Ambient Air Quality Status in Uttarakhand (India): A Case Study of Haridwar And Dehradun Using Air Quality Index

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ABSTRACT: This paper examines the significant differences in seasonal variations of air pollutants concentrations at urban, industrial, commercial and agricultural areas of Uttarakhand. PM_{10} (RSPM), suspended particulate matter (SPM), sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) were collected over four sites in Haridwar and Dehradun Valley, Uttarakhand. The first one, Shivalik Nagar, Haridwar is an urban area. The second site SIDCUL, which is one of the most industrial areas of Haridwar. The third site is famous Clock Tower of Dehradun Valley, one of the busiest commercial centres. The fourth site was an agricultural area where pollution level was very low, considered as a control site. The present study deals with the effect of industrialization, urbanization and automobile emission on ambient air quality in Haridwar and Dehradun City. Meteorological parameters like temperature, relative humidity, wind speed and rainfall were also recorded simultaneously during the sampling period. Monthly and seasonal variation of these pollutants have been observed and recorded. The annual average and range values have also been calculated. It has been observed that the concentrations of the pollutants are high in winter in comparison to the summer or the monsoon seasons. In the present study, it was noticed that the SPM and PM_{10} levels at all selected sites (excluding Roshnabad) exceeds the prescribed limits as stipulated by Central Pollution Control Board (CPCB) New Delhi, India. Apart from this the SO_2 and NO_x levels in residential, industrial and commercial areas remain under prescribed limits of CPCB. [Journal of American Science 2010; 6(9):565-574]. (ISSN: 1545-1003).

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1. Introduction

In India the ambient atmospheric conditions have progressively deteriorated due to urbanization, industrial development, lack of awareness, poor maintenance of motor vehicles and poor road conditions. Transport vehicles and industrial emissions are the major sources of pollutants in the Haridwar and Dehradun Valley atmosphere, a problem that has been aggravated by the tremendous increase in the number of mobile sources. In Haridwar and Dehradun, the concentration of SO_2 and NO_2 is always under the Indian air quality standard. But the concentration of PM_{10} and SPM exceeds the Indian air quality guideline in this area (Joshi et al., 2005; Joshi and Chauhan, 2008; Chauhan, 2008; Chauhan and Joshi, 2010; Chauhan, 2010). So, there is need to evaluate the air quality improvement in Haridwar and Dehradun Valley, Uttarakhand. Among the particles, those having median diameters higher than 10 μm are stopped in the upper areas of the respiratory system. Smaller particles with median diameters less than 10 μm (PM_{10}) can reach the lungs and provoke respiratory problems (Healy et al., 2007), depending on their physico-chemical properties. The smallest ones, with diameters less than 2.5 μm reach bronchial alveolus and may have long residence time inside, increasing health effects, such as asthma and respiratory allergies.

The WHO/UNEP report (1992) reveals air pollution problems in metropolitan cities of India as some of these are among the most polluted cities of the worlds. India has 23 major cities of over 1 million people and ambient air pollution levels exceed the WHO standards in many of them (Gupta et al., 2002). The main reason for deterioration of air quality in the cities is the growing number of vehicles. Vehicular pollution contributes of 70% of total pollution in Delhi, 52% in Mumbai and 30% in Calcutta (C.P.C.B., 2003). Urban air pollution poses a significant threat to human heath, property and the environment throughout the developing and developed parts of the world. The United Nations (UN) estimates that 4.9 billions inhabitants out of 8.1 billion will be living in cities by 2030 (UNSCD, 2001). The rapid industrialization, fast, drastic increases in vehicles on the roads and other activities of human beings have disturbed the balance of natural atmosphere (Chauhan, 2008). Over the years there has been a tremendous increase in human population, road transports, vehicular traffic and industries in Haridwar region, has lead to increases in the concentration of gaseous and particulates pollutants in the ambient air (Chauhan and Joshi, 2007). This paper is an attempt to investigate the air quality status and air quality index (AQI) at selected monitoring sites of Uttarakhand State.

2. Materials and methods

2.1. Study area

Haridwar is referred as holy city which is one of the oldest living cities mentioned in the ancient Hindu scriptures, considered as the gateway to the four pilgrimages, Badrinath, Kedarnath, Gangotri and Yamnotri of Uttarakhand. Haridwar is extended from latitude 29° 58' in the north to longitude 78° 13' in the east and has subtropical climate. It is about 60 kms in length from east to west and about 80 kms in width from north to south. Total area of district Haridwar is 2,360 sq km at an altitude of 294.7 m with a population of 14, 44,213 (according to 2001 census). The four distinct season's autumn, winter, spring and summer can be seen here. The climate of the area is relatively temperate with an average rainfall of about 1127.2 mm which is chiefly confined to monsoon months. It receives millions of tourists every month, sometimes just in one day.

Dehradun is a capital of newly formed state Uttarakhand which known for its beauty in the world, extended from latitude 30° 31' in the north to longitude 78° 04' in the east. Total area of district Dehradun is 3,088 sq km at an altitude of 635 meter with a population of 12, 79083 (according to 2001 census). Dehradun is bounded in the north by the higher range of lesser Himalaya and in south by the younger Shivalik mountain ranges. Dehradun is an important business, educational and cultural destination of north India. The climate and strategic location of Dehradun makes it a popular tourist destination. The wafting fragrance of rice, tea and litchi gardens add to the beauty of the valley.

2.2. Study Sites

Total four monitoring sites were selected for present study. The first one in Shivalik Nagar is a residential area of Hardwar, posses a very high number of motor vehicles throughout the day and night and also surrounded by two industrial areas namely Bhadrabad Industrial Area and SIDCUL in west and north direction, respectively. The second site in SIDCUL (State Industrial Development of Uttarakhand Corporation Limited), which is the newly developed state industrial belt and about 400 industries already started functioning and some 400 are yet to arrive. Many of these industries emits air pollutants through their chimneys, can be seen easily and besides this area bear a very heavy traffic load, including large trucks, loaded trucks, mini trucks, private buses, very high number of three wheelers, cars, scooters, bikes etc. throughout the day and night. The third site is famous Clock Tower of Dehradun Valley, one of the main and busy road of the city, posses a high number of two wheelers, three wheelers and four wheelers vehicles throughout the day. The fourth site was an agricultural area in Hardwar where pollution level is almost very low, posse's very dense forest and vegetations covers. The present study deals with the effect of industrialization, urbanization and automobile emission on ambient air quality in Haridwar and Dehradun City. The main objective of the study is to monitor the ambient air quality of residential, industrial, commercial and agricultural areas of Uttarakhand.

2.3. Monitoring and Analysis

Air pollutants (SO_2, NO_x, SPM and RSPM) monitoring data for site 1, 2 and 4 was measured with the help of RDS APM 460 by sucking air into appropriate reagent for 24 hours at every 30 days and after air monitoring it procured into lab and analysis for the concentration level. The SPM and RSPM were analyzed using Respirable Dust Sampler (RDS) APM 460 and operated at an average flow rate of 1.0-1.5 m^3 min^{-1}. Preweighed glass fiber filters (GF/A) of Whatman were used as per standard methods. SO_2 and NO_x were collected by bubbling the sample in a specific absorbing (sodium tetrachloromercuate of SO_2 and sodium hydroxide for NO_x) solution at an average flow rate of 0.2-0.5 min^{-1}. The impinger samples were put in ice boxes immediately after sampling and transferred to a refrigerator until analyzed. The concentration of NO_x was measured with standard method of Modified Jacobs- Hochheiser method (1958), SO_2 was measured by Modified West and Geake method (1956), SPM and RSPM using filter paper methods. The apparatus was kept at a height of 2 m from the surface of the ground. However air pollutants data for site 3 was collected from Uttarakhand Environment Protection and Pollution Control Board, Dehradun. AQI (air quality index) is then calculated with the concentration values using the following equation (Rao & Rao, 1998).

$$AQI = 1/3\ [(SO_2)/S_{SO_2} + (NO_x)/S_{NOX} + SPM/S_{SPM}] \times 100$$

2.4. Statistical analysis

To evaluate the relationship between air pollutants and meteorological parameter, Person's correlation coefficient values (r) were calculated at each monitoring site using SPSS software (SPSS Inc., version 10.0) for assessing the significance of quantitative changes in different parameters and presented in Table VII.

3. Results and discussion

The present study indicates the air pollutants concentrations and air quality index (AQI) at four monitoring sites of Uttarakhand. Table I represents the characterization of four selected monitoring sites. Figure1 represents the monthly variation of PM_{10}, RSPM, NO_x and SO_2 at four monitoring sites.

It was observed from (Table VIII) the meteorological data that the highest temperature attained was during the month of May at site 1, 2, 3 and 4, whereas the lowest temperature was recorded in the month of December at site 1, 2 and 4, while lowest during January at site 3. Highest humidity was recorded during the month of December at site 1 and 2, whereas highest humidity was rescored during July and February at site 3 and 4, respectively. And the lowest in the month of April at site 1, 2, 3 and 4. Highest rainfall was recorded during June at site 1, 2, 3 and 4. In the case of wind speed, highest observed during June at site 1, 2 and 4, while at site 3 highest during April.

3.1. Site-specific variations

The ambient air concentration of PM_{10} was observed more than the stipulate standard values at the first three sites while at site 4, it was under the stipulated standard. It ranged from 98.47 to 141.28µg/m^3 160.80 to 175.78 µg/m^3, 67.53 to 148.33 µg/m^3 and 19.88-33.39µg/m^3 at site1, 2, 3 and 4, respectively. Further it was observed that average concentrations of SPM ranged from 357.12 to 413.91 µg/m^3, 497.12 to 599.36 µg/m^3, 167.72 to 351.03 µg/m^3 and 84.53 to 113.24 µg/m^3 at site 1, 2, 3 and 4, respectively. The highest concentration of PM_{10} exceeding 250 µg/m^3 was observed in Kolkata and New Delhi (WHO, 1998, 1999). The highest concentrations of RSPM and SPM have been reported in various part of India (Sharma et al., 2005: Chelani and Devotta, 2007: Nidhi and Jayaraman, 2007) and in Haridwar region (Joshi and Swami, 2007; Joshi et al., 2005; Joshi and Chauhan, 2008; Chauhan, 2008; Chauhan and Joshi, 2010) and also in Dehradun (Chauhan, 2010).

According to the present study, annual NO_x and SO_2 concentrations at the monitoring station (Table IV) were well below the maximum allowed limit of National Ambient Air Quality Standards (NAAQS) for different areas (Table II). The concentration of NO_x ranged 13.12 to 19.40 µg/m^3, 18.33 to 24.40 µg/m^3, 23.66 to 30.37 µg/m^{3}and 2.12 to 2.57 µg/m^3 at site 1, 2, 3 and 4, respectively. The concentration of SO_2 ranged between 8.64 to 12.30 µg/m^3, 13.33 to 20.12 µg/m^3, 21.72 to 28.17 µg/m^3 and 1.22 to 1.93 µg/m^3 at site 1, 2, 3 and 4, respectively. Site 1 found to be most polluted site among all the sites as it bears high number of scooters, three vehicles, loaded trucks, cars, motor cycles, surrounded by two industrial areas and poor road conditions. Site 2 present in industrial area and having about 400 industries and this site also bear high traffic load throughout day and night. Site 3 is very busy road which bears high number of scooters, motor cycles, three wheelers, cars, buses and there is always traffic jams condition because roads are narrow.

The high SO_2 concentrations of about 20-40 µg/m^3 in most of the cities of the developing countries, and the daily average values rarely exceed 125 µg/m^3 (WHO, 1998) and annual mean concentration of NO_2 recorded in most cities across the globe, not exceeding 40 µg/m^3 (WHO, 2000). Similar results have been observed by Bhanarkar et al., 2002; Kaushik, 2006; Chauhan, 2008.

3.2. Seasonal variations

It is observed from Table III that the concentration of PM_{10} during summer was recorded as 109.41 to 122.43 µg/m^3, 160.88 to 175.40 µg/m^3, 120.92 to 148.33 µg/m^3 and 27.26 to 32.83 µg/m^3 at site 1, 2, 3 and 4, respectively, while during monsoon it was recorded as 98.47 to 123.12 µg/m^3, 161.66 to 175.78 µg/m^3, 67.53 to 95.54 µg/m^3 and 19.88 to 24.69 µg/m^3 at site 1, 2, 3 and 4, respectively. Highest concentration of SPM was recorded during winter at site 2, 3 and 4, whereas site 1, the highest concentration was recorded during summer. Highest levels of NO_x were observed during winter at all four monitoring sites and the lowest levels of NO_x were observed during summer at four monitoring sites. Higher concentrations of SO_2 were recorded during winter at residential area (site 1), commercial area (site 2) and agricultural area (site 4), while at industrial area (site 2) the higher concentration of it was observed during monsoon. However the lowest concentrations of SO_2 were recorded during the summer at all four selected monitoring sites.

Newly carved state of Uttarakhand suffering intense pressure of a combination of different driving forces e.g. motorization, industrialization and an tremendous increase in urban population density due to search of work, business settlement and also for education purpose. Hardwar and Dehradun two most important tourist destination of Uttarakhand State. Hardwar is world famous and one of the most important holy cities of India, famous for Har ki Pauri, temples, natural beauty, fairs and festivals. It receives millions of tourist every month, sometimes just in one day, which increase the number of automobile of various categories up to 800% per day (Joshi and

Swami, 2007). Dehradun is the capital of Uttarakhand suffering from tremendous increase of population, number of vehicles, narrow roads, parking facility problems, ineffective implementation of laws etc. all these conditions responsible for jam like condition prevalent in almost all the traffic intersections of Dehradun. Moreover there is huge numbers of three wheelers. Most of these three wheelers are carry overload of passengers, poor maintained and conditions besides this they driven by diesel engine. It is estimates that diesel combustion emits 84 g/km of particulates as compared to 11 g/km in CNG (Nylund and Lawson, 2000). Motor vehicles generate a range of particulate matter through the dust produced from brakes, clutch plates, tires and indirectly through the re-suspension of particulates on road surfaces through vehicles–generate turbulence (Watkins, 1991). In a study conducted by Kirchstetter *et al.*, (1999) in Northern California, it is found that heavy diesel vehicles emitted 24 times more fine particles than light day gasoline vehicles.

Over the three decades motor vehicles numbers have been doubling every 10 or fewer year in many Asian countries as against a 2-5% annual growth rate in Canada, the United States, The United Kingdom and the Japan (Faiz et al., 1992; Walsh, 1994). Two wheeler (motorcycles/scooters) are the most rapidly growing type vehicles in India (Table IX). Vehicular pollution contribute about (72%) of the total air pollution load followed by industries (19%) and domestic (9%) in Delhi City (CPCB, 2001).

3.3. Air quality index (AQI):

Air Quality Index (AQI) is developed to provide the information about air quality. Air Quality Index (AQI) was introduced by the Environmental Protection Agency (EPA) in USA to measure the levels of pollution due to major air pollutants. It is one of the important tools available for analyzing and representing air quality status uniformly. The concentrations of the major pollutants are monitored and subsequently converted into AQI (Table VI) using standard formulae and rating scale was also calculated (Table V). The higher value of an index refers to a higher level of air pollution. In the present investigation, the SPM, NO_x and SO_2 levels at all four selected sites have been used to calculate AQI.

Site 1 showed air quality index (AQI) varied from 71.06 (July) to 82.15 (December) and rating scale as MAP "Moderate Air Pollution", HAP "Heavy Air Pollution" and SAP "Severe Air Pollution" during study period. Site 2 showed air quality index (AQI) varied from 178.43 (May) to -215.93 (August) and rating scale as LAP "Light Air Pollution" during study period. Site 3 air quality index (AQI) varied from 50.62 (August) to 86.81 (May) and rating scale as LAP "Light Air Pollution", HAP "Heavy Air Pollution" and MAP "Moderate Air Pollution" during study period. Site 4 air quality index (AQI) varied from 17.33 (June) to 23.47 (May) and rating scale as CA "Clean Air" during study period.

3.4. Correlation of meteorological parameters and air pollutants at selected sites

At site 1 (Table VII) correlation of temperature with humidity (r = -0.73, p<0.01); temperature with PM_{10} (r = -0.69, p<0.05); humidity with NO_x (r = 0.60, p<0.05); rainfall with wind speed (r = 0.58, p<0.05); rainfall with PM_{10} (r = -0.60, p<0.05); rainfall with SPM (r = -0.79, p<0.01); rainfall with AQI (r = -0.73, p<0.01); wind speed with PM_{10} (r = -0.70, p<0.05); SPM with AQI (r = 0.93, p<0.01) and NO_x with SO_2 (r = 0.89, p<0.01). At site 2 correlation of temperature with humidity (r = -0.72, p<0.01); SPM with AQI (r = 0.91, p<0.01) and NO_x with SO_2 (r = 0.59, p<0.05). At site 3 correlation of humidity with rainfall (r = 0.60, p<0.05); humidity with wind speed (r = -0.58, p<0.05); humidity with PM_{10} (r = -0.85, p<0.01); rainfall with PM_{10} (r = -0.63, p<0.05); PM_{10} with SPM (r = 0.71, p<0.01); PM_{10} with AQI (r = 0.67, p<0.05); SPM with AQI (r = 0.96, p<0.01) and NO_x with SO_2 (r = 0.88, p<0.01). While at site 4 correlation of temperature with humidity (r = -0.69, p<0.05); temperature with SO_2 (r = -0.89, p<0.01); humidity with SO_2 (r = 0.64, p<0.05); rainfall with wind speed (r = 0.59, p<0.05) and rainfall with SPM (r = 0.86, p<0.01).

TABLE I. Characterization of four monitoring sites

Sampling station location	Zonal activities	Major sources of pollution in 2 km radius
Shivalik Nagar (Site-1)	Residential/Commercial	• Construction works • Poor road conditions • Spray painting works • Coal burning • Transportation activities • Poor maintained vehicles • Very close and surrounded by two industrial areas
SIDCUL (Site-2)	Industrial	• Coal burning • Spray painting works • Poor road conditions • Construction works • Steel and Iron Plants • Soap manufacturing works • Biscuit factory • Oil mill • Polythene factory • Bricks factory • Battery and Generator factory • Glass factory • Scrub factory • Transportation activities • Poor maintained vehicles
Clock Tower (Site-3)	Commercial	• Transportation activities • Poor maintained vehicles • Congested road
Control Area (Site-4)	Agricultural land	• Unpaved road • Agricultural activities • Dense vegetation

TABLE II. National Ambient Air Quality Standards (CPCB, 2009)

S. No.	Pollutant	Time-weighted average	Concentration in ambient air		
			Industrial Areas, Residential, Rural & other Area	Ecological Sensitive Area	Methods of Measurement
1	Sulphur Dioxide (SO_2)	Annual Average	50 µg/ m^3	20 µg/ m^3	-Improved West and Greek method -Ultraviolet Flurorescence
		24 hours	80 µg/ m^3	80 µg/ m^3	
2	Oxides of Nitrogen as (NO_2)	Annual Average	40 µg/ m^3	30 µg/ m^3	-Modified Jacob and Hochheiser -Chemiluminescence
		24 hours	80 µg/ m^3	80 µg/ m^3	
3	Suspended Particulate Matter	Annual Average	60 µg/ m^3	60 µg/ m^3	-Gravimetric -TOEM -Beta attenuation
		24 hours	100 µg/ m^3	100 µg/ m^3	
4	Respirable Suspended Particulate Matter	Annual Average	40 µg/ m^3	40 µg/ m^3	-Gravimetric -TOEM -Beta attenuation
		24 hours	60 µg/ m^3	60 µg/ m^3	
5	Ozone (O_3)	8 hours	100 µg/ m^3	100 µg/ m^3	-UV Photometric -Chemiluminescence - Chemical Method
		1 hours	180 µg/ m^3	180 µg/ m^3	
6	Lead	Annual Average	0.5 µg/ m^3	0.5 µg/ m^3	-AAS/ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter
		24 hours	1.0 µg/ m^3	1.0 µg/ m^3	
7	Carbon Monoxide (CO)	8 hours	2 mg/ m^3	2 mg/ m^3	-Non Dispersive Infra Red (NDIR) spectroscopy
		1 hours	4 mg/ m^3	4 mg/ m^3	
8	Ammonia	Annual Average	100 µg/ m^3	100 µg/ m^3	-Chemiluminescence -Indophenol blue method
		24 hours	400 µg/ m^3	400 µg/ m^3	
9	Benzene (C_6H_6)	Annual Average	5 µg/ m^3	5 µg/ m^3	-Gas chromatography based continuous analyzer -Adsorption followed by GC analysis
10	Benzo (a) Pyrene (BaP)- particulate phase only	Annual Average	1 ng/ m^3	1 ng/ m^3	-Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As)	Annual Average	6 ng/ m^3	6 ng/ m^3	-AAS/ ICP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel (Ni)	Annual Average	20 ng/ m^3	20 ng/ m^3	-AAS/ ICP method after sampling on EPM 2000 or equivalent filter paper

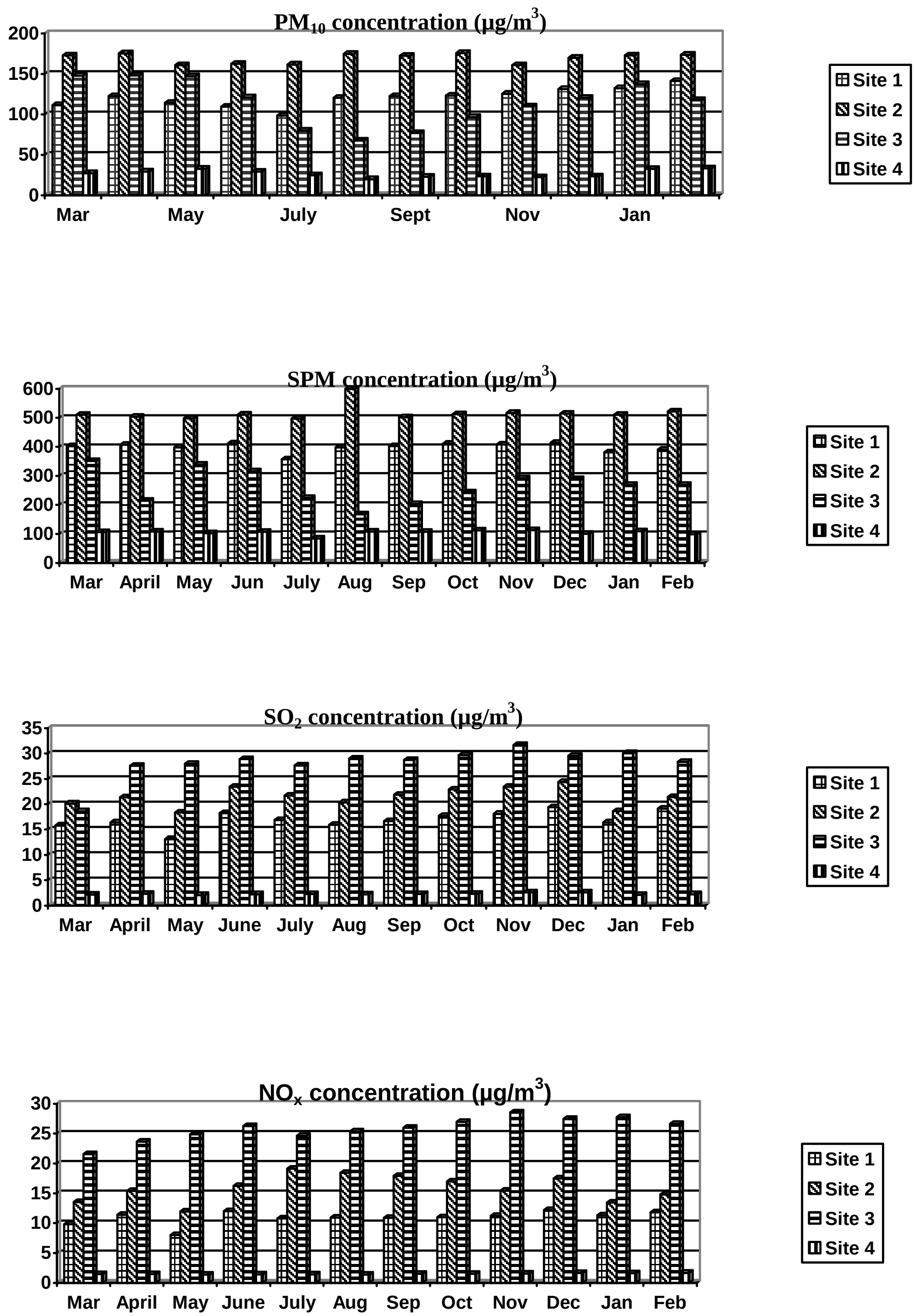

Figure1. Monthly variation of PM_{10}, SPM, NO_x and SO_2

TABLE III. Seasonal variation of PM_{10}, SPM, NO_X, SO_2 and AQI at four selected sites in Haridwar District

Air Pollutants	Site I			Site II			Site III			Site IV		
	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter
PM_{10} (μgm^{-3})	109.41-122.43 [114.33]	98.47-123.12 [116.13]	125.40-144.28 [132.54]	160.88-175.40 [167.90]	161.66-177.78 [171.18]	160.80-173.68 [169.32]	120.92-148.33 [141.09]	67.53-96.54 [80.24]	109.82-137.41 [121.27]	27.63-32.83 [29.67]	19.88-24.69 [22.71]	22.39-33.39 [27.92]
SPM (μgm^{-3})	389.21-412.20 [404.96]	375.12-411.12 [392.27]	380.41-413.91 [398.23]	498.32-511.20 [506.02]	497.12-599.36 [527.88]	510.38-522.29 [515.96]	214.06-351.03 [305.01]	167.72-242.88 [209.51]	268.66-292.04 [275.70]	102.44-108.32 [106.13]	84.53-112.60 [103.32]	98.88-113.24 [105.52]
NO_x (μgm^{-3})	13.12-18.23 [15.89]	15.93-17.70 [16.54]	16.41-19.40 [18.26]	18.33-23.42 [20.81]	20.34-22.90 [21.70]	18.64-24.40 [21.98]	18.59-28.89 [28.89]	27.63-29.68 [28.77]	28.36-31.67 [29.92]	2.07-2.33 [2.20]	2.19-2.33 [2.26]	2.08-2.61 [2.38]
SO_2 (μgm^{-3})	8.00-12.00 [10.30]	10.80-10.99 [10.63]	11.20-12.20 [11.64]	11.96-16.24 [15.04]	16.98-19.12 [18.10]	13.43-17.47 [15.28]	21.55-26.25 [24.09]	26.64-26.95 [25.74]	26.63-28.52 [27.59]	1.39-1.48 [1.44]	1.37-1.51 [1.45]	1.56-1.67 [1.61]
AQI	75.17-81.30 [78.41]	71.06-80.47 [76.91]	74.96-82.15 [78.87]	178.42-186.93 [183.22]	182.72-215.93 [192.54]	184.77-188.85 [186.84]	57.04-86.81 [73.68]	50.62-64.08 [57.63]	67.89-73.75 [70.63]	18.51-19.64 [19.20]	15.63-20.37 [18.77]	18.11-21.20 [19.87]

Range values and average values of PM_{10}, SPM, NO_X, SO_2 and AQI

TABLE IV. Annual ambient air quality status at four monitoring sites

Sampling Sites	PM$_{10}$ (μgm^{-3})			SPM (μgm^{-3})			NO$_x$ (μgm^{-3})			SO$_2$ (μgm^{-3})			AQI		
	Range	Arithmetic Mean	Geometric Mean	Range	Arithmetic Mean	Geometric Mean	Range	Arithmetic Mean	Geometric Mean	Range	Arithmetic Mean	Geometric Mean	Range	Arithmetic Mean	Geometric Mean
Site I	98.47-141.28	120.99	120.49	357.12-413.91	398.148	398.17	13.12-19.40	16.90	16.54	8.64-12.30	10.86	10.87	71.06-82.15	78.06	78.00
Site II	160.80-175.78	169.47	169.37	497.12-599.36	516.62	526.14	18.33-24.40	21.41	22.02	13.33-20.12	17.12	15.74	178.43-215.93	187.53	187.33
Site III	67.53-148.33	114.20	110.58	167.72-351.03	264.74	259.01	23.66-30.37	27.94	28.22	21.72-28.17	25.97	25.74	50.62-86.81	67.31	66.59
Site IV	19.88-33.39	26.76	26.40	84.53-113.24	104.99	104.70	2.12-2.57	2.28	2.28	1.22-1.93	1.54	1.50	15.63-21.20	19.28	19.23

TABLE V. Rating scale of AQI values

S.No.	Index value	Remarks
1	0-25	Clean air (CA)
2	26-50	Light air pollution (LAP)
3	51-75	Moderate air pollution (MAP)
4	76-100	Heavy air pollution (HAP)
5	Above100	Severe air pollution (SAP)

TABLE VI. Monthly variation in AQI and its rating scale at four monitoring sites

Months	Site 1		Site 2		Site 3		Site 4	
	AQI	Rating Scale	AQI	Rating Scale	AQI	Rating Scale	AQI	Rating Scale
March	77.72	HAP	184.12	SAP	75.23	MAP	22.65	CA
April	79.44	HAP	183.40	SAP	57.04	MAP	18.84	CA
May	75.17	HAP	178.43	SAP	86.81	HAP	23.47	CA
June	81.30	HAP	186.93	SAP	75.65	MAP	17.33	CA
July	71.06	MAP	182.72	SAP	59.12	MAP	17.95	CA
August	77.55	HAP	215.93	SAP	50.62	MAP	18.57	CA
September	78.57	HAP	184.01	SAP	56.70	LAP	19.69	CA
October	80.47	HAP	187.50	SAP	64.08	MAP	19.81	CA
November	80.37	HAP	188.51	SAP	73.75	MAP	20.02	CA
December	82.15	SAP	188.85	SAP	71.99	MAP	20.43	CA
January	74.96	MAP	184.77	SAP	68.88	MAP	19.43	CA
February	77.98	SAP	185.21	SAP	67.89	MAP	19.99	CA

TABLE VII. Correlations (Pearson) of meteorological parameters and air pollutants at selected sites during study period

Sites		Temperature	Humidity	Rainfall	Wind Speed	PM_{10}	SPM	NO_x	SO_2
Humidity	1	-0.73**							
	2	-0.72**							
	3	-0.04							
	4	-0.69*							
Rainfall	1	0.32	0.04						
	2	0.33	0.08						
	3	0.52	0.60*						
	4	0.34	0.08						
Wind Speed	1	0.45	-0.35	0.58*					
	2	0.53	-0.43	0.54					
	3	0.21	-0.58*	-0.42					
	4	0.34	-0.14	0.59*					
PM_{10}	1	-0.69*	0.48	-0.60*	-0.70*				
	2	-0.23	0.09	-0.45	-0.31				
	3	-0.28	-0.85**	-0.63*	0.31				
	4	-0.19	-0.17	-0.02	0.15				
SPM	1	-0.00	-0.24	-0.79**	-0.27	0.30			
	2	0.06	0.21	-0.14	-0.11	0.34			
	3	-0.25	-0.37	-0.44	-0.02	0.71**			
	4	0.01	-0.17	-0.86**	-0.48	-0.14			
NO_x	1	-0.54	0.60*	-0.08	-0.00	0.43	0.21		
	2	-0.15	0.25	-0.05	0.05	-0.11	-0.07		
	3	-0.10	0.31	-0.12	0.02	-0.37	-0.38		
	4	-0.36	0.24	-0.21	-0.25	-0.55	0.11		
SO_2	1	-0.42	0.48	-0.15	0.05	0.42	0.15	0.89**	
	2	0.22	0.28	0.39	0.15	0.09	0.32	0.59*	
	3	-0.47	0.38	-0.33	-0.10	-0.27	-0.11	0.88**	
	4	-0.89**	0.64*	-0.31	-0.40	0.19	0.03	0.45	
AQI	1	-0.19	0.01	-0.73**	-0.23	0.42	0.93**	0.54	0.48
	2	0.01	0.26	-0.26	-0.15	0.37	0.91**	0.32	0.52
	3	-0.19	-0.32	-0.45	0.02	0.67*	0.96**	-0.16	0.06
	4	-0.19	-0.17	-0.27	-0.43	0.26	0.09	-0.16	0.05

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed)

TABLE VIII. Monthly variation in temperature, humidity, rainfall and wind speed as recorded from different study sites during 2007-08

S.NO	Months (March 2007 - Feb. 08)	Temperature (°C)				Humidity (%)				Rainfall (m.m.)				Wind Speed (m/sec)			
		Site-1	**Site-2**	**Site-3**	**Site-4**	**Site-1**	**Site-2**	**Site-3**	**Site-4**	**Site-1**	**Site-2**	**Site -3**	**Site-4**	**Site-1**	**Site-2**	**Site-3**	**Site-4**
1	March	21.0	21.5	20.0	21.6	74	72	57	73	29.0	29.0	121.92	29.0	0.5	0.8	0.7	0.9
2	April	32.2	32.5	25.9	31.3	52	51	40	53	0.00	0.00	14.47	0.00	0.6	1.0	0.9	0.6
3	May	36.0	36.2	28.1	36.0	60	59	60	62	106.0	106.0	152.92	106.0	0.6	0.9	0.8	0.5
4	June	35.1	35.2	28.1	34.9	70	69	62	73	80.0	80.0	126.5	80.0	1.5	1.6	0.8	1.5
5	July	33.0	33.2	27.1	33.2	81	81	84	82	392.0	392.0	639.58	392.0	1.2	1.3	0.4	1.4
6	August	34.1	34.1	26.8	34.0	79	79	81	81	74.0	74.0	468.39	74.0	0.3	0.8	0.8	0.5
7	September	31.0	31.1	25.7	31.1	80	78	78	80	41.0	41.0	181.36	41.0	0.2	0.5	0.7	0.3
8	October	32.0	32.0	22.8	32.0	78	76	68	77	51.0	51.0	19.05	51.0	0.3	0.7	0.8	0.6
9	November	21.0	21.0	17.9	20.1	84	83	70	84	15.0	15.0	0.00	15.0	0.2	0.3	0.7	0.3
10	December	9.00	8.9	13.8	8.40	93	91	73	92	8.00	8.00	2.28	8.0	0.3	0.6	0.5	0.5
11	January	13.1	13.6	12.3	13.4	92	90	63	92	8.00	8.00	0.51	8.0	0.3	0.5	0.7	0.6
12	February	12.0	12.3	14.4	11.9	92	91	73	93	113.0	113.0	132.07	113.0	0.4	0.8	0.8	0.5

TABLE IX. Motor vehicle growth in India, 1971-2001

Motor vehicle numbers, millions

Year	Cars, jeeps, taxis	Two wheelers	Trucks	Buses	Others[a]	Total motor vehicles
1971	0.682	0.576	0.343	0.094	0.17	1.865
1981	1.16	2.618	0.554	0.162	0.897	5.391
1991	2.954	14.2	1.356	0.331	2.533	21.374
2001	7.058	38.556	2.948	0.634	5.795	54.991

Annual growth rate, %

	All motor vehicles	Two wheelers
1971-1981	18.9	35.5
1981-1991	29.6	44.2
1991-2001	15.7	17.2

Source: Ministry of Road Transport and Highways (2004). [a] Others-includes tractors, trailers

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