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RESEARCH ARTICLE

AIR QUALITY INDEX, VENTILATION COEFFICIENT AND POLLUTION POTENTIAL STUDIES OVER BAREILLY CITY, UTTAR PRADESH

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ABSTRACT

Ambient air quality monitoring (AAQM) along with assimilative capacity and Air Quality Index (AQI) studies 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. Maximum temperature and relative humidity was varied from 35°C to 45°C (March to May) and 96 % to 97 % (December) during 2013 to 2017. Maximum wind speeds were varying from 4 to 8 m s^{-1} during the month of June to September and predominant wind was blowing from W and E followed by NW and WNW directions over the study area. Maximum ventilation coefficient (VC) values were ranging from 9000 m^2s^{-1} to 12000 m^2 s^{-1}(from 13:00 h to 16:00 h) and for minimum wind speeds, VC values were ranging from 3000 m^2 $s^{-1}$to 4500 m^2 s^{-1}(from 12:00 h to 16:00 h) throughout the year. A maximum negative assimilative potential of 190 to 230 μg m^{-3} and 150 to 130 μg $m^{-3}$was observed for RSPM and SPM, which were exceeding the NAAQS of 100 and 300 μg m^{-3}, respectively. SO_2 and NOx concentrations were found to be within 90 % of guideline values and assimilative potentials were ranging from 40 – 60 μg m^{-3}at both the locations. AQI was found to be ranging from 350 – 400 during winter season and 300 – 360 during summer and monsoon seasons. The annual average AQI was found to be ranging from 300 – 400, varying from 'very poor' to 'sever' AQI.

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INTRODUCTION

Due to the rapid urbanization and industrialization, air pollution has become a major environmental problem in both developed and developing countries (Chaurasia *et al*., 2013). Rapidly growth of motor vehicleswith time has resulted in traffic congestion, air pollution and noise problems (Mishra *et al*., 2016). About 60 % of air pollution is contributed from automobile exhaust emission in Indian cities. Further, vehicular emission contains more than 450 different organic chemical compounds (Chaurasia *et al*., 2013). Transportation sector is associated with the emission for about 50% of nitrogen oxide (NOx) and 90% of the carbon monoxide (CO) (Nagurney, 2000). In view of the above air pollution is often linked to substantial burdens of ill-health in developed and developing countries, especially in India (Gorai *et al*., 2014; Bruce *et al*., 2000; Smith *et al*., 2000).Vehicular exhaust contains CO, hydrocarbons (HC), NOx, lead (Pb), dust (PM), carbon particles, sulphur dioxide (SO_2), etc. Some of these pollutants react in presence of sunlight to produce secondary pollutants such as, O_3, NO_3, SO_2, PAN.These pollutants may pose harmful effect (acute and chronic diseases) on human health (Afroz *et al*., 2003; Kampa and Castanas, 2008) such as cardiovascular and respiratory disease, Neurological impairments, increased risk of preterm birth and even mortality and morbidity (Dohare and Panday, 2014). Further, many researchers have reported that outdoor air pollution negatively affects the productivity of indoor environment as well as workers (Wargocki *et al*., 2000; Kosonen, and Tan, 2004; Choi *et al*., 2015). Dispersion of air pollutants is mainly dependent on meteorological factors.The two important meteorological factors which contributes the dispersion of pollutants include: mixing layer height (MLH) and wind speed (Emeis *et al*.,

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2008; Schafer *et al*., 2006; Ghiaus *et al*., 2006; Chan *et al*., 2012). The MLH indicates the vertical dilution of air pollutants, and wind speed represents the horizontal ventilation, which helps to reduce ground level pollutant concentration. Further, ventilation coefficient (VC) is a product of mean mixing depth (MMD) and average wind speed, which gives an indication of the air quality in terms of the ability of the atmosphere to disperse the pollutants over a region (Motesaddi *et al*., 2008; Goyal *et al*., 2007; Iyer and Raj, 2013). Many researchers have conducted studies on assimilative capacity based on ventilation coefficient and pollution potential (Maria *et al*., 2000; Rigby *et al*., 2006; Goyal *et al*., 2002; Chan *et al*., 2012; Sujatha *et al*., 2016; Iyer and Raj, 2013; Abiye *et al*., 2016; Alappattu *et al*., 2009).Chan *et al*. (2012) have stated that VC was significantly variable and maximum was found to be during day-time, while VC was relatively invariable and minimum during night-time. It indicates that, the reasonable time to emit maximum amount of air pollutant is during daytime particularly at noon due to the occurrence of highest VC. However, Iyer and Raj (2013) have reported in Delhi city VC decreased at the rate of 49 and 32 $m^2 s^{-1} year^{-1}$ in the months of December and February, respectively, during last 30-year period. However, in Mumbai, average decrease in VC in winter seasons was 15 $m^2 s^{-1} year^{-1}$and for Kolkata it was 14 and 17 $m^2 s^{-1} year^{-1}$in December and February, respectively. Kumar *et al*. (2015) have developed a conjunction model of Wavelet-Neuro-fuzzy model for accurate prediction of the VC over the capital region of Delhi, India. The result of the predicted values obtained from the model was found to be satisfactory.It was also quoted that, Wavelet-Neuro-fuzzy model has mean absolute error of 0.0058 in testing series and 0.0312 in training series. Abiye *et al*. (2016) have reported characteristic values of the atmospheric ventilation coefficients varied from month to month and from daytime (08:00 to 19:00, GMT+1) to night-time (20:00 to 07:00, GMT+1) with daily maximum values occurring in the late afternoon between (13:00 to 17: 00, GMT+1) in Nigeria. The maximum VC values obtained were 1216 $m^2 s^{-1}$and 1156 $m^2 s^{-1}$, 1760 $m^2 s^{-1}$and 1038 $m^2 s^{-1}$, 1225 $m^2 s^{-1}$and 691 $m^2 s^{-1}$, and 1334 and 436 $m^2 s^{-1}$from September to December, 2012 and 2013, respectively. On the other hand, Air Pollution Index (API) Reporting System is an important tool for risk communication, which informs public about the ambient air pollution level and the potential health risk associated with the pollution level (Taieb and Brahim, 2013).

Earlier many researchers (Sharma *et al*., 2003a, 2003b; Murena, 2004; Nagendra *et al*., 2007; Wen *et al*., 2009; Eder *et al*., 2010; Choi *et al*., 2015; Bhuyan *et al*., 2010) have calculated AQI developed by the USEPA to analyse the daily air quality.Wang and Lu (2006) have developed revised AQI for Hong Kong city and varying trends of AQI and analysed during 1999 and 2003. It was found that, daily mean AQI during the seasonal period can be regarded as stationary time series (Wang and Lu, 2006). However, Prakash *et al*. (2017) have reported during winter season AQI was found to be 'Moderate' (141) at Hebbal industrial area, due to high pollution load of PM_{10} (> 100 μg m^{-3}). However, during summer and monsoon season AQI was found to be 'Satisfactory' and 'good' due to high wind speeds and occurrence of precipitation. Sonibare *et al*. (2010) have stated that, the AQI for measured CO concentrations in Niger Delta area, Nigeria, ranged between 1 and 44, which indicates a 'good' AQI category and over 97 % of the measured NO_2 concentrations were below 0.60 ppm which also implies a good category of AQI with no health effects. The number of vehicular population is increasing with time in Bareilly city, which results in a poor air quality near to the road canyon. Hence, an attempt was made to represent the overall meteorological factors and carrying capacity of the atmosphere in terms of ventilation coefficient and pollution potential over Bareilly city, Uttar Pradesh, India.

Study area

Bareilly city is in North Indian state of Uttar Pradesh, India. It is the capital of Bareilly division and the geographical region of Rohilkhand.In the present study, ambient air quality monitoring (AAQM) have been conducted at Indian Veterinary Research Institute (I.V.R.I), Izatnagar (Location 1) and Petrol Pump, Civil lines, (Location 2) Bareilly, India (Fig. 1 a-b).

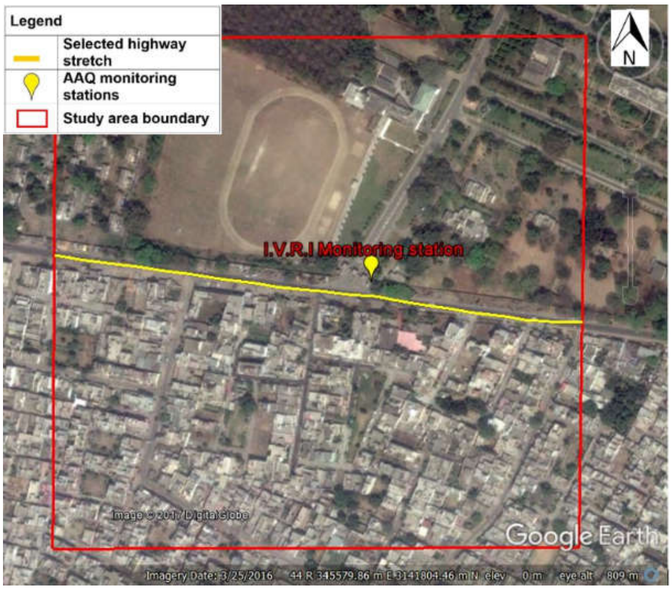

Fig. 1(a). Google Earth view of Location 1 with Ambient Air Quality Monitoring Station (AAQMS) and selected highway near to the Indian Veterinary Research Institute (I.V.R.I) Izatnagar

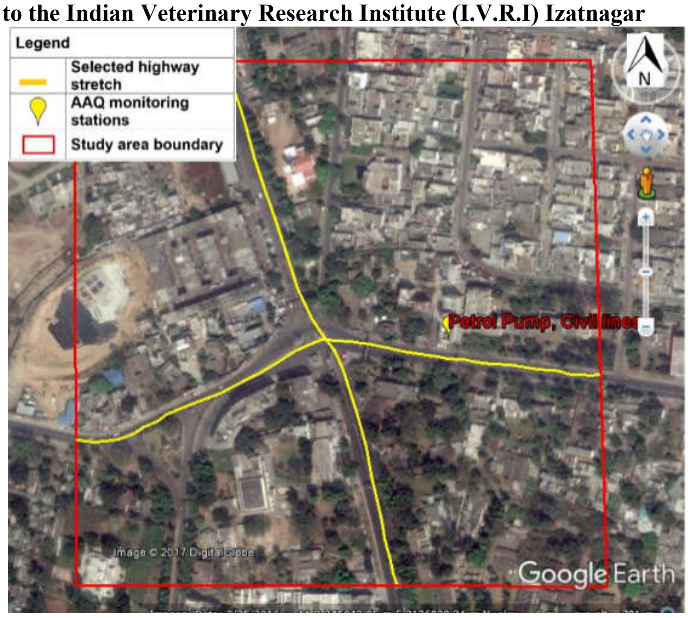

Fig. 1(b). Google Earth view of Location 2 with Ambient Air Quality Monitoring Station (AAQMS) and selected highway near to the Petrol Pump, Civil lines, Bareilly

Location 1 (IVRI institute) is located at the Northern part of Bareilly district, Izatnagar, Uttar Pradesh. On the other hand, Petrol Pump is located Southern part of Bareilly district, Civil lines, Uttar Pradesh, India. The elevation of the study area varies from 162 m to 176 m. Minimum elevation observed in the centre of the Location 1 (IVRI institute) and North West part of the Location 2 (Petrol Pump). However, Location 1 (IVRI institute) comprises of institutional area, residential area and commercial area. The second location (Petrol Pump, Civil lines) comprises of commercial area, traffic intersection and market area. Near to the AAQM stations there is no nearby industries, and thereby major sources of pollution was mainly due to line sources (vehicular emission).

MATERIALS AND METHODS

Meteorological Data Collection

Various meteorological parameters that influence the dispersion of air pollutants include: wind speed and its direction, temperature, precipitation, relative humidity, mean mixing depth (MMD), atmospheric pressure, cloud cover, heating effects and nature of terrain. Hourly meteorological data was obtained from the website www.wunderground.com which was used for plotting the monthly variation of meteorological factors from 2013 to 2017 over Bareilly city.

Assimilative Capacity

Assimilative capacity or Carrying Capacity refers to the ability of the environment of a particular region to carry the pollutants without adverse effects on the environment or on users of its resources (Manju *et al*., 2002). The assimilative capacity of the atmosphere can be determined using two approaches. First approach isbased on ventilation coefficient (VC), which can be calculated by meteorological parameters and the second approach is based on pollution potential, which is due to the presence of air pollutants in the environment. The pollution potential indicates the capacity of the atmosphere to dilute the pollutants and the resulting effects on air quality.

Assimilative capacity based on ventilation coefficient

Ventilation coefficient is the product of mixing depth and average wind speed and can be calculated by using Eqn. 1. The higher the coefficient, the more efficiently the atmosphere can able to disperse the pollutants and better is the air quality. On the other hand, low ventilation coefficients lead to poor dispersion of pollutants causing stagnation and poor air quality leading to possible pollution related hazards (Iyer and Raj, 2013).

Ventilation coefficient (m^2s^{-1}) = Wind speed ($m\ s^{-1}$)xMMD (m) (1)

The US National Meteorological Centre and Atmospheric Environment Services, Canada, has classified that, high pollution potential or low assimilative capacity occurs during afternoon, when ventilation coefficient is < 6000 m^2s^{-1} and mean wind speed does not exceed 4 $m\ s^{-1}$ and during morning hours, when mixing height is < 500 m.

Assimilative capacity based on pollution potential

The second approach is based on the pollution potential in terms of pollutant concentrations measured during AAQM days. Assimilative capacity was determined by considering the difference between the permissible and the existing pollutant concentration levels, for the study region, using Eqn. 2.

Available assimilation potential = Permissible standard – Pollutant concentration (2)

Air Quality Index (AQI)

Air Quality Index (AQI) is a tool introduced by Environmental Protection agency (EPA), USA to measure the levels of pollution due to major air pollutants. AQI focuses on health effects that may experience within a few hours or days after breathing the polluted air. EPA calculates the AQI for five major air pollutants regulated by the Clean Air Act. These include: ground-level ozone, particle pollution (as particulate matter), carbon monoxide, sulphur dioxide and nitrogen dioxide. In the present study AQI was calculated as specified by Sharma *et al*. (2001, 2003b) (Eqn. 3) for the study period, based on the ambient air quality monitored data obtained from 2013 to 2017. The AQI focuses on health effects that may experience within a few hours or days after breathing polluted air.

$$I_P = \left[\frac{I_{HI} - I_{LO}}{B_{PHI} - B_{PLO}} * \left(C_P - B_{PLO} \right) \right] + I_{LO} \quad (3)$$

Where, I_P is AQI for pollutant "P", C_P is the actual ambient concentration of pollutant "P", B_{PHI} is the upper end breakpoint concentration that is greater than or equal to C_P, B_{PLO} is the lower end breakpoint concentration that is less than or equal to C_P, I_{LO} is the sub index or AQI value corresponding to B_{PLO}, I_{HI} is the sub index or AQI value corresponding to B_{PHI}.

RESULTS AND DISCUSSION

Meteorological data

Monthly, seasonal and annual variation of temperature, relative humidity and precipitation

The data of maximum and minimum temperature and relative humidity of the atmosphere were collected from IMD Lucknowover a period of 5 years from 2013 to 2017 considering winter, summer and monsoon seasons from January to December over the study area. Plots of ambient temperature and humidity against time were made shown in Figures 2 and 3. It was observed that, maximum temperatures were varied from 35°C to 45°C, in the month of March to May, of 2013 to 2015 and 2017. However, minimum temperatures were varied from 8°C to 10°Cduring December to February of 2013 to 2017. The maximum temperature of ~ 45°C was observed in the month of April, 2017 and a minimum temperature of 7°C was observed in the month of January, 2017. It was noticed that, temperature was minimum at 03:00 h to 07:00 h and it gradually increased and reached the peak at 13:00 to 16:00 h and then started decreasing during winter, summer and monsoon seasons. Further, a maximum temperature of 40°C was observed in the month of May, 2013 and 2014, and a minimum temperature of ~ 7°C was noticed in the month of January, 2013 and 2014. As temperature increases wind speed also increases which leads to an unstable atmospheric condition, which is more favourable for rapid dispersion of pollutants. Relative humidity (RH) is the ratio of the partial pressure of water vapour to the equilibrium vapour pressure of water at a given temperature. Relative humidity depends on temperature and the pressure of the system of interest. Figure 3, shows a plot of relative humidity versus time for month wise annual variation of maximum and minimum relative humidity (RH). A minimum humidity of 25 % was noticed during the month of January, 2017. Low relative humidity and low clouds represents low pollution levels. However, maximum humidity of 96 % to 97 % was observed in Month of December, 2016 and 2017, respectively, which represents high pollution levels. It was also found that, maximum RH were varied from 80 – 97 % throughout the year, depending upon the atmospheric conditions such as, temperature and precipitation. It was also observed that, RH was minimum at 02:00 to 07:00 h and it gradually increased and reached peak value at 14:00 to 17:00 h and then started decreasing. Figure 4 shows a plot of precipitation versus time over a period of 5 years from 2013 to 2017. It was found that, maximum precipitation occurs in the month of July to October and minimum precipitation occurred in rest of the months. It was also found that, a maximum precipitation of 50 mm, 38 mm and 28 mm recorded in the month of July to August, 2013, 2014 and 2015, respectively. From the precipitation data, it can be ascertained that, during the month of July to September ambient pollutant concentration found to be minimum due to the occurrence of maximum precipitation.

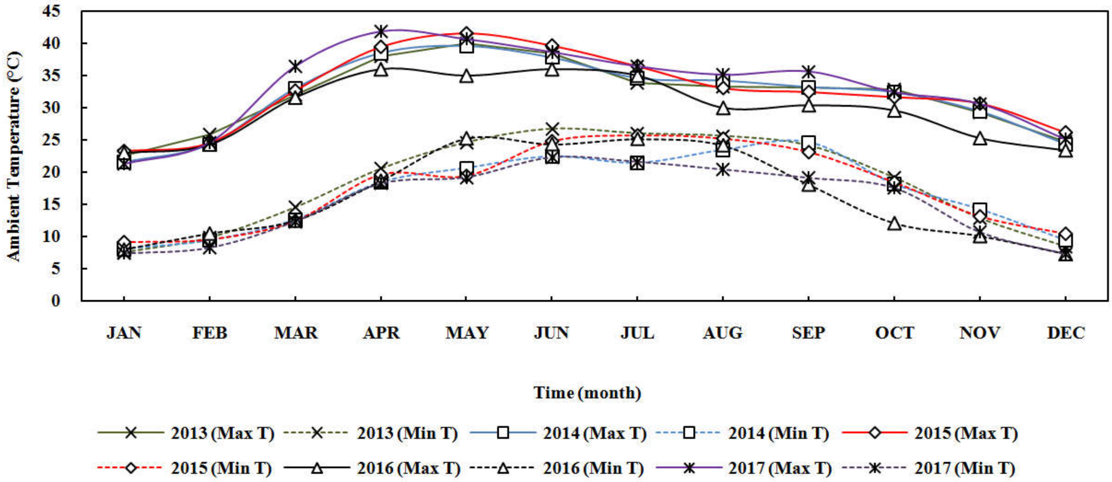

Fig. 2. Monthly variation of maximum and minimum ambient temperature over Bareilly city from 2013 to 2017

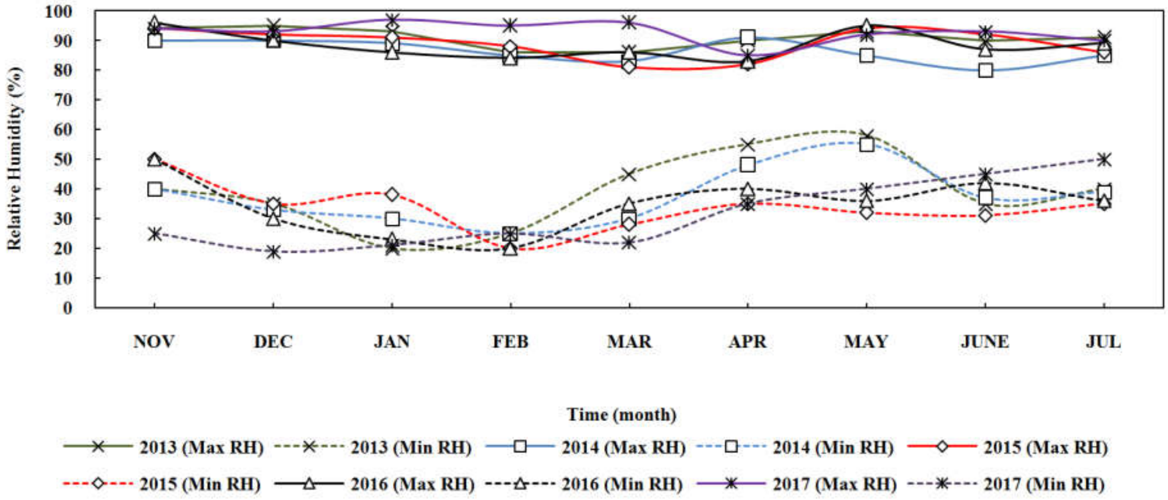

Fig. 3. Monthly variation of maximum and minimum relative humidity over Bareilly city from 2013 to 2017

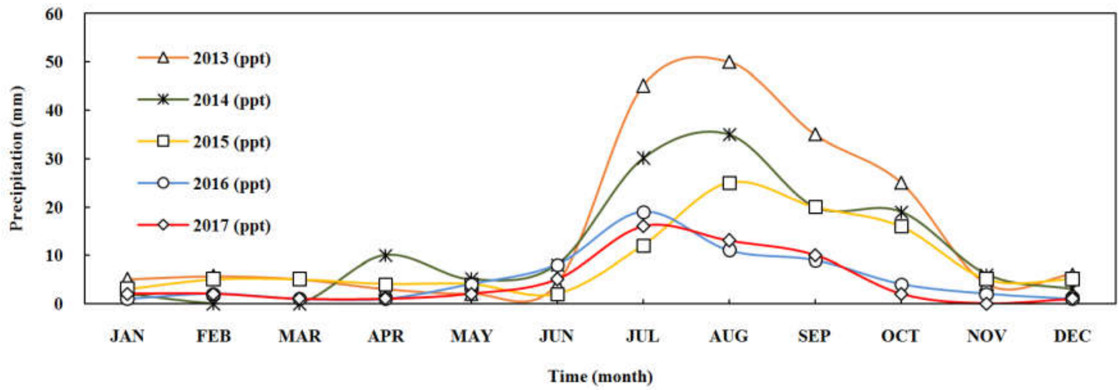

Fig. 4. Monthly variation of maximum precipitation over Bareilly city from 2013 to 2017

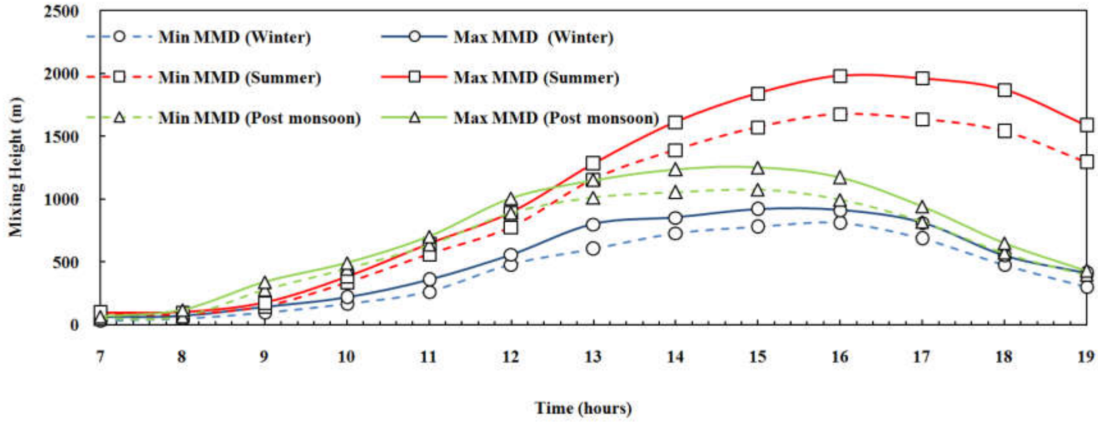

Fig. 5. Plot of minimum and maximum MMD during winter, summer and post-monsoon season over Bareilly city

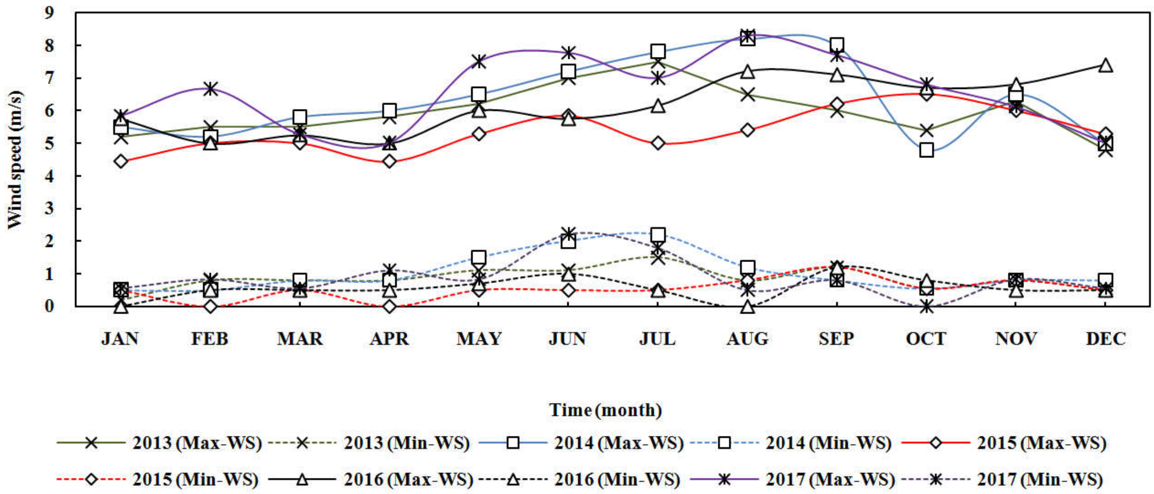

Fig. 6. Monthly variation of maximum and minimum wind speeds over Bareilly city from 2013 to 2017

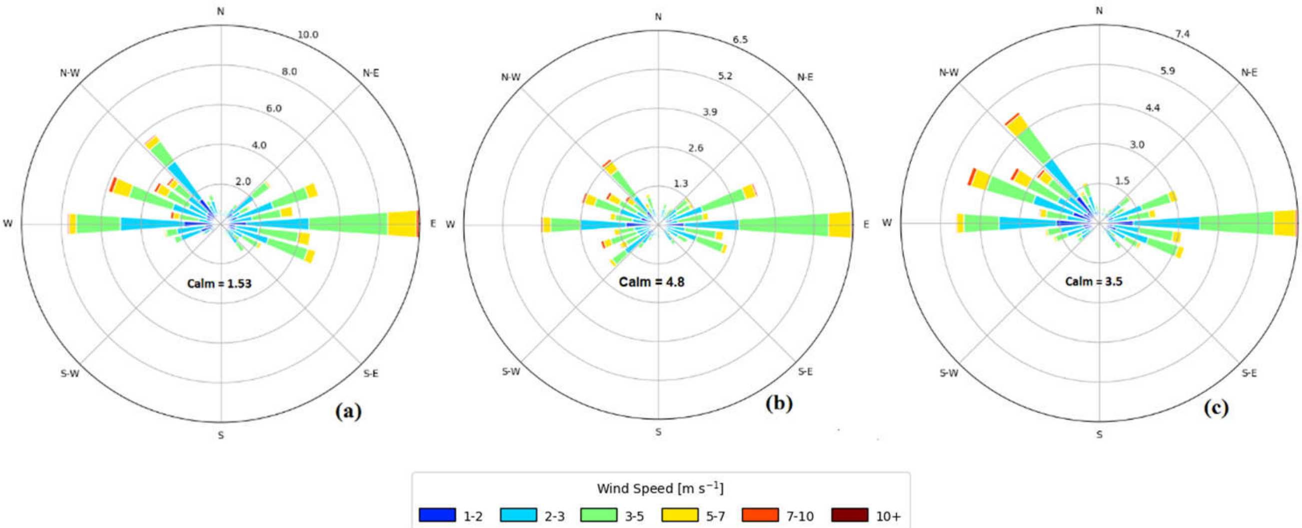

Fig. 7. Windrose plots for (a) 2013, (b) 2017 and (c) 2013 to 2017 over Bareilly city, Uttar Pradesh, India

Seasonal variation of maximum mixing depth (MMD)

MMD is the amount of air available to dilute pollutants is related to the wind speed and to the extent to which emissions can rise into the atmosphere. Mixing depth is used to quantify the vertical mixing of pollutants in the atmosphere. A plot of minimum and maximum MMD during winter, summer and post-monsoon season against time is made shown in Figure 5.

It was found that, the mean mixing depth varies seasonally as well as hourly. From the plot it was observed that, MMD was minimum during morning hours, it gradually increased and reached the peak at 14:00 to 16:00 h and there onwards it started decreasing in all the seasons. The variation of MMD was mainly due to ambient temperature and wind speeds. It is observed that, mixing depth was found to be maximum during mmer season, which may be due to the high ambient temperature and relatively high wind velocities during summer season (March to May) when compared to during winter season. It is also observed that, mixing heights were lowest during post-monsoon season; this may be due to lower inversion layer and cloud cover. The very low values of mixing height during late nights and early morning hours could be due to the occurrence of ground-based inversions which reducesdegree of dispersion (Padmanabhamurty and Mandal, 1979).

pollutants over a study area. A plot of wind velocity versus time for season wise monthly varied wind speeds has been made shown in Figure 6. It was found that, maximum wind speeds were varying from 4 to 8 m s^{-1} during June to September, 2013 to 2017. However, a minimum wind speed of ~ 0 m s^{-1} was observed during 2015. It can be seen that, a maximum wind velocity of 8 m s^{-1} was recorded in the month of August, 2014 and 2017, which implies a favourable atmospheric condition for the dispersion of pollutants.

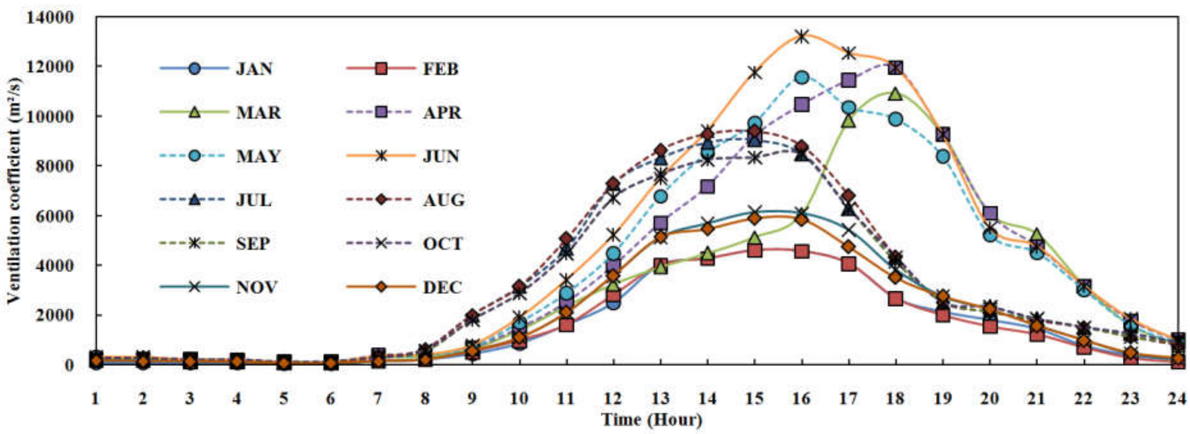

Fig. 8(a). Diurnal variation of maximum ventilation coefficients during January to December for maximum wind speeds and MMD

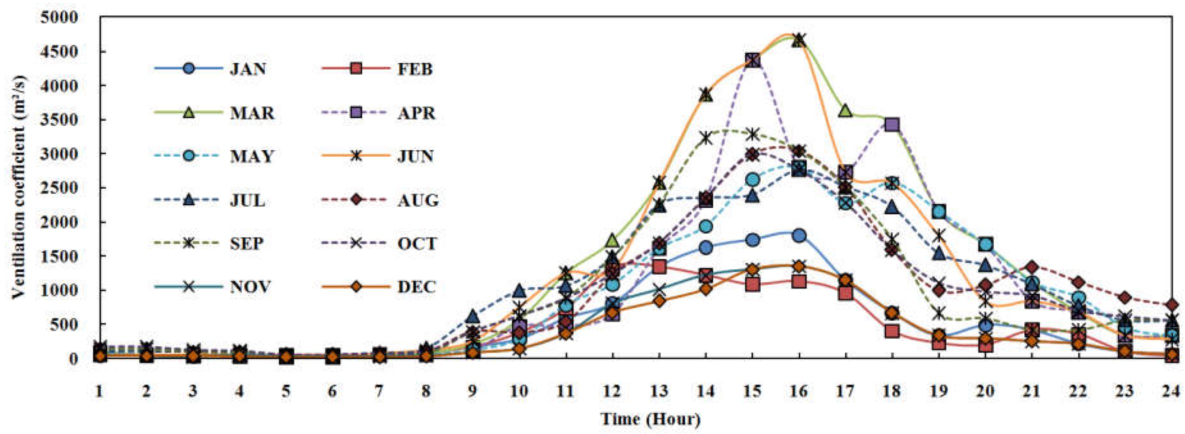

Fig. 8(b). Diurnal variation of maximum ventilation coefficients during January to December for minimum wind speeds and MMD

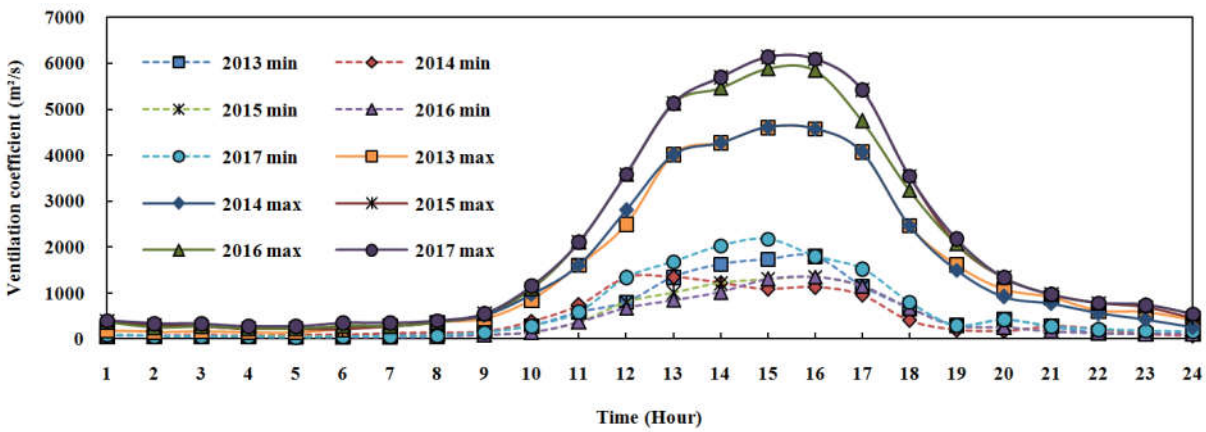

Fig. 9(a). Diurnal variation of maximum ventilation coefficients over Bareilly city during winter season from 2013 to 2017 for maximum and minimum wind speeds

Monthly, seasonal and annual variation of wind speeds

The magnitude and directionof wind arethe major meteorological factors which govern the dispersion of air

However, a fluctuation of wind speeds was noticed throughout the year due to variation in temperature and stability class. The average wind speeds were varying from 2.22 m $s^{-1}$to 3.889 m s^{-1}during the study period.

Wind rose plots

Wind rose plot is a graphical representation of frequency and distribution of wind over a period of time at a specific location. To create a wind rose, average wind velocity and its directions are logged at a site, at short intervals, over a period of time i.e., from 2013 to 2017. Annual variation of wind rose diagrams for the study period from 2013 to 2017 were plotted using WRPLOT and shown in Figure 7 (a, b and c). The annual wind rose plot during 2013 and 2017 showed similar wind directions with predominant wind directions 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 average wind velocity were ranging from 2 – 5 m s^{-1} with a calm period of 0.5 to 4.8 %.

Carrying Capacity of the Atmosphere

Assimilative capacity refers to the ability of the atmosphere to carry pollutants without adverse effects on the environment. The assimilation potential (assimilative capacity) of the atmosphere can be represented by two ways i.e., ventilation coefficient, which is a product of product of MMD and wind speeds and the second approach is dispersion potential of emission loads discharged into the region (Goyal and Rao, 2007). The details of the role of ventilation coefficient and pollution potential on the dispersion of air pollutants in the atmosphere have been discussed in the following sub-sections.

Carrying capacity based on ventilation coefficient (VC)

Ventilation Coefficient (VC) is directly proportional to the carrying capacity or assimilative potential of the atmosphere can be calculated using MMD and wind speeds from January to December over a period of 5 years i.e., from 2013 to 2017. Ventilation coefficient plays an important role on the dispersion of aerosols, and can be considered as one of the factors determining pollution potential over a region (Chan *et al*., 2012). Plots of maximum ventilation coefficients for maximum and minimum wind speed, MMD against time during January to December were made shown in Figures 8 (a, b). It was observed that, wind speeds, MMD and ventilation coefficient (VC) values were found to be less during late nights and early morning periods. During January, a maximum VC of 4500 m^2s^{-1} (at 15:00 h) (Figure 8a) was observed with maximum wind speeds. A minimum VC of 1800 m^2 s^{-1} (at 16:00 h) was noticed with minimum wind speeds and MMD. However, both the VCs were found to be less than the favourable VC for safe dispersion of 6000 m^2 s^{-1}. The reason for obtaining lower VC may be due to the stable atmospheric conditions during the month of January. Wind speeds were found to be ranging from 2 – 3 m s^{-1}, which allows a calm atmospheric condition. Further, in the month of February, a maximum VC of 4600 m^2 s^{-1} (at 15:00 h) was observed with maximum wind speeds. A minimum VC of 1400 m^2 s^{-1} (at 12:00 h) was noticed with minimum wind speeds and MMD.

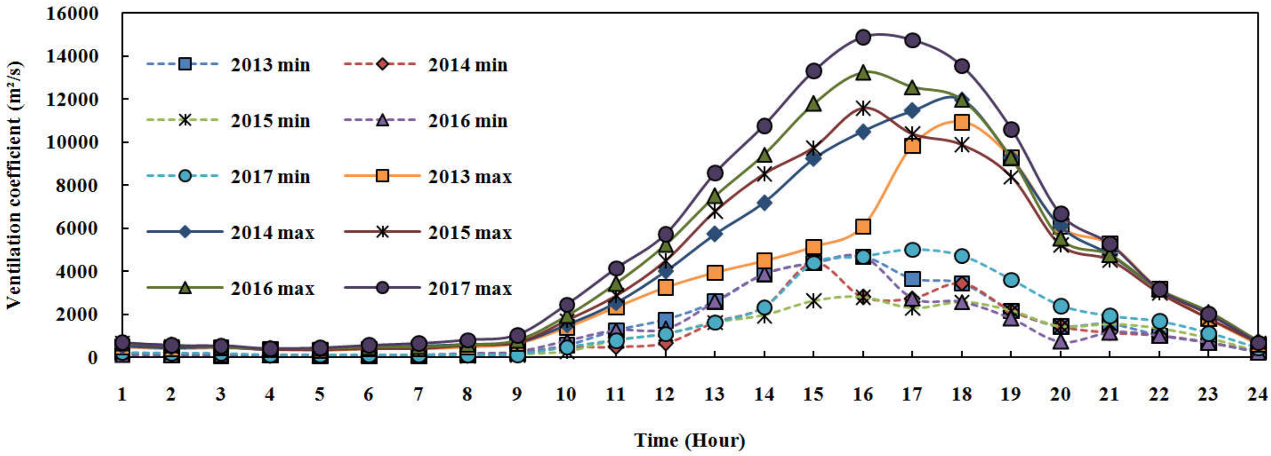

Fig. 9(b). Diurnal variation of maximum ventilation coefficients over Bareilly city during summer season from 2013 to 2017 for maximum and minimum wind speeds

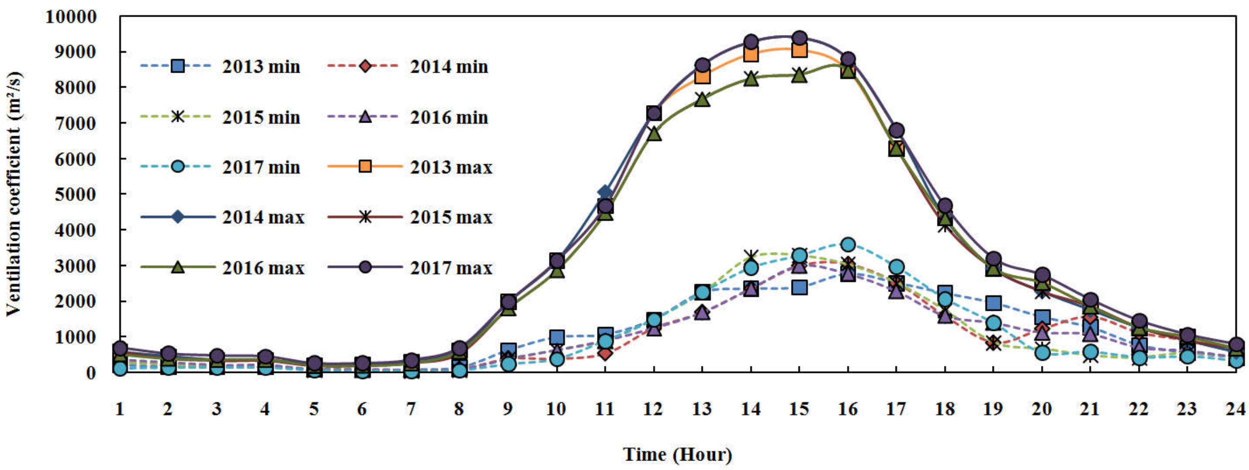

Fig. 9(c). Diurnal variation of maximum ventilation coefficients over Bareilly city during monsoon season from 2013 to 2017 for maximum and minimum wind speeds

The reason for obtaining lower VC may be due to the stable atmospheric condition in the winter season. However, in the month of March, April and May a maximum VC of 10000 m^2 $s^{-1}$to 12000 m^2 s^{-1} (at 17:00 h to 18:00 h) was observed with maximum wind speeds (Figure 8a). A minimum VC of 3000 m^2 $s^{-1}$to 4500 m^2 s^{-1} (at 15:00 h to 16:00 h) was observed with minimum wind speeds and MMD. The maximum VCs were found to be more than the favourable VC for safe dispersion of 6000 m^2 s^{-1}, which implies a better mixing of pollutants occurred in the atmosphere. The reason for obtaining higher VC values during March and April may be due to the unstable atmospheric condition as the wind speeds were varying from 6 – 9 m s^{-1}. The variation of VC in all the months were found to be similar except the variation of the VC values. Maximum VC values were ranging from 9000 m^2 $s^{-1}$to 12000 m^2 s^{-1}(from 13:00 h to 16:00 h) and minimum VC values were ranging from 3000 m^2 $s^{-1}$to 4500 m^2 s^{-1}(from 12:00 h to 16:00 h) during the month of June to December. Manju *et al.* (2002) have reported that, maximum VC was recorded as 7900 m^2 s^{-1}in summer followed by pre-monsoon and monsoon with 4340 m^2 $s^{-1}$and 4060 m^2 s^{-1}, respectively, in Manali, India. Krishna *et al.* (2004) have reported a maximum VC of 13,924 m^2 $s^{-1}$was noticed during season when compared to 9781 m^2 s^{-1}during summer, at Visakhapatnam, India.

Further, plots of diurnal variation of minimum and maximum ventilation coefficient versus time over Bareilly city during winter, summer and monsoon seasons from 2013 to 2017 were made shown in Figures 9 (a, b, c). Hourly computed VC showed a similar diurnal trend in all the three seasons. Various researchers have calculated VC to understand the assimilative potential of the atmosphere (Krishna *et al*., 2004; Goyal *et al*., 2005; Goyal and Rao, 2007, Thepanondh and Jitbantoung, 2014; Thawonkaew *et al*., 2016). With an increase in solar insolation, as the day advances VC also increases reaching a maximum value during afternoon hours. Further, in the evening hours when incoming solar radiation ceases the VC gradually decreases (Viswanadham and Kumar, 1989). The ventilation coefficient values were very low (less than 1000 m^2 s^{-1}) during the morning (01:00 – 09:00 h) and evening/night hours (20:00 – 24:00 h) indicating high pollution potential or low assimilative capacity during these periods (Figure 9). Duringwinter, maximum VC was found to be ~ 2200 m^2 s^{-1} (at 16:00 h) during 2017, followed by 2000 m^2 s^{-1} (at 17:00 h during 2013) and 1400 m^2 s^{-1}(at 12:00 h during 2014) at minimum wind speeds and MMD (Figure 9a). High or low wind speeds and variation in mixing heights were the causes for varied ventilation coefficients. The minimum VCs were found to be < 6000 m^2 s^{-1}, which indicate high pollution potential. Further, during the winter season, maximum VC was found to be ~ 6000 m^2 s^{-1} (at 16:00 h) during 2016 and 2017, followed by 4500 m^2 s^{-1} (at 15:00 h during 2013 and 2014) at maximum wind speeds and MMD (Figure 9a). The maximum VCs were found to be < 6000 m^2 s^{-1}, which indicates high pollution potential or low assimilative capacity during these periods. During summer season ventilation coefficient values were found to be less than 1000 m^2 s^{-1}during morning early morning and evening/night hours. During summer, maximum VC was found to be maximum of ~ 5000 m^2 s^{-1} (at 14:00 h to 17:00 h) at minimum wind speeds during 2014 to 2017 (Figure 9-b), which was found to be < 6000 m^2 s^{-1}, indicating high pollution potential. Further, during summerseason, maximum VC was found to be ~ 15000 m^2 s^{-1}(at 16:00 h) during 2017, followed by 13000 m^2 s^{-1} (at 16:00 h during 2016), 11000 m^2 s^{-1} (at 16:00 h during 2015). The maximum VCs were found to be > 6000 m^2 s^{-1} indicating that low pollution potential or high assimilative capacity during these periods. The ventilation coefficient was found to be highest in summer season than winter. Infect, during monsoon season maximum VC was found to be ~ 9000 m^2 s^{-1}(at 15:00 h) during 2013, 2014 and 2017, followed by 8000 m^2 s^{-1}(at 16:00 h during 2016) (Figure 9c). High or low wind speed and mixing height are responsible for the variability (Goyal and Rao, 2007). From the above it is observed that, pollution potential found to be high during winter as compared to summer and monsoon periods. Thus, it can be concluded that, the VC simply provides a broad indication of the dispersion potential in terms of low (< 2000 m^2 s^{-1}), medium (2000 – 6000 m^2 s^{-1}) or high (> 6000 m^2 s^{-1}) of the atmosphere. However, it does not give any idea about the amount of emission loads that can be assimilated in the given air-shed of the region (Goyal and Rao, 2007). Sujatha *et al.* (2016) have estimated ventilation coefficient (VC) in order to understand the dispersion of pollutants over the urban region of Hyderabad during 2009 – 2011. The result showed that, boundary layer height (BLH) was maximum in summer and minimum in monsoon period, whereas, the maximum VC was observed during summer and minimum in winter.

Effect of emission loads on carrying capacity of the atmosphere

In the present study, pollution potential was determined by considering the difference between permissible and existing pollutant concentration levels. Existing ambient air pollutant concentration levels may be monitored in ambient air or can be predicted using an appropriate air quality model for the existing sources that contribute to air pollution (Goyal and Rao, 2007). In the present study, observed pollutant concentrations were considered. Assimilative capacity in terms of pollutant concentration was determined by subtracting pollutant concentration from 90 % of air pollution standard with the existing measured air concentration in the study area. The National Ambient Air Quality Standard (NAAQS) was used as ceiling limit for ambient air quality. The calculated assimilative capacity at Indian Veterinary Research Institute (I.V.R.I), Izatnagar (Location 1) and Petrol Pump, Civil lines, (Location 2) Bareilly, in terms of pollution potential from 2013 to 2017 during January to December were determined and are shown in Tables 1 to 4. From the Table 1, it is observed that RSPM concentration was found to be more than the standard 100 µg m^{-3}throughout the year. Hence, RSPM concentration was found to be exceeding 90 % of guideline values during 2013, which implies a negative assimilative potential at IVRI institute and petrol pump (Table 1). A maximum assimilative potential of - 190 to - 230 µg m^{-3} was found in the month of February and January, 2013. A negative assimilative capacity in terms of RSPM indicates a poor environmental condition which can affect human beings as well as animals and plants. On the other hand, from the Table 2, it was observed, SPM concentration was found to be exceeding the standard 300 µg m^{-3}throughout the year, which found to be similar observation made for RSPM. Hence, SPM concentration was found to be exceeding 90 % of guideline values from January to December during 2013 to 2017, which implies a negative assimilative potential (Table 2). A maximum negative assimilative potential of 150 to 130 µg $m^{-3}$was found in the month of February, 2013. However, observed SO_2 and NOx concentrations were found to be within the National Ambient Air Quality Standards (NAAQS) of 80 µg m^{-3} (Tables 3 and 4).

Table 1. Assimilative capacity of the atmosphere in terms of pollution potential for RSPM from 2013 – 2017

Month	NAAQS (µg/m³)	90% of guideline (µg/m³)	IVRI institute (µg m^{-3})					Petrol Pump (µg m^{-3})				
			2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
January	100	90	-158	-120	-185	-230	-170	-230	-235	-230	-230	-260
February	100	90	-190	-130	-135	-150	-160	-210	-185	-210	-210	-210
March	100	90	-140	-110	-135	68	-170	-210	-185	-160	-260	-260
April	100	90	-140	-100	-110	-110	-160	-210	-185	-160	-160	-210
May	100	90	-110	-100	-135	-130	-120	-190	-160	-210	-160	-210
June	100	90	-110	-135	-135	-130	-140	-210	-160	-185	-170	-140
July	100	90	-110	-120	-110	-110	-90	-160	-160	-170	-210	-110
August	100	90	-110	-120	-110	-110	-100	-185	-210	-170	-190	-130
September	100	90	-110	-110	-130	-110	-100	-190	-190	-190	-185	-160
October	100	90	-90	-110	-130	-90	-110	-170	-185	-170	-210	-210
November	100	90	-140	-160	-140	-100	-120	-210	-230	-210	-220	-410
December	100	90	-160	-160	-175	-130	-130	-210	-210	-220	-230	-260

Table 2. Assimilative capacity of the atmosphere in terms of pollution potential for SPM from 2013 – 2017

Month	NAAQS (µg/m³)	90% of guideline (µg/m³)	IVRI institute (µg m^{-3})					Petrol Pump (µg m^{-3})				
			2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
January	300	270	-100	-30	-55	-105	-70	-130	-130	-130	-130	-180
February	300	270	-150	-50	-50	-80	-40	-80	-80	-80	-80	-180
March	300	270	-100	-30	-30	-30	-50	-80	-55	-30	-60	-280
April	300	270	-80	-30	-30	-10	-50	-105	-50	-40	-105	-180
May	300	270	-80	-10	-30	-30	-55	-55	-30	20	-105	-130
June	300	270	-30	-50	-30	-30	-70	-130	-55	-55	-130	-80
July	300	270	-30	-50	-30	-30	-5	-55	-50	-50	-55	-80
August	300	270	-30	-30	-30	-30	-5	-80	-80	-60	-80	-80
September	300	270	-30	-30	-50	-30	0	-55	-70	-40	-105	-80
October	300	270	-30	-30	-30	-30	-10	-55	-80	-80	-110	-130
November	300	270	-130	-80	-40	0	-30	-80	-130	-105	-100	-480
December	300	270	-110	-80	-55	-80	-40	-80	-105	-130	-130	-180

Table 3. Assimilative capacity of the atmosphere in terms of pollution potential for SO_2 from 2013 – 2017

Month	NAAQS (µg/m³)	90% of guideline (µg/m³)	IVRI institute (µg m^{-3})					Petrol Pump (µg m^{-3})				
			2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
January	80	72	61	62	61	62	61	60	59	60	58	57
February	80	72	62	60	59	60	60	58	57	60	58	58
March	80	72	60	60	60	61	61	54	58	59	59	60
April	80	72	62	59	61	60	60	58	60	57	58	56
May	80	72	59	60	61	60	61	57	59	57	57	56
June	80	72	62	59	59	58	60	55	57	56	58	57
July	80	72	59	62	61	61	62	59	60	60	61	54
August	80	72	65	60	61	59	61	58	59	59	60	58
September	80	72	60	60	61	61	61	58	60	58	57	52
October	80	72	62	61	60	60	60	58	58	59	59	57
November	80	72	60	58	59	60	60	55	57	60	56	56
December	80	72	60	63	60	60	59	59	58	59	59	57

Table 4. Assimilative capacity of the atmosphere in terms of pollution potential for NOx from 2013 – 2017

Month	NAAQS (µg/m³)	90% of guideline (µg/m³)	IVRI institute (µg m^{-3})					Petrol Pump (µg m^{-3})				
			2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
January	80	72	51	51	50	51	51	45	46	43	46	40
February	80	72	52	52	49	48	51	46	46	44	45	37
March	80	72	52	50	50	47	50	44	47	45	45	44
April	80	72	42	50	46	48	48	44	46	44	42	35
May	80	72	40	48	47	52	48	45	42	47	40	35
June	80	72	47	47	42	50	51	46	41	46	46	42
July	80	72	50	52	48	49	52	47	42	47	40	43
August	80	72	47	53	50	47	52	40	36	45	44	47
September	80	72	52	51	49	48	53	44	42	42	46	47
October	80	72	43	48	45	46	52	43	39	43	42	37
November	80	72	52	47	40	48	48	46	41	44	45	40
December	80	72	49	47	42	47	48	46	34	41	47	37

Table 5. Air Quality Index at IVRI institute and Petrol pump, Izatnagar during 2013

Month	IVRI institute (Conc. in µg m^{-3})					Petrol Pump (Conc. in µg m^{-3})				
	RSPM	SPM	SO_2	NOx	AQI	RSPM	SPM	SO_2	NOx	AQI
January	248	370	11	21	398	320	400	12	27	454
February	280	420	10	20	423	300	350	14	26	438
March	230	370	12	20	385	300	350	18	28	438
April	230	350	10	30	385	300	375	14	28	438
May	200	350	13	32	362	280	325	15	27	423
June	200	300	10	25	362	300	400	17	26	438
July	200	300	13	22	362	250	325	13	25	400
August	200	300	7	25	362	275	350	14	32	419
September	200	300	12	20	362	280	325	14	28	423
October	180	300	10	29	346	260	325	14	29	408
November	230	400	12	20	385	300	350	17	26	438
December	250	380	12	23	400	300	350	13	26	438

Hence, SO_2 and NOx concentrations were found to be within 90 % of guideline values from January to December during 2013, indicated a positive assimilative potential at both the locations. However, SO_2 concentration was found to be minimum when compared to NOx, thus a maximum assimilative potential was found for SO_2. Assimilative potentials were ranging from 40 – 60 µg m^{-3}at location 1 and 2, shows a significantly good carrying capacity of the atmosphere in terms of SO_2 and NOx (Tables3 and 4). Further, a negative assimilative potential was found during 2014 – 2017 for the pollutants RSPM and SPM (Tables 1 and 2), which may be due to vehicular exhaust and fugitive emissions and increased number of vehicles during the study period. However, pollution potential was found to be maximum during winter season (December to February) when compared to summer and monsoon seasons (March to September).

Table 6. Air Quality Index at IVRI institute and Petrol pump, Izatnagar during 2014

Month	IVRI institute (Conc. in µg m^{-3})					Petrol Pump (Conc. in µg m^{-3})				
	RSPM	SPM	SO_2	NOx	AQI	RSPM	SPM	SO_2	NOx	AQI
January	210	300	10	21	369	325	400	13	26	458
February	220	320	12	20	377	275	350	15	26	419
March	200	300	12	22	362	275	325	14	25	419
April	190	300	13	22	354	275	320	12	26	419
May	190	280	12	24	354	250	300	13	30	400
June	225	320	13	25	381	250	325	15	31	400
July	210	320	10	20	369	250	320	12	30	400
August	210	300	12	19	369	300	350	13	36	438
September	200	300	12	21	362	280	340	12	30	423
October	200	300	11	24	362	275	350	14	33	419
November	250	350	14	25	400	320	400	15	31	454
December	250	350	9	25	400	300	375	14	38	438

Table 7. Air Quality Index at IVRI institute and Petrol pump, Izatnagar during 2015

Month	IVRI institute (Conc. in µg m^{-3})					Petrol Pump (Conc. in µg m^{-3})				
	RSPM	SPM	SO_2	NOx	AQI	RSPM	SPM	SO_2	NOx	AQI
January	275	325	11	22	419	320	400	12	29	454
February	225	320	13	23	381	300	350	12	28	438
March	225	300	12	22	381	250	300	13	27	400
April	200	300	11	26	362	250	310	15	28	400
May	225	300	11	25	381	300	250	15	25	438
June	225	300	13	30	381	275	325	16	26	419
July	200	300	11	24	362	260	320	12	25	408
August	200	300	11	22	362	260	330	13	27	408
September	220	320	11	23	377	280	310	14	30	423
October	220	300	12	27	377	260	350	13	29	408
November	230	310	13	32	385	300	375	12	28	438
December	265	325	12	30	412	310	400	13	31	446

Table 8. Air Quality Index at IVRI institute and Petrol pump, Izatnagar during 2016

Month	IVRI institute (Conc. in µg m^{-3})					Petrol Pump (Conc. in µg m^{-3})				
	RSPM	SPM	SO_2	NOx	AQI	RSPM	SPM	SO_2	NOx	AQI
January	320	375	10	21	454	320	400	14	26	454
February	240	350	12	24	392	300	350	14	27	438
March	22	300	11	25	250	350	330	13	27	477
April	200	280	12	24	362	250	375	14	30	400
May	220	300	12	20	377	250	375	15	32	400
June	220	300	14	22	377	260	400	14	26	408
July	200	300	11	23	362	300	325	11	32	438
August	200	300	13	25	362	280	350	12	28	423
September	200	300	11	24	362	275	375	15	26	419
October	180	300	12	26	346	300	380	13	30	438
November	190	270	12	24	354	310	370	16	27	446
December	220	350	12	25	377	320	400	13	25	454

Table 9. Air Quality Index at IVRI institute and Petrol pump, Izatnagar during 2017

Month	IVRI institute (Conc. in µg m^{-3})					Petrol Pump (Conc. in µg m^{-3})				
	RSPM	SPM	SO_2	NOx	AQI	RSPM	SPM	SO_2	NOx	AQI
January	260	340	11	21	408	350	450	15	32	477
February	250	310	12	21	400	300	450	14	35	438
March	260	320	11	22	408	350	550	12	28	550
April	250	320	12	24	400	300	450	16	37	438
May	210	325	11	24	369	300	400	16	37	438
June	230	340	12	21	385	230	350	15	30	385
July	180	275	10	20	346	200	350	18	29	362
August	190	275	11	20	354	220	350	14	25	377
September	190	270	11	19	354	250	350	20	25	400
October	200	280	12	20	362	300	400	15	35	438
November	210	300	12	24	369	500	750	16	32	800
December	220	310	13	24	377	350	450	15	35	477

This may be due to low wind speeds and calm atmospheric conditions during winter seasons, which reduces the dispersion of air pollutants into the atmosphere. Thawonkaew *et al.* (2016) have also reported NOx and SO_2 concentration predicted by AERMOD dispersion model in Thailand were not exceeding the annual AAQS. Thepanondh and Jitbantoung (2014) reported assimilative capacity of PM_{10}, SO_2 and NO_2 in Dawai area, Thailand were found to be 0.0025, 0.0031 and 0.0075 kg $ha^{-1}day^{-1}$, respectively. Low carrying capacity of air pollutants was resulted from the effect of complex topographical characteristic of the area. Further, Prakash *et al.* (2017) have reported pollutant such as, PM_{10} and $PM_{2.5}$ concentrations were found to be more than the NAAQS of 100 and 60 μg m^{-3}, respectively, during winter season due to calm atmospheric conditions.It was also observed that, RSPM and SPM concentrations were found to be more than the NAAQS during 2014 – 2017, which may be due to the high emissions from the vehicles in the study area. A total number of 35,000 vehicles were counted per day at location 2.

Pollutant concentrations were found to be more at location 2 when compared to location 1, this may be due to the topography and increasing number of commercial activities in the study area. It was also observed that, pollutant concentrations were found to be less during 2013 when compared to 2017, which implies an increasing trend of pollutant concentration with time. This may be due to the urbanization and modernized way of living, which increases the number of vehicles rapidly with time. Sarella and Khambete (2015) have quoted NOx and SO_2 concentration was within the NAAQS of 80 μg m^{-3}during 2013 – 2014 at Vapi city, Gujarat, India. However, PM_{10} concentration was found to be exceeded the standard of 100 μg m^{-3} during August to September. Chaurasia *et al.* (2013) have reported air pollution and air quality at Bhopal city indicated PM_{10} and $PM_{2.5}$ always found beyond the permissible limit, however, SO_2 and NOx were observed below the permissible limit at sampling site located in Madhya Pradesh, India during winter and summer season.

Air Quality Index (AQI) of Mysuru Industrial Area

Air quality index (AQI) is a numerical scale used for reporting day to day air quality with regard to human health and the environment. Daily results of the index are being used to convey to the public an estimate of air pollution level. An increase in air quality index signifies increased air pollution and severe threats to human health. In most cases, AQI indicates how clear or polluted the air in our surrounding is, and the associated health risks it might present. AQI describes air quality in terms of very unhealthy, very poor, poor (unhealthy for sensitive groups), moderate and good. Many researchers have used AQI to express the ambient air quality (Trozzi *et al.* (1999), Sharma *et al.* (2003 & 2003), Murena (2004), Nagendra *et al.* (2007), Wen *et al.* (2009), and Eder *et al.* (2010)). In the present study, air quality index at IVRI institute Izatnagar and Petrol pump station at intersection of commercial highway intersections were estimated between 2013 and 2017 are presented in Tables 5 to 9. AQI was found to be ranging from 300 – 400, which comes under 'very poor' to 'sever' AQI. It was noticed that, with 'very poor' AQI condition people with breathing or heart problems will experience reduced endurance in activities. Under such conditions individuals and elders should remain indoors and restrict activities. Further, with 'severe' AQI condition, there may be strong irritations and symptoms and may trigger other illnesses. Elders and the sick should remain indoors and avoid exercise. It signifies how clean or unhealthy atmospheric air is, and what associated health effects might be a concern. The AQI focuses on health effects that may experience within a few hours or days after breathing unhealthy air. In the present study, the concentration of RSPM and SPM were varying from 150 to 250 μg m^{-3} and 250 to 400 μg m^{-3}(Table 5 to 9). RSPM and SPM concentrations were found to be more than the NAAQ standard of 100 μg $m^{-3}$and 300 μg m^{-3}, respectively, throughout the year at location 1 and 2.

Pollutant concentrations were found to be more at location 2 when compared to location 1, this may be due to the topography and increasing number of commercial activities in the study area. Hence, the AQI value of location 2 was also higher than that was found at location 1. AQI was found to be ranging from 350 – 400 during winter i.e., December to February at Indian Veterinary Research Institute (I.V.R.I), Izatnagar (Location 1) and Petrol Pump, Civil lines, (Location 2) Bareilly, which comes under 'severe' AQI (Table 5 to 9). This may be due to the calm atmospheric conditions and minimum wind speeds which caused less atmospheric pollutant dispersions. 'Severe' AQI may cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity. However, AQI was found to be ranging from 300 – 360 during summer and monsoon season which was less than that found during the winterperiod. Due to high wind speeds during summer and precipitation occurred in monsoon, AQI was found comparatively low.

'Very poor' AQI may cause respiratory illness in humans on prolonged exposure. The effect may be more pronounced with people having lung and heart diseases. However, it can be concluded that, the air quality near to the road canyon is found to be highly polluted in terms of RSPM and SPM, which may significantly cause respiratory problems to the pedestrians and nearby localities. Lanzafame *et al.* (2015) have reported annual frequencies of AQI category 'Good' was 'dominant' by reaching an annual rate between 77 % and 95 %. However, the 'Moderate' category was ranging from of 2 % and 7 % in an annual distribution during 2010 to 2014 in metropolitan city of Catania. However, Mamta and Bassin (2010) have calculated AQI values of SO_2 and NO_2 fall under 'good' and 'good-to-moderate' categories in Delhi city and overall AQI was found to be 'poor' and 'very poor' category due to high RSPM and SPM concentration, respectively. Dohare and Panday (2014) have reviewed SO_2, NOx, PM, O_3, Lead, CO, Benzene and Nickel concentration in Puducherry, Rohtak City, Nashik City, Uttarakhand, Jaipur City, Udaipur (Rajasthan), Pune, Hosur Town (Tamilnadu), Cuttack District, Odisha. The result of which showed, pollutant concentrations were found to be highest near to the industrial site, followed by commercial sites and lowest at residential and rural sites.

Conclusion

Ambient air quality monitoring (AAQM) studies were conducted for pollutantssuch as, PM_{10}, $PM_{2.5}$, SO_2 and NOx at I.V.R.I, Izatnagar and Petrol Pump, Civil lines, Bareilly, India over a period of 5 years from 2013 to 2017. Maximum temperatures were varied from 35°C to 45°C, in the month of March to May, during 2013 to 2017 and minimum temperatures were varied from 8°C to 10°C, in the month of December to February from 2013 to 2017. Maximum relative humidity (RH) was varying from 80 – 97 % throughout the year, depending upon the atmospheric conditions such as, temperature, wind speed and precipitation. However, MMD was found to be maximum during summer, which may be due to the high ambient temperature and wind velocities (March to May) when compared to during winter. Maximum wind speeds were varying from 4 to 8 ms^{-1} during June to September, 2013 to 2017 and a minimum wind speed of ~ 0 m s^{-1} was observed during 2015. The annual wind rose plot during 2013 and 2017 showed similar wind directions with predominant wind directions from W and E followed by NW and WNW directions, which were blowing towards E, W, SE and ESE directions over the study area. During January, maximum VC of 4500 m^2 s^{-1}(at 15:00 h) was observed with maximum wind speeds and during March, April and May a maximum VC was found to be 10000 m^2 $s^{-1}$to 12000 m^2 s^{-1}(at 17:00 h to 18:00 h) with maximum wind speeds and a minimum VC of 3000 m^2 $s^{-1}$to 4500 m^2 s^{-1}(at 15:00 h to 16:00 h) was noticed to be minimum wind speeds and MMD. During winter, maximum VC was found to be ~ 6000 m^2 s^{-1}(at 16:00 h) during 2016 and 2017, followed by 4500 m^2 s^{-1}(at 15:00 h during 2013 and 2014). However, during summer season, maximum VC was found to be ~ 15000 m^2 s^{-1}(at 16:00 h) during 2017, followed by 13000 m^2 s^{-1}(at 16:00 h during 2016), 11000 m^2 s^{-1}(at 16:00 h during 2015). RSPM and SPM concentrations were found to be exceeding 90% of guideline values throughout the year, which implies a negative assimilative potential at both the locations. A maximum assimilative potential of - 190 to - 230 µg $m^{-3}$and - 150 to - 130 µg $m^{-3}$was found for RSPM and SPM, respectively. A negative assimilative capacity in terms of RSPM indicates a poor environmental condition which can affect human beings as well as animals and plants. However, observed SO_2 and NOx concentrations were found to be within the National Ambient Air Quality Standards (NAAQS) of 80 µg $m^{-3}$and assimilative potentials were ranging from 40 – 60 µg m^{-3}at locations 1 and 2. The concentration of RSPM and SPM were varying from 150 to 250 µg $m^{-3}$and 250 - 400 µg m^{-3}, which found to be more than the NAAQS of 100 and 300 µg m^{-3}. AQI was found to be ranging from 350 – 400 during winter season and 300 – 360 during summer and monsoon seasons. The annual average AQI was found to be ranging from 300 – 400, which comes under 'very poor' to 'sever' AQI. It was noticed that, with 'very poor' AQI condition people with breathing or heart problems will experience reduced endurance in activities.

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