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Spatial and Temporal Variations of SO_2, NO_x, PM_{10} and TSPM Concentration in Ambient Air of Jalna City, India

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Abstract

The ambient air quality monitoring data of Jalna City, India for SO_2, NO_x, PM_{10} and TSPM at two sites (residential and industrial) and over a one year period are presented within this paper. The diurnal and seasonal variation in concentrations of SO_2, NO_x, PM_{10} and TSPM has been analyzed. It has been observed that all pollutants showed higher concentration during daytime as compared to night. The seasonal cycle at both the sites generally showed for SO_2, PM_{10} and TSPM higher concentrations during the winter season. At both the sites no distinct seasonal cycle could be detected for NO_x. The annual mean concentrations recorded for SO_2, NO_x, PM_{10} and TSPM were 4.93µg/m^3, 26.68µg/m^3, 61.85µg/m^3 and 166.11µg/m^3 at residential site and 6.44µg/m^3, 64.64µg/m^3, 126.82µg/m^3 and 306.27µg/m^3 at industrial site. The annual mean concentrations of all four pollutants measured at residential site were found within the permissible limits of Indian National Ambient Air Quality Standards (NAAQS) whereas annual PM_{10} concentration at residential and industrial site violated the prescribed standard.

Highlights

- Higher concentrations of air pollutants at Industrial site as compared to residential site
- Air pollutant concentration higher during daytime as compared to night
- Air pollutants shows seasonal pattern with higher concentration during winter

Keywords: Ambient air quality, Air pollution, PM_{10}, TSPM, SO_2, NO_x

Urban areas of many developing countries are suffering from serious air pollution mainly due to over population, lack of sufficient public facilities (Tashiro and Taniyma, 2002), increasing development (Atash, 2007), automobile emissions (Lam *et al*., 1999; Baldauf *et al*., 2009; Hong-di *et al*., 2012) and industrialization (Harison and Yin, 2000; Kim *et al*., 2002; Skarek *et al*., 2007; Hrdlickova *et al*., 2008) posing a significant threat to human health, property and environment (Gupta, 2003; Celis, 2004; Zhang *et al*., 2007; Franchini and Mannucci, 2007; Allen *et al*., 2009; Kumar and Goyal, 2011). It has been estimated that 4.9 billion inhabitants out of 8.1 billion will be living in cities by 2030 (UNSCD, 2001). Besides impact on human health, air pollutants adversely influence many atmospheric processes including cloud formation, visibility, solar radiation, and precipitation and play a major role in acidification of clouds, rain and fog (Hong *et al*., 2002; Fang *et al*., 2002). Based on the potential to cause significant damage and occurrence, sulphur dioxide, oxides of nitrogen and particulates are the important pollutants identified by EPA. The concentrations of these airborne pollutants within a metropolitan city depend on many factors including strength and the distribution of local pollution sources, presence of distant pollution sources that have impact on the city, and metrological and topographical conditions of the area (Morawska *et al*., 2002) which causing spatial and temporal variations (Murthy, 2004; Gomiscek *et al*., 2004; Rao *et al*., 2009), hence have to be monitored regularly (Jacquinot *et al*., 2001).

Adequate knowledge of air quality parameters, their ambient levels, including spatial and temporal variations and appropriate field data are required in evaluating the exposure of population in urban area and sound management of that environment (Suess, 1979; Tiitta, *et al*., 2002) otherwise it would hamper environmental planning activities (Carmichael *et al*., 2003). This paper hence provides the temporal and spatial variation of atmospheric concentration of SO_2, NO_x, PM_{10} and TSPM in ambient air of Jalna City in India.

Materials and Methods

Study Area

Jalna district is approximately situated at the centre part of Maharashtra state and in northern direction of Marathwada region in India. The Jalna district lies between 19°1' to 21°3' North Latitudes and 75°4' to 76°4' East Longitude. It covers an area of 7,612 Km^2, which is 2.47% of total area of Maharashtra State in India. The district has a sub-Tropical climate, in which the bulk of rainfall is received from the southwest monsoon, between June to September. The average annual rainfall of the district ranges between 650 to 750 mm. The district often experiences drought with rainfall recording as low as 400 to 450 mm. The rainy season is followed by winter, which last up to February, during which the minimum temperature ranges between 9 to 10°C and maximum temperature ranges 30-31°C. The winter is followed by hot summer, which continues up to June. The maximum day temperature ranges between 42 & 43°C during summer.

Jalna is having good Industrial background, especially famous for the Seed and Steel industries. The industrial development at Jalna is widely based on Engineering, Plastic and Agriculture. At present six industrial areas are under Maharashtra Industrial Development Corporation (MIDC), Jalna accommodating Pulses mills, oil mills, refineries, steel re-rolling, plastic, tiles & cement pipe, fertilizers, insecticides, pesticides and the co-operative sugar factories. These industries and growing number of the automobiles are the major sources of air pollution in the city.

Sample Collection and Analysis

Particulate Pollutants (PM_{10} and TSPM)

The samples of PM10, TSPM, SO_2 and NOx were collected twice in a week from January – December, 2010 in selected industrial and residential site. High Volume air sampler (Model: RDS APM 460 NL with Gaseous sampling attachment APM 411 TE, Make: Envirotech India Pvt. Ltd) was used to collect the samples by running the equipment for a period of 24 hours.

The samples for particulate pollutants i.e. PM_{10} and TSPM were collected by drawing the air at a flow rate of 1.1 to 1.2 m^3 per minute for eight hours. The air inside the sampler passed through a combination of cyclone separator and filter in two stages. At the first stage, the cyclone separator was used to collect the bigger particles i.e. non respirable particulate matter (NRSPM) (particles size >10µm) in a previously weighed dust collector. The rest of the particulates i.e. PM_{10} (size <10µm) were collected over a previously dried and weighed glass micro fibre filters (Whatman GF/A, 203 X 254 mm). The concentration of PM_{10} and TSPM were calculated gravimetrically as per standard methods (CPCB, 2011).

Gaseous Pollutants (SO_2 and NO_x)

The ambient air samples for sulphur dioxide were collected by absorbing SO_2 from known volume of air in an absorbent solution of potassium tetrachloromercurate

Table 1. Monthly mean concentrations of SO_2 and NO_x at residential site (μg/m^3)

Month	SO_2				NO_x			
	Sampling Hours			24 hrs Mean	Sampling Hours			24 hrs Mean
	06-14 hrs	14-22 hrs	22-06 hrs		06-14 hrs	14-22 hrs	22-06 hrs	
Jan	3.95	5.07	5.19	4.74	18.03	31.91	32.96	27.63
Feb	3.92	5.31	4.06	4.43	37.68	24.64	29.32	30.54
Mar	4.13	2.82	3.72	3.56	23.79	23.67	30.99	26.15
Apr	4.43	4.56	3.98	4.32	30.97	29.93	31.46	30.79
May	6.44	5.00	3.89	5.11	37.78	27.88	24.22	29.96
Jun	8.26	5.22	4.11	6.14	25.72	31.02	26.32	28.98
Jul	5.09	5.04	3.12	4.46	29.89	25.85	18.41	24.90
Aug	5.70	4.00	3.71	4.47	29.80	22.37	19.84	24.00
Sep	4.90	4.69	4.10	4.57	21.36	17.24	16.98	18.53
Oct	4.14	4.48	4.41	4.34	25.18	23.02	20.20	22.80
Nov	4.36	4.57	5.53	4.82	23.46	22.79	21.95	22.73
Dec	11.90	7.54	5.10	8.18	43.98	33.13	22.48	33.20
Annual Average	5.60	4.86	4.24	4.93	28.97	26.12	24.59	26.68

Table 2. Monthly mean concentrations of SO_2 and NO_x at industrial site (μg/m^3)

Month	SO_2				NO_x			
	Sampling Hours			24 hrs Mean	Sampling Hours			24 hrs Mean
	06-14 hrs	14-22 hrs	22-06 hrs		06-14 hrs	14-22 hrs	22-06 hrs	
Jan	6.42	6.08	3.56	5.35	18.12	25.35	21.11	21.52
Feb	6.90	6.60	5.60	6.37	36.92	39.82	36.91	37.88
Mar	5.50	7.33	6.47	6.43	43.05	43.74	41.17	42.66
Apr	5.39	4.54	4.22	4.72	35.10	37.30	40.57	37.66
May	5.99	6.09	6.47	6.18	41.19	39.20	35.01	38.47
Jun	8.82	9.63	9.92	9.45	46.90	47.17	48.55	47.54
Jul	6.31	5.52	6.19	6.01	31.21	27.36	29.39	29.32
Aug	5.74	5.64	5.91	5.76	28.01	28.45	28.12	28.19
Sep	5.66	6.22	6.23	6.04	33.54	33.06	33.48	33.36
Oct	7.15	6.91	7.20	7.09	39.64	37.12	40.79	39.18
Nov	7.21	7.37	7.86	7.48	30.00	31.46	33.43	31.63
Dec	6.54	6.44	6.30	6.43	25.05	32.47	27.35	28.29
Annual Mean	6.47	6.53	6.33	6.44	34.06	35.21	34.66	34.64

Table 3. Diurnal and seasonal concentrations of pollutants at different sites (µg/m^3)

Pollutant	Industrial						Residential					
	Diurnal			Seasonal			Diurnal			Seasonal		
	06-14 Hr	14-22 Hr	22-06 Hr	Summer	Monsoon	Winter	06-14 Hr	14-22 Hr	22-06 Hr	Summer	Monsoon	Winter
SO_2	6.5	6.5	6.3	5.9	6.8	6.6	5.6	4.9	4.2	4.4	4.9	5.5
NO_x	34.1	35.2	34.7	39.2	34.6	30.2	29.0	26.1	24.6	29.4	24.1	26.6
PM_{10}	137.2	123.7	119.5	102.0	124.7	153.7	63.5	61.1	61.0	71.3	33.5	80.7
TSPM	346.3	315.3	257.2	281.5	283.4	354.0	191.9	154.0	152.5	181.7	131.3	185.3

Table 4. Monthly mean concentrations of PM_{10} and TSPM at residential site (µg/m^3)

Month	PM_{10}				TSPM			
	Sampling Hours			24 hrs Mean	Sampling Hours			24 hrs Mean
	06-14 hrs	14-22 hrs	22-06 hrs		06-14 hrs	14-22 hrs	22-06 hrs	
Jan	65.30	95.01	70.09	76.80	203.77	182.07	152.64	179.50
Feb	77.00	77.78	64.80	73.19	225.23	203.01	190.15	206.13
Mar	76.41	89.71	94.35	86.82	202.72	190.66	182.63	192.00
Apr	88.24	88.81	98.40	91.82	191.21	179.88	166.53	179.21
May	90.07	57.78	65.51	71.12	209.93	129.10	109.89	149.64
Jun	50.61	34.95	40.22	41.50	128.90	113.60	97.88	112.82
Jul	36.92	27.10	32.16	32.11	168.82	115.15	114.77	133.50
Aug	31.28	32.13	30.65	31.35	156.21	122.27	109.60	129.36
Sep	26.00	25.55	36.01	29.19	140.12	109.77	198.91	149.60
Oct	130.13	123.81	145.03	132.99	384.96	271.94	261.32	306.07
Nov	32.11	40.80	42.57	38.50	141.20	115.28	116.85	124.45
Dec	27.78	40.29	42.40	36.82	149.94	114.87	128.25	131.02
Annual Average	60.99	61.14	63.52	61.85	191.92	153.97	152.45	166.11

Table 5. Monthly mean concentrations of PM_{10} and TSPM at industrial site ($\mu g/m^3$)

Month	PM_{10}				TSPM			
	Sampling Hours			24 hrs Mean	Sampling Hours			24 hrs Mean
	06-14 hrs	14-22 hrs	22-06 hrs		06-14 hrs	14-22 hrs	22-06 hrs	
Jan	120.53	104.15	68.34	97.67	291.55	284.23	158.55	244.78
Feb	114.91	97.00	88.90	100.27	326.65	324.39	200.02	283.68
Mar	125.93	113.48	100.40	113.27	340.21	322.15	236.92	299.76
Apr	112.38	105.01	90.48	102.62	328.40	237.22	221.02	262.21
May	71.13	102.13	102.57	91.94	291.55	291.87	257.39	280.27
Jun	68.39	134.67	121.16	108.07	204.17	285.57	217.30	235.68
Jul	155.49	163.32	193.55	170.78	372.91	304.03	308.42	328.45
Aug	100.00	102.50	113.70	105.40	282.36	292.30	255.88	276.84
Sep	132.18	128.16	83.25	114.53	345.00	315.55	216.76	292.43
Oct	120.13	107.67	70.51	99.44	415.66	291.15	180.47	295.76
Nov	215.29	286.09	243.84	248.41	508.58	475.07	489.73	491.12
Dec	148.55	202.02	157.61	169.40	448.92	360.02	343.94	384.29
Annual Mean	123.74	137.18	119.53	126.82	346.33	315.29	257.20	306.27

(TCM). A stable dichlorosulphitomercurate complex formed was then made to react with para rosaniline and methyl sulphonic acid. The absorbance of the colored solution was measured at 530 nm using spectrophotometer. The concentration of sulphate ions formed in absorbent was calculated according to Modified West & Gaeke Method. (IS 5182(Part 2): 2001; CPCB, 2011).

Ambient nitrogen dioxides were collected by bubbling known volume of air through a solution of sodium hydroxide and sodium arsenite. The concentration of nitrite ion produced during sampling were determined calorimetrically by reacting the nitrite ion with phosphoric acid, sulphanilamide and N-(1-naphthyl)-ethy lenediamine di-hydrochloride (NEDA) and measuring the absorbance of the highly coloured azo-dye at 540 nm (Jacob and Hochheiser, 1958; IS 5182 (Part 6):2006; CPCB, 2011).

Results and Discussion

Gaseous Pollutants

The monthly and hourly mean concentrations of SO_2 and NO_x monitored at residential and industrial site has been presented in Table 1 and Table 2.

Sulphur dioxide (SO_2)

The monthly mean concentration of SO_2 at residential site was varied between 3.56-8.18 $\mu g/m^3$ whereas it was ranged between 4.72-9.45 $\mu g/m^3$ at industrial site (Table 1). The highest concentration of SO_2 (8.18 $\mu g/m^3$) at residential site was recorded in the month of December followed by June (6.14 $\mu g/m^3$). The lowest concentration of SO_2 (3.56 $\mu g/m^3$) was observed in the month of March at residential site. The industrial site recorded higher concentration of SO_2 during entire period of investigation as compare to residential site (Table.2). The SO_2 concentration at industrial site in the month of June (9.45 μg/m^3) was observed highest followed by November (7.48 μg/m^3) while 4.72 μg/m^3 was reported lowest in April.

The diurnal and seasonal trend in concentration of SO_2 was observed during the study (Table. 3). The highest seasonal concentration of SO_2 at residential site was observed in winter (5.52 μg/m^3) followed by monsoon (4.91 μg/m^3). Least concentration of SO_2 at residential site was observed in summer season (4.35 μg/m^3). The industrial site recorded highest concentration of SO_2 in monsoon (6.82 μg/m^3) followed by winter (6.59 μg/m^3) and lowest was reported similar to residential i.e. in summer (5.92 μg/m^3). The diurnal data (24 hourly i.e. 6-14 hrs, 14-22 hrs and 22-06 hrs) of SO_2 concentration at residential site ranged between 2.82-11.90 μg/m^3 (Table.1). The highest concentration 11.90 μg/m^3 was observed between morning hours (6-14 hrs) in December followed by June (8.26 μg/m^3). The lowest concentration (2.82 μg/m^3) was recorded during night hours (22-06 hrs μg/m^3) in March. The monthly mean diurnal concentrations of SO_2 at residential site did not shown any particular trend but annual mean reported higher concentrations during morning hours (6-14 hrs) (5.60 μg/m^3) followed by evening hours (14-22 hrs) (4.86 μg/m^3) whereas night hours (22-06 hrs) recorded lowest concentrations (4.24 μg/m^3). At industrial site SO_2 concentration showed different trend than residential site. The highest concentration (6.53 μg/m^3) was during evening hours followed by morning hours (6.47 μg/m^3) and lowest (6.33 μg/m^3) again during night hours (Table.3).

The annual mean concentration of SO_2 at residential and industrial site was recorded 4.93 μg/m^3 and 6.44μg/m^3 respectively which were well below the National Ambient Air Quality Standards (NAAQS) stipulated by Central Pollution Control Board (CPCB, 2009).

Oxides of nitrogen (NO_x)

The monthly mean concentrations of oxides of nitrogen (NO_x) at residential site were varied from 18.53-33.20μg/m^3 (Table.1). The highest monthly mean concentration was reported in December (33.20μg/m^3) followed by March (30.79μg/m^3) while 18.53μg/m^3 being lowest reported in September month. At industrial site the NO_x ranged from 21.52 to 47.54μg/m^3 with highest was recorded in the month June (47.54μg/m^3) (Table.2).

Seasonally, the highest mean concentration was observed during summer at both the sites. The lowest concentration of NO_x at residential site was observed during monsoon (24.10μg/m^3) while at industrial site it was recorded 30.16μg/m^3 during winter. Uniform diurnal concentration of NO_x at industrial site was observed. The NO_x levels were found higher (28.97μg/m^3) during morning hours than evening hours (26.12μg/m^3) followed by night hours (24.59μg/m^3) at residential site (Table.3).

The annual mean concentration of NO_x at residential and industrial site was recorded 26.68μg/m^{3}and 34.64μg/m^3 respectively which was found below the NAAQS (CPCB, 2009).

Automobiles and industries are the major contributors of sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) to ambient air (Baldauf *et al*., 2009; Muchate and Chaugule, 2011). The diurnal and seasonal concentration pattern of air pollutants is driven by emission characteristics of the dominant sources and the meteorological conditions (Gomiscek *et al*., 2004). Similar results were reported by Bhanarkar *et al*., 2002; Kaushik *et al*., 2006; Chauhan *et al*., 2010; Muchate and Chaugule, 2011.

Particulate Pollutants

The monthly and hourly mean concentrations of PM_{10} and TSPM monitored at residential and industrial site has been presented Table. 4 and Table. 5.

Respirable Suspended Particulate Matter (PM_{10})

The annual mean concentration of PM_{10} at residential site was observed 61.85μg/m^3 which is above the maximum permissible limits of NAAQS, India (Table.4). The highest monthly mean concentration 133μg/m^3 was recorded in the month of December while lowest reported during September with 29μg/m^3.

The diurnal trend resulted higher concentration of PM_{10} during morning hours followed by evening hours and lowest concentrations were reported during night hours at both the sites (Table.3). Seasonally, winter reported highest levels of PM_{10} at residential and industrial sites with 80.74 and 153.73µg/m^3 respectively. The monthly mean concentration of PM_{10} at industrial site was varied between 92-248µg/m^3 (Table 5). The annual mean reported was 119.33µg/m^3 at industrial site which violated the exiting NAAQS.

Total suspended particulate matter (TSPM)

The monthly mean concentration of TSPM was ranged between 113-306µg/m^3 and 236-384µg/m^3 and annual mean concentrations were recorded166µg/m^3 and 306µg/m^3 at residential and industrial sites respectively (Table.4 and Table 5). The highest monthly mean concentration at residential site was observed 306µg/m^3 in October followed by 206µg/m^3 in February. June recorded lowest monthly mean concentration of 113µg/m^3. At industrial site, highest TSPM concentration 491µg/m^3 was recorded during November followed by December (384µg/m^3) with lowest in June (236µg/m^3).

Significant seasonal variation in TSPM concentrations were found at both the monitoring sites. The highest TSPM levels were recorded in winter with 185 µg/m^3 and 354 µg/m^3 followed by summer (182µg/m^3 and 282µg/m^3) for residential and industrial stations respectively (Table.3). Lowest TSPM concentration was recorded in monsoon for both residential (131µg/m^3) as well as industrial (283µg/m^3) site. The annual average hourly data shows the declining trend in TSPM concentration for both the sites. The TSPM concentration was higher during morning hours (346µg/m^3) than evening hours (315µg/m^3) followed by lowest during night hours (257µg/m^3) at industrial site. The diurnal concentration of TSPM at residential site was found in the order of morning(06-14 hrs)>evening(14-22 hrs)>night(22-06 hrs) i.e. (192µg/m^3>154µg/m^3>152µg/m^3).

The major sources of particulate pollutants in ambient air are automobiles and industrial processes (Watkins, 1991: Nylund and Lawson, 2000; Hrdlickova *et al*., 2008). The seasonal pattern of PM_{10} and TSPM concentration can be seen from the monthly means as presented in Table. 3. Both the sites i.e. industrial and residential show a quite similar characteristic with highest mass concentration in winter followed by summer. The pattern is caused by meteorological effects (vertical mixing in summer and frequent inversions in winter) (Gomiscek *et al*., 2004). Gehring and Buchmann, 2003; Chauhan *et al*., 2010 reported similar results. The diurnal concentration pattern of air pollutants is driven by emission characteristics of the dominant sources and the meteorological conditions (Gomiscek *et al*., 2004). The pattern for urban sites are basically similar for both seasons (winter and summer) which suggests that the most important emission sources are seasonally independent for urban areas they are surely traffic emissions and industries (Buzorius *et al*., 1999). The maximum of the diurnal variation appeared around noon in the summer and during the afternoon hours in winter. This is due to the production and presence of the secondary aerosol built during photo-chemically active time (Gomiscek *et al*., 2004). Kuhlbusch *et al*., (2001) reported higher concentration of particulates during daytime compared to the night.

Conclusion

Analyses of the temporal and spatial variations of SO_2, NO_x, PM_{10} and TSPM based on one year study of continuous measurements at Jalna area (residential and industrial site) revealed that the particulate as well as gaseous pollutants concentrations at industrial site was found higher as compared to the residential site. The annual mean concentrations of gaseous pollutants measured at residential site were found within the permissible limits of Indian National Ambient Air Quality Standards (NAAQS) whereas PM_{10} concentration violated the prescribed limit at residential and industrial site.

The diurnal variation of concentrations of SO_2, NO_x, PM_{10} and TSPM showed higher concentration during daytime as compared to night. The seasonal cycle at both the sites generally showed for SO_2, PM_{10} and TSPM higher concentrations during the winter season. At both the sites no distinct seasonal cycle could be detected for NO_x.

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