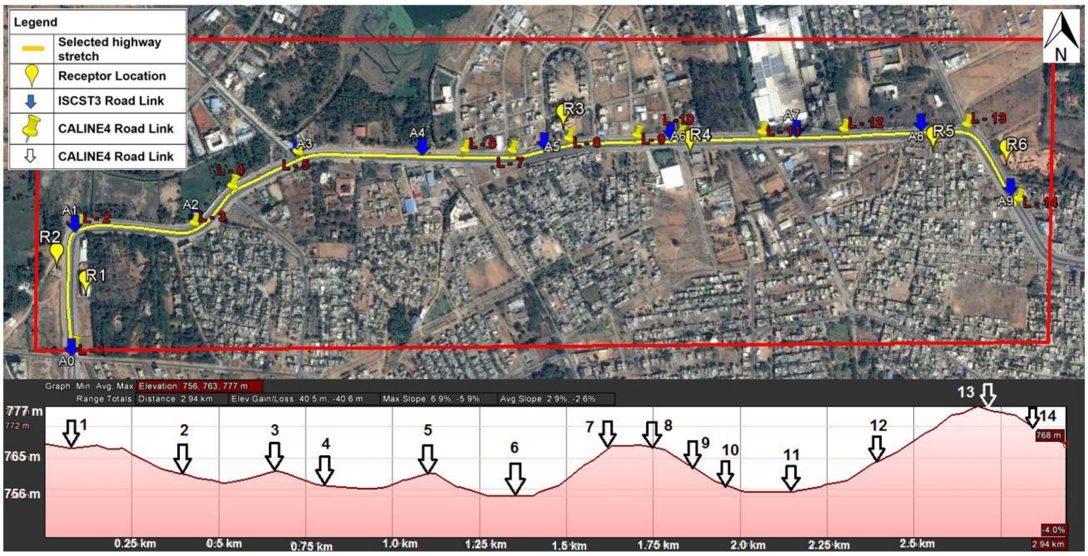

Fig – 1: Study area showing the receptor locations with road links for ISCST3 and CALINE4 models along the elevation profile of highway passing through the industrial area of Mysuru.

2. STUDY AREA

The present study investigates the status of ambient air (November, 2016 to July, 2017) along the highway passing through industrial area of Mysuru city, which connects the highway with the industries and residential areas located in northern and eastern part of the study area, respectively. The major portion of the ring road is being six lanes with service roads on the either side. The entire length of outer ring road starts from Bangalore – Mysuru road (SH-17) and circumferences Mysuru city. The selected stretch along the ring road is of 3.3 km with elevation profile varying from 746 m to 786 m. Three monitoring stations (six receptor locations) (Figure 1) with 1 km interval were selected to predict Ambient Air Quality (AAQM) using ISCST3 and CALINE4 models. The receptor points were selected as, Seshadripuram College (R1), Weigh Bridge (R2), V-LEAD Institute (R3), Prema Fuel Station (R4), Dexter Logistics (R5) and JSS Urban Haat (R6). For CALINE4 model predictions road stretch was divided into 14 links based on elevation, intersection and direction of the road. However, the highway was divided into 10 area sources and further, these area sources were converted into line sources for ISCST3 model predictions.

3. MATERIALS AND METHODS

3.1 Emission inventory

A traffic count study is a detailed examination and analysis of a transportation system supported by data collection. The data collection process was conducted using the CCTV camera at the monitoring location in an orderly manner which ensures that, data gathered is both defined and accurate. The collected data provides a baseline for further analysis. Traffic volume studies were conducted to determine the number, movements, and classifications of roadway vehicles at a given location. Automotive Research Association of India [17] emission factors were considered in the present study. These emission factors along with total number of vehicles per hour were used to calculate Weighted Emission Factor (WEF) developed by US-EPA [4,9,18].

$$WEF = \frac{(EF_1 * V_1) + (EF_2 * V_2) + (EF_3 * V_3) + (EF_4 * V_4)}{\sum V} \quad (1)$$

Where, EF = Emission factor for different category of vehicles, V = volume of different category of vehicles. In the present study WEF in g/mile was calculated using ARAI standards. The calculated emission factors were used as inputs for ISCST3 and CALINE4 models and as well as to identify the emission load distribution over the study area.

3.2 Micro-meteorology

Meteorological parameters such as: wind speed, wind direction, temperature, relative humidity (RH), are responsible for the dispersion of air pollutants in the atmosphere. The daily variation of meteorological data were collected from www.wunderground.com [19]. Hourly meteorological data were used to plot season wise diurnal variation of temperature, wind speed and relative humidity (Figures 2a-c). Minimum temperature and wind speeds were observed during late night and early morning periods (01:00 to 07:00 h) in all the seasons and gradually increased during day time with solar radiation. On the other hand, RH was found to be maximum during 01:00 h to 10:00 h and it gradually decreased and reached the minimum at 11:00 h to 17:00 h and then started increasing. The trend was found to be similar for winter, summer and monsoon seasons.

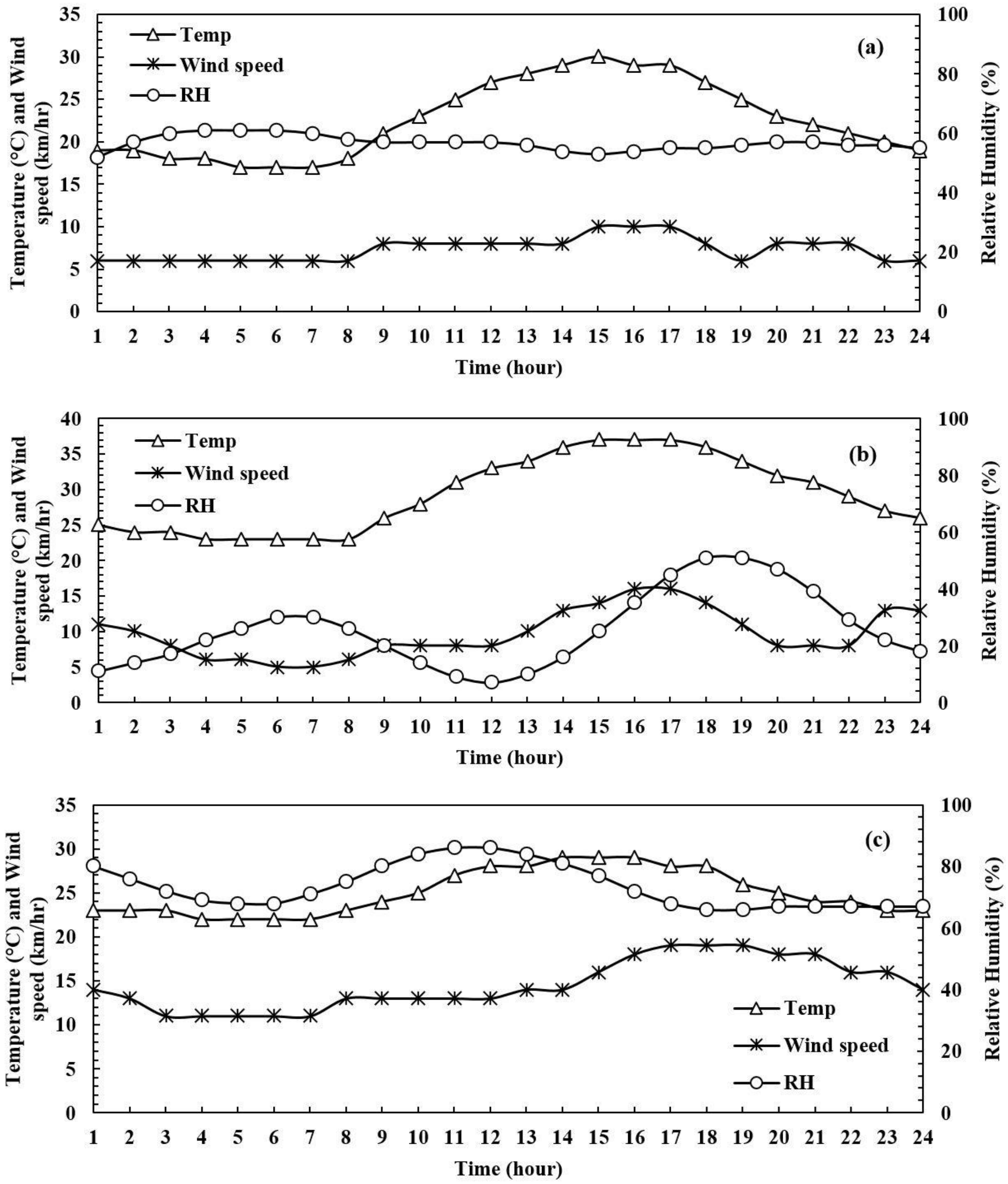

Fig – 2: Diurnal variation of Temperature, Wind speed and Relative Humidity during (a) winter, (b) summer and (c) monsoon season over Mysuru city.

However, a maximum temperature of 37°C was found in summer season followed by 30°C in winter and 29°C in monsoon season. The average temperature was varying from 22°C to 26°C. Further, RH was found to be ranging from 50-65% during winter season, 7-51% during summer season and 66-86% during monsoon season. A maximum and minimum wind speed of 19 km/h and 5 km/h was noticed during monsoon and winter season, respectively. The average wind speeds were varying from 6 km/h to 11 km/h in all the seasons. The wind rose plot for winter season (Figure 3a) showed predominant wind was blowing from E (90°) and ENE (68°) directions. The resultant vector of wind directions from winter season to summer season showed, wind direction was changing from E to WSW direction. However, wind rose plots for summer and monsoon seasons (Figures 3b-c) showed predominant wind was blowing from SW (225°) and WSW (248°) towards NE (45°) and ENE (68°) directions, respectively.

3.3 Ambient air quality modeling

In order to predict NO_2 and PM_{10} concentrations emitted from line/mobile sources at selected receptor points, ISCST3 and CALINE4 models were used in the present study.

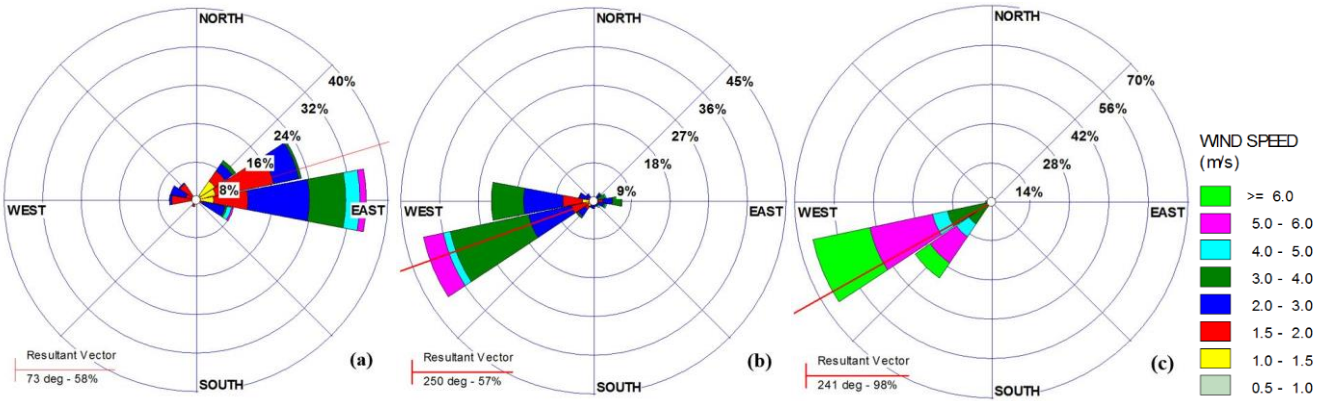

Fig – 3: Windrose plots for (a) winter, (b) summer and (c) monsoon season over Mysuru city.

3.4 ISCST3 dispersion model

The USEPA developed ISCST3 air pollution dispersion model was used to predict NOx and PM_{10} concentrations at selected receptor locations [20]. The model has the capability to handle Polar or Cartesian coordinates, simulating point, area, volume, and line sources, considering wet and dry deposition, accounting for terrain adjustment, building downwash algorithm [3]. ISCST3 algorithm is based on numerical solution of three dimensional diffusion-convection equation assuming a Gaussian plume mechanism and used to compute GLCs of non-reactive pollutants [21,22,23]. ISCST3 Gaussian plume model for prediction of downwind pollutant concentrations from line sources can be described by eqn. (2).

$$C = \frac{2Q_L}{\sqrt{2\pi}u\sigma_z}\exp\left(\frac{-H^2}{2\sigma_z^2}\right) \qquad (2)$$

Where, C = the downwind pollutant concentration (μg/m^3), Q_L = line source emission rate (g/m^{2}s), σ_z = vertical dispersion coefficients (m) based on stability class, u = average wind speed at pollutant release height (m/s), H = effective height above ground of emission source (m).

3.5 CALINE4 dispersion model

CALINE4 model is the fourth generation line source Gaussian plume dispersion model. CALINE4 predicts the concentration of carbon monoxide (CO), nitrogen dioxide (NO_2) and suspended particulates (PM_{10}) near roadways. It employs a mixing zone concept to characterize pollutant dispersion over the roadway due to vehicles plying on the road corridor [4,9]. CALINE 4 can predict the pollutant concentrations for receptors located within 500 m under given traffic and meteorological conditions [24,25]. It represents a line source as a series of finite length elements each oriented perpendicular to the wind. The length of each element is determined based on its distance from the receptor of interest. The model uses Pasquill Gifford categories to characterize the stability of the atmosphere [7].

4. RESULTS AND DISCUSSION

4.1 Traffic volume studies

To estimate the contribution of vehicular emissions to the ambient air quality, the numbers of vehicles passing through the study area were collected by installing CCTV camera at Seshadripuram College, Mysuru, India. The vehicular density / volume have been counted with the help of a compact disc having the record of 7 days x 24 hours of traffic flow in .mp4 format. The traffic volume have been categorized into five groups i.e., 2 wheelers (2W), 3 wheelers (3W), 4 wheelers (4W), Light duty vehicles (LDV) and Heavy duty vehicles (HDV) and used to conduct emission inventory studies. It was observed that, number of 2W vehicles were found to be maximum (12,775 nos./d) (Figure 4a) followed by 4W (4,464 nos./d), HDV (2,790 nos./d) and LDV (2,080 nos./d). However, Sharma et al. (2013) [4] and Dhyani et al. (2017) [11] showed that, traffic flow was dominated by 4W, followed by 2W, 3W and HDVs at a highway in Delhi city, India. During weekdays the peak traffic volumes were observed during 08:00 h – 11:00 h (morning peak hours) and 18:00 h – 21:00 h (evening peak hours). Khare et al. (2012) [26], Sharma et al. (2013) [4] and Dhyani et al. (2017) [11] have also observed peak traffic hours between 08:00 – 10:00 hours and 18:00 – 20:00 hours in Delhi, India. However, during weekends (Figure 4b) peak traffic volume was noticed only between 17:00 and 21:00, during evening peak hours. The reason for lower vehicular density in the morning hour during weekends may be due to absence of schools, colleges and offices (Holiday) and higher vehicular density in the evening hours during weekends may be due to as people go out for recreational activities. A maximum number of ~23,000 vehicles were observed during weekdays and ~17,500 vehicles were counted during weekends, near to Seshadripuram College. Further, 7 days traffic variation near Seshadripuram College showed similar trend of vehicular density during peak morning and evening traffic hours as shown in Figure 4c. The Heavy duty vehicles were found to be maximum during morning hours, which may be due to supply of raw materials to the industries located on the highway, however, a similar observation was also made by Prakash et al. (2015 and 2016) [27,28].

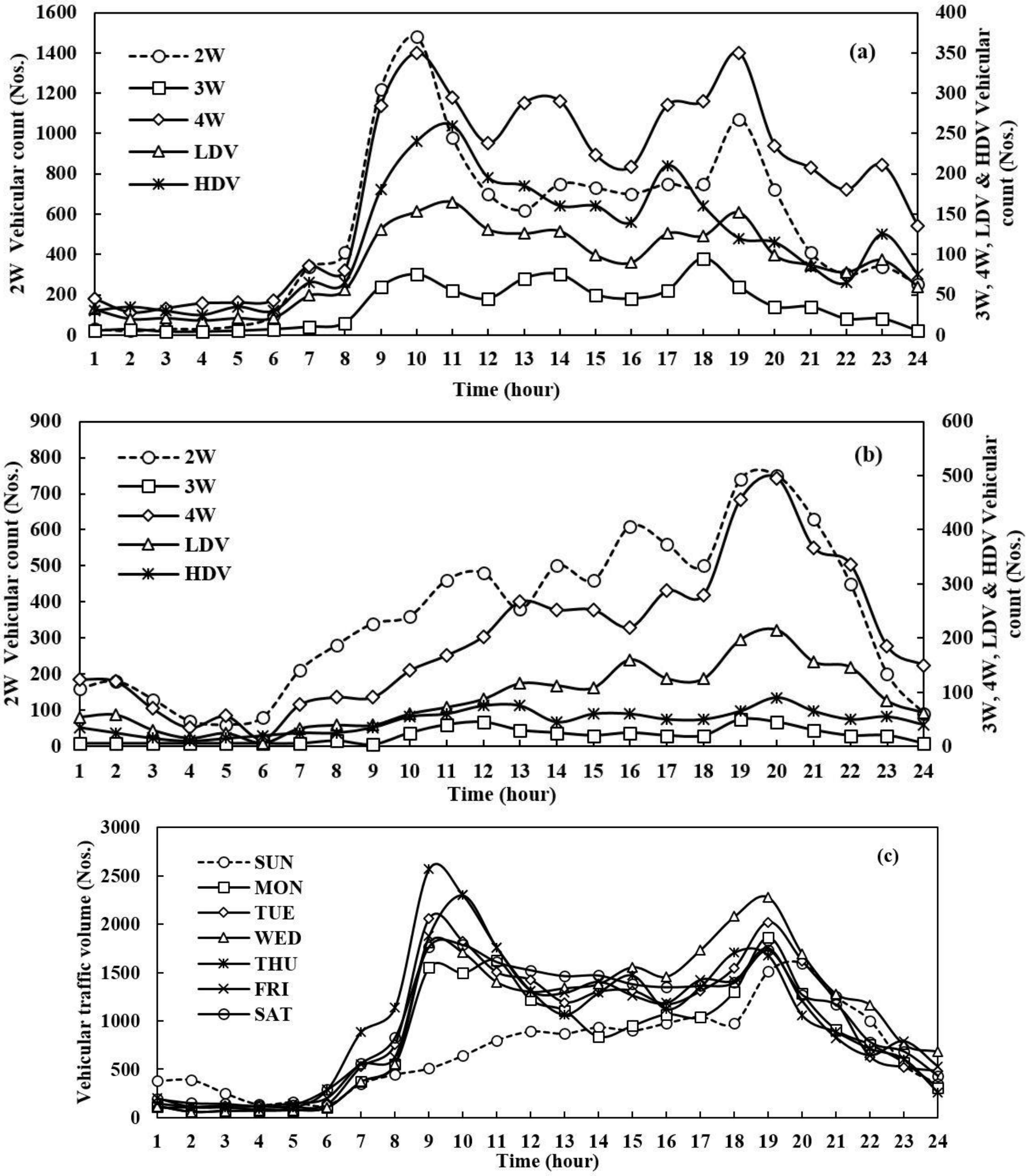

Fig – 4: Traffic variations during (a) weekdays, (b) weekends and (c) daily variation, near to Seshadripuram College.

4.2 Percentage distribution of vehicles and emission factors (EF)

Traffic composition was mainly dominated by 2W during weekdays and weekends and varying from 50–56%, followed by 4W (19–28%), LDV (9–12%), HDV (6–12%) and 3W (3–4%) at the study area (Figures 5a-b). It was also observed that, during weekdays number of HDV was more, however, during weekend number of LDV was found to be more. Goud et al. (2015) reported that, traffic composition was dominated by 2W (42–43%), followed by 4W (39–40%), 3W (8–9%), LDV (5–6%) and HDV (4%) at Central Silk Board intersection, Bengaluru, India [30]. However, in the present study, maximum traffic was observed during summer season (~25,000 vehicles/day) followed by winter (~22,000 vehicles/day) and monsoon season (~20,000 vehicles/d). The maximum number of vehicles observed during summer season may be due to summer vacation/holidays. ARAI emission factors were used to identify the NO_2 and PM_{10} emission factors from each category of vehicles. From the Figure 6 a-b, it was observed that, during weekdays and weekends, NO_2 (EFs) was mainly contributed from HDV (75–86%) followed by 2W (6–10%), LDV (5–10%), 3W and 4W (1–3%). A similar observation was made for PM_{10} pollutant also (Figure 7a-b).

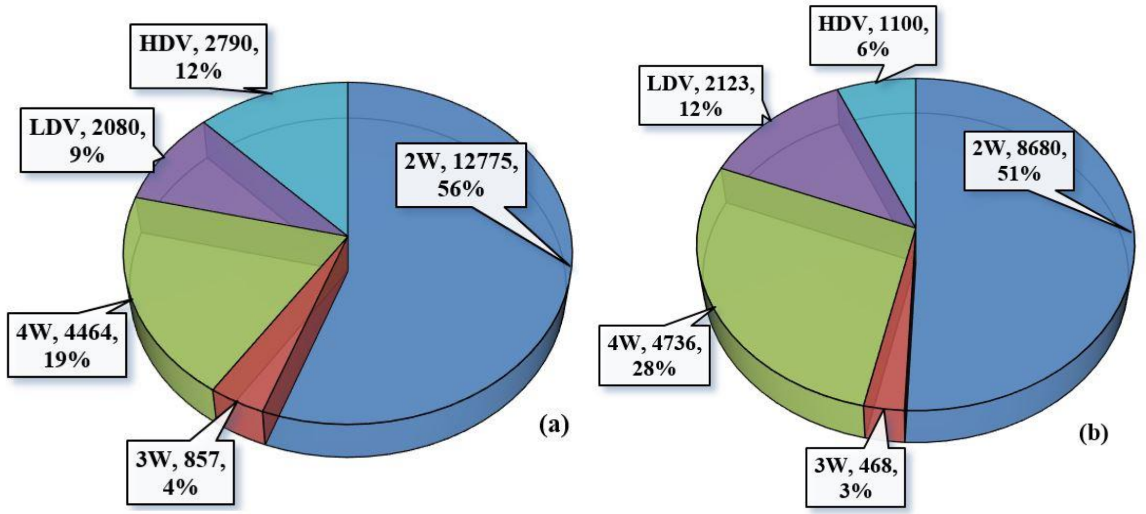

Fig – 5: Percentage contribution of traffic volume during (a) weekdays and (b) weekends.

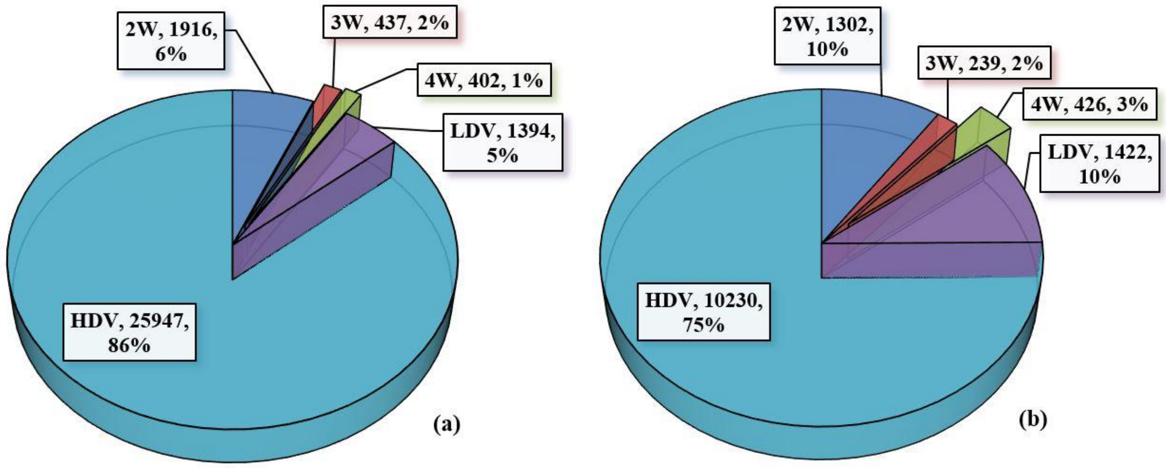

Fig – 6: Percentage contribution of NO_2 Emission factors (gm/km) from different category of vehicles during (a) weekdays and (b) weekends.

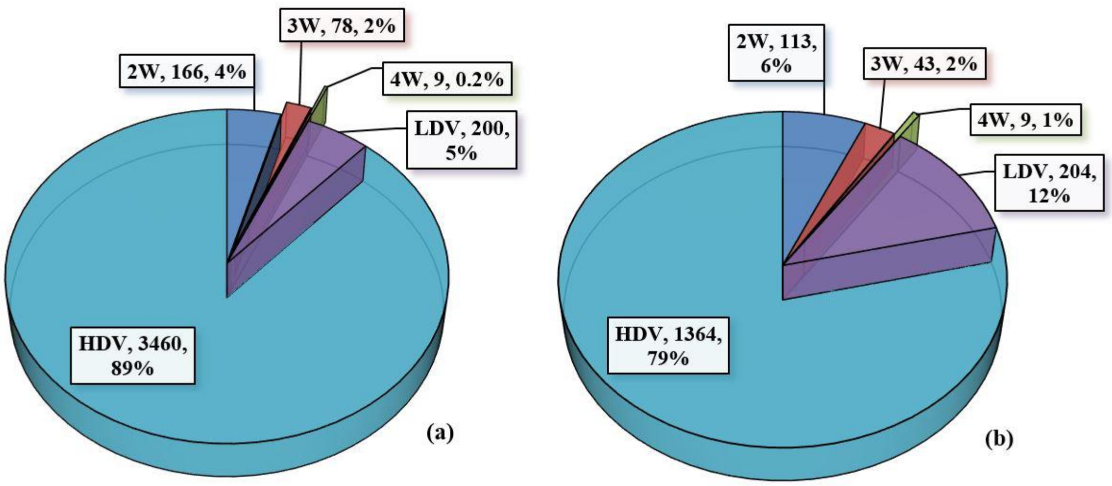

Fig – 7: Percentage contribution of PM_{10} Emission factors (gm/km) from different category of vehicles during (a) weekdays and (b) weekends.

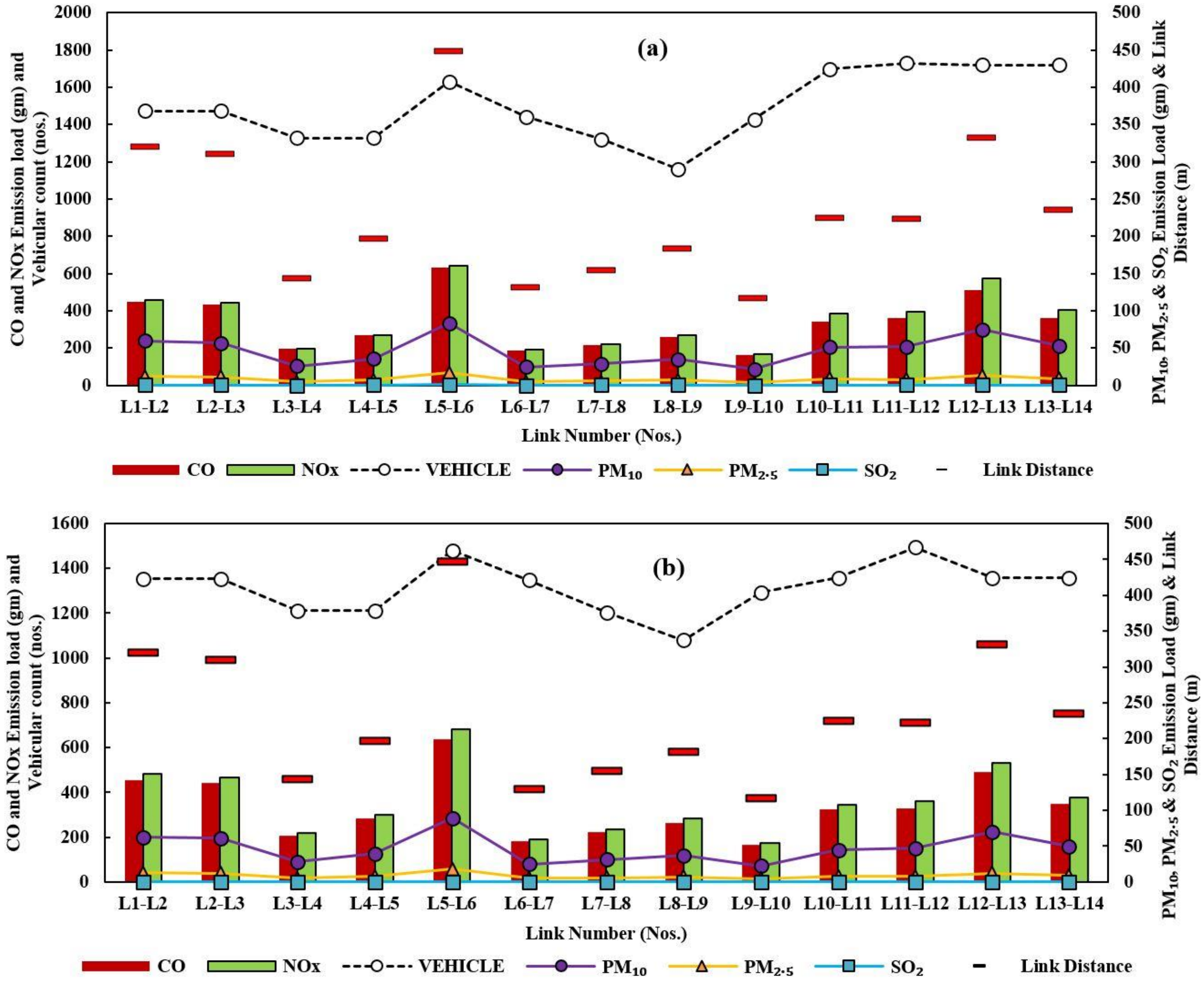

Fig – 8: Average Hourly Emission Loads (gm) at 14 links during (a) weekdays, and (b) weekends from 9 am to 6 pm.

PM_{10} was mainly contributed from HDV (87–89%) followed by 2W, LDV (5–12%) and 3W, 4W (<1–2%). It was clearly understood that, even though the number of 2W was found to be maximum, but the contribution of maximum emission loads were from HDV, LDV and 4W vehicles. Bhanarkar et al. (2005) have also reported, largest contribution of NO_2 (57%) among the vehicular emissions was due to heavy-duty vehicles in Jamshedpur region, India [3].

4.3 Emission load distribution along the highway

An emission inventory is accounting the amount of pollutants emitted into the atmosphere and it usually contains the total emissions for one or more air pollutants, originating from all source categories within a specified span of time. Emission inventory depends upon location, elevation, frequency and duration of emission, etc. and it provides the information about the status of air pollution in the urban fringes. Emission inventory of different pollutants in various urban cities of India have been reported by a number of researchers [3,27-38]. However, in the present study the length of the selected highway was 3.3 km, which was divided into 14 links based on elevation, intersection and direction of the road. Emission factors for CO, NOx, PM_{10}, $PM_{2.5}$ and SO_2 was considered based on ARAI (2008) [17] and Road Transport emission factor (NAEI, 2013) [39] to identify the emission load over the study area. These emission factors along with total number of vehicles per hour (VPH) were further used to calculate weighted emission factor (WEF) developed by US-EPA. CALINE4 model requires an input of WEF at each link along the identified highway stretch. Emission factor is a function of total number of vehicles. In the present study emission factors of $PM_{2.5}$ and SO_2 were found to be very less (0.04 and 0.002 gm/km) when compared to CO and NOx emission factors (1.4 and 1.7 gm/km). This may be due to vehicular exhaust mainly contains CO, CO_2 and NOx compared to $PM_{2.5}$ and SO_2 [40]. A similar study of calculating of emission factors was conducted by Goyal et al. (2010) [38], Goud et al. (2015) [29] and Prakash et al. (2015 and 2016) [27,28]. The average hourly emission factors and emission loads, which are based on distance between the links, during weekdays and weekends from 09:00 am to 06:00 pm are shown in Figures 8 (a-b). Emission loads were calculated based on emission factor (gm/km) and link distance (km). From the plots it was observed that, emission load of CO and NOx was high at link 1, 2, 5, 6, 12 varying from 400 – 600 gm. The reason for higher emission loads were due to more numbers of vehicles, as the places were near to Hebbal industrial area main road (L5 – L6), J.K. Tyres (L12 – L13) and also due to the larger link distances (~ 300–400 m). However, there was a little variation of emission load for weekdays and weekends because of less difference in hourly variation of total number of vehicles over 14 links from 09:00 am to 06:00 pm.

4.4 ISCST3 and CALINE4 model predictions

ISCST3 and CALINE4 models were applied to predict NO_2 and PM_{10} concentrations (Figures 9a-c) emitted from line sources within the study area. Highway (3.3 km length and 36 m width) passing through the Industrial area of Mysuru was considered as major area/line source of pollution, as the daily number of vehicular density varies from 20,000 to 25,000 vehicles. A standard ±5% error was also considered in model predictions. It was observed that, NOx concentration predicted by ISCST3 and CALINE4 model during winter season (Figure 9a) were found to be 9–25 μg/m^3 and 10–40 μg/m^3, respectively. However, ISCST3 and CALINE4 model predicted PM_{10} concentrations were found to be ranging from 18–43 μg/m^3. Maximum concentrations were found near to R1, R2 and R3, which may be due to more number of vehicles at the receptor locations. An approximate of 10,000 to 14,000 vehicles were counted from 10:00 h – 18:00 h. The reason for difference in prediction of pollutant concentrations may be due to ISCST3 model was higher version model and also due to the limitations of CALINE4 model predictions. This may also be due to the input parameters into the CALINE4 model was very limited and it predicts the NOx concentration in ppm, which further has to convert into μg/m^3. Palmgren et al. (2003) found that traffic density and diesel vehicles were important explanatory variable for particulate concentrations along the roads of Denmark [41]. As the number of vehicle increases pollutants such as, CO, NOx and PM_{10} concentration also increases with the vehicular exhausts [40,42,43].

However, during summer season (Figure 9b) pollutant concentrations were found to be less compared to winter due to high wind speeds and wind directions. Wind speeds were found to be more during summer season compared to winter season. NOx and PM_{10} concentrations during summer season were found to be 4–20 μg/m^3 and 11–40 μg/m^3, respectively. Benson (1992) has reported that, dispersion models do not perform well under low wind conditions [25]. It was also observed that, CALINE4 model was not applicable for the pollutant with less concentration and model accuracy was found to be upto two decimal points.

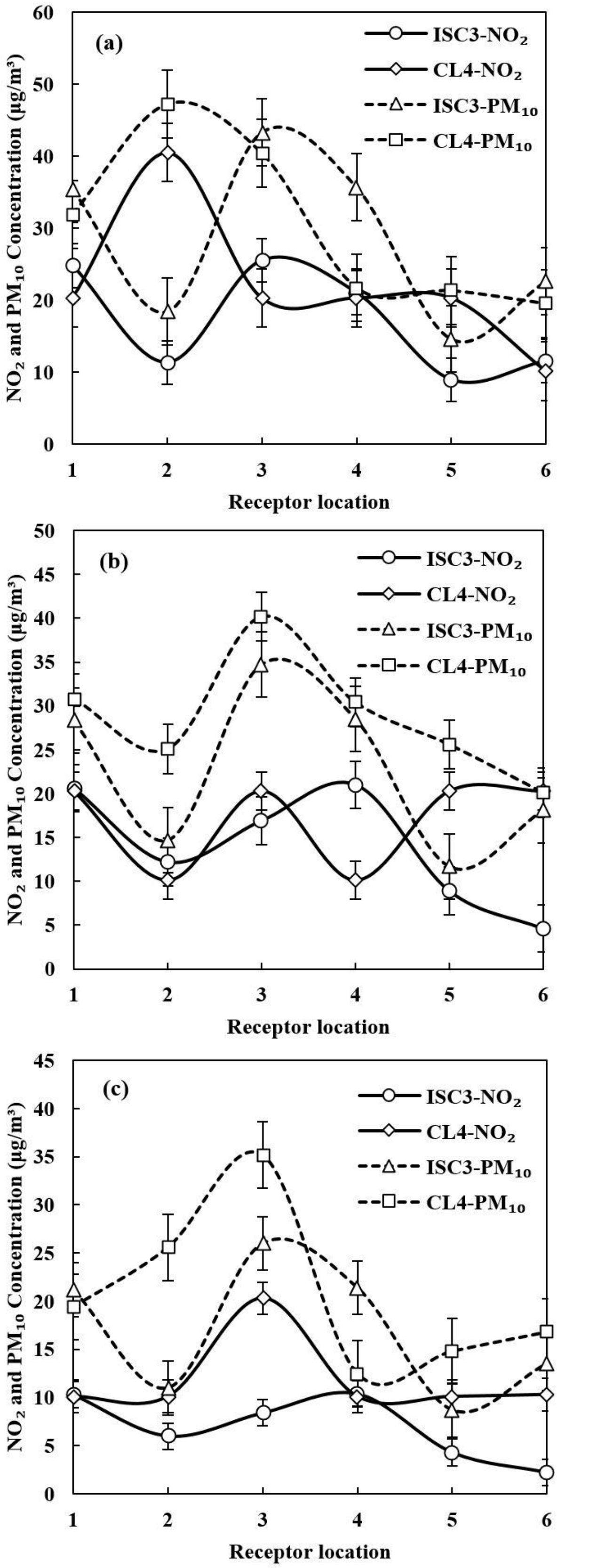

Fig – 9: ISCST3 and CALINE4 model prediction for NO_2 and PM_{10} during (a) winter, (b) summer and (c) monsoon season.

According to Sharma et al. (2013) CALINE4 model should not be used in urban environmental conditions where roadside air quality is influenced by industrial, thermal power plants and urban street canyons, which plays a vital role in determining the resultant pollutant concentrations [4]. Further, the result of ISCST3 and CALINE4 models for monsoon season (Figure 9c) was found to be minimum because of less number of vehicles and high wind speeds (> 24 km/h) compared to winter and summer seasons. The reason for less concentration obtained during summer and monsoon seasons may be due to the receptors (R3-6) were located upwind to the source as wind was blowing from W, WSW and SW towards E, ENE and NE direction, respectively. In the present study scatter plots of ISCST3 and CALINE4 predictions for NO_2 and PM_{10} concentrations combined winter, summer and monsoon seasons are made shown in Figure 10. The "factor-of-two" or FAC2 plot was used to assess model performance. If, 75% of the data sets fall within the FAC2 band, the model predictions are considered as good correlation with each other [7,44,45]. For the prediction of NO_2 (Fig. 10a), it was observed that, most of the points were within the FAC2 lines but some of the points were found to be outside of FAC2 line because of the variation in model predictions. The reason may be due to CALINE4 model is a lower version model with limited input data and ISCST3 model is a higher version model and can calculated hourly variation of pollutant concentration. However, for prediction of PM_{10} (Fig. 10b), almost all points were found to be within the FAC2 line. This may be due to CALINE4 model was more applicable for particulate pollutants than gaseous pollutants.

5. CONCLUSIONS

ISCST3 and CALINE4 models were used to predict NO_2 and PM_{10} concentrations emitted from line sources. The meteorological parameter showed an average temperature of 22°C to 26°C over the study area. Further, relative humidity was found to maximum during monsoon season (66-86%) and minimum during summer season (7-51%). A maximum wind speed of 19 km/h was noticed during monsoon season, indicating higher dispersion of air pollutants. The windrose plots indicate that, wind direction gradually changes from NE direction towards SW and WSW direction during winter to summer and monsoon seasons. Traffic count studies showed, number of 2W vehicles were maximum (12,775 nos./d) followed by 4W (4,464 nos./d), HDV (2,790 nos./d) and LDV (2,080 nos./d). The number of 2W were maximum in traffic distribution, but NOx and PM_{10} (EFs) were mainly contributed from HDV (75–86%) followed by 2W (6–10 %), LDV (5–10%), 3W and 4W (1–3%). $PM_{2.5}$ and SO_2 emission factors were found to be very less (0.04 and 0.002 g/km) compared to CO and NOx emission factors (1.4 and 1.7 g/km). Further, emission loads for CO and NOx pollutants were found to be high at link 1, 2, 5, 6, 12 and 13 due to heavy traffic densities.

On the other hand, NOx concentrations predicted by ISCST3 and CALINE4 models during winter season were found to be ranging from 9–25 μg/m³ and 10–40 μg/m³, respectively. However, PM_{10} concentrations were found to be 18–43 μg/m³. Maximum concentrations were found near to R1, R2 and R3, which may be due to maximum vehicular density. NO_2 and PM_{10} predictions by ISCST3 and CALINE4 model showed a significant difference due to the input parameters into the CALINE4 model which were very limited and CALINE4 predicts NOx concentration in ppm, which further have to convert into μg/m³. ISCST3 and CALINE4 model predicted NO_2 and PM_{10} concentrations were found to be maximum during winter season due to calm atmospheric conditions (low temperature and wind speeds). However, NO_2 and PM_{10} concentrations were found to be within NAAQS of 80 μg/m³ and 100 μg/m³, respectively.

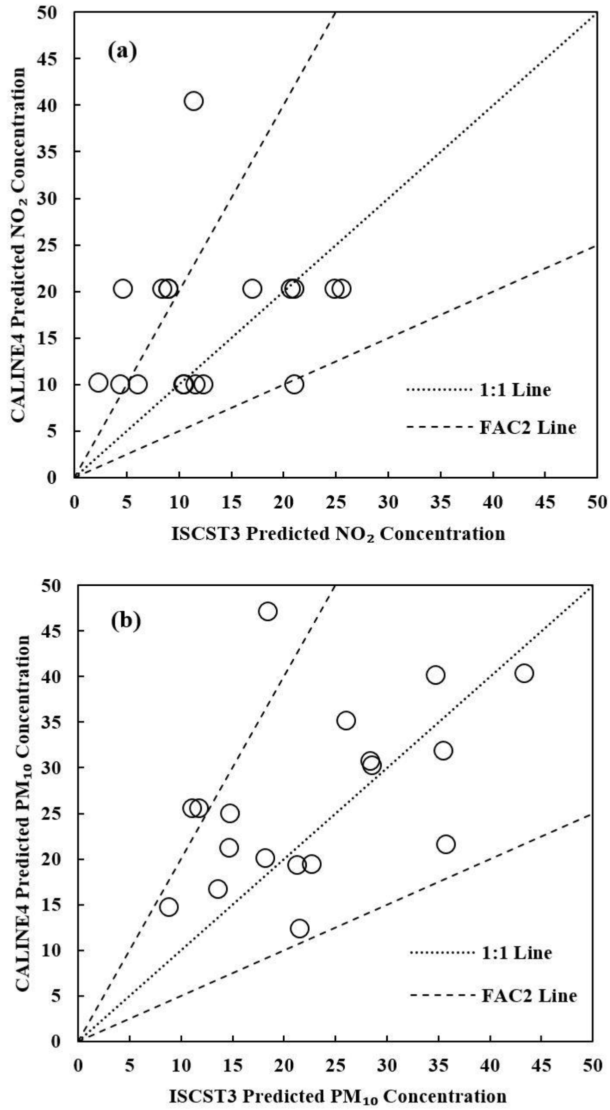

Fig – 10: Scatter plots for ISCST3 and CALINE4 model predictions for (a) NO_2 and (b) PM_{10}.

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REFERENCES

[1] M. G. Badami, "Urban transport policy as if people and the environment mattered: pedestrian accessibility the first step," Economic & Political Weekly, 2009, 44(33).

[2] CPCB, Status of the vehicular pollution control programme in India, Central Pollution Control Board, Ministry of Environment and Forest, New Delhi, Govt. of India, 2010.

[3] A. D. Bhanarkar, S. K. Goyal, R. Sivacoumar and C. V. C. Rao, "Assessment of contribution of SO_2 and NO_2 from different sources in Jamshedpur region, India," Atmospheric Environment, 2005, 39, 7745–7760.

[4] N. Sharma, S. Gulia, R. Dhyani and A. Singh, "Performance evaluation of CALINE 4 dispersion model for an urban highway corridor in Delhi," Journal of Scientific and Industrial Research, 2013, 72, 521–530.

[5] W. B. Faulkner, B. W. Shaw and T. Grosch, "Sensitivity of Two Dispersion Models (AERMOD and ISCST3) to Input Parameters for a Rural Ground-Level Area Source," J. Air & Waste Manage. Assoc., 2008, 58, 1288–1296.

[6] A. Kansal, M. Khare and C. S. Sharma, "Air quality modelling study to analyse the impact of the World Bank emission guidelines for thermal power plants in Delhi," Atmospheric Pollution Research, 2011, 2, 99–105.

[7] P. E. Benson, "CALINE4: A Dispersion Model for Predicting Air Pollutant Concentrations near Roadways," California Department of Transportation, Sacra-mento, CA, USA, 1984.

[8] R. Ganguly, B. M. Broderick and R. O'Donoghue, "Assessment of a General Finite Line Source Model and CALINE4 for Vehicular Pollution Prediction in Ireland," Environ Model Assess, 2009, 14, 113–125.

[9] R. Dhyani, A. Singh, N. Sharma and S. Gulia, "Performance evaluation of CALINE 4 model in a hilly terrain – a case study of highway corridors in Himachal Pradesh (India)," Int. J. Environment and Pollution, 2013, 52, 244–262.

[10] R. Dhyani, S. Gulia, N. Sharma and A. Singh, "Air quality impact assessment of a highway corridor through vehicular pollution modeling," International Journal of Renewable Energy and Environmental Engineering, 2014, 2, 93-99.

[11] R. Dhyani, N. Sharma and A. K. Maity, "Prediction of $PM_{2.5}$ along urban highway corridor under mixed traffic conditions using CALINE4 model," Journal of Environmental Management, 2017, 198, 24–32.

[12] R. Dhyani and N. Sharma, "Sensitivity Analysis of CALINE4 Model under Mix Traffic Conditions," Aerosol and Air Quality Research, 2017, 17, 314–329.

[13] P. Zito, H. B. Chen and M. C. Bell, "Predicting Real-time Roadside CO and NO_2 Concentrations using Neural Networks," IEEE Transactions on Intelligent Transportation Systems, 2008, 9, 514–522.

[14] F. Galatioto and P. Zito, "Traffic Parameters Estimation to Predict Road Side Pollutant Concentrations using Neural Networks," Environmental modeling & assessment, 2009, 14, 365–374.

[15] H. D. He and W. Z. Lu, "Urban Aerosol Particulates on Hong Kong Roadsides: Size Distribution and Concentration Levels with Time," Stochastic Environmental Research and Risk Assessment, 2012, 26, 177–187.

[16] R. C. Prakash, Traffic & Transportation Issues of Mysuru. State Institute of Urban Development Mysore, 2015.

[17] ARAI, Draft Report on Emission Factor Development for Indian Vehicles, Report Submitted to CPCB/MOEF as a Part of Ambient Air Quality Monitoring and Emission Source Apportion Study. Automotive Research Association of India, Pune, India, 2008.

[18] D. Wang, Z. Wang and R. P. Zhong, "Performance Evaluation of CAL3QHC and CALINE4 for Short-Term Simulation of Fine Particulate Matter and Carbon Monoxide Concentrations at a Road Intersection," Transportation Research Board, 2014, 1–15.

[19] Weather underground, Station Mysore, India, Retrieved from https://www.wunderground.com/q/zmw:00000.46.43291?sp=VOMY, 2017.

[20] USEPA, Users Guide for Industrial Source Complex (ISC3) Dispersion Models (EPA – 454/B-95 – 003 a). US Environmental Protection Agency, NC, 1995.

[21] T. Banerjee, "Assessment and model performance evaluation of air quality at Integrated Industrial Estate-Pantnagar" Doctor of Philosophy Thesis, Department of Environmental Science, G. B. Pant University of Agriculture and Technology, Pantnagar, India, 2010.

[22] T. Banerjee, S. C. Barman and R. K. Srivastava, "Application of air pollution dispersion modeling for source-contribution assessment and model performance evaluation at integrated industrial estate – Pantnagar," Environmental Pollution, 2011, 159, 865–875.

[23] S. K. Goyal and C. V. C. Rao, "Assessment of atmospheric assimilation potential for industrial development in an urban environment: Kochi (India)," Science of the Total Environment, 2007, 376, 27–39.

[24] P. E. Benson, "CALINE 4: A Dispersion Model for Predicting Air Pollutant Concentrations near Roadways," California Department of Transportation, Sacra-mento, CA, USA, 1989.

[25] P. E. Benson, "A Review of the Development and Application of the CALINE3 and 4 Models," Atmospheric Environment, 1992, 26, 379–390.

[26] M. Khare, S. Nagendra and S. Gulia, "Performance evaluation of air quality dispersion models at urban intersection of an Indian city: a case study of Delhi city," WIT Transactions on Ecology and The Environment, 2012, 157, 249–259.

[27] B. M. Prakash, M. Mahadevaswamy, S. Mahesh and S. R. Sharadhini, "Air Quality Assessment along the Highway Due to Vehicular Emissions and Validation of Air Quality Monitored Data with the CALINE4 Model," International Journal of Innovative Research in Science, Engineering and Technology, 2015, 4, 8369–8376.

[28] B. M. Prakash, M. Mahadevaswamy, S. Mahesh and N. Vishala, "Prediction of Air Pollutants Dispersion Emitted from Point and Line Sources along the Highway Passing

Through Industrial Area of Mysuru - AERMOD and CALINE4 Models," International Journal of Innovative Research in Science, Engineering and Technology, 2016, 5, 14497–14508.

[29] B. S. Goud, S. Savadatti and D. Prathibha, "Application of CALINE4 Model to Predict $PM_{2.5}$ Concentration at Central Silk Board Traffic Intersection of Bangalore City," International Journal of Civil Engineering and Technology (IJCIET), 2015, 6, 191–200.

[30] A. Garg, S. Bhattacharya, P. R. Shukla and V. K. Dhadhwal, "Regional and sectoral assessment of greenhouse gas emissions in India: assessment of inventories and mitigation," Atmospheric Environment, 2001b, 35, 2679–2695.

[31] A. Garg, P. R. Shukla, S. Bhattacharya and V. K. Dhadhwal, "Subregion (district) and sectoral level SO_2 and NOx emission in India: assessment of inventories and mitigation," Atmospheric Environment, 2001a, 35, 703–713.

[32] C. Sharma, A. Dasgupta and A. P. Mitra, "Inventory of GHGs and other urban pollutants from Delhi and Calcutta," 2002a.

[33] C. Sharma, A. Dasgupta and A. P. Mitra, "Inventory of GHGs and other urban pollutants from transport sector in Delhi and Calcutta," 2002b.

[34] C. Sharma, A. Dasgupta and A. P. Mitra, "Inventory of GHGs and other urban pollutants from agriculture and waste sectors in Delhi and Calcutta," 2002c.

[35] M. L. Mittal and C. Sharma, "Anthropogenic emissions from energy activities in India: generation and source characterization (Part—I. Emissions from thermal power generation in India)," 2003a.

[36] M. L. Mittal and C. Sharma, "Anthropogenic emissions from energy activities in India: generation and source characterization (Part—II. Emissions from vehicular transport in India)," 2003b.

[37] B. R. Gurjar, J. A. Aardenne van, J. Lelieveld and M. Mohan, "Emission estimates and trends (1990–2000) for megacity Delhi and implications," Atmospheric Environment, 2004, 38, 5663–5681.

[38] P. Goyal, N. Jaiswal, A. Kumar, J. K. Dadoo and M. Dwarakanath, "Air quality impact assessment of NOx and PM due to diesel vehicles in Delhi," Transportation Research Part D, 2010, 15, 298–303.

[39] NAEI, Road Transport Emission Factors, National Atmospheric Emissions Inventory, 2013, Retrieved from http://naei.beis.gov.uk/data/ef-transport.

[40] Whiteside, L., The 2004 year vehicle classification data at the I-75 PTR 9799, 2006.

[41] F. Palmgren, P. Wahlin, J. Kildeso, A. Afshari and C. L. Fogh, "Characterisation of Particle Emissions from the Driving Car Fleet and the Contribution to Ambient and Indoor Particle Concentrations," Phys. Chem. Earth, 2003, 28, 327–334.

[42] R. Sivacoumar, "Vehicular pollution near highways in Chennai city," Indian Journal of Environmental Protection, 2000, 20, 592–596.

[43] R. Sivacoumar and K. Thanasekaran, "Line source model for vehicular pollution prediction near roadways and model evaluation through statistical analysis," Environmental Pollution, 1999, 104, 389–395.