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Assessment of urban air pollution and it's probable health impact

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Abstract: *The present study deals with the quantitative effect of vehicular emission on ambient air quality during May, 2006 in urban area of Lucknow city. In this study, SPM, RSPM, SO_2, NO_x and 7 trace metals associated with RSPM were estimated at 10 representative locations in urban area and one village area for control. Beside this, air quality index (AQI), health effects of different metals and mortality were assessed. The 24 hr average concentration of SPM, RSPM, SO_2 and NO_x was found to be 382.3, 171.5, 24.3 and 33.8 $\mu g\ m^{-3}$ respectively in urban area and these concentrations were found to be significantly ($p<0.01$) higher by 94.8, 134.8, 107.4 and 129.6% than control site respectively. The 24 hr mean of SPM and RSPM at each location of urban area were found to be higher than prescribed limit of National Ambient Air Quality Standard (NAAQS) except SPM for industrial area. The 24 hr mean concentration of metals associated with RSPM was found to be higher than the control site by 52.3, 271.8, 408.9, 75.81, 62.7, 487.54 and 189.5 % for Fe, Cu, Pb, Zn, Ni, Mn and Cr respectively. The inter correlation of metals Pb with Mn, Fe and Cr; Zn with Ni and Cr; Ni with Cr; Mn with Fe and Cu with Cr showed significant positive relation either at $p<0.05$ or $p<0.01$ level. Metals Pb, Mn and Cr ($p<0.01$) and Cu ($p<0.05$) showed significant positive correlation with RSPM. These results indicate that ambient air quality in the urban area is affected adversely due to emission and accumulation of SPM, RSPM, SO_2, NO_x and trace metals. These pollutants may pose detrimental effect on human health, as exposure of these are associated with cardiovascular and respiratory diseases, neurological impairments, increased risk of preterm birth and even mortality and morbidity.*

Key word: *Air pollutants, Air quality index, Metals, Health risk*
PDF of full length paper is available online

Introduction

Urban air pollution due to vehicular emission is a matter of concern because of exposure of large number of people to it. Vehicular emission is responsible for higher level of air pollutants like SPM, RSPM, SO_2, NOx and other organic and inorganic pollutants including trace metals and their adverse effects on human and environmental health (Caselles *et al.,* 2002; Kaushik *et al*., 2006; Maitre *et al.,* 2006 ; Curtis *et al.,* 2006; Sharma *et al.,* 2006; Jayaraman, 2007). Technological upgradation and scientific know how has reduced the pollution level, especially of the gaseous pollutants, but increase in number of vehicles causes more emission of pollutants and also changes the composition ratio of the pollutants especially the particulate matter (Zanini *et al.,* 2006), which includes the fine and ultrafine particles. Vehicular exhaust is one of the most important source of fine particles (Nolte *et al.,* 2002; Fang *et al.,* 2005; Barman *et al.,* 2008). The major sources of air pollutants which are secondary sulphates, wood combustion, diesel and gasoline powered exhaust and road dust are responsible for the higher level of air pollutants in urban area especially of the PM. Besides that, various types of vehicles and their different operating modes such as idling, stop and start, accelerating and decelerating, combined with a high density of vehicles leads to a pollution source problem (Kumar *et al.,* 2001). Many trace metals are present in leaded and unleaded petrol, diesel oil, antiwear substances which are added to lubricants, brake pads and tyres and are emitted by vehicles *via* their exhaust pipe (Monacci and Bargagli, 1997).

The respirable particles are responsible for the cardiovascular as well as respiratory diseases (Sagai *et al.,* 1996) of human being because these particles can penetrate deep into the respiratory system, and studies indicates that the smaller the particle, more severe the health impacts (Dockery *et al.,* 1993; Pope et *al.,* 1995; Schwartz *et al.,* 1996). Ambient particulate matter may be carriers of acidic or toxic species (*e.g.*, heavy metals, acids and carcinogenic organic compounds) and may have detrimental effects on human health and ecosystems. Besides the effect of particulate matter, literature also suggests that there is a strong relationship between higher concentration of SO_2 and NOx and several health effects (Curtis *et al.,* 2006), like cardiovascular diseases (Zanobetti and Schwartz, 2002; Peters *et al.,* 2004; Chen *et al.,* 2005; Dockery e*t al.,* 2005) respiratory health effects such as asthma and bronchitis (Ye *et al.,* 2001; Barnett *et al.,* 2005) and reproductive and developmental effects such as increased risk of preterm birth (Liu *et al*., 2003).

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At elevated concentrations all the metals are harmful to living beings including humans (Yasutake and Hirayama, 1997). Exposure can occur through a variety of routes; among which inhalation of particles (< 10 μm) is one of the important routes. The inorganic components constitute a small portion by mass of the particulates; however, it contains some trace elements such as As, Cd, Co, Cr, Ni, Pb and Se which are human or animal carcinogens even in trace amounts (ATSDR, 2003; Wang *et al.,* 2006). The high level of Pb can induce severe neurological and hematological effects on the exposed population especially children, whereas Cd and Ni are known for inducing carcinogenic effects in humans through inhalation. Occupational exposure of Cd is a risk factor for chronic lung diseases (Benoff *et al.,* 2000). Cr (VI) is known to have toxic and carcinogenic effects on the bronchial tree (Hu *et al.,* 2002; Manalis *et al.,* 2005). Mn exposure leads to increased neurotoxic impairments (Santos-Burgoa *et al.,* 2001). The increased level of Cu can lead to respiratory irritance (ATSDR, 2002; Manalis *et al.,* 2005).

Vehicular traffic is the main source of particulate air pollution in Lucknow city (Kisku *et al.,* 2003; Sharma *et al.,* 2006; Barman *et al.,* 2008). Continuous emission of pollutants from vehicular traffic is a matter of concern because of adverse effects on ambient air quality as well as on the human health. The number of vehicles registered with RTO (Regional Transport Office) Lucknow is 8,24,003 as on 31.03.2006 which is 9.89% higher over the last year. As per Indian Oil Corporation (IOC), the consumption/sale of diesel and petrol was 1,15,480 and 96,009 KL as on 31-03-2006. Considering the above, assessment of ambient air quality of Lucknow city was carried out at 11 locations during pre monsoon (May), 2006 with respect to SPM, RSPM, SO_2 and NO_x and trace elements associated with RSPM. The quantification of the main pollutants due to vehicular emission is the primary objective of the study while probable health effects due to these pollutants are secondary.

Materials and Methods

Site and sample collection: Lucknow is the capital of Uttar Pradesh, India, situated in Northern India with a population of 2.245 million, (2001 census) and lies between 26°52' Latitude and 80°56' Longitude. Monitoring of SPM, RSPM, SO_2, and NOx were done in the ambient air of Lucknow city at 10 locations (four residential areas namely Aliganj, Vikas Nagar, Indira Nagar and Gomti Nagar; five commercial- Hussainganj, Charbagh, Alambagh, Aminabad and Chowk, and One Industrial area- Amausi) and one location at village area (Gourigaon) considered as control. Monitoring was conducted during the month of May, 2006 for 2 days, 24 hr for TSPM and RSPM and 8 hr for SO_2 and NOx. Trace metals namely Fe, Zn, Cu, Pb, Mn, Ni and Cr associated with RSPM were estimated.

Monitoring and analysis: Monitoring of SPM and RSPM was carried out using Respirable Dust Sampler (Model-415, Envirotech, New Delhi) at a flow rate of 1.0- 1.2 $m^3 min^{-1}$ for 24 hr (6.0 A.M. to 6.0 A.M.) and SO_2 and NOx 8 hr (6.0 A.M. to 2.0 P.M, 2.0 P.M to 10:00 P.M. and 10 P.M. to 6 A.M) . The Respirable Dust sampler has been provided with a cyclone for the separation of RSPM. The suspended particles enters the cyclone, coarse non-respirable dust is separated from the air stream by centrifugal forces. The suspended particulate matter falls through the cyclone's conical hopper and gets collected in the cyclonic-cup. The fine dust comprising the respirable fraction of SPM passes through the cyclone and gets collected on filter paper.

Preweighed cellulose filters, Whatman (EPM-2000) of 20 x 25 cm size were used and reweighed after sampling in order to determine the mass of the particles collected (RSPM). The concentration of the particulate matter in the ambient air was then computed on the net mass collected divided by the volume of air sampled. The amount of non-respirable suspended particulate matter (NRSPM) was summed up with respirable particulate matter (RSPM) for calculation of SPM (Suspended Particulate Matter). The sampling instruments were fixed at a breathing height of 1.5 m above the ground level.

The analysis of SO_2 and NO_x was done by Bureau of Indian Standard methods IS 5182 (Part II): and IS 5182: (Part VI) (IS: 2001 and 1975) respectively. A known quantity of air was passed through the impinger containing known volume of absorbing solution; SO_2 was absorbed in absorbing solution, sodium tetrachloromecurate. A dichlorosulphitomercurate complex was formed which was made to react with para-rosaniline and methysulphonic acid. The absorbance of the solution was measured at a wavelength of 560 nm on spectrophotometer (Spectronic-20). Whereas, Nitrogen oxides (NOx) as nitrogen dioxide (NO_2) was absorbed in absorbing solution, sodium hydroxide which formed a stable solution of sodium nitrite. The nitrite ion so produced, was determined colorimetrically at wavelength 540 nm by reacting the exposed absorbing reagent with phosphoric acid, sulphanilamide and N (1-naphthyl) ethylenediamine dihydrochloride.

Air quality index (AQI): The Air Quality Index (AQI) was calculated using the method suggested by Tiwari and Ali (1987) and followed by Kaushik *et al.,* (2006). For AQI, the air quality rating of each pollutant was calculated first by the following formula.

$$Q = 100 \frac{V}{Vs}$$

Where, Q represents quality rating, V the observed value of the pollutant and Vs the standard value recommended for that pollutant. The Vs values used are the recommended national ambient air quality standards (CPCB 1994), for different areas.

Metal analysis: Total sixty-nine circles of 1" diameter [(11 locations + 1 blank (unexposed filter paper)] were punched out in triplet from the sampled filter paper and digested with concentrated nitric acid on hot plate till white fumes arose and reduced to 2-3 ml. The content was filtered through Whatman filter paper no. 42 and final volume made-up to 25 ml by double distilled water. The filtrate was examined for the concentration of, Fe, Zn, Cu, Pb, Mn, Ni, and Cr

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by AAS (Model-AAnalyst 300, Perkin Elmer, USA). The AAS values of blank filter papers of each metal were deducted from the sample value for final calculations. The instrument was calibrated for each metal using known CRM (Accucheck) before analysis.

Statistical analysis: Groups (locations area) were compared by one way analysis of variance (ANOVA) and the significance of mean difference of different groups with control was done by Dunnett's post hoc test. Association between pollutants was done by Pearson correlation. All analysis were performed on $\log_{10}$ transformed data. A two-tailed (α=2) probability $p<0.05$ was considered to be statistically significant. STATISTICA (version 7.0) were used for the analysis.

Health risk assessment: The average metal concentration at each location of residential, commercial, industrial and village area (control site) was compared with appropriate standards for characterization of health risk with reference to the ingestion quantity of metals by human beings. For this, the ventilation rates of 20 m^3 day^{-1} for adults and 6 m^3 day^{-1} for 2 year old children were used (LaGrega *et al.,* 1994; Khodja *et al.,* 2007) and discussed the effect of metals on human health if ingested at elevated level.

Results and Discussion

Levels of SPM, RSPM, SO_2 and NOx: In residential areas, the average concentration of SPM and RSPM, were found to be 374.5 (315.6-442.8) and 168.2 (141.9-199.9) $\mu g\ m^{-3}$ respectively whereas, SO_2 and NOx were found to be 21.5 (18.0-25.7), 31.3 (27.4-36.6) $\mu g\ m^{-3}$ respectively. In Commercial areas, the average concentration of SPM and RSPM, were found to be 399.5 (361.0-432.2) and 180.2 (154.6-206.5) $\mu g\ m^{-3}$ respectively whereas, SO_2 and NOx were found to be 27.9 (21.0-32.4), 38.4 (27.0-46.0) $\mu g\ m^{-3}$ respectively. In the only industrial area and village area, Gourigaon (Control) the concentration was found to be 327.8 and 196.3 for SPM, 141.4 and 73.1 for RSPM, 16.9 and 11.7 for SO_2 and 20.0 and 14.7 $\mu g\ m^{-3}$ for NOx respectively (Table 1). The mean concentration of air pollutants (SPM, RSPM, SO_2 and NOx) found in the reducing order of Village area (Control) < Industrial area < Residential area < Commercial area. Overall the mean concentration of pollutants at all the urban locations were found to be significantly ($p< 0.001$) higher than the control site which was in the order of 134.8 (RSPM) > 129.6 (NOx) > 107.4 (SO_2) and 94.8% (SPM) (Fig. 1). The RSPM fraction in the SPM, over all the urban locations varied between 41.7 to 49.3 and the minimum was 37.2% at the control site .

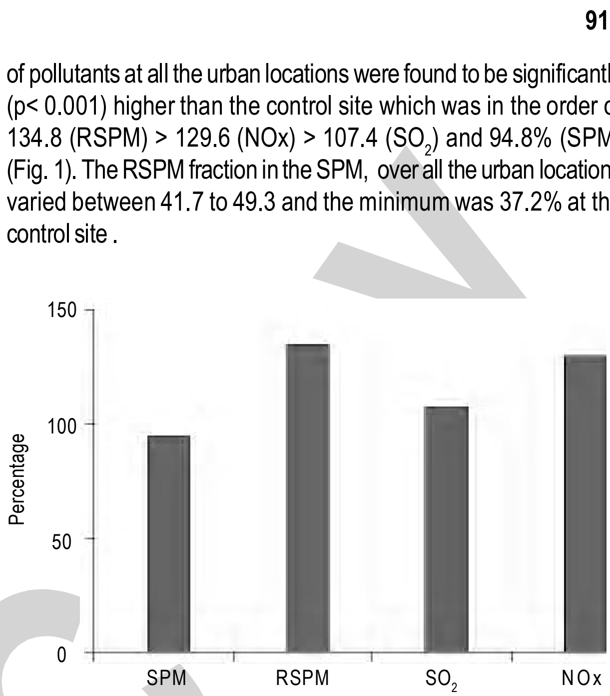

Fig. 1: Percentage of air pollutants in urban with respect to control area during 2006

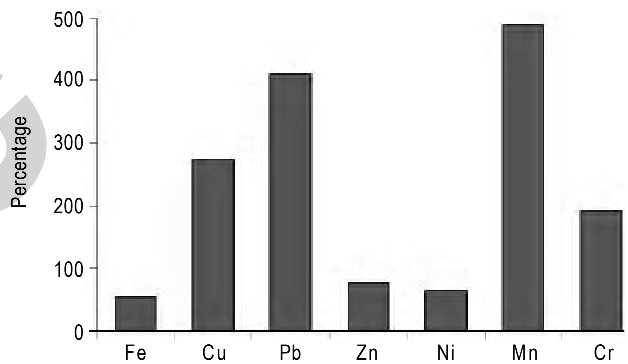

Fig. 2: Percent of trace metal concentration in urban site with respect to control during 2006

Table - 1: Mean concentration ($\mu g\ m^{-3}$) of air pollutants (SPM, RSPM, SO_2 and NOx) and air quality index (AQI) at different locations

Area/Location	SPM	RSPM	SO_2	NOx	AOI	Description
Residential	374.5	168.2	21.5	31.3	V	Polluted
Aliganj	371.6	161.6	21.3	32.8	V	Polluted
Vikas Nagar	368.0	169.9	20.9	27.4	IV	Moderately polluted
Indira Nagar	442.8	199.9	25.7	36.6	V	Polluted
Gomti Nagar	315.6	141.9	18.0	28.5	IV	Moderately polluted
Commercial	399.5	180.2	27.9	38.4	V	Polluted
Hussainganj	432.2	180.3	30.5	44.6	V	Polluted
Charbagh	414.5	206.5	32.4	46.0	V	Polluted
Alambagh	389.4	169.5	28.8	38.4	V	Polluted
Chowk	361.0	154.6	27.1	36.2	V	Polluted
Aminabad	400.7	190.4	21.0	27.0	V	Polluted
Industrial areaAmausi	327.8	141.4	16.9	20.0	III	Fairly Clean
Village area (Gaurigaon)	196.3	73.1	11.7	14.7	II	Clean

The 24 hr mean concentration of SPM and RSPM, at all the locations in urban area were found higher than the respective prescribed National Ambient Air Quality Standards (NAAQS) except SPM for industrial area Amausi. Whereas the mean concentration of gaseous pollutants were within the limit of NAAQS. On the other hand the Air Quality Index (AQI) based on the calculation of 24 hr average concentration of SPM, RSPM, SO_2 and NOx at different locations showed moderately (IV) polluted to polluted (V) category at all the residential and commercial areas, whereas, the only industrial and village area (Gourigaon) showed fairly clean (III) and clean (II) category respectively (Table 1). Higher index values indicates higher health risks and maximum value was found in the commercial area of Charbagh. The only industrial area showed fairly clean category because of higher NAAQS.

Table - 2: Location wise summary (Mean ± SE) of total trace metals concentrations (ng m^{-3})

Locations	Metals		
	Min.	**Max.**	**Mean ± SE**
Residential area (mean)	3.18	1066.98	155.21 ± 22.24
Aliganj	6.42	559.96	140.72 ± 77.63
Vikas Nagar	3.30	541.30	116.87 ± 73.76
Indira Nagar	9.37	1066.98	219.42 ± 144.52
Gomti Nagar	3.18	856.66	143.84 ± 118.90
Commercial area (mean)	5.96	2434.85	235.15 ± 44.52
Hussainganj	7.07	745.94	142.77 ± 101.46
Charbagh	11.93	1165.11	217.48 ± 158.78
Alambagh	6.54	1476.63	255.98 ± 204.44
Chowk	7.88	945.56	169.94 ± 129.65
Aminabad	5.96	2434.85	396.77 ± 339.83
Industrial area			
Amausi	4.74	506.47	118.02 ± 67.46
Village area (Control)			
Gourigaon	2.39	676.34	111.74 ± 92.81

Metal concentration in ambient air: Mean concentrations of total trace metals in each location (between locations) and each metal concentration within locations has been shown in Table 2 and 3 respectively.

The 24 hr mean concentration of metals were found to be Fe = 1029.65 (506.47- 2434.85), Cu = 127.64, (40.12-266.67), Pb = 74.60 (23.28 – 249.95), Zn = 49.63 (18.93-99.89), Ni = 36.77 (22.40-52.45), Mn =19.80 (4.74 -73.02), Cr = 6.92 (3.18-11.93) ng m^{-3} and which were Fe = 51.54, Zn = 75.81, Cu = 271.6, Pb = 408.93, Mn = 444.65, Ni = 62.73 and Cr = 189.46% higher than the control site (village area) (Fig. 2).

The maximum mean concentrations of all metals were found at Aminabad (396.77 ng m^{-3}) and minimum at Amausi (118.02 ng m^{-3}) among the urban locations. Similarly, maximum and minimum mean concentration was found for Fe (1029.95 ng m^{-3}) and Cr (6.92 ng m^{-3}) respectively. The hierachy of metals were arranged in descending order of their mean concentrations as given below.

Metals: Fe>Cu>Pb>Zn>Ni> Mn>Cr

Inter correlations of metals (Table 4), Pb with Mn ($r=0.57$, $p<0.01$), Fe ($r=0.47$, $p<0.05$), Cr ($r = 0.62$, $p<0.01$); Zn with Ni ($r = 0.43$, $p<0.05$) and Cr ($r=0.65$, $p < 0.01$); Ni with Cr ($r = 0.44$, $p<0.05$), Mn with Fe ($r =0.81$, $p<0.01$) and Cu with Cr ($r = 0.49$, $p<0.05$) were found significantly correlated with each other indicating that their sources are the same. Similarly SPM, RSPM, SO_2 and NOx also show very strong correlations ($p<0.01$) with each other. Metals Pb, Cu and Cr which showed a significant association with

Table - 3: Summary statistics (Mean ± SE) of different pollutants in ambient air of urban and village (control) areas.

Pollutants	Village area control (n=2)	Urban areas of Lucknow			Lucknow total (n=20)
		Residential (n=8)	Commercial (n=10)	Industrial (n=2)	
Particulates ($\mu g\ m^{-3}$)					
SPM	196.30 ± 20.80	374.46 ± 20.15**	399.54 ± 11.83**	327.75 ± 19.45**	382.33 ± 10.94**
RSPM	73.10 ± 14.10	168.19 ± 8.67**	180.23 ± 7.46**	141.35 ± 6.75**	171.53 ± 5.61**
Gaseous ($\mu g\ m^{-3}$)					
SO_2	11.65 ± 0.75	21.49 ± 1.19**	27.95 ± 1.33**	16.90 ± 1.40^{ns}	24.26 ± 1.20**
NO_x	14.65 ± 0.85	31.34 ± 1.55**	38.44 ± 2.35**	20.00 ± 1.60^{ns}	33.76 ± 1.84**
Metals (ng m^{-3})					
Pb	14.66 ± 1.09	98.38 ± 33.23**	65.83 ± 4.22**	23.28 ± 1.12ns	74.60 ± 13.95**
Zn	28.23 ± 5.59	38.90 ± 7.54^{ns}	48.33 ± 7.00^{ns}	99.89 ± 7.99*	49.63 ± 6.01^{ns}
Ni	22.00 ± 3.04	35.54 ± 4.49^{ns}	35.78 ± 4.57^{ns}	46.21 ± 2.48^{ns}	36.77 ± 2.91^{ns}
Mn	3.76 ± 0.68	13.71 ± 2.53^{ns}	27.62 ± 8.73*	5.02 ± 1.41^{ns}	19.80 ± 4.75*
Fe	682.64 ± 31.53	756.22 ± 95.68	1353.62 ± 203.05^{ns}	524.35 ± 109.30^{ns}	1029.65 ± 129.83^{ns}
Cu	34.82 ± 2.45	137.77 ± 35.78*	117.26 ± 11.03*	132.14 ± 35.07^{ns}	127.64 ± 15.14**
Cr	2.39 ± 0.02	5.96 ± 1.09^{ns}	7.88 ± 0.73**	5.94 ± 1.28^{ns}	6.92 ± 0.60**

* = Significant ($p<0.05$), ** = Significant ($p<0.01$), ns = Not significant ($p>0.05$)

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Table - 4: Correlation (DF=20) between different pollutants in ambient air of all the study areas

	SPM	RSPM	SO_2	NOx	Pb	Zn	Ni	Mn	Fe	Cu	Cr
SPM	1.00										
RSPM	0.97**	1.00									
SO_2	0.81**	0.79**	1.00								
NOx	0.82**	0.79**	0.94**	1.00							
Pb	0.79**	0.77**	0.68**	0.69**	1.00						
Zn	0.34	0.32	0.22	0.17	0.23	1.00					
Ni	0.30	0.30	0.08	0.04	0.22	0.43*	1.00				
Mn	0.51*	0.57**	0.43*	0.42*	0.57**	0.00	0.14	1.00			
Fe	0.34	0.37	0.32	0.30	0.47*	0.10	0.14	0.81**	1.00		
Cu	0.53*	0.51*	0.48*	0.42*	0.26	0.25	0.21	0.02	-0.11	1.00	
Cr	0.74**	0.71**	0.77**	0.75**	0.62**	0.65**	0.44*	0.35	0.29	0.49*	1.00

* = Significant ($p<0.05$), ** = Significant ($p<0.01$), Unmarked = Not significant ($p>0.05$)

Table - 5: Comparison of PM_{10} with national ambient air quality standard (NAAQS) and mortality rate during 2006

Area / Locations	RSPM (PM10) (µg m^{-3})	NAAQS	Relative difference (%)	Mortality rate (%)
Residential	168.2	100	68	6.8
Aliganj	161.6		62	6.2
Vikas Nagar	169.9		70	7.0
Indira Nagar	199.9		100	10.0
Gomti Nagar	141.9		42	4.2
Commercial Area	180.3	100	80	8.0
Hussainganj	180.3		80	8.0
Charbagh	206.5		107	10.7
Alambagh	169.5		70.0	7.0
Chowk	154.6		55	5.0
Aminabad	190.4		90	9.0

Table - 6: Probable exposure/ventilation of air pollutants and trace metals and health risk in child and adult people of Lucknow city

Pollutants / Metal	Concentration (ng m^{-3})	Adults (70 kg) intake		2-year old Children		Standard
		µg day^{-1}	µg $(kg.day^{-1})$	µg day^{-1}	µg $(kg.day^{-1})$	
RSPM	171.50	3432.30	49.03	1029.6	79.20	Adult=2000.0 µg day^{-1} Child= 600.0 µg day^{-1} Calculation based on NAAQS
Pb	74.60	1.49	0.0209	0.45	0.034	*Tolerable daily intakes = 7.14 and 3.57 µg $(kg.d)^{-1}$ for adults/ and children respectively
Zn	49.63	0.99	0.0132	0.30	0.021	—
Ni	36.78	0.74	0.0105	0.221	0.02	**RfD for chronic oral exposure=20 µg $(kg.day)^{-1}$
Mn	19.80	0.40	0.01	0.12	0.01	***RfD for chronic inhalation and oral exposure = 0.0114 and 10 µg $(kg.day)^{-1}$ for adults/ and children respectively
Fe	1029.65	20.27	0.29	6.08	0.47	—
Cu	127.64	2.55	0.04	0.77	0.06	****Intermediate-duration oral MRL (14-365 days) = 0.1 µg $(kg.day)^{-1}$
Cr	6.92	0.14	0.0016	0.04	0.003	*****RfD for chronic oral exposure=3 µg $(kg.day)^{-1}$

* = Organisation Mondiale de la Sante (OMS) 1987 , ** = IRIS 1996, *** = LaGrega *et al.*, 1994, **** = ATSDR 2002, ***** = ATSDR 2000

SPM, RSPM, SO_2 and NOx suggest their inter-dependence. Sharma *et al.,* (2006) estimated metal concentrations in ambient air PM_{10} (RSPM) of Lucknow city during May, 2005 and also found the same association among metals as well as PM_{10}. The correlation of some metals (Pb, Fe, Cu and Cr) which differ with previous study (Sharma *et al.,* 2006) might be due to the change in fuel used (increasing number of diesel, CNG, LPG run vehicles) and their technologies.

Spatial variation of pollutants: In, Urban area the concentration of air pollutants (SPM, RSPM, SO_2 and NO_x in µg m^{-3}) including

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total metals (ng m^{-3}) was found to be higher than control site (Gourigaon) at all the locations *i.e.* Aliganj, Vikas Nagar, Indira Nagar, Gomti Nagar (residential area), Hussainganj, Charbagh, Alambagh, Chowk, Aminabad (commercial area), Amausi (industrial area). The details are summarized below in descending order:

SPM (μg m^{-3}): Indira Nagar (442.8) > Hussainganj (432.2) > Charbagh (414.5) > Aminabad (400.7) > Alambagh (389.4) > Aliganj (371.6) > Vikas Nagar (368.0) > Chowk (361.0) > Amausi (327.8) > Gomti Nagar(315.6) > control site (196.3).

RSPM(μg m^{-3}): Charbagh (206.5) > Indira Nagar (199.9)> Aminabad (190.4)> Hussainganj (180.3) > Vikas Nagar (169.9) > Alambagh (169.5)> Aliganj (161.60) > Chowk (154.6) > Gomti Nagar (141.9) > Amausi (141.4) > control site (73.1).

SO_2 (μg m^{-3}): Charbagh (32.4) > Hussainganj (30.5) >Alambagh (28.8) > Chowk (27.1) > Indira Nagar (25.7) > Aliganj (21.3) > Aminabad (21.0)> Vikas Nagar (20.9) > Gomti Nagar (18.0) > Amausi (16.9) > control site (11.7).

NOx (μg m^{-3}) : Charbagh (46.0) > Hussainganj (44.6) > Alambagh (38.4) > Indira Nagar (36.6) > Chowk (36.2) > Aliganj (32.8) > Gomti Nagar(28.5) > Vikas Nagar (27.4) > Aminabad (27.0) > Amausi (20.0) > control site (14.7).

AQI : Charbagh (99.9) > Hussainganj (95.4) > Indira Nagar (89.8) > Alambagh (86.9) > Chowk (80.9) > Aliganj (75.7) > Vikas Nagar (72.7) > Gomti Nagar (65.1) > control site (37.3) > Amausi (34.7).

Total metal concentration in ambient air (ng m^{-3}) = Aminabad (2777.38) > Alambagh (1791.89)> Charbagh (1522.39) > Indira Nagar (1493.74)> Chowk (1189.55) > Gomti Nagar (1006.91) > Hussainganj (999.4) > Aliganj (985.02) > Amausi (826.17) > Vikas Nagar (818.06) > control site (782.18).

The results of the present study were compared with our earlier study during pre monsoon, 2005 (ITRC report 2005; Sharma *et al.,* 2006) during the year 2005 and it was found that the average concentration of air pollutants like SPM and RSPM at ten locations of urban area, showed slightly higher value in 2006 which was 1.72 and 7.46% respectively than the previous year whereas SO_2 showed 15.51% higher value but NOx showed 27.44% lower value than the previous year value. On the other hand in case of metal, the average concentrations of total metals (7 metals) of all the locations decreased 24.61% and incase of individual metal Pb = 113.67, Zn = 47.91, Fe=20.63, Cu = 26.66 and Cr = 84.54% were found at lower concentrations whereas only Ni= 363.77 and Mn = 5.46% higher value than the previous year value.

The decrease of metal concentration might be due to the composition of the vehicles types. In Lucknow city, CNG vehicles have been introduced in recent past especially the city bus and auto rickshaw. There might be an influence of the prevailing meteorological conditions which are responsible for the dispersion of fugitive emissions of road side soil dust.

Tripathi *et al.* (2004) reported on the concentration of SPM and trace metals at 4.5 m height of a residential area of Mumbai and found average SPM level 134 μg m^{-3} and the concentration of Cr= 5.0, Cu = 158, Fe = 1620, Mn = 40.39, Pb = 100.6, Zn = 260 ng m^{-3}. Shukla *et al.,* (2006) reported monitoring values during the June 2003 of 2 locations of Delhi Metro city with higher concentration of SPM (414-849 μg m^{-3}) and RSPM (256-551 μg m^{-3}). Badhwar *et al.* (2006) reported based on the data generated to determine the status and trends in different major cities under National Ambient Air Quality Programme and found that the concentration of SPM and PM_{10} exceeds the NAAQS at almost all the locations whereas the level of SO_2 and NOx were within the NAAQS and showed decreasing trends in major cities like Delhi, Kolkata, Chennai, Bhopal, Lucknow. Bhaskar *et al.* (2008) observed that the concentrations of RSPM varied from 88.1 to 226.9 μg m^{-3} and Pb level ranged between 0.21 to 1.18 μg m^{-3} during the monitoring period (July 2005 to June 2006) at six locations of Madurai city (India). They noticed that the maximum concentration of RSPM was found in the month of May at all the sites and during the summer season the average value of RSPM was 158.8 μg m^{-3}.

Health risk: At elevated levels, all the pollutants including metals have adverse effects on human and environmental health. Accumulation of pollutants in the human body through inhalation of air is an important route. Results of present study revealed that higher level of particulate matter especially the RSPM, is more dangerous for human health and responsible for several cardiovascular and respiratory diseases such as asthma, bronchitis, reproductive development, increased risk of preterm birth and even mortality and morbidity rate. Lippmann (1998) estimated that the total daily mortality increased by approximately 1% for every 10 μg m^{-3} increase in RSPM concentration. Keeping in view this fact and considering NAAQS as a standard we predicted the mortality rate (%) for all the locations which exceeded the NAAQS value. Mortality rate in Charbagh was calculated to be highest (10.7%) and minimum was in Gomti Nagar (4.2%). The effect of PM depends on the mass and number concentration, shape and size and the composition and concentration of other inorganic and organic pollutants associated with it.

In the present study inhalation/deposition fluxes of the average concentration of particulate matter (RSPM) and each metal of the urban locations were calculated daily by considering ventilation rates of air 20 m^3 day^{-1} for 70 kg adult and 6 m^3 day^{-1} for 2 year child suggested by LaGrega *et al.* (1994) and followed by Khodja *et al.* (2007) for human risk characterization. Calculations revealed (Table 6) that inhalation of RSPM by 70 kg adult is 3366 μg d^{-1} and 1009 μg d^{-1} for 2 year child. Normally it would be below 2000 and 600 μg d^{-1} respectively (value calculated by considering the NAAQS *i.e.* 100 μg m^{-3}) (CPCB 1994). The concentration of RSPM at all the commercial and residential areas showed higher than the permissible values and based on AQI, all the locations are either in polluted or moderately polluted category and might be due to the harmful effect of the RSPM dwelling in the area.

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In the present study, the concentration of SO_2 and NOx were found to be below permissible limit (80 µg m^{-3}) of NAAQS (CPCB, 1994), but there are several reports that gaseous pollutants are related with respiratory diseases and reproductive and developmental effect even at low concentration (Curtis *et al.,* 2006; Liu *et al.,* 2003). Jayaraman (2007) reported 32.5% increase of hospital admission in Delhi which is associated with SO_2 level below NAAQS. Vineis *et al.,* 2004 reported that in four out of five studies in Europe and US exposure to higher outdoor level of PM_{10}/$PM_{2.5}$, vehicle traffic and NO_2 are associated with significantly higher risk of lung cancer.

Concentration of seven metals of RSPM were reported in this study and their inhalation/ventilation for adult (70 kg) and child (2 year) were calculated (LaGrega *et al.,* 1994) and compared with available standards (Table 6).

The daily average inhalation rate originating from RSPM was for Pb = 1.49 and 0.45; Zn = 0.99 and 0.30; Ni = 0.74 and 0.22 ; Mn= 0.40 and 0.12, Fe = 20.27 and 6.08; Cu = 2.55 and 0.77; Cr = 0.14 and 0.04 µg d^{-1} for adults and Children respectively. These values were below the tolerable limits (Table 6) for all sources but such continuous additional exposure contributes to the total intake of the human body and may pose serious threat in the long duration.

The quantitative results of SPM, RSPM, SO_2, NOx and trace metals indicated that urban area is polluted due to the accumulation of these pollutants which were found to be several times higher than the control area. All the 24 hr average concentrations of SPM and RSPM were found to be higher than the NAAQS. Correlation of metals showed that the RSPM were significantly correlated with Pb, Mn, Cu and Cr indicating that the same sources might be due to the vehicular pollution.

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