

# Air quality assessment of Mandi Gobindgarh city of Punjab, India

Abhishek Gupta<sup>1</sup> · Amit Dhir<sup>2</sup>

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**Abstract** The present study assessed the air quality of an industrial town Mandi Gobindgarh, one of the critically polluted areas specified by Central pollution control board, India. Air quality was assessed in terms of Indian Air Quality Index (IND-AQI) by analyzing concentration of the air pollutants like particulate matter (PM<sub>10</sub>, PM<sub>2.5</sub>), sulfur dioxide (SO<sub>2</sub>), and nitrogen dioxide (NO<sub>2</sub>). Half-yearly wind roses were prepared from wind data from October, 2013 to March, 2015 for selecting sites on the basis of prevailing wind direction and speed. On the basis of wind roses, land use pattern and industrial clusters, 11 sampling sites were selected, i.e., 7 were industrial, 2 were residential, and 1 was agricultural. AQI was calculated for different seasons from March, 2015 to February, 2016; on the basis of IND-AQI. Results indicate that pollutant responsible for maximum sites for higher AQI was PM<sub>10</sub> and industrial sites were having “Poor” air quality, making area more susceptible to a large number of airborne disease. Annual cycle shows highest concentration of pollutants and water soluble ions to be higher in winter season and the lower during monsoon season. The concentration of water soluble ions for samples collected during winter season at commercial site was found to vary in the order of NH<sub>4</sub><sup>+</sup> > Cl<sup>-</sup> > SO<sub>4</sub><sup>2-</sup> > Na<sup>+</sup> > Ca<sup>2+</sup> > K<sup>+</sup> > NO<sub>3</sub><sup>-</sup> > Mg<sup>2+</sup>. Values of SO<sub>2</sub>/NO<sub>2</sub> obtained vary from 1.23 to 1.99 at various selected sites which depict that the impacts of vehicular sources were marginally less, when compared to industrial sources.

**Keywords** Particulate matter · Air quality index · Urban pollution · Ion chromatography · Seasonal and spatial variations

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✉ Abhishek Gupta  
abhishek.gupta@marwadieducation.edu.in

<sup>1</sup> Department of Environmental Science and Engineering, Marwadi University, Rajkot 360001, India

<sup>2</sup> School of Energy and Environment, Thapar University, Patiala, Punjab 147004, India

## 1 Introduction

Modernization and industrialization in developing countries has led to the increase in use of fossil fuels and their derivatives (Gautam et al. 2016). The anthropogenic emissions of pollutants in urban area can alter the atmospheric composition, chemistry and life cycles in downwind regimes (Gupta et al. 2008). Thus, developing countries are confronted with huge challenge of controlling the atmospheric pollution especially in the rapidly growing mega cities. Recent report indicated that about two million people die prematurely every year as a result of air pollution, while many more suffer from breathing ailments, heart disease, lung infections and even cancer in developing countries (WHO 2012).

India, a developing country, is one of the first ten industrial countries of the world, and literature revealed that air pollution problems in metropolitan cities of India are alarming (Chauhan et al. 2010). India has 23 major cities with more than 1 million population, and ambient air quality in many of these cities has been deteriorated (Gupta et al. 2002).

To represent local, regional and global air quality data, Air Quality Index (AQI), which is also known as Pollutant Standards Index (PSI) or Air Pollution Index (API) has been developed (Cheng et al. 2007). An “Air Quality Index” may be defined as a number used by government agencies to characterize air quality & associated health effects at a given location. AQI can be calculated using different methodology IND-AQI, USEPA-AQI, Oak Ridge AQI (Kumar et al. 2011; Chauhan et al. 2010). For India, Central Pollution Control Board (CPCB) had developed IND-AQI, to be used in representing air quality at a site. Singh (2010) proposed an index that measures depreciation in air quality which was more precised as compared to National ambient air quality standards.

AQI studies have been carried out for various Indian cities such as Kanpur (Sharma et al. 2003) and Jharia Coal Fields (Jha et al. 2010) with high or moderate Air Quality Index. Suspended particulate matter (SPM) levels were found to be responsible for overall AQI during the most period of monitoring. Chauhan et al. (2010) studied the effects of industrialization, urbanization and automobile emission on ambient air quality in Haridwar and Dehradun City on seasonal basis. Kumar et al. (2011) interpret AQI for Jaipur where results showed “Very poor” air quality in industrial areas and “Poor” in other residential sites. Mittal et al. (2009) studied status of ambient air quality in Patiala during wheat and rice crop stubble burning episodes pointing out a distinct increase in aerosol, SO<sub>2</sub> and NO<sub>2</sub> levels during the crop stubble burning periods. Agarwal et al. (2012) studied the air quality and pulmonary function tests for the period (2007–2009) at Patiala city, and results indicated decrease in air quality due to open rice crop residue burning, which have sub-acute effect on pulmonary functions of healthy subjects. Health studies were conducted to compare air quality at Mandi Gobindgarh and a non-industrial town “Morinda” which showed higher prevalence of symptoms of angina and cardiovascular disease because of the high PM pollution in Mandi Gobindgarh (Nautiyal et al. 2007). Basha et al. (2014) studied seasonal variations using Z score and Cumulative Air Quality Index at Tumulapalle Uranium Mining Site and Surrounding Villages.

Water soluble ion analysis can suggest variability in concentration of different cations and anions presents in ambient air which gets easily soluble in water vapors in the lower troposphere under certain conditions and are usually significant components by mass of atmospheric particulate matter (Kumar et al. 2007). Mass size distribution of particulate showed bimodal distribution with peaks in coarse and fine mode. Zhang et al. (2006) investigated the seasonal characteristics of particulate matters (PM<sub>2.5</sub>, PM<sub>10</sub>, total suspended particle) and their sources elements and ions with different sizes in the aerosols in Beijing from July, 2001 to April, 2003. Study has reported highest levels of crustal

elements in the dust season; pollutant elements and ions in winter and of secondary ions in both summer and in winter. Vega et al. (2011) studied chemical composition for water soluble ionic species, carbonaceous aerosols and trace elements within Mexico City. The water soluble inorganic components and their seasonal variations between the period of July, 2009 to June, 2010 were studied in Durg city, India, and concentrations of  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  were highest in all size fractions and accounted for 32.76 and 13.38% of the total mass of the water soluble ions in  $\text{PM}_{2.5}$  and 32.78 and 12.21% in  $\text{PM}_{1.0}$  size fractions (Deshmukh et al. 2011).

The rapid increase in urbanization, industrialization and automobile emissions has deteriorated air quality of Mandi Gobindgarh City in Indian state of Punjab which is secondary steel industrial area, and it was identified as one of the critically polluted areas in India (CPCB 2012). This paper presents the assessment of air quality in terms of Air Quality Index (IND-AQI) and Z score after monitoring air pollutants which include  $\text{SO}_2$ ,  $\text{NO}_2$ ,  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  at different sampling sites. The water soluble ions concentration was also assessed in winter season at commercial site.

## 2 Data and methodology

### 2.1 Study area

The area selected for the study was Mandi Gobindgarh town, District Fatehgarh Sahib, one of critically polluted industrial clusters (CPCB 2012). It lies between north latitude  $30^\circ\text{-}37'\text{-}30''$  and  $30^\circ\text{-}42'\text{-}30''$  and east longitude  $76^\circ\text{-}15'$  and  $76^\circ\text{-}20'$  (PPCB 2010). The town is spread over an area of  $10.64 \text{ km}^2$  and accommodates a population of 73,130 as per 2011 census. The topography of the area is typical representative of an Alluvial plain with dry climate except a brief spell of monsoon season in a very hot summer and a bracing winter. As per the published inventory prepared by the CPCB in 2015, there are 496 (i.e., 390 in Mandi Gobindgarh and 106 Khanna area) air polluting industries in Mandi Gobindgarh which are using coal/furnace oil as fuel.

### 2.2 Instruments

Fine Dust Sampler, IPM-FDS-2.5  $\mu/10 \mu$  of INSTRUMEX (based on USEPA and CPCB norms), was used in air sampling for  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  which was operated at a flow of 16.67 LPM (accuracy  $\pm 2\%$ ) having programmable real-time control system with accuracy of  $\pm 2 \text{ min/month}$ . Glass fiber (GF) filter papers of 46.2 mm diameter were used for  $\text{PM}_{10}$ , whereas, 46.2 mm PTFE filters along with silicon oil dipped 37 mm GF filters were used for  $\text{PM}_{2.5}$  sampling. Envirotech APM 415 high-volume samplers with its attachment for gaseous pollutant monitoring APM 411 were used for monitoring of  $\text{SO}_2$  and  $\text{NO}_2$  ( $\pm 2\%$  accuracy). The weather monitoring station used in this study was of Watch Dog 2000 series to monitor parameters such as wind speed, wind direction using 3 cup digital anemometer (Model No. 3305ADD) installed with wind vane having accuracy of  $\pm 2 \text{ mph}$  and  $\pm 3^\circ$ , respectively, while for rainfall tipping bucket rain gauge was used. UV-VIS Spectrophotometer (Hitachi V-500 UV/VIS (Japan) double-beam spectrophotometer) was used for measuring the absorbance. Analysis of ions was done using Ion Chromatography from Metrohm and Dionex. Metrohm-761 IC has been equipped with a Shodex YK-421 column with an eluent of 4 mM  $\text{H}_3\text{PO}_4$  for cations determination and Shodex SI-90 4E

column, and an eluent of 1.8 mM  $\text{Na}_2\text{CO}_3$  + 1.7 mM  $\text{NaHCO}_3$  was used for anionic determination. The anionic-IC is equipped with a suppressor, and 4 mM  $\text{H}_2\text{SO}_4$  solution was used to regenerate suppressor.

## 2.3 Wind roses and impact area diagrams

Hourly averaged wind data were collected for the period of one and a half year using weather monitoring station (Watch Dog of Spectrum Series 2000), starting from October, 2013 to March, 2015 at Thapar University, Patiala ( $30^\circ 21' 18''\text{N}$ ,  $76^\circ 22' 14''\text{E}$ ), and wind speed less than 1 km/h was considered as calm period. Collected wind data were then used to plot non-conventional wind roses and impact area diagrams (George et al. 2008; Gupta and Dhir 2013). Wind Rose PRO was used to create wind roses by analyzing and plotting wind speed and direction as variables.

## 2.4 Selection of sampling site

Sampling sites within study area were selected on the basis of industrial clusters, wind roses and impact area. Different residential areas and industrial clusters were identified using Google Map and visiting study area. The total industrial hub of Mandi Gobindgarh was subdivided into six industrial clusters (PPCB 2010). Moreover, residential areas near to these industrial zones were chosen as they get mostly affected from industrial pollution. All the sampling sites were selected near Mandi Gobindgarh which lies on National Highway 1 (NH-1) that links the national capital New Delhi to Amritsar in Punjab near the India–Pakistan border and is 456 km long.

## 2.5 Sampling and analysis

In order to assess the air quality, ambient air sampling was conducted for four pollutants, namely  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{SO}_2$  and  $\text{NO}_2$  at all the selected sites twice a month for 24-h averaged value, for a period starting from March, 2015 to February, 2016. For  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ , pre-weighed and preconditioned PTFE filter papers were used. Air flow rate was kept fixed at 16.67 L/min for all sampling site with duration of 24 h.  $\text{SO}_2$  and  $\text{NO}_2$  were estimated using Indian standard method, i.e., Improved West and Gaeke; Modified Jacob and Hochheiser (Na-Arsenite) method, respectively (IS 2001, 2006). The gaseous sampling flow rate was maintained to be 2 L/min. The characteristic wavelength for analysis of  $\text{NO}_2$  and  $\text{SO}_2$  was 540 and 560 nm, respectively. Ion chromatography of the filter samples for the commercial site was done to know the variation the concentration of water soluble ions present in the particulate matter during different seasons. Concentrations of  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{SO}_2$  and  $\text{NO}_2$  were standardized by means of Z scores of the pollutants and to find out pollutant on which basis, sites can be characterized. Z score for all pollutants was calculated using (Basha et al. 2014; Majumder et al. 2012):

$$Z = (X - u) / \sigma$$

where Z—Standardized Z score value of pollutant  
X—Average concentration of pollutant in specific zone  
u—Average concentration of pollutant for all the zones  
 $\sigma$ —Standard deviation of pollutant

If Z score comes to be greater than 0 then the pollution level is considered to be higher than the average value of all zones, whereas if Z score is less than 0, pollution level infers

comparatively low level and if  $Z = 0$ , it means the pollution is at average level. Ratio of  $\text{SO}_2/\text{NO}_2$  was also calculated to observe the impact of mobile source (vehicular sources) on to the air quality when compared to industrial sources as reported in Robert and Howard (2012).

## 2.6 AQI calculation

AQI was calculated for all sampling sites by calculating sub-index values (sub-AQI) for the sampled gas in terms of  $\text{SO}_2$ ,  $\text{NO}_2$ ,  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  (Kumar et al. 2011). Sub-indices were calculated using following equation:

$$q = 100 \left( \frac{V}{V_s} \right)$$

$q$  = Quality Rating  $V$  = Observed values of the parameter, and  $V_s$  = Standard value recommended for the parameter

Out of all sub-AQIs, the highest value becomes the overall index and reported as IND-AQI. The pollutant with highest value of sub-AQI becomes the responsible pollutant and is indicated alongside the IND-AQI value. Based on the value of AQI, air quality can be categorized a good (0–100), moderate (101–200), poor (201–300), very poor (301–400) or severe (401–500).

## 3 Results and discussion

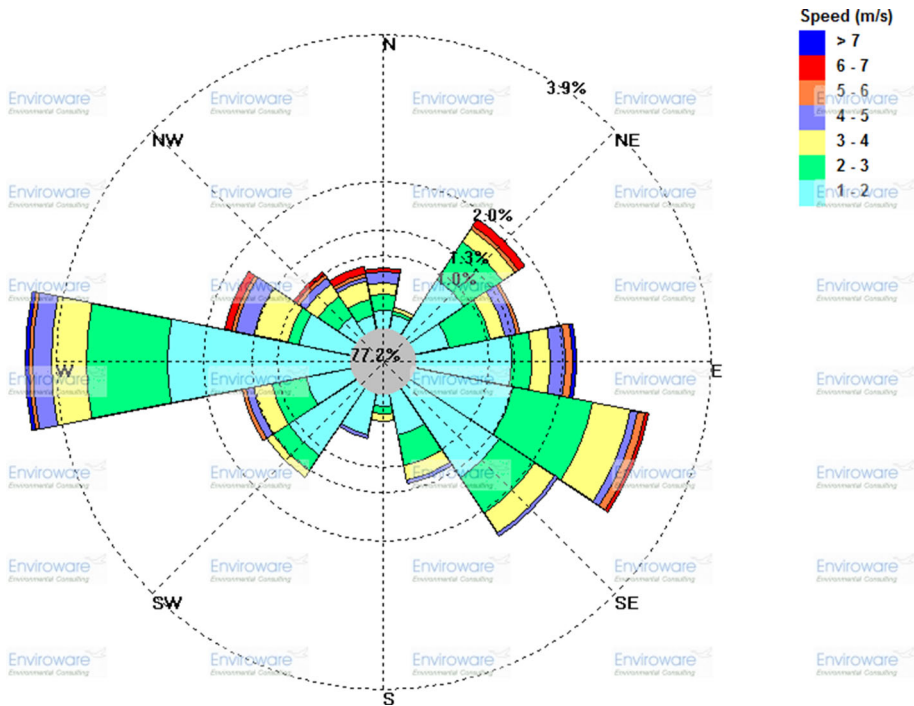
### 3.1 Site selection

All the sampling sites were selected near Mandi Gobindgarh which lies on National Highway 1 (NH-1) that links the national capital New Delhi to Amritsar in Punjab near the India–Pakistan border and is 456 km long. The total industrial hub of Mandi Gobindgarh was subdivided into six industrial clusters (PPCB 2010). Data pertaining to wind speed and direction were collected for the period of one and a half year (October, 2013–March, 2015) in order to plot wind roses (Fig. 1). Results shows that the predominant wind direction was west and south for the period ranging from October, 2013 to September, 2014 and October, 2014 to March, 2015, respectively. Overall predominant wind direction was found to be west. Impact area diagram and impact area reported in our previous findings (Gupta and Dhir 2013) showed the maximum affected direction was northwest and east of study area and impact area was found to be less which represents pollutant concentration within small area.

Land use pattern of study area (Table 1) shows that maximum land use is for industrial sectors followed by residential sector and only 10.66% for agricultural and water bodies. On the basis of industrial clusters, wind roses, impact area diagrams and land use pattern of study area, eleven sampling sites were selected, including seven industrial areas, two residential areas, one each in commercial and agricultural area (Fig. 2). Details of sampling sites along with its type of sources and land use are expressed in Table 2.

### 3.2 Spatial distribution of pollutants

Monitoring of air pollutants was conducted at different sampling sites, and their results of statistical analysis are presented in Table 3. The results indicate that highest  $\text{PM}_{10}$



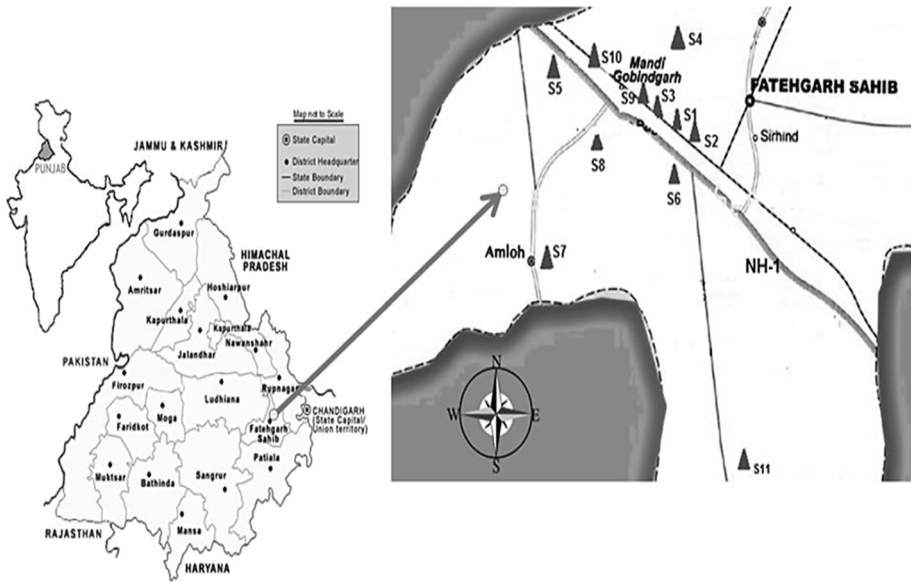
**Fig. 1** Wind rose diagram for the wind data in the area of Mandi Gobindgarh during the period of October, 2013–March, 2015

**Table 1** Details of area within Municipal Corporation Gobindgarh in year 2009

Sr. no.	Land use	Area (acres)	In percentage
1	Residential	700	31.49
2	Commercial	97	4.36
3	Industrial	750	33.74
4	Traffic and transportation	304	13.68
5	Agriculture and water bodies	237	10.66
6	Others	135	6.07
	Total	2223	100%

concentration among industrial sites was found at site  $S_7$  ( $347 \mu\text{g}/\text{m}^3$ ). This site is away from the residential area as well as National Highway (NH 1) which depict that industries were mainly responsible for poor air quality of the region. Annual average concentration at all industrial sites except  $S_2$  was observed to be more than  $250 \mu\text{g}/\text{m}^3$  which are well above the permissible standard (CPCB 2009). Nautiyal et al. (2007) also reported higher level of  $\text{PM}_{10}$  within Mandi Gobindgarh and also higher prevalence of symptoms of angina and cardiovascular disease caused by inhaling of particulate matter. The minimum concentration was found at  $S_{11}$ .

Among industrial sites, maximum concentration of  $\text{PM}_{2.5}$  was observed at site  $S_5$  on National Highway toward Khanna side which may be due the generation of pollutants by both industrial and heavy vehicular sources (Table 3). Least concentration was observed at



**Fig. 2** Sampling sites for the study

**Table 2** Selected sampling sites in the study area

Site code	Land use	Sampling site	Type of sources
S1	Industrial sampling sites	Talwara road	Rolling mills, refractories
S2		Near RIMT*	Rolling mills
S3		Prem Nagar	Induction furnaces, rolling mills, refractories
S4		Guru ki Nagri	Induction furnaces, rolling mills
S5		GT road, Khanna side	Induction furnaces, rolling mills, heavy vehicles
S6		Focal Point	Induction furnaces, rolling mills, heavy vehicles
S7		Near village Kumbh, Amloh road	Induction furnaces, rolling mills, refractories
S8	Residential sampling sites	Motia Khan	Light vehicles
S9		Shastri Nagar	Light vehicles, small-scale industries
S10	Commercial site	Near bus stand	Rolling mills, heavy vehicles
S11	Agricultural site	Kharorha	Light vehicle, agricultural burning

\*RIMT The Regional Institute of Management and Technology, Mandi Gobindgarh

**Table 3** A statistical summaries of pollutant concentrations measured at selected sites during the study period

Sampling sites	PM <sub>10</sub>		PM <sub>2.5</sub>		SO <sub>2</sub>		NO <sub>2</sub>	
	Mean ± SD	Max-min	Mean ± SD	max-min	Mean ± SD	Max-min	Mean ± SD	Max-min
S1	258.97 ± 27.10	292-211	90.18 ± 7.21	101-79	45.87 ± 2.24	48-41	23.08 ± 2.94	29-19
S2	174.41 ± 8.43	188-159	82.25 ± 6.89	91-70	38.01 ± 3.54	44-32	19.75 ± 1.81	23-17
S3	273.83 ± 17.27	297-237	95.46 ± 4.02	102-89	45.41 ± 2.78	50-41	25.31 ± 2.06	29-22
S4	248.92 ± 23.30	288-217	83.41 ± 4.10	89-77	35.08 ± 2.61	38-29	22.58 ± 3.47	29-17
S5	289.74 ± 13.81	312-269	97.23 ± 8.08	110-85	44.77 ± 2.81	49-39	25.72 ± 2.30	31-23
S6	292.91 ± 14.41	324-275	99.87 ± 6.61	110-91	47.30 ± 3.15	52-43	28.70 ± 1.59	31-26
S7	304.29 ± 28.03	347-268	89.03 ± 4.69	97-83	42.88 ± 2.89	48-39	26.01 ± 2.63	30-21
S8	177.63 ± 11.32	196-158	71.41 ± 5.59	77-61	26.15 ± 3.95	31-18	16.93 ± 2.81	23-13
S9	169.86 ± 11.84	189-154	77.17 ± 6.93	89-65	31.15 ± 3.85	36-25	16.76 ± 1.82	19-13
S10	184.60 ± 7.57	199-175	105.70 ± 7.68	121-96	30.63 ± 4.29	37-24	16.96 ± 2.34	21-14
S11	88.11 ± 6.09	95-77	42.69 ± 3.51	47-36	12.86 ± 1.17	15-11	9.25 ± 2.01	14-7

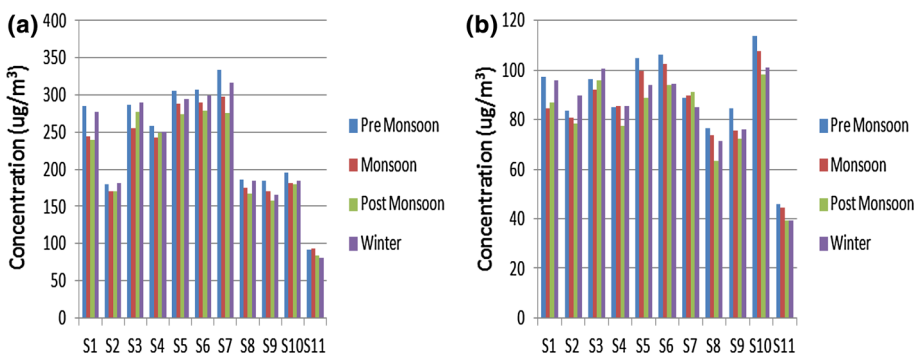


site within Guru ki Nagri since it is far away from the NH-1. A critical examination of the spatial distribution for  $PM_{2.5}$  over sites revealed that the traffic-clogged areas, i.e., commercial area  $S_{10}$ , had the highest concentrations with mean annual values of  $105.7 \mu\text{g}/\text{m}^3$ . The concentration of both  $PM_{10}$  and  $PM_{2.5}$  was found to be more than permissible standards (CPCB 2009) in all industrial, commercial and residential sites except agricultural site ( $S_{11}$ ). So to assess the variability of particulates, relative amplitudes for the sites were calculated:  $RA (\%) = \{[(\text{Max} - \text{Min}) \times 100]/\text{Mean}\}$  which becomes very less (15–30%) for maximum sites due to combined effects of stationary and vehicular sources.

Among industrial sites, maximum annual average concentration of  $SO_2$  ( $47.3 \mu\text{g}/\text{m}^3$ ) and  $NO_2$  ( $28.7 \mu\text{g}/\text{m}^3$ ) was observed at Focal Point ( $S_6$ ) and minimum concentration of  $SO_2$  was observed at site  $S_4$  ( $35.08 \mu\text{g}/\text{m}^3$ ) and for  $NO_2$  at site  $S_2$  ( $19.75 \mu\text{g}/\text{m}^3$ ). All values were found to be well below the prescribed standards for  $SO_2$  and  $NO_2$  provided by CPCB, i.e.,  $80 \mu\text{g}/\text{m}^3$  for 24 h sampling (CPCB 2009). The results are in agreement with the facts that the area mainly consists of secondary steel industry which makes use of fuel having higher sulfur content leading to more formation of  $SO_2$  as compared  $NO_2$  contribution from vehicles.

### 3.3 Temporal distribution of pollutants

Pollutants concentrations for all sites in different seasons represented as winter (Jan–Feb), pre-monsoon (March–May), monsoon (June–Sept) and post-monsoon (Oct–Dec) averages are plotted in Fig. 3. Sample size for winter, pre-monsoon, monsoon and post-monsoon were 44, 65, 84 and 66, respectively. Due to heavy rain, five samples were not possible to be estimated. Levels of pollutants underwent a seasonal change with lower levels in monsoon and post-monsoon season than the pre-monsoon and winter season. Highest concentration of  $PM_{10}$  ( $338.43 \mu\text{g}/\text{m}^3$ ) was observed in pre-monsoon season at site  $S_7$  and lowest at site  $S_2$  ( $163.29 \mu\text{g}/\text{m}^3$ ) in monsoon season among the industrial sites (Fig. 3a) which may be attributed to the washout mechanism during rainy season and the results are in agreement previous finding for the Visakhapatnam city, India (Police et al. 2016). Ouyang et al. (2015) reported that washout of  $PM_{2.5}$  due to rain results in decrease of  $10\text{--}30 \mu\text{g}/\text{m}^3$  with 5 mm of rainfall for Beijing City. Site  $S_{10}$  showed highest concentration of  $PM_{2.5}$  in all seasons because of the movement of vehicles as the site was near to bus station (Fig. 3b). During pre-monsoon season all the industrial sites had high level particulates of than the standard (CPCB 2009) which may be due to re-suspension of dust or



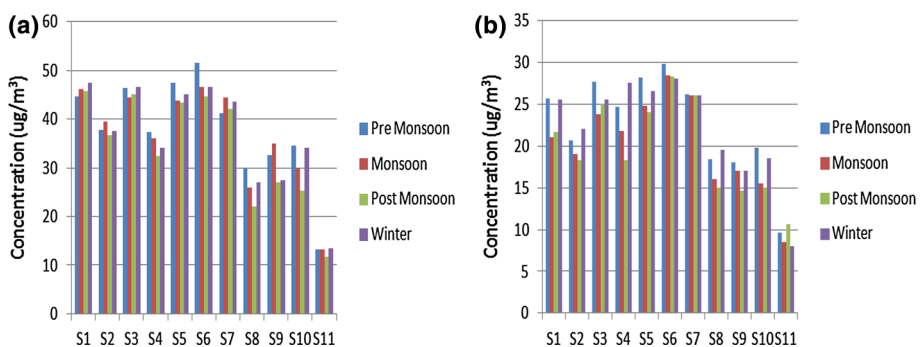
**Fig. 3** Seasonal variation of particulates ( $PM_{10}$  (a) and  $PM_{2.5}$  (b)) concentration in the area of Mandi Gobindgarh

pollution from point and nonpoint sources as heavy winds took place during that period as depicted in Fig. 1. The observed seasonal variation in  $PM_{10}$  is similar in most of East Asian countries (Massey et al. 2012).

Higher  $PM_{10}$  concentrations in winters may be probably because of longer retention time of particulates in atmosphere due to least average wind speed, i.e., 0.69 Kmph as compared to all other seasons, and the findings are in agreement with previous study (Gupta et al. 2008). This can also be due to the well-known fact of agricultural residue burning incidences taking place in state of Punjab and Haryana. Concentration found was least during  $SO_2$  concentration and showed less variability among different season than the particulates which may be due to their ability to settle down easily during rain (Davies 1976). Removal of gaseous pollutant due to rain depends upon the rate emissions of pollutants, growth rate of raindrop, rate of rain drop falling, etc. (Shukla et al. 2008).  $NO_2$  concentration was maximum ( $29.89 \mu\text{g}/\text{m}^3$ ) at site  $S_6$  in pre-monsoon season and lowest of  $17.94 \mu\text{g}/\text{m}^3$  at  $S_2$  in post-monsoon season (Fig. 4a, b). Similar trends have been reported by Jha et al. (2010) for Jharia coal field area in West Bengal for the concentration variation between pre-monsoon and post-monsoon season.

### 3.4 Aqi

IND-AQI was calculated using seasonal average concentration of all pollutants at different sites, and results (Fig. 5) showed that industrial site ( $S_7$ ) near village Kumbh on Amloh road was having highest AQI of 342.59 which comes under “Very Poor” category during pre-monsoon season. Other sites, i.e., at  $S_2$  (RIMT Talwara road),  $S_3$  (Prem Nagar),  $S_4$  (Guru ki Nagri),  $S_5$  (GT road, toward Khanna) and  $S_6$  (Focal Point) have values of AQI between 200 and 300, which comes under “Poor” category. Only  $S_2$  site near to RIMT comes under “Moderate” category. The order of AQI was observed to be Pre-monsoon > Winter > Monsoon > Post-monsoon season. Only site  $S_{11}$  found to have good air quality since it is a control site (agricultural site) situated far away from industrial and nonpoint sources emission. Responsible pollutant for IND-AQI at all sites was  $PM_{10}$  except  $S_{10}$  where  $PM_{2.5}$  was found to be responsible since its sub-indices value was maximum among all other sub-indices.



**Fig. 4** Seasonal variation of gaseous pollutant ( $SO_2$  (a) and  $NO_2$  (b)) concentration in the area of Mandi Gobindgarh

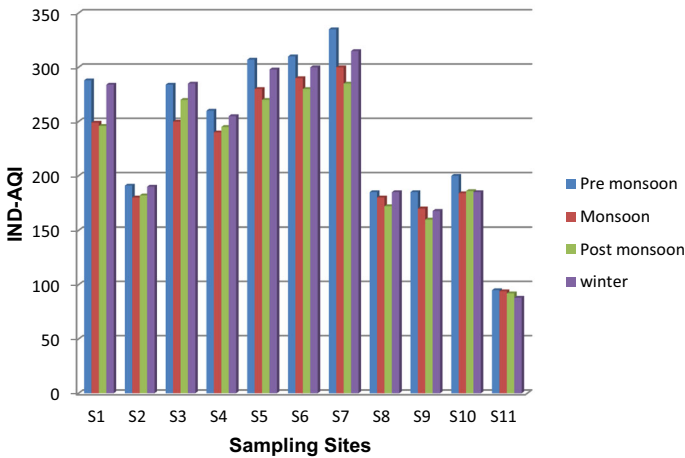


Fig. 5 Seasonal IND-AQI at different sampling sites

### 3.5 Z score

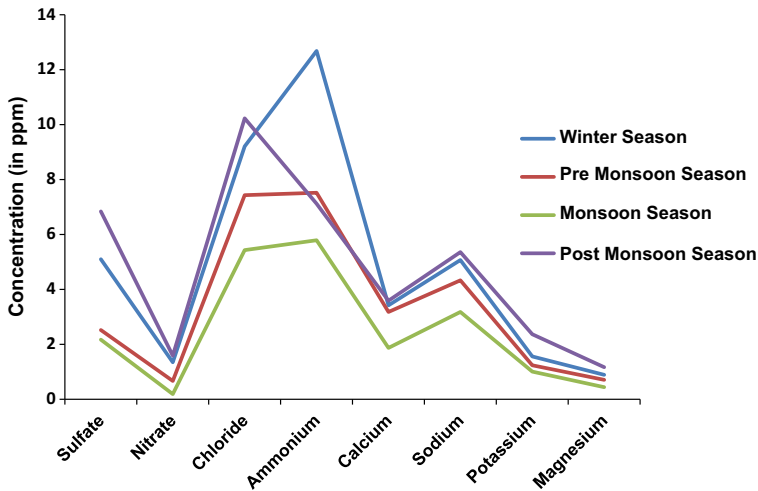
Air pollution characteristics of industrial sites, commercial sites, residential sites and agricultural sites; indicated by Z score test are given in Table 4. In case of Industrial sites, average Z score for all pollutants is greater than 0, and average Z score for PM<sub>10</sub> (Z = 0.58), SO<sub>2</sub> (Z = 0.6) and NO<sub>2</sub> (0.58) is higher than compared to PM<sub>2.5</sub> (0.34), so industrial zone may be characterized as PM<sub>10</sub>/SO<sub>2</sub>/NO<sub>2</sub> pollution zone. In commercial zones, all Z values are less than 0 except PM<sub>2.5</sub> (Z = 1.18), indicating as PM<sub>2.5</sub> pollution zone which is observed due to high vehicular pollution. In residential and agricultural sites, all Z scores are even less than zero showing low pollution zone, so air pollution for this group may be characterized as low PM<sub>10</sub>/PM<sub>2.5</sub>/SO<sub>2</sub>/NO<sub>2</sub>. Similar results were reported by Basha et al. (2014) for the uranium underground mining site is located in Tummalapalle village, where Z score at sites near to source was characterized as high TSP/SO<sub>x</sub> pollution zone.

### 3.6 Ionic analysis

Concentration of different water soluble anions and cations was analyzed in different seasons as depicted in Fig. 6. Results indicate that the concentration was found to be on higher side during winter season which may be due to low-temperature condition, whereas, least during monsoon season, which may be due to precipitations. Among cations, highest

Table 4 Z score for pollutants for all sites

Zone	Z score			
	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	NO <sub>2</sub>
Industrial sites	0.58	0.34	0.6	0.58
Commercial sites	- 0.58	1.18	- 0.54	- 0.68
Residential sites	- 0.74	- 0.6	- 0.73	- 0.71
Agricultural sites	- 3.27	- 2.4	- 2.22	- 1.98



**Fig. 6** Seasonal variation of concentration of ions (in ppm) present in air

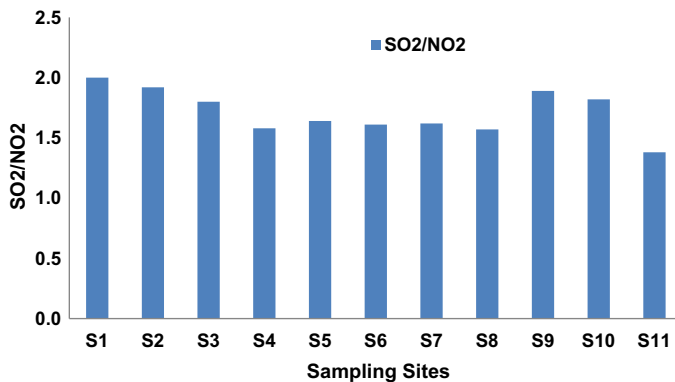
concentration of 12.68 ppm of  $\text{NH}_4^+$  was observed in winter season. The trend for the water soluble ionic concentrations for samples collected during winter season was  $\text{NH}_4^+ > \text{Cl}^- > \text{SO}_4^{2-} > \text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{NO}_3^- > \text{Mg}^{2+}$ . In post-monsoon season, chloride ions concentration is on higher side than of  $\text{NH}_4^+$  ion, whereas, in pre-monsoon season trend was  $\text{NH}_4^+ > \text{Cl}^- > \text{Na}^+ > \text{Ca}^{2+} > \text{SO}_4^{2-} > \text{K}^+ > \text{Mg}^{2+} > \text{NO}_3^-$ . The ions like  $\text{Na}^+$ ,  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  were higher in all seasons except monsoon as they are mainly derived from the soil dust particles, get added to air due to re-suspension of soil particles. The ions like  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  ions get added into the atmosphere due to anthropogenic sources, which gets removed during monsoon season. Concentration of all water soluble ions is higher in both winters and post-monsoon season when compared to pre-monsoon and monsoon season. Zhang et al. (2006) also reported higher levels of secondary ions ( $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{NH}_4^+$ ) which were observed both in summer and winter. Kumar et al. (2007) and Deshmukh et al. (2011) also reported similar pattern for some of ions for an urban and suburban site in the Agra and Durg city, respectively.

### 3.7 Vehicular impacts

$\text{SO}_2/\text{NO}_2$  was also calculated to assess the impact of vehicular movement, and it was found to lie from 1.23 to 1.99 at various sites (Fig. 7). Site ( $S_1$ ) was having maximum  $\text{SO}_2/\text{NO}_2$  ratio value which means that there was minimum impact of moving vehicles on the air quality when compared to agricultural site ( $S_{11}$ ) where ratio of  $\text{SO}_2/\text{NO}_2$  is minimum. Similar results have been reported by Fulekar et al. (2014) for New Delhi for the study period of 2016–2012.

## 4 Conclusion

Ambient air quality study of Mandi Gobindgarh in terms of Air Quality Index (AQI) was assessed by monitoring the quantum of particulate and gaseous air pollutants in the study area. On the basis of wind roses diagrams, two predominant wind directions were found to



**Fig. 7** SO<sub>2</sub>/NO<sub>2</sub> ratio for sampling sites

be southwest and east. On the basis of wind data, impact area and land use pattern; eleven sites were selected for sampling (inclusive of seven industrial, two residential, one commercial and one agricultural site). Industrial sites at RIMT, Talwara road, GT road, Focal Point, Amloh Road had concentrations of PM<sub>10</sub> more than 250 µg/m<sup>3</sup>, whereas, all residential area had concentrations of 180 µg/m<sup>3</sup>. SO<sub>2</sub> and NO<sub>2</sub> concentrations at all sites were found to be within stipulated standards. IND-AQI values are calculated for each site and found to be highest at site near village Kumbh, Amloh road which comes under “Very Poor” category, i.e., respiratory illness to the people on prolonged exposure and effect may be more pronounced in people with lung and heart diseases. Most of the sites have IND-AQI value above 200 indicating need of effective air pollution management strategy. In 2013, Government of Punjab and Punjab Pollution Control Board persuaded rolling and forging units to switch over to the greener fuels such as CNG/RLNG. CPCB itself had revised national air quality standards for more stringent limits of pollutants in 2009. Industrial zones are characterized as PM<sub>10</sub>/SO<sub>2</sub>/NO<sub>2</sub> pollution zone, whereas residential and agricultural sites are all characterized as PM<sub>10</sub>/PM<sub>2.5</sub>/SO<sub>2</sub>/NO<sub>2</sub> pollution zone on the basis of Z score. Values of SO<sub>2</sub>/NO<sub>2</sub> obtained vary from 1.23 to 1.99 at various selected sites which depict that the impacts of moving sources were marginally less, when compared to industrial sources. Variation in ionic concentration of various cations and anions was studied for different season. Moreover, impact of vehicular emission is very less on the sampling sites which are nearer to industrial sources as compared to agricultural site. To better understand the impact of local emission on overall air quality, temporal data of higher resolution with more metrological data will be more helpful. For future endeavor, we can use receptor model like chemical mass balance, positive matrix factorization, etc., to have in-depth understanding and better clarity of source contribution. Further more sophisticated instrument techniques can be employed to get real-time data that will contribute to further knowledge to this research.

## References

- Agarwal, R., Awasthi, A., Singh, N., Gupta, P. K., & Mittal, S. K. (2012). Effects of exposure to rice-crop residue burning smoke on pulmonary functions and oxygen saturation level of human beings in Patiala (India). *Science of the Total Environment*, 429, 161–166.

- Basha, M., Yasovardhan, N., Satyanarayana, S. V., Reddy, G. V. S., Savitri, P. P., Prasad, K. V., et al. (2014). Seasonal variation of air Quality and CAQI at tummalapalle uranium mining site and surrounding villages. *Journal of Scientific Research & Reports*, 3(5), 700–710.
- Chauhan, A., Pawar, M., Kumar, R., & Joshi, P. C. (2010). Ambient air quality status in Uttarakhand (India): A case study of Haridwar and Dehradun using air quality index. *Journal of American Science*, 6(9), 565–574.
- Cheng, W., Chen, Y., Zhang, J., Lyons, T. J., Pai, J., & Chang, S. (2007). Comparison of revised air quality index with the PSI and AQI indices. *Science of the Total Environment*, 382, 191–198.
- CPCB. (2009). *National Ambient Air Quality Standards – 2009*. [http://www.cpcb.nic.in/National\\_Ambient\\_Air\\_Quality\\_Standards.php](http://www.cpcb.nic.in/National_Ambient_Air_Quality_Standards.php), Accessed 14 Dec 2011.
- CPCB. (2012). *National ambient air quality status & trends in India-2010. National ambient air quality monitoring naaqms/35/2011–2012*, Central Pollution Control Board, India, Page 21.
- Davies, T. D. (1976). Precipitation scavenging of sulphur dioxide in an industrial area. *Atmospheric Environment*, 10(10), 879–890.
- Deshmukh, D. K., Deb, M. K., Tsai, Y. I., & Mkoma, S. L. (2011). Water soluble ions in PM<sub>2.5</sub> and PM<sub>1</sub> aerosols in Durg city, Chhattisgarh India. *Aerosol and Air Quality Research*, 11, 696–708.
- Fulekar, M. H., Bhawana, Pathak, & Kale, R. K. (2014). *Environment and sustainable development* (pp. 83–85). Berlin: Springer.
- Gautam, S., Yadav, A., Tsai, C. J., & Kumar, P. (2016). A review on recent progress in observations, sources, classification and regulations of PM<sub>2.5</sub> in Asian environments. *Environmental Science and Pollution Research*, 23(21), 21165–21175.
- George, K. V., Verma, P., & Devotta, S. (2008). Locating air quality monitoring station using wind impact area diagram. *Environmental Monitoring and Assessment*, 145, 113–118.
- Gupta, A., & Dhir, A. (2013). Estimation of horizontal pollution potential by calculating impact area for Patiala, Punjab using wind data. *International Journal of Innovative Research in Science, Engineering and Technology*, 2(6), 2271–2279.
- Gupta, H. K., Gupta, V. B., Rao, C. V. C., Gajghate, D. G., & Hasan, M. Z. (2002). Urban air quality and its management strategy for a metropolitan city of India. *Bulletin of Environmental Contamination and Toxicology*, 68, 347–354.
- Gupta, A. K., Karar, K., Ayoob, S., & John, K. (2008). Spatio - temporal characteristics of gaseous and particulate pollutants in an urban region of Kolkata India. *Atmospheric Research*, 87(2), 103–115.
- IS. (2001). *Methods for Measurement of Air Pollution, Part 2: Sulphur Dioxide [CHD 32: Environmental Protection and Waste Management]*. <https://law.resource.org/pub/in/bis/S02/is.5182.02.2001.pdf>, Accessed 17 Dec 2011.
- IS. (2006). *Methods for Measurement of Air Pollution, Part 6: Oxides of nitrogen [CHD 32: Environmental Protection and Waste Management]*. <https://law.resource.org/pub/in/bis/S02/is.5182.06.2006.pdf>, Accessed 17 Dec 2011.
- Jha, M., Misra, S., & Bharati, S. K. (2010). A report on seasonal variation in SPM, SO<sub>x</sub> and NO<sub>x</sub> in Jharia coalfields. *Ecoscan*, 4(4), 281–284.
- Kamruzzaman, Majumder Ahmad, Nazmul, Islam K. M., Roshan, Man Bajracharya, & Carter, William S. (2012). Assessment of occupational and ambient air quality of traffic police personnel of the Kathmandu valley, Nepal; in view of atmospheric particulate matter concentrations (PM<sub>10</sub>). *Atmospheric Pollution Research*, 3(1), 132–142.
- Kumar, A., Garg, A., & Pandel, U. (2011). A study of ambient air quality status in Jaipur city (Rajasthan, India), using air quality index. *Nature and Science*, 9(6), 38–43.
- Kumar, R., Srivastava, S. S., & Kumari, K. M. (2007). Characteristics of aerosols over urban and suburban site of semiarid region in India: Seasonal and spatial variations. *Aerosol and Air Quality Research*, 7, 531–549.
- Massey, D., Kulshrestha, A., Masih, J., & Taneja, A. (2012). Seasonal trends of PM<sub>10</sub>, PM<sub>5.0</sub>, PM<sub>2.5</sub> & PM<sub>1.0</sub> in indoor and outdoor environments of residential homes located in North-Central India. *Building and Environment*, 47, 223–231.
- Mittal, S. K., Singh, N., Agarwal, R., Awasthi, A., & Gupta, P. K. (2009). Ambient air quality during wheat and rice crop stubble burning episodes in Patiala. *Atmospheric Environment*, 43(2), 238–244.
- Nautiyal, J., 3rd, Garg, M. L., Kumar, M. S., Khan, A. A., Thakur, J. S., & Kumar, R. (2007). Air pollution and cardiovascular health in Mandi-Gobindgarh, Punjab, India - a pilot study. *International Journal of Environmental Research and Public Health*, 4(4), 268–282.
- Ouyang, W., Guo, B., Cai, G., Li, Q., Han, S., Liu, B., et al. (2015). The washing effect of precipitation on particulate matter and the pollution dynamics of rainwater in downtown Beijing. *Science of the Total Environment*, 505, 306–314.

- PPCB. (2010). *Action Plan, Abatement of Pollution in Critically Polluted Area of Mandi Gobindgarh*. Punjab Pollution Control Board, India. [www.indiaenvironmentalportal.org.in/files/ActionPlanGGGarh.pdf](http://www.indiaenvironmentalportal.org.in/files/ActionPlanGGGarh.pdf). Accessed on Feb 2012.
- Robert, J. L., & Howard, M. K. (2012). Respiratory health effects of air pollution: Update on biomass smoke and traffic pollution. *Journal of Allergy and Clinical Immunology*, 129(1), 3–11.
- Sandeep, Police, Sahu, S. K., & Pandit, G. G. (2016). Chemical characterization of atmospheric particulate matter and their source apportionment at an emerging industrial coastal city, Visakhapatnam India. *Atmospheric Pollution Research*, 7(4), 725–733.
- Sharma, M., Pandey, R., Maheshwari, M., & Sengupta, B. (2003). Interpretation of air quality data using an air quality index for the city of Kanpur, India. *Journal of Environmental Engineering and Science*, 2, 453–462.
- Shukla, J. B., Misra, A. K., Shyam, Sundar, & Ram, Naresh. (2008). Effect of rain on removal of a gaseous pollutant and two different particulate matters from the atmosphere of a city. *Mathematical and Computer Modelling*, 48(5), 832–844.
- Singh, G. (2010). An index to measure depreciation in air quality in some coal mining areas of korba industrial belt of Chhattisgarh, India. *Journal of Environment Science & Engineering*, 49(1), 77–86.
- Vega, E., Ruiz, H., Escalona, S., Cervantes, A., Lopez-Veneroni, D., Gonzalez-Avalos, E., et al. (2011). Chemical composition of fine particles in Mexico City during 2003–2004. *Atmospheric Pollution Research*, 2, 477–483.
- WHO. (2012). *Air quality and health, Fact sheet Number 313*, Updated September 2011. <http://www.who.int/mediacentre/factsheets/fs313/en/>. Accessed on Mar 2012.
- Zhang, W. J., Sun, Y. L., Zhuang, G. S., & Xu, D. Q. (2006). Characteristics and seasonal variations of PM<sub>2.5</sub>, PM<sub>10</sub>, and TSP aerosol in Beijing. *Biomedical and Environmental Sciences*, 19(6), 461–468.