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Ambient Air Quality Monitoring And Prediction of Air Pollutants Using ISCST3 And CALINE4 Dispersion Models For Vehicular Emissions At Bareilly, Uttar Pradesh, India

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Abstract: *Ambient air quality monitoring (AAQM) of RSPM, SPM, SO_2 and NOx from January to December were carried out at Indian Veterinary Research Institute (I.V.R.I), Izatnagar and Petrol Pump, Civil lines, Bareilly, India over a period of 5 years from 2013 to 2017. The maximum 2W count was varying from 1200–1800 VPH (Vehicles per Hour) at IVRI institute and 1600–2400 VPH at Petrol Pump during the peak traffic hours i.e., 08:00-11:00 h and 18:00-20:00 h during all the months from January to December. Emission factors were found to be maximum during early morning and late night when vehicular density was minimum and found to be minimum during maximum traffic hours. RSPM and SPM concentrations were varying from 150–350 and 250–450 $\mu g/m^3$, respectively, in all the seasons, which was exceeding the National ambient air quality standard (NAAQS) of 100 and 300 $\mu g/m^3$, respectively. However, SO_2 and NOx concentrations were ranging from 5–17 and 15–35 $\mu g/m^3$, respectively, found to be within the NAAQS of 80 $\mu g/m^3$. ISCST3 model predictions were found to be good agreement with observed NOx and SO_2 concentrations and model was underpredicting RSPM and SPM concentrations. CALINE4 model was overpredicting NOx concentration and underpredicting SPM concentrations. However, CALINE4 model predictions were found to be satisfactory with observed SPM concentrations.*

Keywords : *CALINE4, Emission inventory, ISCST3, NOx, RSPM, SO_2, SPM, Vehicular count*

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I. Introduction

Urban air quality in megacities getting deteriorated day by day due to increase in industrialization and urbanization [1, 2]. The rapid urban growth is also associated with transportation sector and road networks which supports various vehicular movements on roads [3]. The vehicular emission accounted for 70 % of CO, 50 % of HC, 30 – 40 % of NOx, 30 % of SPM (Suspended Particulate Matter) and 10 % of SO_2 of the total air pollution load in the major metropolitan cities in India [4]. Goyal et al. (2010) have reported 17 % and 28 % of total NOx and PM concentration, respectively, are contributed by vehicular emissions, which was almost equal to the combined sources such as industry, power plants and domestic sectors in Delhi, India [5]. However, over the last two decades petrol and diesel consumption have grown by 400 % and 300 %, respectively, which was mainly due to rise of vehicular numbers, DG sets, industries and waste incinerators [6 ,7]. The environmental impacts are severe in urban areas due to high population density, traffic levels, intense motor vehicle use, driving patterns, vehicle characteristics and complex urban geometry [1, 8, 9, 10, 11]. Emission due to vehicular exhaust is associated with a number of chronic and acute health effects [12, 13]. A number of studies proved, cancers, heart attacks and asthma associated with NOx, SO_2 and PM emissions from vehicular exhaust [14, 15]. In urban areas, air pollution is affected mainly due to construction of buildings, traffic composition and meteorological conditions [16]. Air quality models and impact due to pollutant concentration assessment studies provide a tool to understand the implications of pollutant emissions which help us to decide, control and manage the environmental pollutions [17]. Air pollutant dispersion modeling has been accomplished with the aid of Gaussian Dispersion Plume models that, accounted for the spatial and temporal dispersion characteristics of various pollutants. However, line source models are used to assess the effects of roadway emissions and dispersion of the pollutants [18, 19]. Traffic estimation studies can either be done by on-site traffic counting (manually or installing CCTV camera) [20, 21, 22], or derived from travel demand and traffic simulation models [23, 24, 25]. Emissions are often estimated considering average link speeds and average emission factors [20, 22, 23, 25] or real-time link drive-cycles [24]. Many researchers have conducted studies on ambient air quality monitoring and modeling (Gulia et al., 2014 [26]; Masood and Ahmad, 2017 [27]; Dubey et al., 2013 [3]; Wang et al., 2016 [28]; Mishra et al., 2016 [29]; Pan et al., 2016 [30]; Balashanmugam and Nehrukumar, 2016 [31]).

Balashanmugam and Nehrukumar (2016) have reported that, the observed SPM, SO_2, NOx and CO concentrations were ranging from 320 – 380 $\mu g/m^3$, 45 – 50 $\mu g/m^3$, 110 – 120 $\mu g/m^3$, 1.5 – 2.5 $\mu g/m^3$, respectively, at Pondicherry city, India, which found to exceed the NAAQS due to maximum vehicular traffic [31]. However, Banerjee et al. (2011) reported, annual average concentration of NO_2 was observed to be 32.6 $\mu g/m^3$, signifying persistence of lower level of NO_2 pollution at integrated industrial estate, Pantnagar, India [32]. ISCST3 (Industrial Source Complex Short Term Model 3) and AERMOD (American Meteorological Society-Environmental Protection Agency Regulatory Model) modeling study conducted by AL-Haddad et al. (2012) on CO, NO, SO_2, and VOCs at Fhaheel area, Kuwait, showed all pollutant concentrations studied were exceeding the international limits, except for CO, which may be due to low traffic volume and high ambient temperature in Kuwait [33]. Further, Masood and Ahmad (2017) have used ISCST3 model to predict the dispersion of pollutant generated from diesel generators at Jamia university campus, New Delhi, India [27]. The result of predicted ISCST3 model showed 11.33 $\mu g/m^3$, 58.43 $\mu g/m^3$, 176.50 $\mu g/m^3$ and 57.02 $\mu g/m^3$ for PM_{10}, SOx, NOx and CO, respectively. Gramotnev et al. (2004) have used CALINE4 (California Line Source Dispersion Model 4) for the analysis aerosols generated by vehicles on a heavy traffic road in Brisbane, Australia, and found a good agreement between observed and predicted pollutant concentrations [34]. Gulia et al. (2014) have reported that, ISCST3 model performance was satisfactory (d=0.69) for predicting CO concentrations when compared with AERMOD (d=0.50) and ADMS-Urban (d=0.45). However, among all the models, ISCST3/AERMOD and CALINE4 models are commonly being used due to its simplicity and accuracy [26]. In India, not much work have been done on the study of adverse impacts of air pollution due to vehicular emission on the natural environment. Hence, in the present study, an attempt has been made to monitor ambient air quality of Bareilly city, India, over a period of 5 years (i.e., from 2013 to 2017), to conduct traffic count studies and segregation of category of vehicle passing and to predict the ambient air quality along the highway passing through Bareilly city, using ISCST3 and CALINE4 air pollutant dispersion models. An attempt has been made to check the model accuracy by comparing the model outputs with the observed pollutant concentrations.

II. Study Area

Ambient air quality monitoring (AAQM) studies have been conducted at Indian Veterinary Research Institute (I.V.R.I), Izatnagar (Location 1) and Petrol Pump, Civil lines, (Location 2) Bareilly, Uttar Pradesh, India. Location 1 (IVRI institute) is at the Northern part of Bareilly city, Izatnagar, Bareilly, Uttar Pradesh. On the other hand, Location 2 (Petrol Pump) is placed at the Southern part of Bareilly city, Civil Lines, Bareilly, India. Study area comprises a grid of 500 m x 500 m for ISCST3 and CALINE4 models and are shown in Figure 1 (a, b). Location 1 (IVRI institute) comprised of institutional area, residential area and commercial area. On the other hand, location 2 (Petrol Pump, Civil lines) is comprised of commercial area, traffic intersection and market area. It was also observed that, there is no industries located nearby to these monitored locations and hence, the major sources of pollution was assumed to be due to line sources.

III. Materials and Methods

3.1 Vehicular emission

Vehicular emission is one of the major sources of air pollution in the study area. Pollutants from vehicular exhaust are released at ground level and hence, their impacts on the recipient population are likely to be of significant. A traffic count study of the different category of vehicles was conducted by installing CCTV camera at the monitoring locations. A critical traffic count study includes: counting total number of vehicles, segregation of different types of vehicles, vehicular movement speed and age profile of vehicle at a given location. Automotive Research Association of India (ARAI), Government of India, New Delhi, has developed the Emission Factor for different types and category of vehicles such as, 2 wheelers (2W), 3 wheelers (3W), 4 wheelers (4W) which comprised of cars, Light Duty Vehicles (LDVs) and Heavy Duty Vehicles (HDVs), which is, based on mass emission tests conducted on limited number of in-use vehicles covering different engine technologies, types of vehicle, types of fuels, etc. Emission factors along with total number of vehicles per hour are used to calculate Weighted Emission Factor (WEF) developed by US-EPA, as calculated by [35, 36, 37].

$$WEF = ((EF_1*V_1) + (EF_2*V_2) + (EF_3*V_3) + (EF_4*V_4)) / (\Sigma V) \quad (1)$$

Where, EF = Emission factor for different category of vehicles, V = volume of different category of vehicles. In the present study air pollutant load, i.e., WEF in g/mile was calculated using ARAI standards. The calculated emission inventories were used as inputs for ISCST3 and CALINE4 dispersion models.

Fig. 1(a). Google map view of ISCST3 model area/line source road link distribution along with the AAQMS at Indian Veterinary Research Institute (I.V.R.I) Izatnagar (Location 1).

Fig. 1(b). Google map view of ISCST3 model area/line source road link distribution along with the AAQMS at Petrol Pump, Civil lines, Bareilly (Location 2).

3.2 Micro-meteorology

Various meteorological parameters which influence the dispersion of air pollutants include: wind speed, wind direction, temperature, precipitation, relative humidity, mean mixing depth (MMD) and nature of terrain. Hourly meteorological data was obtained from IMD Allahabad, which were used for plotting annual variation of average wind speed, relative humidity and temperature (Figure 2a) and windrose plot from January, 2013 to December, 2017 (Figure 2b) over Bareilly city, Uttar Pradesh, India. It was observed that, maximum temperature was varying from 35°C to 45°C, in the month of March to May, during 2013 to 2017 (Figure 2a). However, minimum temperature was varying from 8°C to 10°C, in the month of December to February from

2013 to 2017. It was observed that, temperature was found to be maximum during summer season (March to May) when compared in winter season (December to February). Further, a minimum relative humidity was varying from 25 – 30 % was noticed during the month of March to April (summer season). However, maximum humidity of 96 % to 97 % was noticed in Month of December to February (winter season), representing prone to a high pollution levels. It was found that, maximum wind speeds were varying from 6 to 8 m/s between May and September, indicating maximum dispersion of pollutants. Further, a minimum wind speed of ~ 0.5 m/s was observed during winter season. The annual wind rose plot during 2013 and 2017 showed predominant wind was blowing from W and E followed by NW and WNW directions, which were blowing towards E, W, SE and ESE directions over the study area. The calm periods were found to be ranging from 1.5 to 4.8 %.

3.3 Ambient air quality monitoring (AAQM)

Ambient air quality monitoring (AAQM) for pollutants such as, RSPM, SPM, SO_2 and NOx were conducted at identified locations over a period of 5 years from 2013 to 2017 along the highway near Indian Veterinary Research Institute (I.V.R.I) Izatnagar and Petrol Pump, Civil lines, Bareilly, India. Analysis of NOx and SO_2 were carried out as per Indian Standards IS: 5182 (Part 6 (BIS, 2006) [38] and Part 2 (BIS, 2001) [39]). Gravimetric technique was used to analyze PM_{10} concentrations as per IS: 5182 Part 23 (BIS, 2006) [40].

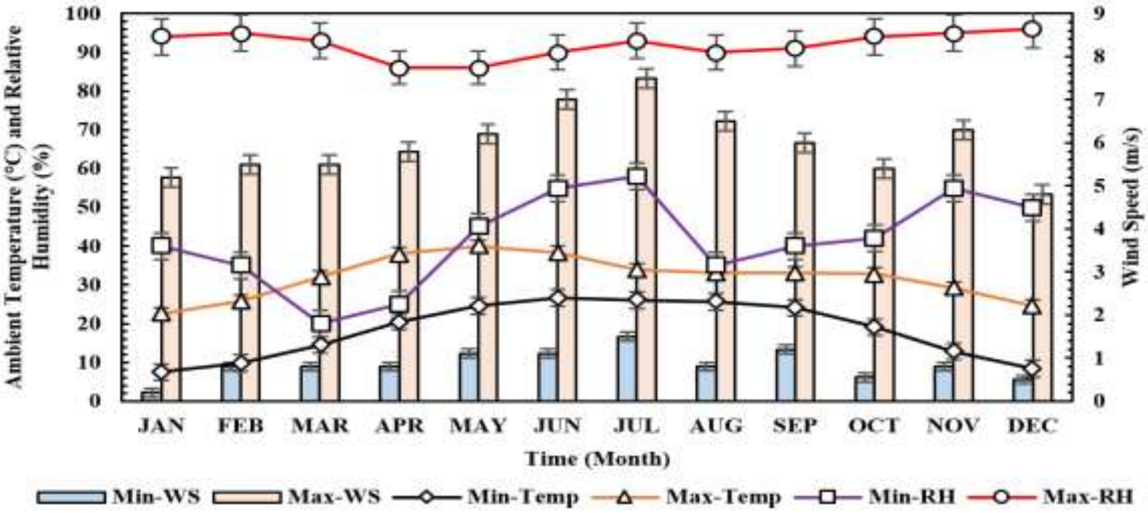

Fig. 2(a). Annual variation of average Wind Speed, Relative Humidity and Temperature over Bareilly city, Uttar Pradesh from 2013 – 2017**.**

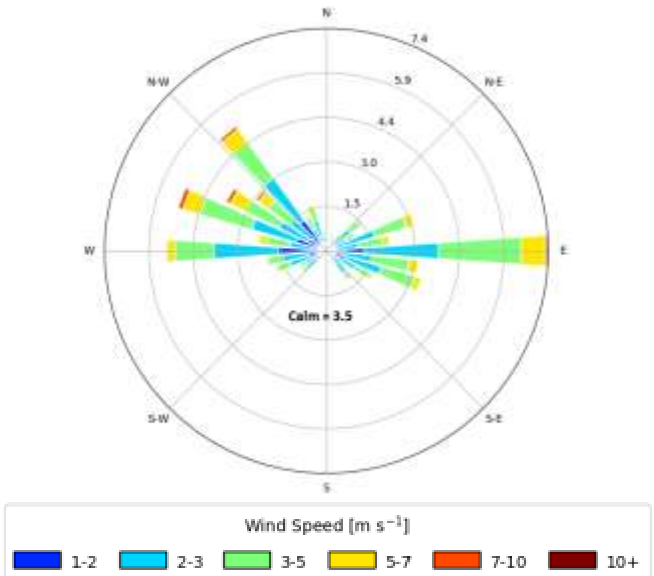

Fig. 2(b). Annual windrose plot from January, 2013 to December, 2017 over Bareilly city, Uttar Pradesh, India.

3.5 Ambient air quality modeling

Line source models are used to simulate the dispersion of pollutants emitted from vehicles near the highways. Several models have been used to predict pollutant concentrations near highways or roads by approximating them as line sources [4]. However, in the present study ISCST3 and CALINE4 model have been used to predict the dispersion of pollutants over the study area.

3.7 Industrial Source Complex Short Term Model (ISCST3)

ISCST3 model is based on Gaussian plume dispersion model, which is the simplified form of the three-dimensional transmission-distribution equation [41, 42]. The Short Term model incorporates the COMPLEX1 screening model dispersion algorithms for receptors in complex terrain. ISCST3 model is capable of handling multiple sources, including point, volume, area and open pit source types. However, line sources may also be modeled as a string of volume sources or as elongated area sources [43]. To run the model, the main model input files include: input run-stream file and meteorological data file. Run-stream setup file contains modeling options, source information, receptor locations, meteorological data file specifications and output options. However, meteorological data file contains all the required meteorological data on hourly basis [44]. ISCST3 Gaussian plume model for predicting downwind pollutant concentrations from line sources can be described by Eqn. (2).

$$C = \frac{2Q_L}{\sqrt{2\pi}\, u\, \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right) \quad \text{(For line source)} \qquad (2)$$

Where, C is the downwind pollutant concentration (μg/m^3), Q_L is line source emission rate (g/m^{2}s), σ_y and σ_z = lateral and 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) and y is the cross wind direction (m).

3.8 California Line Source Dispersion Model (CALINE4)

CALINE4 model is the fourth generation line source Gaussian plume dispersion model which can predict the concentration of carbon monoxide (CO), nitrogen dioxide (NO_2) and suspended particulates (PM_{10}/$PM_{2.5}$) near highways. It employs a mixing zone concept and divide it equivalent finite line sources to represent the road segment to characterize pollutant dispersion [3, 45]. CALINE 4 model can predict air quality up to 500 m from the highway and air quality modeling near to the street canyons, intersections and parking facilities [46] with respect to specific meteorological conditions (wind speed, wind direction, mixing height, stability class, temperature, background concentrations), source strength (vehicular density and emission factor) and road-geometry (roadway height, receptor locations and heights, number of links, surface roughness, mixing zone width, etc.) [31].

IV. Results And Discussion

4.1 Traffic volume studies

Vehicular emissions or line sources are the prime sources of air pollution at Indian Veterinary Research Institute (I.V.R.I), Izatnagar (Location 1) and Petrol Pump, Civil lines, (Location 2) Bareilly, India. To estimate the contribution of pollutants from the vehicular exhaust into the ambient air, numbers of vehicles passing through the study area during the monitoring days were collected by installing CCTV camera at IVRI institute and Petrol Pump, Civil Lines. The total number of vehicles have been counted with help of external hard drive having the record of 7 days x 24 hours for different months of traffic flow in .mp4 format. The traffic volume have been categorized into five major groups i.e., 2 wheelers (2W), 3 wheelers (3W), 4 wheelers (4W), Light-duty vehicles (LDV) and Heavy duty vehicles (HDV). The plots for average variation in the traffic flows from January to December at Indian Veterinary Research Institute (I.V.R.I), Izatnagar and Petrol Pump, Civil lines are shown in the Figure 3 (a, b). From the plots, it was observed that, number of 2W vehicles were found to be maximum in traffic count in any month followed by 4W, HDV and LDV. Peak traffic volume was found to be between 08:00 and 11:00 hours (morning peak hours) and, 17:00 and 20:00 (evening peak hours) (Figure 3 (a, b)). The reason for maximum traffic density at 08:00 and 11:00 hours was due to school and college timings, office timings and peak time for other commercial activities. Maximum 2W count was varying from 1200 – 1800 VPH (Vehicles per Hour) at Location 1 and 1600 – 2400 VPH at Location 2 at the peak traffic hours i.e., 08:00 - 11:00 hours and 18:00 - 20:00 hours during all the months from January to December. However, maximum 4W counts were found to be varying from 250 – 350 VPH at location 1 and 250 – 400 VPH at Location 2 during peak traffic hours. On the other hand, a maximum number of HDV and LDV were ranging from 50 – 350 VPH and 50 – 250 VPH, respectively, at Location 1 and 2 during 08:00 - 11:00 hours and 17:00 - 20:00 hours (Figure 3 (a, b)). However, number of 3W vehicles were ranging from 30 -100 VPH at both the locations. It was also observed that, number of vehicles were found to be more at Location 2 (Petrol Pump) when compared to Location 1, this may be nearby commercial traffic junctions (Civil Lines). It was also observed that, daily traffic variations were ranging from 22,000 to 28,000 VPD (Vehicles per Day) at location 1 and 25,000 – 34,000 VPD. Further, pollution load is directly proportional to the number of vehicles, if number of vehicles are more, pollutant concentration will be more. It can be assumed that, pollution load occurring from line sources were more at location 2 when compared to location 1, as the number of total vehicles were found to be more at location 2. However, the study conducted by Dhyani et al. (2014) at Chowk – CRRI (NH-2), New Delhi, showed that, traffic flow was dominated by 4W, followed by 2W, 3W and HDVs. A maximum 4Ws of 4500 vehicles were observed between 09:00 – 10:00 h [45]. Further, Prakash et al. (2016 and 2017) [47, 48], Khare et al. (2012) [49] and Sharma et al. (2013) [36] also found peak traffic volumes during 08:00 – 11:00 hours (morning peak hours) and 17:00 – 20:00 hours (evening peak hours). Even, Bhanarkar et al. (2005) stated that, maximum vehicular density was noticed between 10:00 and 12:00 h in the morning and between 16:00 and 18:00 h in Jamshedpur region, India, with vehicular density varying from 1400 and 2200 VPH and contributing to about 60 % of the total vehicular emissions in a day [50].

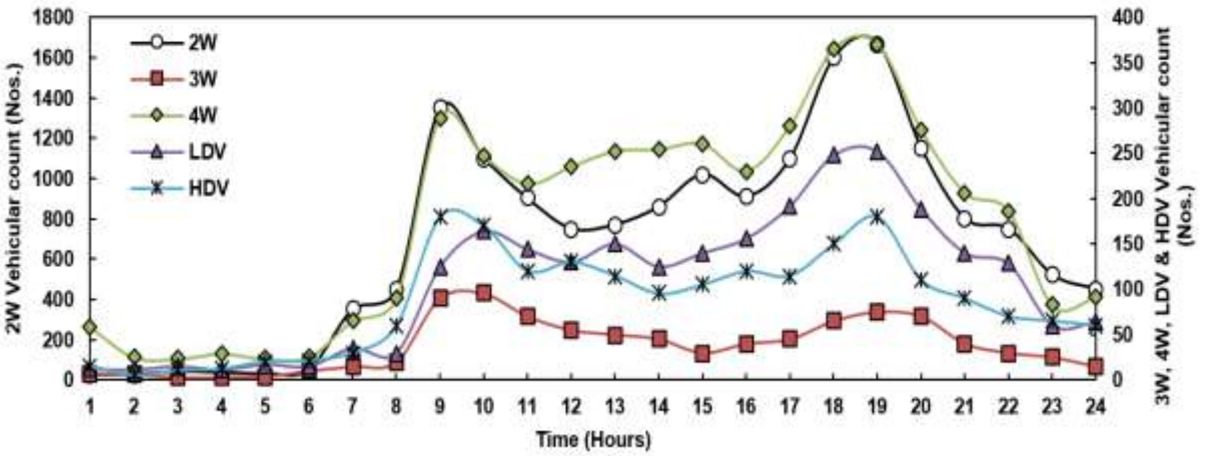

Fig. 3(a). Average hourly variation of different category of vehicles from January to December at IVRI institute (Location 1**).**

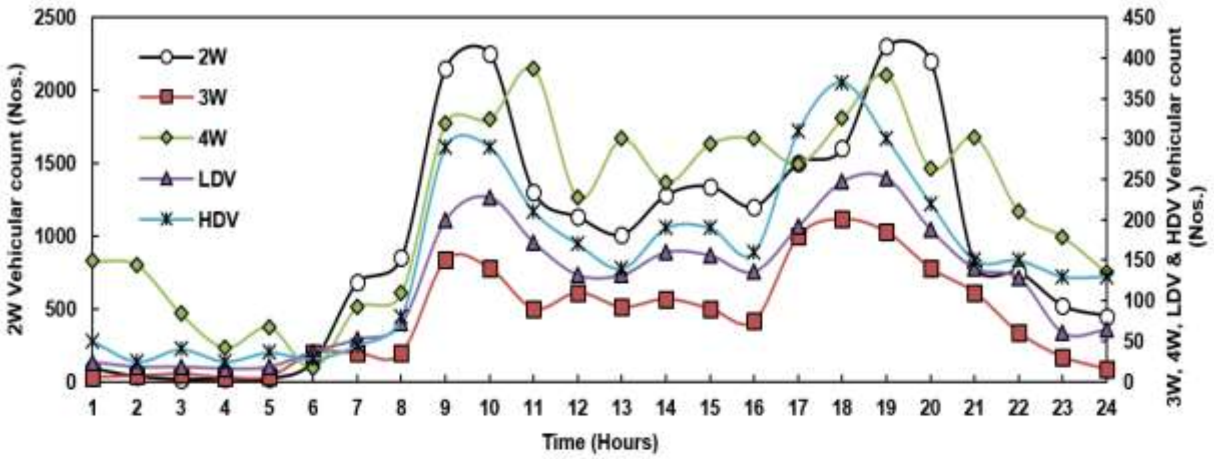

Fig. 3(b). Average hourly variation of different category of vehicles from January to December at Petrol Pump (Location 2).

4.2 Emission Inventories

An emission inventory is a database which gives the sources and amount of air pollutants discharged into the atmosphere during a given time period. Emission Inventory depends upon the location, elevation, frequency and duration of emission, etc. and it provides the information about the status of air pollution in the urban fringes. On the other hand, ISCST3 and CALINE4 models require an input of weighted emission factor (WEF) at each of the 10 selected links along the identified highway stretch. The emission factors relevant to vehicle categories such as 2W, 3W, 4W, LDV, HDV and for the pollutants CO, HC, CO_2, PM_{10} and NO_x were obtained from the Automotive Research Association of India (ARAI), New Delhi, India. These emission factors along with the observed data such as of number of vehicles were used to calculate the WEF which was an input into the ISCST3 and CALINE4 models. The average hourly variation in the emission factors for the pollutants such as CO, HC, CO_2, PM_{10} and NO_x are shown in Figures 4 (a, b). From these plots, it was observed that, due to variations in traffic flow at different hours of the day, the amount of air pollutants emitted into the atmosphere was also varied. Emission factors were found to be maximum during early morning (03:00 – 07:00 h) time and late night (22:00 – 02:00 h) and found to be minimum between 08:00 and 11:00 hours (morning peak hours) and, 17:00 and 20:00 (evening peak hours). It was observed that, as the vehicular number increases emission factors decreases. Hence, during peak traffic hour's minimum emission factors were observed. However, maximum emission factor was noticed for the pollutant CO_2 followed by CO, HC and PM. Maximum emission factors for CO_2 was varying from 250 – 700 g/mi at monitored location 1 and 2. However, emission factors for CO and HC were varying from 6 -16 g/mi and 2 – 6 g/mi (Figure 4a). Emission factors were found to be more at location 1 when compared to location 2. This may be due to less number of vehicles moving at location 1. However, the variation of emission factors were found to be marginal at both the locations throughout the year. On the other hand, the average composition of traffic variation from January to December at location 1 and 2 are made shown in Figures 5 (a, b). It was found that, the number of 2W were found to be maximum in the traffic distribution which was varying from 50 – 60 % (12000 – 17000 VPD) in a day at location 1. However, HDV and LDV were ranging from 6 – 15 % (2000 – 5000 VPD) in a day at location 1 (IVRI institute) (Figure 5a).Further, at location 2, number of 2W were found to be maximum with a traffic distribution varying from 55 – 65 % (17000 – 22000 VPD) in a day (Figure 5b) and HDV and LDV were ranging from 8 – 12 % (2500 – 4000 VPD). It was observed that, number of vehicles were found to be more at Location 2 (Petrol Pump) when compared to Location 1 may be due to the intersection of major roads (Civil Lines) and also presence of commercial activities.

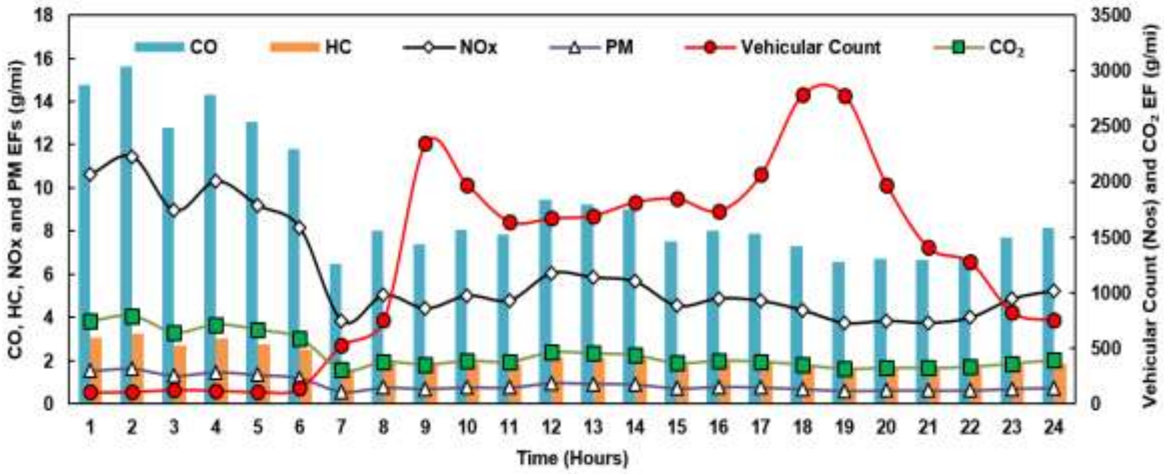

Fig. 4(a). Average hourly variation of emission factors from January to December at IVRI institute.

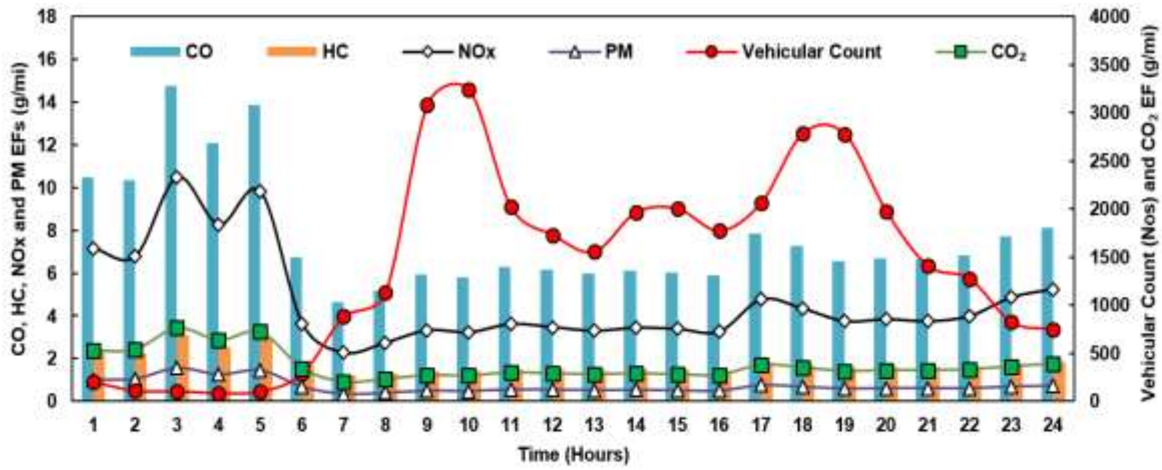

Fig. 4(b). Average hourly variation of emission factors from January to December at Petrol Pump.

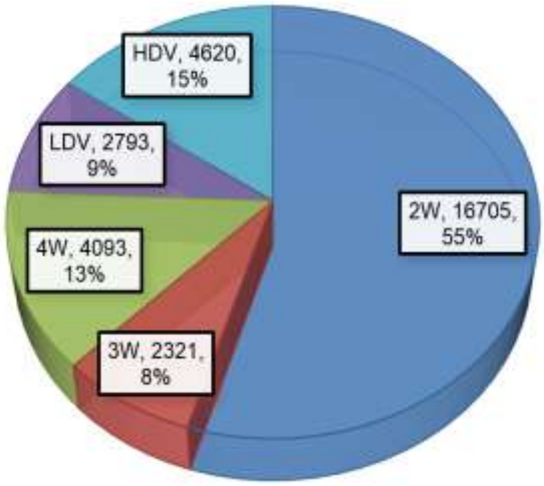

Fig. 5(a). Average daily variation of different category of vehicles from January to December at IVRI institute.

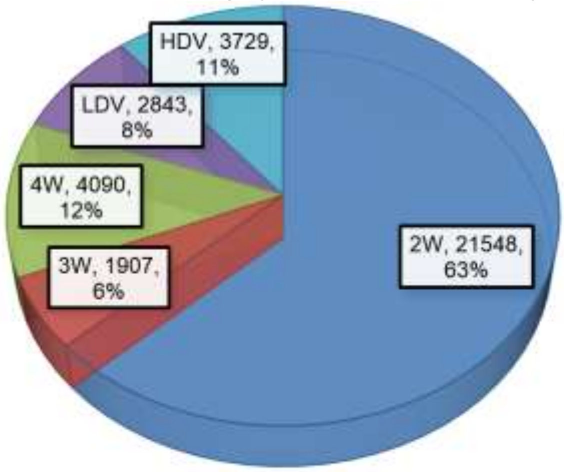

Fig. 5(b). Average daily variation of different category of vehicles from January to December at Petrol Pump.

Ettouney et al. (2009) [51] have estimated the emission inventory of SO_2, CO and NOx in Kuwait and observed that, emission sources were mainly contributing from power plants, motor vehicles, oil fields and oil refineries. Balashanmugam and Nehrukumar (2016) have reported that, 2Ws were ranging from 60 – 70 % followed by 3Ws (11 – 12 %), LDV (10 – 12%) and HDV (9 – 10 %) at Puducherry, India [31]. Talaiekhozani et al. (2017) have reported an average emission of 13,297 tons NOx, 0.13 tons SOx, 691 tons HC, 727 tons VOCs, 329 tons PM_{10}, 319 tons $PM_{2.5}$ and 1374 tons CO into the atmosphere of Isfahan metropolitan by locomotives [52]. Masood et al. (2017) have reported cars/jeep dominated the traffic density by 43 % followed by 2W (36 %), HDV (11 %), 3W (8 %) and LDV (2 %) in Delhi city, India [53].

4.3 Ambient Air Quality Monitoring (AAQM)

Ambient air quality monitoring (AAQM) gives the total concentration estimate for air pollutants arising from various sources including the background concentration of the study area. In the present investigation, two different study area such as, Indian Veterinary Research Institute (I.V.R.I) Izatnagar (Location 1) and Petrol Pump, Civil lines (Location 2), Bareilly, India were selected for AAQM studies. These areas were selected based on traffic density, road canyon, commercial activities, major pollution sources and wind direction. Dispersion of air pollutant is dependent upon many meteorological factors [54], most significantly dependent upon wind speed and Boundary Layer Height (BLH), which defines the volume of air through which the pollution will be mixed. The major governing meteorological parameters for dispersion of air pollutants considered in the study area include: wind velocity, wind direction, temperature, relative humidity and precipitation. The AAQM studies have been conducted over a period of 5 years from 2013 to 2017, considering winter, summer and monsoon seasons. The AAQM was conducted over 24 hours for the pollutants such as, RSPM, SPM, NOx and SO_2. The results of ambient air quality monitoring studies from 2013 to 2017 for the pollutants such as, RSPM, SPM, NOx and SO_2 at IVRI institute and Civil Lines during January to December are presented in Figures 6 and 7 (a, b). It was observed from the monitored results that, the pollutant concentrations such as SO_2 and NO_x was found to be within the National Ambient Air Quality Standards (NAAQS) of 80 μg/m^3 in all the seasons (Figures 6b). However, RSPM and SPM concentrations were found to be exceeding NAAQS of 100 μg/m^3 and 300 μg/m^3, respectively, throughout the year at location 1 (Figures 6a). The reason for obtaining higher concentration of RSPM and SPM may be due to high vehicular density and emissions from the vehicular exhaust. This may be also due to calm atmospheric condition which hindered the mixing of pollutants at the ground level. It was found that, RSPM and SPM concentrations were varying from 150 – 250 μg/m^3 and 250 – 430 μg/m^3, respectively, in all the seasons at location 1 during 2013. SO_2 and NOx concentrations were ranging from 5 – 13 μg/m^3 and 15 – 30 μg/m^3, respectively, during 2013. Further, RSPM and SPM concentrations were found to be from 200 – 250 μg/m^3 and 350 – 450 μg/m^3 at location 1 during 2014 to 2016. SO_2 and NOx concentrations were ranging from 10 – 15 μg/m^3 and 25 – 40 μg/m^3, respectively, during 2014 to 2016. The AAQ studies conducted by Prakash et al. (2015, 2016 and 2017) in the industrial area of Mysuru, have also showed similar type of result of exceeding pollutant concentrations during winter season due to calm atmospheric conditions and lower wind speed [47, 48, 55]. Maximum pollutant concentrations were found during winter seasons i.e., December to February due to low wind speeds which allows a calm atmospheric condition, where pollutant dispersion was minimum. On the other hand, during summer season pollutant concentrations were found to be less when compared to winter season, may be due to high wind speeds and reduced humidity, which allows pollutant for a rapid mixing. However, pollutant concentrations were found to be minimum during monsoon season due to the occurrence of precipitation, which scavenged all pollutants to the ground level.

It was observed from the monitored results at location 2 that, the pollutants concentrations such as, SO_2 and NO_x were found to be within the NAAQS of 80 μg/m^3 in all the seasons. However, RSPM and SPM concentrations were found to be exceeding NAAQS of 100 μg/m^3 and 300 μg/m^3, respectively, throughout the year (Figure 7a). The reason for obtaining higher concentration of RSPM and SPM at Civil Lines may be due to the commercial activities, high vehicular density and exhaust emissions. This may be also due to fugitive dust emission which increased the pollutant concentration at ground level. It was found that, RSPM and SPM concentrations were varying from 250 – 300 μg/m^3 and 300 – 450 μg/m^3 (Figure 7a) in all the seasons at location 2 during 2013. However, SO_2 and NOx concentrations were ranging from 10 – 17 μg/m^3 and 25 – 33 μg/m^3 (Figure 7b) during 2013. Further, RSPM and SPM concentrations were found to be from 300 – 350 μg/m^3 and 350 – 450 μg/m^3 at location 2 during 2014 to 2017 (Figure 7a). SO_2 and NOx concentrations were ranging from 12 – 17 μg/m^3 and 20 – 35 μg/m^3 during 2014 to 2017. Maximum pollutant concentrations were found during winter seasons i.e., December to February, this is similar to the observation made at location 1 due to low wind speeds and calm atmospheric condition. Further it was notice that, pollutant concentration was found to be more at location 2 when compared to location 1. This may be due to high vehicular density at location 2 and commercial activities. A total count of 34,000 Vehicle per Day (VPD) have been counted at location 2 when compared to 28000 VPD at location 1. This may also due to the road canyon effects and topography of the study area, which was influencing the pollutant concentration at location 2. AL-Haddad et al. (2013) [56] have observed the pollutant concentrations were increased by factor of 1.2, 5.5, and 2 for SO_2, NOx, and CO, respectively between 2001 and 2008 due to the increase of Kuwait's population and daily activities. They also stated increase in SO_2 concentration level was mainly due to increase in the industrial activities in the vicinity of Umm-Alhyman, Kuwait. Further, Al-Baroud et al. (2012) have stated highest concentrations of SO_2 were found between 10:00 h to 15:00 h due to the increase in power plants capacities to accommodate increase in power consumption in office buildings as well as residential areas, in Jahara, Kuwait. However, variations in NOx and CO concentrations were found to be maximum at 7:00 h and at 20:00 h due to morning and evening rush hours [57].

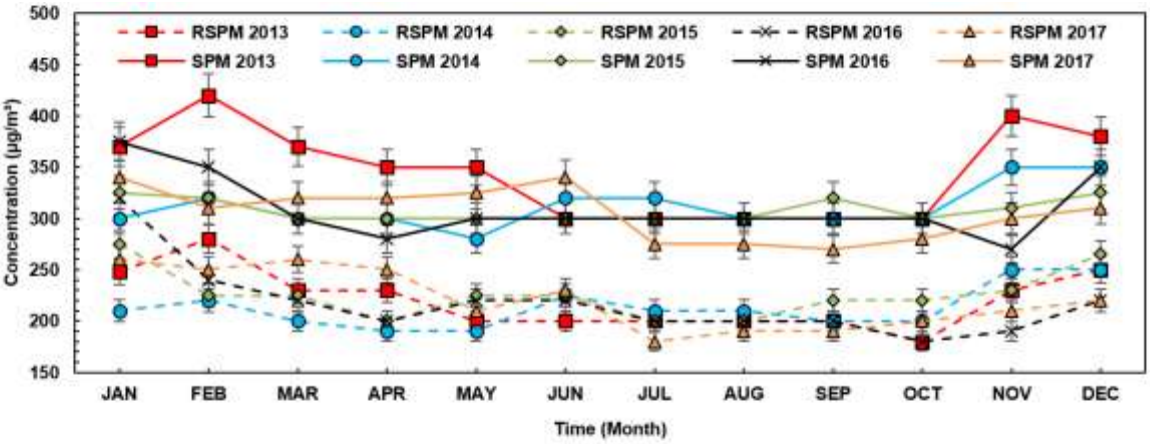

Fig. 6(a). Monthly variation of RSPM and SPM concentrations at IVRI institute (Location 1) from 2013 to 2017.

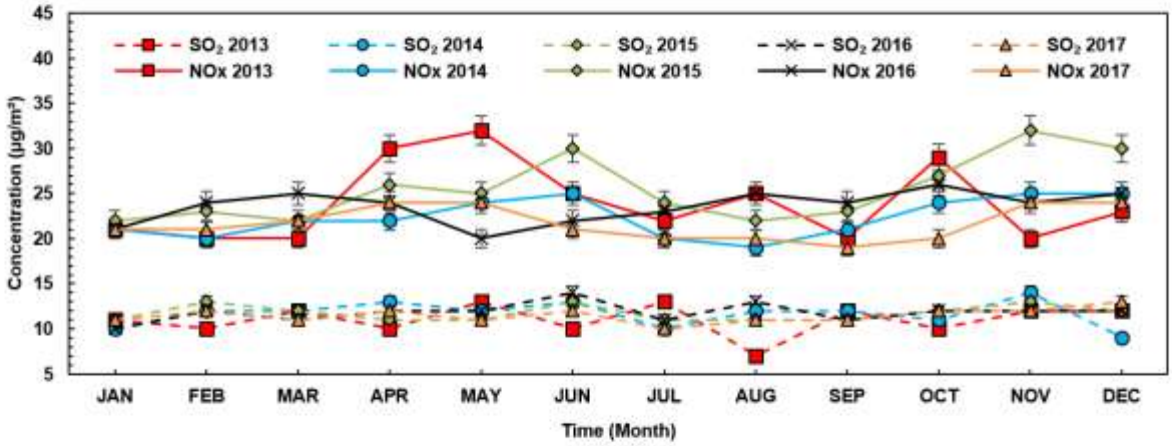

Fig. 6(b). Monthly variation of SO_2 and NOx concentrations at IVRI institute (Location 1) from 2013 to 2017.

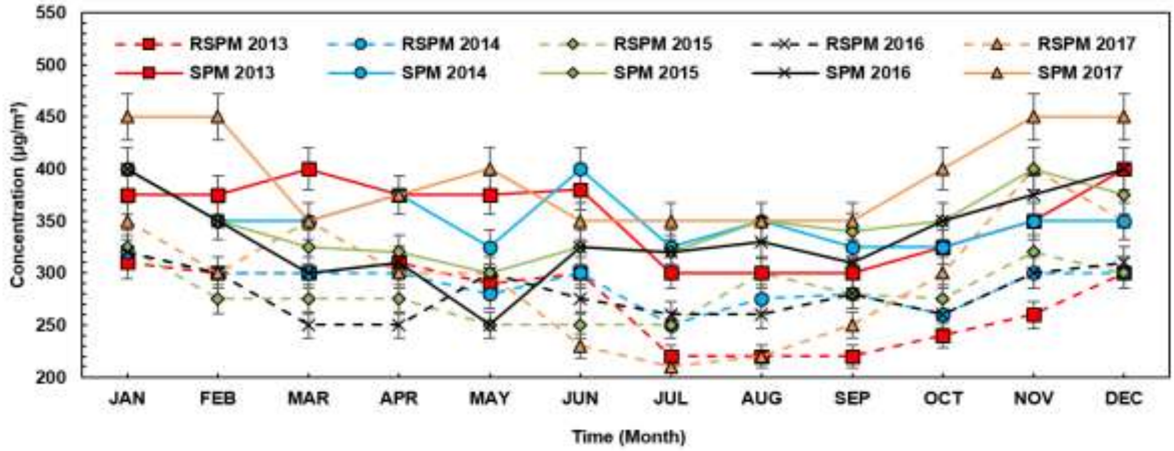

Fig. 7(a). Monthly variation of RSPM and SPM concentrations at Petrol Pump (Location 2) from 2013 to 2017.

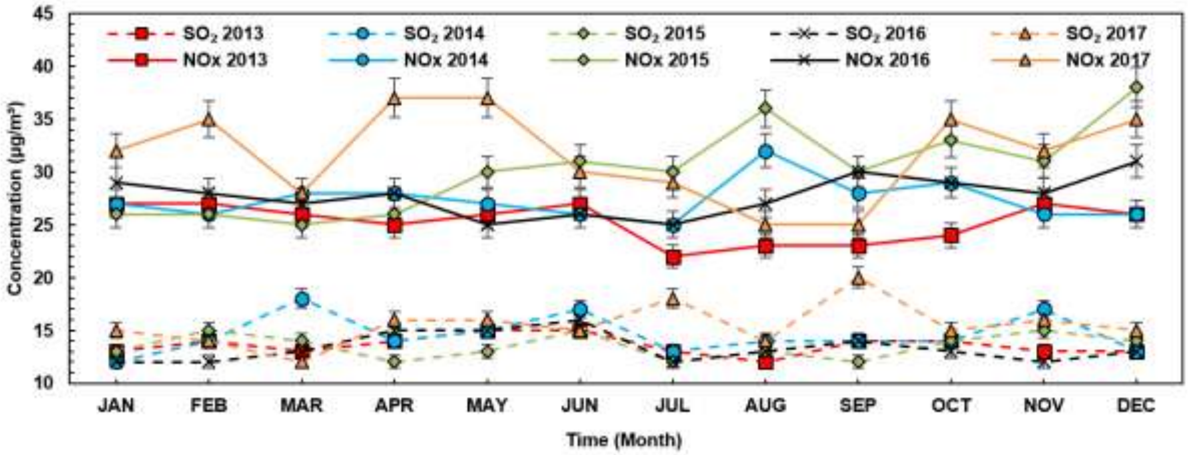

Fig. 7(b). Monthly variation of SO_2 and NOx concentrations at Petrol Pump (Location 2) from 2013 to 2017.

4.4 Comparisons of ISCST3 and CALINE4 Model Predictions with Observed Values

ISCST3 and CALINE4 models have been used to predict NOx, SO_2 and PM_{10} concentrations at two identified study area such as, Indian Veterinary Research Institute (I.V.R.I) Izatnagar (Location 1) and Petrol Pump, Civil lines (Location 2), Bareilly, India. A total of 10 area/line sources were considered for ISCST3 model, which was further converted into line sources. However, for CALINE4 model 10 links were selected based on elevation, direction and intersection. ISCST3 and CALINE4 model results were compared with the observed pollutant concentration to validate the model applicability. Plots of observed and predicted concentrations of NOx, SO_2, RSPM, SPM verses time were made using ISCST3 and CALINE4 models at locations IVRI institute and Petrol Pump station, Bareilly, India from January to December are shown in Figures

8 and 9 (a, b). From the Figure 8a, it was observed that, NOx concentrations were varying from 19 – 24 μg/m^3 from January to December. However, maximum NOx concentration of 24 μg/m^3 was observed during December, due to calm atmospheric condition. The monthly variation of pollutant concentrations were mainly due to variation in wind velocity and its direction. However, ISCST3 model predictions were varying from 15 – 21 μg/m^3 throughout the year. The model predictions were found to be good agreement with the observed pollutant concentration. However, from February to May and November to December, ISCST3 model was underpredicting the pollutant concentrations. This may be due to the consideration of only area sources in the model study. However, point sources and background pollutant concentration may also influence the observed concentrations. Further, CALINE4 model predictions were varying from 20 to 35 μg/m^3 (Figure 8a) throughout the year. It was found that, most of the times CALINE4 model was overpredicting NOx concentrations. This may be due to CALINE4 model is a lower version model and having less input data to the model, which reduces the model accuracy.

Further, SO_2 concentrations prediction by ISCST3 model showed, model was over-predicting the SO_2 concentration (Figure 8a). This may be due to the emission factors, which was influencing the prediction of SO_2. Further, ARAI emission factors were considered based on average age profile of different category of vehicles, which may have influenced for the over-prediction of SO_2 concentration. However, NOx and SO_2 concentrations were found to be within the National Ambient Air Quality Standards of 80 μg/m^3. Sharma and Chandra (2008) [58] have stated that, due to low wind speeds and low mixing height in the winter and post-monsoon season, the dispersion of PM reduces and high concentrations was observed over Kanpur city, India. As number of vehicle increases, the pollutant concentration of CO, NOx and PM_{10} also increases [59, 60, 61]. Observed SPM concentrations were found to be varying from 300 to 350 μg/m^3 through-out the year (Figure 8b). SPM concentrations were found to be exceeding the NAAQS of 300 μg/m^3. This may be due to calm atmospheric conditions with high pollution load due to vehicular traffic in the study area. ISCST3 model predictions were found to be good in agreement with the observed values. However, the variation in the model predictions were due to the varying meteorological data and emission factors, which influences the dispersion of pollutant in the atmosphere. ISCST3 model predictions were varying from 280 – 300 μg/m^3 in all the seasons. It was observed that, ISCST3 model was slightly underpredicting SPM concentration, which may be due to the variation of emission factor data and wind speeds, as the observed pollutant concentration was found to be higher than the NAAQ standard. On the other hand, CALINE4 model predictions were varying from 250 – 280 μg/m^3 in all the seasons. It was found that, CALINE4 model was underpredicting the SPM concentration throughout the year. Ganguly et al. (2009) [62] have reported that, model performance with the increase of downwind distance. Pollutant concentration prediction by models were mainly due to the data input. Emission data may have uncertainties in magnitude and variation in hourly meteorological data may influence the final model output. Further, observed RSPM concentrations were also found to be exceeding the NAAQS of 100 μg/m^3 (Figure 8b), which may be due to the natural and anthropogenic sources. It was observed that, ISCST3 model was slightly underpredicting the $PM_{2.5}$ concentrations, which may be due to not considering the point sources and background concentrations. However, model predictions were found to be good agreement with the observed values. Jiming et al. (2001) estimated emission inventory and showed that, nearly 77 % and 40 % of the total CO and NOx emissions in urban areas in Beijing are dominated by mobile sources / line sources [63].

From Figure 9 (a) it was observed that, NOx concentrations were varying from 25 – 35 μg/m^3 from January to December at location 2. Maximum NOx concentration of ~35 μg/m^3 was observed during December and February, and April to May. Monthly variation of pollutant concentrations were mainly due to wind speeds and wind direction. ISCST3 model predictions for NOx were varying from 27–37 μg/m^3 throughout the year (Figure 9a). The observed pollutant concentrations of NOx at Petrol Pump were found to be more than the concentrations observed at IVRI institute (location 1), which may be due to heavy vehicular densities at Petrol pump (location 2). It was observed that, Petrol pump was having traffic density of 3000 vehicles per hour, whereas, IVRI location was having 2000 vehicles per hour. It was found that, ISCST3 model was overpredicting the pollutant concentration during June to September. This may be due to the emission factors, which was influencing the prediction of pollutant concentrations. However, CALINE4 model predictions were varying from 20 to 35 μg/m^3 (Figure 9a) throughout the year. CALINE4 model predictions were found to be in good agreement with the observed NOx concentration (except April to June) though CALINE4 model was slightly underpredicting NOx concentration. This may be due to CALINE4 model gives NOx output as ppm which further has to convert to μg/m^3. However, CALINE4 is having less input data to the model, which reduces the model accuracy. Further, ARAI emission factors were considered based on average age profile of different category of vehicles, which may have influenced for the over-prediction or under-prediction of pollutant concentrations. Further, SO_2 concentrations prediction by ISCST3 model showed, a good correlation with the observed values (Figure 9a). However, NOx and SO_2 concentrations were found to be within the NAAQ Standards of 80 μg/m^3.

In the present study, at both the monitored stations the observed SPM concentrations were found to be varying from 350 to 450 μg/m^3 through-out the year. SPM concentrations were found to be exceeding the NAAQS of 300 μg/m^3. This may be due to calm atmospheric conditions with heavy pollution load into the study area. ISCST3 model predictions were found to be good in agreement with the observed values. However, the variation in the model predictions were due to the varying meteorological data and emission factors, which were influencing the final pollutant concentrations. On the other hand, CALINE4 model predictions were varying from 300 – 370 μg/m^3 in all the seasons (Figure 9b). CALINE4 model predictions were found to be satisfactory with the observed SPM concentration though CALINE4 model was underpredicting SPM concentration. However, Majumdar et al. (2008) have reported that CALINE4 model with correction factors (0.37) can be applied for the prediction of CO in Kolkata city, India [64]. Further, Prakash et al. (2016, 2017) [47, 48] have reported that, ISCST3 and AERMOD model performance was better than CALINE4 model. Further, observed RSPM concentrations were also found to be exceeding the NAAQS of 100 μg/m^3, (Figure 9b) which may be due to heavy traffic density into the study area. It was observed that, ISCST3 model was overpredicting the $PM_{2.5}$ concentrations from May to September due to the emission factors and influence of varied meteorological conditions. However, model predictions were found to be satisfactory with the observed values.

V. Conclusions

Ambient Air Quality (AAQ) has been monitored over a period of 5 years from 2013 to 2017 at Indian Veterinary Research Institute (I.V.R.I), Izatnagar (Location 1) and Petrol Pump, Civil lines, (Location 2) Bareilly, India. Meteorological data showed maximum temperature and humidity was varying from 35°C to 45°C and 96 % to 97 %, respectively over the study area. Temperature was found to be maximum (~ 45°C) during summer season (March to May) and found 9°C in winter season (December to February).

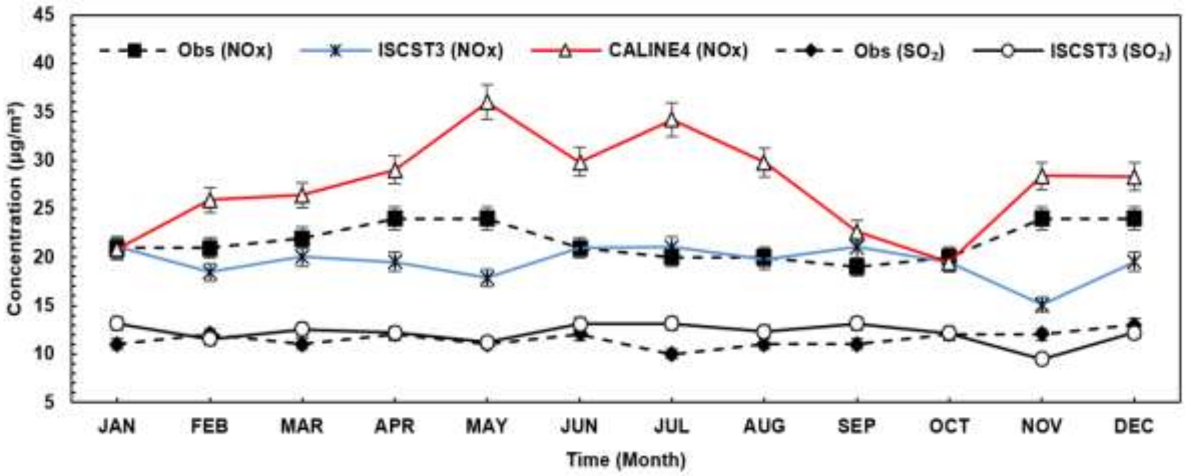

Fig. 8(a). Observed NOx and SO_2 concentration vs. ISCST3 and CALINE4 model predictions near IVRI institute, Izatnagar (Location 1) from January to December**.**

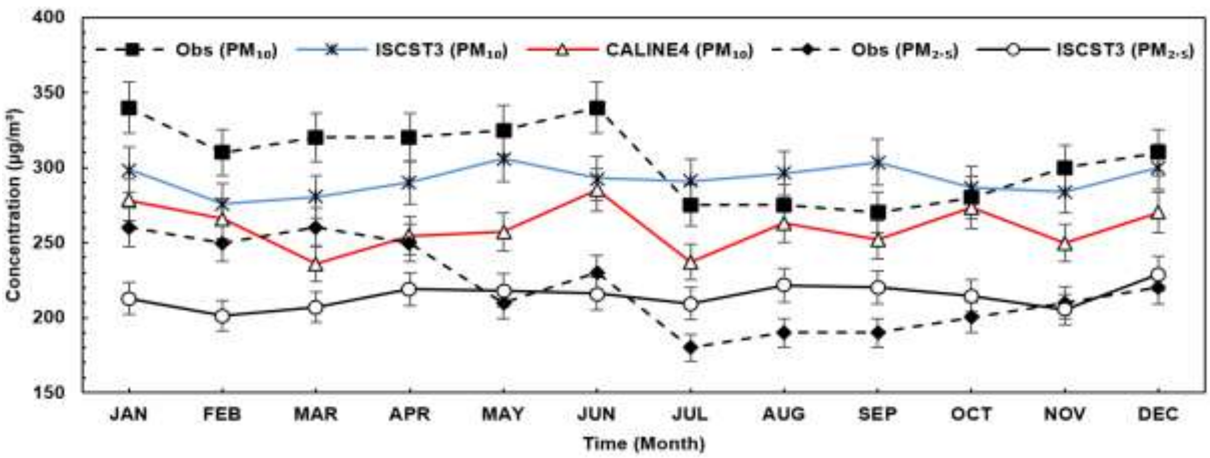

Fig. 8(b). Observed PM_{10} and $PM_{2.5}$ concentration vs. ISCST3 and CALINE4 model predictions near IVRI institute, Izatnagar (Location 1) from January to December.

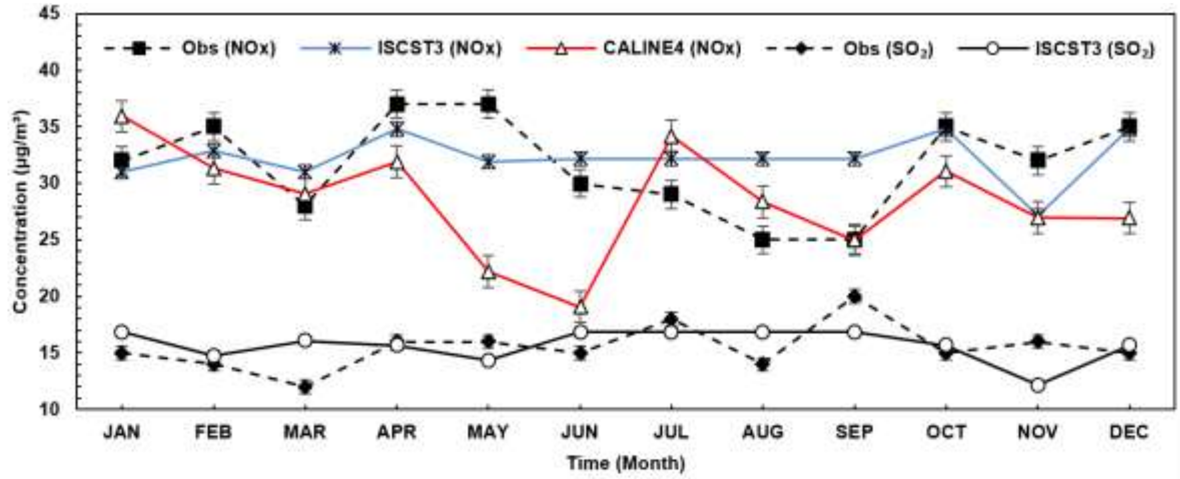

Fig. 9(a). Observed NOx and SO_2 concentration vs. ISCST3 and CALINE4 model predictions near Petrol Pump, Civil lines (Location 2) from January to December.

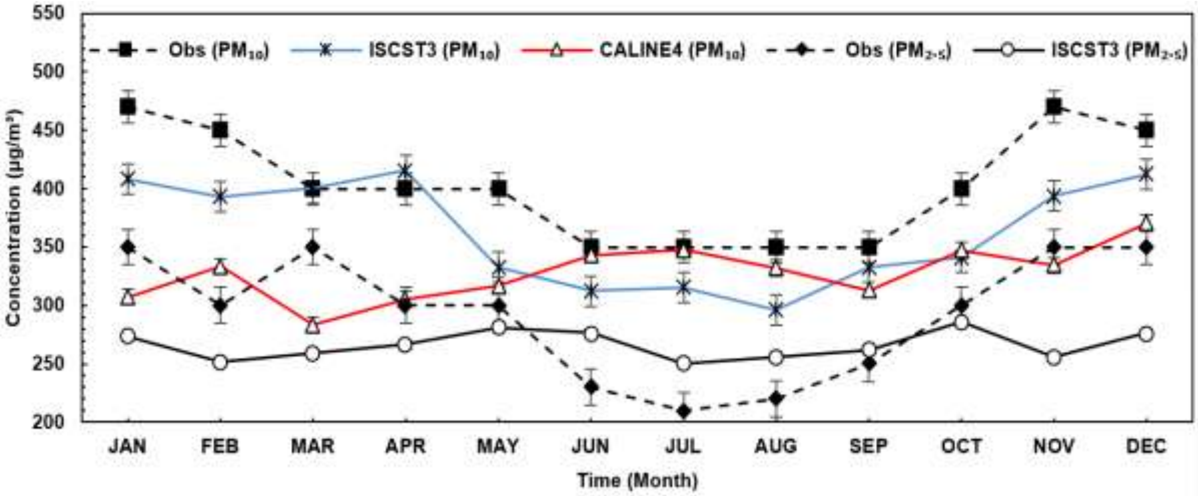

Fig. 9(b). Observed PM_{10} and $PM_{2.5}$ concentration vs. ISCST3 and CALINE4 model predictions near Petrol Pump, Civil lines (Location 2) from January to December**.**

It was found that, maximum wind speed was varying between 6 and 8 m/s during the month of May to September, which implies a favourable atmospheric condition for pollutant dispersion. The maximum 2W count was varying from 1200–1800 VPH at Location 1 and 1600–2400 VPH at Location 2 at the peak traffic hours i.e., 08:00 - 11:00 hours and 18:00 - 20:00 hours during all the months from January to December. However, maximum 4W were found to be varying from 250–400 VPH at peak traffic hours. A maximum number of HDV and LDV were ranging from 50–350 VPH and 50–250 VPH, respectively, during 08:00 - 11:00 hours and 17:00 - 20:00 hours. Number of vehicles were found to be more at Location 2 (25,000–34,000 VPD) when compared to Location 1 (22,000 to 28,000 VPD). Emission factors were found to be maximum during early morning (03:00–07:00 hours) and late night (22:00 – 02:00 hours) and found to be minimum between 08:00 and 11:00 hours and, 17:00 and 20:00. Maximum emission factors for CO_2 was varying from 250–700 g/mi and emission factors for CO and HC were varying from 6-16 g/mi and 2–6 g/mi. It was found that, the number of 2W were found to be maximum in the traffic distribution which was varying from 50–60 % (12000–17000 VPD) in a day at location 1. However, HDV and LDV were ranging from 6–15 % (2000–5000 VPD) in a day. Further, at location 2 the number of 2W were found to be maximum in the traffic distribution i.e., 55–65 % (17000–22000 VPD) followed by HDV and LDV were ranging from 8–12 % (2500–4000 VPD). RSPM and SPM concentrations were varying from 150–250 µg/m^3 and 250–450 µg/m^3, respectively, in all the seasons at location 1. However, SO_2 and NOx concentrations were ranging from 5–13 µg/m^3 and 15 – 30 µg/m^3, respectively. RSPM and SPM concentrations were varying from 250 – 300 µg/m^3 and 300–450 µg/m^3, respectively, in all the seasons at location 2 and SO_2 and NOx concentrations were ranging from 10–17 µg/m^3 and 25–33 µg/m^3, respectively. RSPM and SPM concentrations were found to be exceeding the NAAQS of 100 and 300 µg/m^3, respectively.

ISCST3 model predictions for NOx were varying from 15–35 μg/m^3 over the entire year. ISCST3 model predictions were found to be in good relation with the observed pollutant concentration. However, from February to May and November to December, ISCST3 model was underpredicting the pollutant concentrations. Further, CALINE4 model predictions for NOx were varying from 20 to 35 μg/m^3. It was found that, most of the times CALINE4 model was overpredicting NOx concentrations. SO_2 concentrations prediction by ISCST3 model showed, model was over-predicting the SO_2 concentrations. This may be due to the emission factors, which was influencing the prediction of SO_2. ISCST3 model predictions for SPM were varying from 280 – 430 μg/m^3 in all the seasons. It was observed that, ISCST3 model was slightly underpredicting SPM concentration, which may be due to the variation of emission factor data and wind speeds. CALINE4 model predictions were varying from 250 – 350 μg/m^3 and the CALINE4 model predicted values were found to be satisfactory with the observed SPM concentrations.

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