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Studies on Respirable Particulate Matter and Heavy Metal Pollution of Ambient Air in Delhi, India

[1]Pramod R. Chaudhari, [2]D.G. Gajghate, [3]Dheeraj Kumar Singh
[1,2]National Environmental Engineering Research Institute, Nehru Marg, Nagpur (Maharashtra) (India)
[3] Grass Roots Research and Creation India (P) Ltd., F-375, Sec 63, Noida 201301 (U.P.) (India)

Abstract : *Delhi is the large metro city and capital of India which has been reported to be having worst air pollution as per urban data base released by the World Health Organization in September 2011. Ambient air quality survey of Respirable Particulate Matter (PM10) and heavy metal pollution of air was carried out in Delhi in industrial, commercial and residential area in 2006 and 2011. Vehicular emission, dust emanated from heavy traffic and construction activity and industrial activities were found to be responsible for air pollution in Delhi. In this paper, PM10 and heavy metal pollution of air in Delhi were observed to be increased in 2011 many more times above the recommended standards or guidelines for protection of public health as compared to 2006 level with the increase in human activity. Heavy metals are observed to be associated with RPM. Though, Delhi government has taken number of measures to reduce the air pollution, more efforts will be required in future to control emission of air pollutants due to increasing population of Delhi and supporting facilities like industries, transport, construction etc.*
Key Words : *Delhi, Industrial, Commercial, Residential, RPM, Heavy Metals*

I. INTRODUCTION

Most of the developing countries are facing the problem of air pollution and public health problems due to pressure from increasing population, transport, industrialization and other activities. The latest World Bank report on leveraging urbanization in South Asia has identified air pollution as a big challenge for major cities in the region, including Delhi. Delhi is reported to be the worst amongst 381 cities from developing countries by World Health Organization in September 2011. The report also mentions that under-five mortality is higher in urban areas than in rural setting. Air pollution is a pernicious problem and its health impacts set to worsen as several regions of the world urbanize rapidly. The major urban air pollutants i.e. NOx, SO_2, Ozone, particulate matter & CO, and their impacts have been studied widely in the ambient air of Delhi. Though heavy metals in air were analyzed in the some air monitoring programme but were not interpreted comprehensively.

Ambient Respiratory Particulate Matter, RPM (PM10), may be the carriers of toxic species like heavy metals which have adverse effect on environment as well as human health [1]. Understanding the types of heavy metals and their spatio-temporal patterns of urban air pollution and their relation with PM10 is crucial to exploring its implications for human and ecosystem health. Therefore, dynamics and interrelationships of RPM and heavy metal concentrations in the air of Delhi was studied in 2006 and 2011 to understand the spatial and temporal variation with increasing population and human activity in the environment of metro city of India.

II. MATERIALS AND METHODS

Ambient air quality monitoring was carried out at three sites in Delhi, viz. Mayapuri Industrial area (West Delhi), Commercial area (Chandni Chowk area, North Delhi), & Residential area (Sarojini Nagar, South Delhi). RPM was collected from the locations using samplers operated at a rate of 1.5 m^3/min for 24 hours on pre-weighted glass fibre filter of 20x25 cm size and reweighted after sampling in order to determine the mass concentration of the RPM collected. The concentrations of particulate matter in ambient air were then computed on the net mass collected divided by the volume of sampled air. Twelve circles of 1" diameter were punched out from the filter paper and digested in concentrated nitric acid. The content was filtered through Whatman paper No. 42 and final volume made-up to 100 ml by double distilled water. The filtrate was used to determine the metals Cr, Cd, Fe, Pb, Zn and Ni by atomic Absorption Spectrophotometer. The RPM and each metal concentration were averaged for month in 2006 and 2011.

III. RESULTS AND DISCUSSION

Sampling Stations

Delhi is the capital city of India. This metro city is increasing fast in size and industrial, commercial and transport activity. Three sampling sites representing residential area, commercial area and industrial area were selected for the study.

The first sampling station Mayapuri Industrial Area (West Delhi) was used to be a major hub of small scale industries, but following recent government sanctions, most of the heavy metal industries moved out. The place is now a combination of residential flats, light metal factories and automobile service stations. Apart from these, the area has three malls, bus terminal of Delhi Transport Corporation (DTC). One of the main businesses at Mayapuri is the recycling of metal scraps and sale of salvage vehicle parts. It is the biggest market for used automotive and industrial spare parts in India. Many small workshops specialized in different metals are active in the Mayapuri area. The presence of toxic heavy metals and of harmful chemicals in the waste generated by these activities presents a direct threat for the health of the people living in the area.

The second sampling site is commercial area around Chandni Chowk in North Delhi. This area is densely populated with heavy traffic, famous for diverse market goods like books in Nai Sarak area; pearl, gold and silver jewellery and natural perfumes at Dariba Kalan; spice-lover in Khari Baoli; cloth market, areas for electric equipments and allopathic medicines, shawls and pearls.

The third sampling site is Sarojini Nagar in South West Delhi. It is large residential area with very large market and is one of the places in the city to buy clothes and fabrics. The area comprises a large number of large sized showrooms, apart from street side shops which sell garments of all sizes, designs and colors. The vicinity of Sarojini Nagar Market is very much developed. The back-streets of market are also crowded by the most famous Export Market for clothes.

Climatic Conditions

Delhi has humid sub-tropical bordering semi-arid climate with extreme temperatures during summer and winter. There are four seasons, winter (December to February), summer (March to May), rainy season or monsoon (June to September) and post-monsoon (October to November). In summer, the average temperature is 32 ^{0}C (90 ^{0}F) and highest temperature close to 45 ^{0}C (114 ^{0}F). The total rainfall in monsoon is 797.3 mm and the temperature ranged from 25 ^{0}C (78 ^{0}F) to 32 ^{0}C (90 ^{0}F) with average temperature around 29 ^{0}C (85 ^{0}F). The average temperature during post-monsoon season remains around 21 ^{0}C (71 ^{0}F). In winter, the average temperature ranges around 12-13 ^{0}C (54-55 ^{0}C). The lowest temperature may go up to -2.2 ^{0}C certain times [2] (Table I).

Respirable Particulate Matter

Air quality monitoring was carried out for RPM and heavy metals in air in 2006 and 2011. RPM recorded in 2006 and 2011 in industrial, commercial and residential areas of Delhi are given in Table II and in Figure 1 and 2. In 2006, RPM Concentrations were observed to be higher in all the months in industrial area ranging from 75 to 295 µg/m^3. Though RPM values in commercial and residential areas are more or less similar, the RPM values in residential area were slightly higher in most of the months ranging from 48 to 253 µg/m^3. RPM values in commercial area ranged from 45 to 220 µg/m3. This indicates that the human activity was more in industrial area followed by residential and commercial area, leading to considerable dust pollution in Delhi. The highest RPM concentration was observed in January month. The RPM concentration was lowest in July month and then gradually increased through August and September and attained maximum in October, December and January. A slight reduction in RPM concentration was noticed in February and March and in November. Therefore, the RPM showed bimodal peak during the year, one in November-December-January and another in April. When compared with AAQM standard of 100 µg/m3, the RPM concentration was lower than the standard in commercial and residential area during July to September period and in industrial area during July to August period, while it was well above the standard in all other months at all stations.

In the year 2011, highest RPM concentration was recorded in commercial area, followed by industrial and residential area in decreasing order (Table II, Figure 2). The range of RPM was recorded to be 87 to 449 µg/m^3 in commercial area, 88 to 433 µg/m^3 in industrial area and 53 to 405 µg/m^3 in residential area. Another important observation was that the highest RPM values were observed during November and December. Seasonal dynamics of RPM concentration was otherwise more or less similar to the observations recorded in 2006. Lowest RPM concentration was observed during July to September, then showed gradual increase and attained highest value in December. Other lower values were observed during February and March. Thus, the RPM showed bimodal peak, one in December and another in April-May. When compared with AAQM standard of 100 µg/m^3, the RPM concentration was lower than the standard in residential area during June to September period, in industrial area during July to September period and in commercial area during July to August period, while it was well above the standard in all other months at all stations.

Comparison of seasonal spatial and temporal variation of RPM is shown in Table II and Figure 3. In general, the RPM concentration range was found to be lower in the year 2006 than the range of RPM found in 2011 at all stations. This is clearly evident in Total-Annual RPM values which are lower in 2006 and higher in 2011. Winter was most critical showing highest concentration of RPM followed by post-monsoon and summer season. The percentage increase/decrease in RPM Concentrations in 2011 as compared to those in 2006 is presented in Figure 4. The Total-Delhi value for RPM in different seasons showed 23.45% to 83.65% higher values over that in 2006 values in different seasons, monsoon has highest value over monsoon of 2006 followed by post-monsoon, winter and summer. The Annual mean also showed increase by 29.78%. Commercial area showed higher values in all the seasons as well as with respect to annual mean. It was followed by residential area showing higher values in summer season followed by winter season and post-monsoon season. Industrial area showed higher values in post-monsoon season followed by winter season and monsoon season. Industrial area showed reduction in RPM in summer and residential area in monsoon season. Overall annual mean were less in industrial area and residential area. This shows that the human activity was very much intensely increased in commercial area in 2011. Human activity was also more in residential area due to presence of famous market in residential area which is visited by most of the people from different areas of Delhi and other parts of India. However, industrial activity is not much increased and do not have much impact on RPM in 2011 as compared to the value of 2006, though the values of RPM are mostly above the stipulated standards in this area.

The values of PM10 in the air of Delhi (66 to 365 µg/m3) were considerable higher than that in Bhopal (102-159 µg/m3) [3], however lower than those values recorded in Lucknow (113 to 396.2 µg/m3) (Barman et al., 2012). This shows that the Lucknow is competing Delhi for being highly polluted.

The Air Quality Index (AQI) based on RPM was calculated using the method [4, 5]. For AQI (Q), the air quality rating of each pollutant was calculated by following formula:

$Q = 100 \times V/Vs$ ----------- (1)

Where, Q is quality rating, V the observed value of the pollutant, and Vs the standard recommended for that pollutant. The categories of air quality based on AQI are presented in Table III. The Standard for RPM is 100 µg/m3; therefore, as per above equation (1), the RPM values themselves represent Air Quality Index in different months (Table II). The category of air quality in 2006 and 2011 is shown in Table IV. The values of RPM / AQI (>100) in January to June and from October to December indicated Severe Air Pollution of RPM. During monsoon months of July, August and September, the level of air pollution was observed to be lower (Heavy Air Pollution) in the year 2006 and in residential area in both the years. Industrial area and commercial area showed AQI ranging from 75 to 114 (Heavy to Severe Air Pollution) in 2006 and AQI from 88 to 99 (Heavy Air Pollution) in 2011. Commercial area showed Heavy Air Pollution (AQI: 45 to 66) in 2006 and Severe Air Pollution (AQI: 87 to 101) in 2011. However, residential area showed Heavy Air Pollution (AQI: 48 to 87) in 2006 and Moderate Air Pollution (AQI: 53 to 63) in 2011, indicating some degree of improvement in air quality. In short, the air quality was Heavy Air Pollution in monsoon season in 2006, while it changed to Severe Air Pollution in 2011.

Urban areas in general have been experiencing a higher concentration of air pollution due to extensive vehicular movements and other activities concentrated in urban area. Comparatively similar areas and the cities have been divided into four categories on the basis of Exceedence Factor (EF), which is the ratio of annual mean concentration of a pollutant with that of its standard. The standard four categories of air pollution based on EF are given below:

1) *Critical pollution (C): when EF is > 1.5*
2) *High pollution (H):when EF is between 1 and 1.5*
3) *Moderate pollution (M): when EF is between 0.5 and 1.0*
4) *Low pollution (L): when EF is < 0.5*

The values of EF were determined on annual average values of RPM. Highest EF was recorded in Industrial area in 2006, while the highest in 2011 was in Commercial area, indicating tremendous increase in commercial activity and some reduction in industrial activity. Residential area also showed slight lowering of air pollution The Exceedence Factor (EF) for RPM (Table V) also support the conclusion based on Air Quality Index, that the RPM concentration indicated Critical Pollution in industrial and residential areas during both the years, while in commercial area, RPM level showed High Pollution in 2006, which changed to Critical Pollution in 2011.The above analysis of category of air pollution due to RPM indicates that the air quality is highly risky in Delhi throughout the year including the rainy or monsoon season. This is in conformity with earlier report that exposure to PM10 results in aggregated respiratory and cardiovascular diseases and in some cases premature death [6, 7]. During Budget session of the Rajya Sabha in 2012, the MoEF minister Jayanti Natarajan answered to one question that contribution of transport sector to PM10 pollution in Delhi was between 9-21% of the total. Even if the CNG introduction has been successful intervention as far as reducing pollution from the transport sector is concerned, it accounts for at most a fifth of the pollution in Delhi [8].The traffic generated gaseous and particulate matter emission and trends over Delhi from 2000 to 2010 was studied [9] and observed

that emission of PM10 decreased in 2001 and 2002; however, it is continuously increasing after 2002 due to rapid rise in the annual rate of increase in vehicles.
Delhi city has shown history of many fluctuations in the level of pollution along with measures taken for its control. Delhi has carried out up measures to reduce vehicle emissions, in terms of fuel quality (introduction of CNG for commercial vehicles) and vehicle pollution reduction technologies and other measures like shifting polluting industries outside in industrial area, introduction of alternate transport Metro, conversion of coal based power plants in Delhi into gas based plants [8]. Though these initiatives helped to improve the air quality in early 2000s, they fall short the controlling air pollution due to increasing number of passenger vehicles on road, lack of enough public transport buses and increase in freight movement and construction material and debris by trucks passing through the city, the lack of maintenance of trucks and buses, increase in in-situ generator sets due to increased demand of electricity and industrial growth

Heavy Metals in Ambient Air

A total 6 heavy metals were recorded in the ambient air of Delhi. The dynamics of trace metals in ambient air is given in Table VI. The spatial variation in the heavy metals in the ambient air in the year 2006 is shown in Figure 5 and 6. The zinc and iron were observed in higher concentrations for most of the time followed by lead, nickel, cadmium and chromium. In 2006, a clear bimodal peak in the concentration of heavy metals in ambient air was observed, one during March – May and another in August –September. In 2011, Zn, Fe, and Pb showed relatively lower concentrations as compared to 2006 but highest amongst all other metals in 2011 (Figure 7 and 8). The heavy metals also showed bimodal peak, one in April – June and another in October – December, except zinc, which showed many peaks and furrows. The heavy metals showed similar pattern with RPM, indicating that the sources of emissions for both are same. In Delhi, the sources of emission of heavy metals were the commercial activity and the scattered industries. In Raipur, the source of Fe in air is the sponge iron industries in the area (Suresh et al., 2010-2011). The risk of heavy metal exposure is observed to be in summer and post – monsoon season.
Based on annual average values, the gradient of concentration of heavy metals in ambient air in 2006 and 2011 is given below:
Zn > Fe > Pb > Ni > Cr > Cd (2006)
Zn > Fe > Pb > Ni > Cr = Cd (2011)
The concentration gradients of heavy metals reported in other areas of India are given below:
Fe > Cu > Zn > Mn > Cr > Cd > Pb > Ni (Coal mining & non-mining area of Dhanbad) [10]
Fe > Zn > Mn > Cr > Pb > Ni > Co (Lucknow) [11])
Mn > Ni > Co > Cd > Pb (Jharia coal field)[12]
This shows that though the basic pattern of concentration gradient of heavy metals are same, the gradient differ slightly in different localities depending on local geology and type of human activity.
The compilation of heavy metals in the ambient air of Delhi and in other areas of India is given in Table VII. Coal mine area, Dhanbad showed higher concentration of Fe, Pb and Cr [9] than those recorded in Delhi. Moradabad with high traffic also showed higher concentrations of all metals [13] and similar is the case of Raipur [14]. In the ambient air of Lucknow, the maximum concentrations of Zn, Fe, Pb and Cr were lower than in Delhi with exception of Ni which was higher in the air of Lucknow by almost double the amount recorded in Delhi [11]. Fe was significantly high in the air of Delhi as compared to Lucknow, which may be due to lot of construction activity going on in Delhi.
The monthly percentage composition of heavy metals in RPM was evaluated on the basis of monthly total values of heavy metals (HM) and RPM, and was observed to be average 1.358% (range: 0.027% to 2.534%) in 2006 and average 0.882% (range: 0.276% to 2.73%) in 2011 (Table VIII). The lower concentration of Zn, Fe, & Pb recorded in 2011 as compared to those in 2006 as well as lower percent composition of heavy metals in RPM in 2011 might be due to emission of more dust due to increase in traffic and construction activity in 2011. Suresh et al. (2010-2011) reported the range of percentage of heavy metals in SPM as 1.17 to 1.87% in Raipur indicating larger industrial sources of heavy metals in ambient air in Raipur as compared to Delhi. These observations show that seasonal variation of climate and fluctuations in human activity are responsible for dynamics of RPM and heavy metal concentration in ambient air of Delhi.
The Pearson's Correlation Coefficient among trace metals and RPM are shown in Table IX. The table indicates that the RPM is moderately correlated with Fe (r: 0.4288) and Pb (r: 0.5056) and poorly with chromium and cadmium and negatively with Zn and Ni. Cadmium is strongly correlated (r: 0.62 to 0.88) with Ni, Cr, and Pb. Zinc is strongly correlated with Cr (r: 0.7351) and moderately with Pb (r: 0.4128). This is in conformity with the observation that the particulates in ambient air may include broad range of chemicals, ranging from metals to organic and inorganic compounds[15, 16]. Similar observations have been made [10] who recorded correlation between RPM (PM10) and heavy metals like, Pb, Ni, Fe, Mn, Zn and Cd. Strong correlation between Cd-Ni, Ni-Mn, and Cd-Mn was observed in Jharia Coal field of Jharkhand [12]. The inter

correlations of metals Pb with Mn, Fe & Cr, Zn with Ni & Cr, Ni with Cr, Mn with Fe, and Cu with Cr was observed in the air of Lucknow [17] .

Out of six metals, only three metals have guideline / standard for ambient air for protection of public health during exposure to polluted air (Table X). Cadmium has limit of 0.005 µg/m3 [18, 19], nickel has limit of 0.020 µg/m3 [18, 20, 19] and lead has limit of 1 µg/m3 [20]. The table also shows that cadmium is present in concentration above the stipulated standard during both the years; nickel exceeds the standard in 2011 while lead concentrations were below the standard in both the years. The values of AQI based on metal pollutants in air and category of heavy metal pollution in 2006 and 2011 are shown in Figure 9 and 10 respectively.

In 2006, all the metals were at Clean Air level in the ambient air for most of the time except cadmium and nickel showing abrupt rise in AQI in April and during the end of monsoon, post-monsoon and December. The AQI based annual mean (AM) showed Cd at Moderate Air Pollution level and nickel & lead at Clean Air status. Monthly dynamics of AQI of metals in ambient air (Figure 9) showed cadmium at upper threshold level of Moderate Air Pollution in April and August months and Severe Air Pollution levels in September, November and December months. Nickel reached Light Air Pollution level in August and Moderate Air Pollution level in September and December. Thus, the risk period with respect to exposure to heavy metals in ambient air is April, August to September and November to December.

In 2011, the ambient air pollution showed more deterioration on the basis of AQI. AQI based on Annual Mean (AM) showed that cadmium changed from Moderate Air Pollution (2006) to Heavy Air Pollution level (2011) and nickel changed from Clean Air (2006) to Light Air Pollution level (2011) but lead remained at Clean Air level (Figure 10). Cadmium was observed to be at Light Air Pollution level in August only, and Moderate Air Pollution level in March, April and July, Heavy Air Pollution level in June and October and Severe Air Pollution level in January, September, November and December. Nickel gained position of Light Air Pollution in May, June, August and October, Moderate Air Pollution level in November, December and Severe Air Pollution in February. Thus, the risk period increased to January-February, June, and September – December.

Above conclusion is also supported by the Exceedence Factor calculated for Cd, Ni, and Pb. The Exceedence Factors (EF) based on annual mean of heavy metals for Cd, Ni, and Pb are shown in Table XI1. The pollution status of cadmium and nickel was Moderate and Low in 2006 respectively which changed to High Pollution in 2011. However, lead was at Low Pollution status in both the years. This is due to lead-free petrol used in the vehicles. This indicates that urban air pollution of heavy metal is more severe. Shifting of some polluting industries to the outskirts of Delhi did not change the pollution status of the heavy metals in the air of Delhi.

Similar observations of urban air pollution in India are also noted by other worker [15] who studied the urban air pollution with village as control and found that heavy metal concentration in the environment of Lucknow was higher than control site by 52.3%, 271.8%, 406.9%, 75.81%, 62.7%, 487.54%, and 189.5% for Fe, Cu, Pb, Zn, Ni, Mn and Cr respectively. Higher concentrations of heavy metals have been recorded in ambient air in coal mining area of Dhanbad, Jharkhand [10] than control site, Cd by 1300%, Zn by 133%, Fe by 5484%, Pb by 137% and Cr by 8300% except nickel. The increase in night time concentrations of the metals Al, Zn., Pb & Cd on Diwali night was also observed at Kolkata by 5-12 times, Cu, Fe, & Mn by 25-40 times and Co & V by70-80 times as compared to normal night-time concentrations [23].

There are various sources emitting these elements into the atmosphere, e.g. fossil fuel combustion contributes Al, Fe, Ca, Mg, K, Na, As, Pb, Cd, Se, Hg [24], Pb and Zn by wood combustion [25], vehicular traffic contributes Cd, Cr, Cu, Ni, Pb, Zn [26], electroplating contributes Cr [27], metal alloy industries emit different elements like Cd, Cr, al, Fe, Ni, Zn, Pb, Cu etc in the air [28].

Impact of Air Pollutants on Public Health

Study was carried out to evaluate the direct health impacts in National Capital Territory of Delhi (NCT Delhi) in terms of mortality and morbidity due to air pollution [29]. About 11394, 3912, 1697, and 16253 excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD respectively were observed for entire NCT Delhi in the year 2000. However, within one decade in year 2010, these figures became 18229, 6374, 2701, and 26525. District wise analysis showed that North West District is having the highest number of mortality and morbidity cases continuously after 2002. Moreover, least excess number cases were observed for New Delhi District.

Short term but high emissions of trace elements such as As, Cd, Co, Cr, Ni, Pb, and Se which are animal and human carcinogens even in trace amounts have severe health impacts [30]. Pb can cause neurological and hematological impacts on the exposed population, Cd and Ni can cause carcinogenic effects in human through inhalation, occupational level of Cd exposure is a risk factor for chronic lung diseases [31, 32]. Cr(VI) has carcinogenic effect on the bronchial tree, increased Mn leads to neurotoxic impairment, increased level of Cu leads to respiratory irritations [31, 33, 34].

IV. CONCLUSION

Impact of big cities on local air quality has long been recognized but the fact that this will trigger the impacts on regional and global climate is just beginning to receive attention. Among the major air pollutants of public health importance, heavy metal is an important parameter from public health point of view which needs to be studied as emission from anthropogenic source. This presently neglected parameter may assume a great risk to public health in future and need to be controlled effectively. Delhi has taken several steps to reduce the level of air pollution in the city during the last 10 years. However, more still needs to be done to further reduce the levels of air pollution [35]. Integrated approach towards urban air pollution control is required including infrastructure development and motivation efforts of government and participation of the community for effective reduction of pollution like use of public transport starting from some car-free days, use of Metro rail with adequate number of feeder buses at Metro stations. More frequent checking of Pollution under Control (PUC) certificates and education of people to switch-off their vehicles when waiting at traffic intersections. The ever-increasing influx of migrants can be reduced by developing job opportunities in the suburban areas, and thus prevent further congestion of the already-choked capital city of Delhi.

REFERENCES

[1] C. Verma and D.K. Deshmukh, The ambient air and noise quality in India during Diwali festival: A Review, *Recent Research in Science and Technology, 6(1)*, 2014, 203-210.

[2] Indian Meteorological Department, *Ever Recorded Maximum and Minimum Temperatures up to 2010*, Indian Meteorological Department, Retrieved, 2015.

[3] Sadhana Chaurasia and A.D. Gupta, Concentration of atmospheric trace metals associated with respirable particulate matter (PM10) and Air Pollution Index (API) of Bhopal City, Madhya Pradesh , India, *3rd World Conference on Applied Sciences, Engineering & Technology*, 27-29 September 2014, Kathmandu, Nepal, ISBN 13: 978-81-930222-0-7, pp 161-166.

[4] C.P. Kaushik, K. Ravindra and K. Yadav, Assessment of ambient air quality in urban centres of Haryana (India) in relation to different anthropogenic activities and health risk, *Environ Monit Assess, 122*, 2006, 27-40.

[5] N. Tiwari and M. Ali, Air Quality Index for Calcutta and its monthly variation for various localities, *Ind J Environ Protect, 7*, 1987, 172-176.

[6] K, Balkrishnan, R.S. Dhaliwal and B. Shah, Integrated urban-rural frameworks for air pollution and health-related research in India: the way forward, *Environ Health Perspectives, 119,* January 2011.

[7] S.K. Chhabra, P. Chhabra, S. Rajpal and R.K. Gupta, Ambient air pollution and chronic respiratory morbidity in Delhi, *Archives of Environmental Health, 56*, 2001, 8.

[8] S. Guttikunda, Air pollution in Delhi, *Economic and Political Weekly, XLVII, 26 & 27*, 2012, 24-27.

[9] Rati Sindhwani, P. Goyal, S. Kumar and A. Kumar, Assessment of gaseous and respirable suspended particulate matter (PM10) emission estimates over megacity Delhi: Past trends and Future Scenario (2000-2020), Presented at *the 13th Annual CMAS Conference*, Chapel Hill, NC, October 27-29, 2014.

[10] B. Dubey, A.K. Pal and G. Singh, Trace metal composition of airborne particulate matter in the coal mining and non-mining areas of Dhanbad Region, Jharkhand, India, *Atmospheric Pollution Research, 3*, 2012, 238-246.

[11] Barman et al., Assessment of ambient Air Quality of Lucknow City during Pre-Monsoon, 2012. Findings of a Random Survey, Presented on *World Environment Day, 2012*. CSIR-Indian Institute of Toxicology Research, Lucknow, 5TH June, 2012.

[12] A.K. Mishra, S.K. Maiti and A.K. Pal, Status of PM10 bound heavy metals in ambient air in certain parts of Jharia coal field, Jharkhand, India, *Int. J Environ Sci, 4(2)*, 2013, 141-150.

[13] R. Pal, M.A. Gupta and A. Tripathi, 2014. Assessment of heavy metals in suspended particulate matter in Moradabad, India, *J Environ Biology, 35*, 2014, 357-361.

[14] S. Suresh and R.D. Patil, *Report on SPM Characterization for Heavy Metals Concentration*, Zonal Office (Central), Central Pollution Control Board, Bhopal, 2010-2011

[15] S.S. Park and Y.J. Kim, Source contributions to fine particulate matter in an urban atmosphere, *Chemosphere, 59*, 2005, 217-226.

[16] Y.I. Tsai and M.T. Cheng, Characterization of chemical species in atmospheric aerosols in a metropolitan basin, *Chemosphere, 54*, 2004, 1171-1181.

[17] S.G. Barman, N. Kumar, R. Singh, G.C. Kisku, A.H. Khan, M.M. Kidwai, R.C. Murthy, M.P.S. Negi, P. Pandey, A.K. Verma, G. Jain and S.K. Bhargava, Assessment of urban air pollution and its probable health impact, *J Environ Biology, 31(6),* 2010, 913-920.

[18] EPA,, *Air Quality Standards*. U.S. Environmental Protection Agency, 2011.

[19] European Commission, *Ambient Air Quality Research Project (1996-2001) on Dioxins, Organics, Polycyclic Aromatic Hydrocarbons and Heavy Metals* (NSW EPA 2002), 2003.

[20] MoEF, *National Ambient Air Quality Standards*, Ministry of Environment and Forests Notification G.S.R. 826(E) dated 16th November, 2009.

[21] NEPC, this is the Australian goal for lead set in the National environmental Protection (Ambient Air Quality) Measure (NEPM). Measurement is based on TotalSuspended Particulates.

[22] WHO, Goals are based on guidelines for the risk of health impacts, 2000.

[23] A. Chatterjee, C. Sarkar, A. Adak, U. Mukherjee, S.K. Ghosh and S. Raha, Ambient air quality during Diwali festival over Kolkata – A mega-city in India, *Aerosol and Air Quality Research, 13*, 2013, 1133-1144.

[24] E. Furimsky, Characterization of trace element emissions from coal combustion by equilibrium calculations, *Fuel Process Technol, 63*, 2000, 29–44.

[25] J. Mohn, R. Figi, P. Graf, E. Gujer, R. Haag, P. Honegger, P. Mattrel, O. Nagel, P. Schmid, C. Seiler, C. Schreiner, E. Steinhauser, M. Zennegg and L. Emmenegger, Wood Combustion-Clean Energy In: *Proceedings of 5th International Conference on Emission Monitoring*, Odense, Denmark, 2002.

[26] Westerlund, *Metal Emissions from Stockholm Traffic, Wear of Brake Lining* (Stockholm Environmental Administration, 2001.

[27] W.L. Flower, L.W. Peng, M.P. Bonin, N.B. French, H.A. Johnsen, D.K. Ottesen, R.F. Renzi and L.V.A. Westbrook, Laser-based technique to continuously monitor metal aerosol emissions, *Fuel Process Technol, 39*, 1994, 277–284.

[28] R.M. Harrison, Metal Analysis. In: *Handbook of Air Pollution Analysis*, R M Harrison and R Perry (eds),Chapman & Hall, London, 215-277, 1986.
[29] A.S. Nagpure, B.R. Gurgar and Jc Martel, Human health risks in National Capital Territory of Delhi due to air pollution, *Atmospheric Pollution Research, 5*, 2014, 371-380.
[30] Y. Wang, G. Zhuang, C. Xu and Z. An, The air pollution is caused by the burning of fireworks during the lantern festival in Beijing, *Atmos Environ, 41*, 2007, 417-431.
[31] S.C. Barman, R. Singh, M.P.S. Negi and S.K. Bhargava, Ambient air quality at Lucknow City (India) during use of fireworks on Diwali festival, *Environ Monit Assess, 137*, 2008, 495-504.
[32] S. Benoff, A. Jacob and I.R. Hurley, Male infertility and environmental exposure to lead and cadmium, *Human Reproduction Update, 6*, 2000, 107-121.
[33] N. Manalis, G. Grivas, V. Protonotarios, A. Moutsatsou, C. Samara and A. Haloulakou, Toxic metal content of particulate matter (PM10) within the greater area of Athens, *Chemosphere, 60(4)*, 2005, 557-566.
[34] C. Santos-Burgoa, C. Rios, L.A. Nercadi, R. Arecguga-Serrano, F. Cano-Vall and R.A. Eden-Wynter, Exposure to manganese: health effects on general population, a pilot study in Central Mexico, *Environ Res, Sect A, 85*, 2001, 90-104.
[35] S.A. Rizwan, N. Baidalyne and S.K. Gupta, Air pollution in Delhi: Its magnitude and effects on health, *Indian J Community Med, 38(1)*, 2013, 4-8

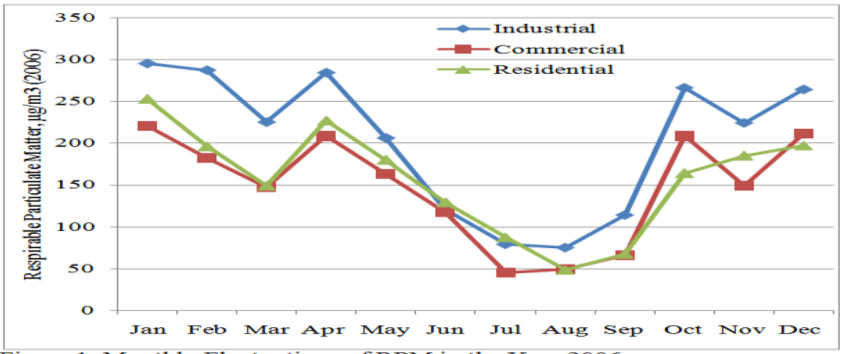

Figure 1: Monthly Fluctuations of RPM in the Year 2006

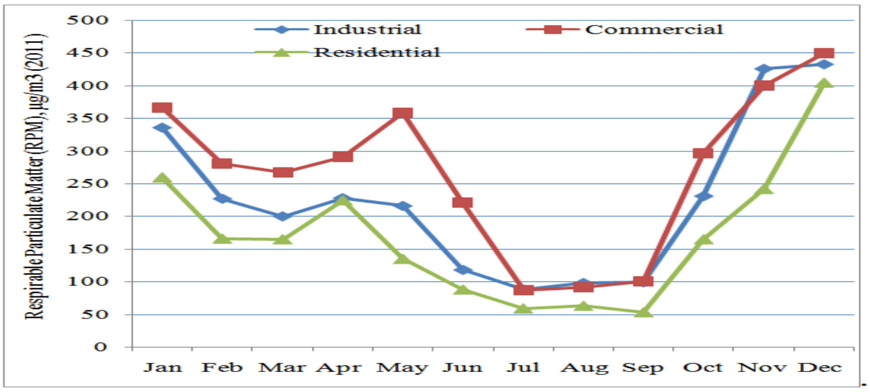

Figure 2: Monthly Fluctuations of RPM in the Year 2011

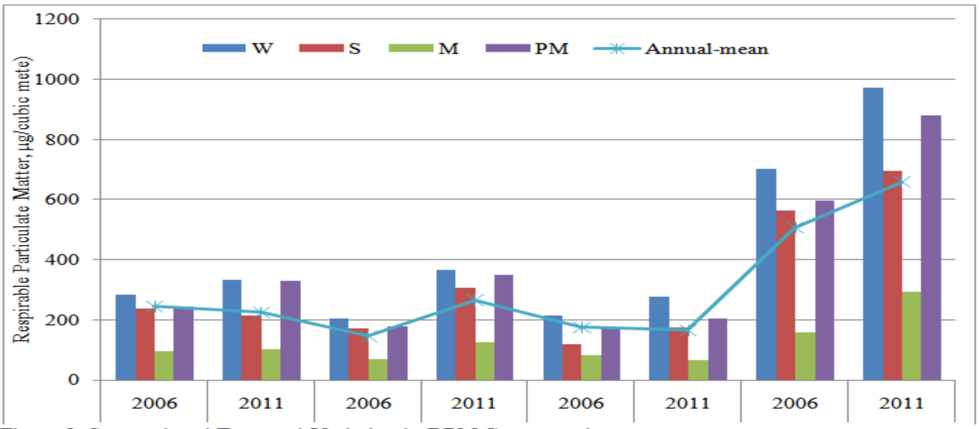

Figure 3: Seasonal and Temporal Variation in RPM Concentration
(W: winter; S: summer; M: monsoon; PM: post-monsoon; Ind: industrial; Com: commercial; Res: residential)

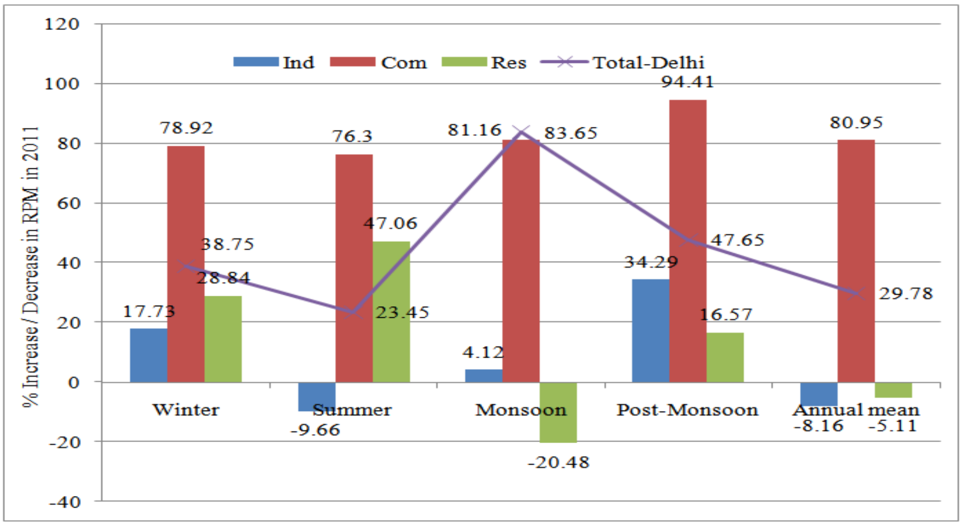

Figure 4: Percentage Increase in RPM Concentration in 2011 as Compared to 2006

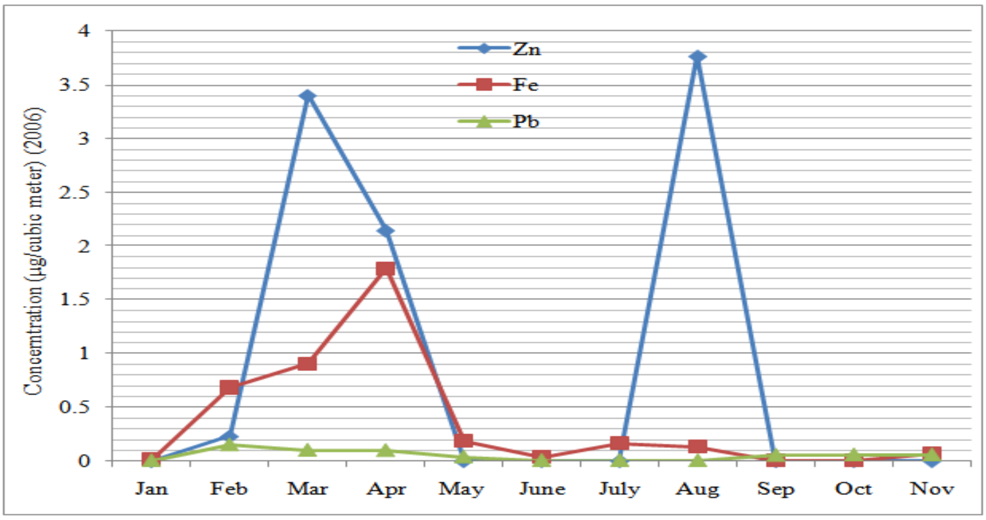

Figure 5: Trace Metal Concentration of Zn, Fe & Pb in Ambient Air in 2006

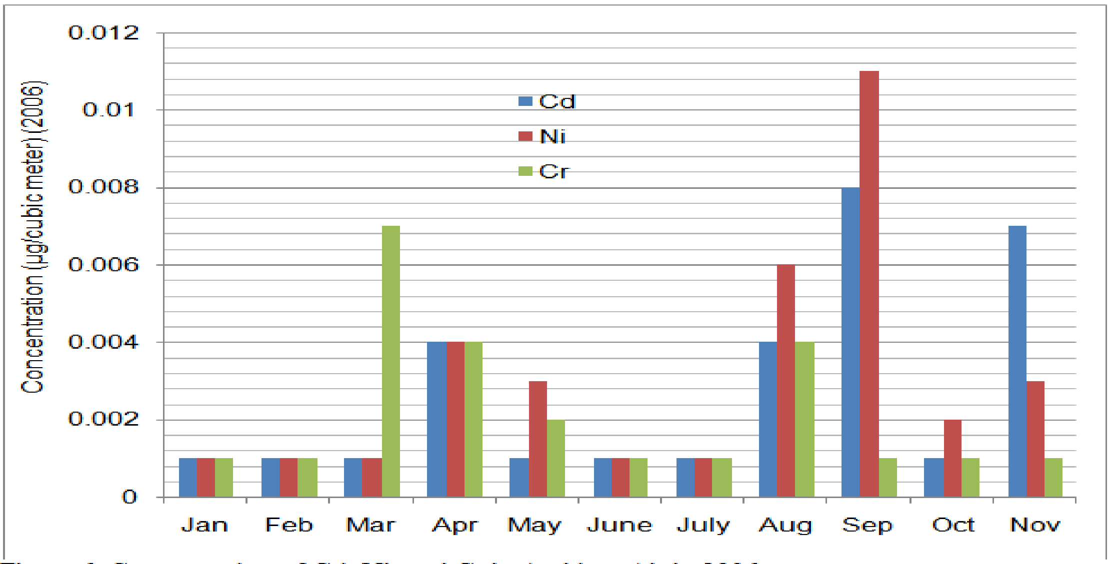

Figure 6: Concentration of Cd, Ni, and Cr in Ambient Air in 2006

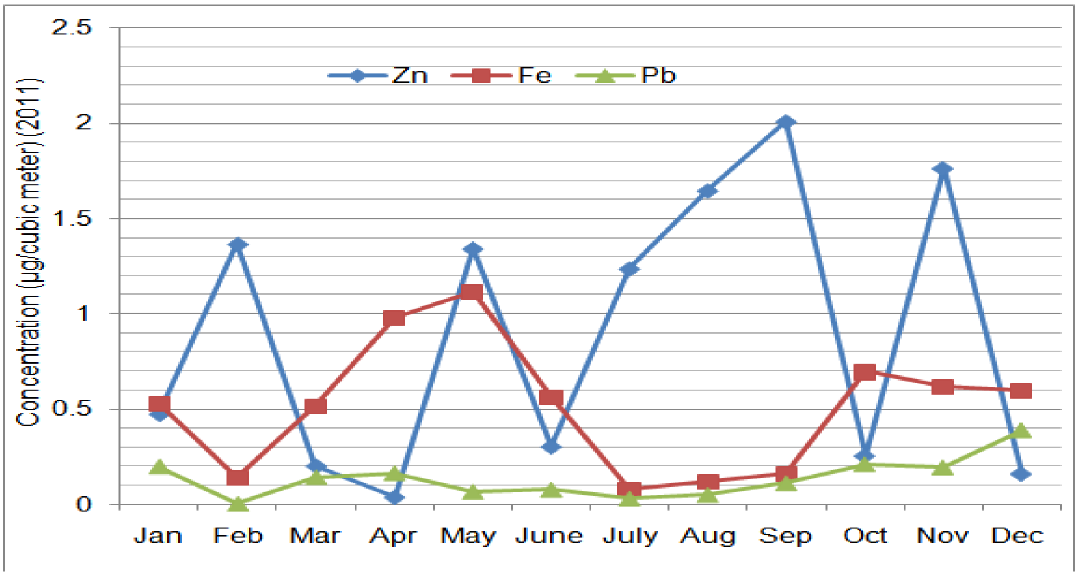

Figure 7: Trace Metal Concentration of Zn, Fe and Pb in Ambient Air in 2011

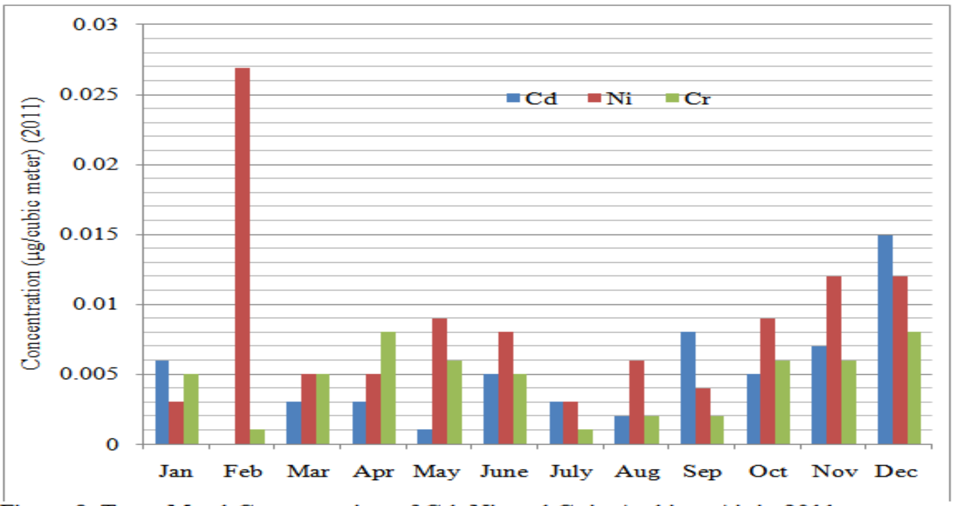

Figure 8: Trace Metal Concentration of Cd, Ni, and Cr in Ambient Air in 2011

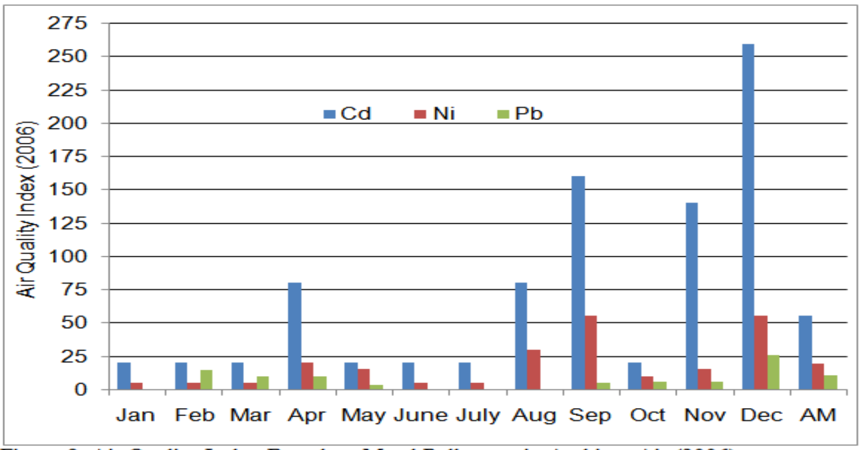

Figure 9: Air Quality Index Based on Metal Pollutants in Ambient Air (2006)
(≤10 – 25: Clean Air; 26-50: Light Air Pollution; 51-75: Moderate Air Pollution; 76-100: Heavy Air Pollution; >100: Severe Air Pollution)

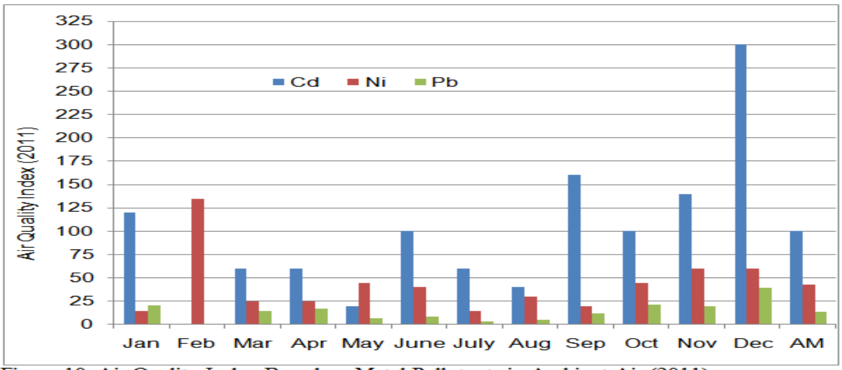

Figure 10: Air Quality Index Based on Metal Pollutants in Ambient Air (2011)
(≤10 – 25: Clean Air; 26-50: Light Air Pollution; 51-75: Moderate Air Pollution; 76-100: Heavy Air Pollution; >100: Severe Air Pollution)

Table I: Climate Data for Delhi (1971-1990)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record High $^0C(^0F)$	30.0 (86)	34.1 (93.4)	40.6 (105.1)	45.6 (114.1)	47.2 (117)	46.7 (116.1)	45.0 (113)	42.0 (107.6)	40.6 (105.1)	39.4 (102.9)	36.1 (97)	29.3 (84.7)	47.2 (117)
Average high $^0C(^0F)$	21.0 (69.8)	23.5 (74.3)	29.2 (84.6)	36.0 (96.8)	39.2 (102.6)	38.8 (101.8)	34.7 (94.5)	33.6 (92.5)	34.2 (93.6)	33.0 (91.4)	28.3 (82.9)	22.9 (73.2)	31.2 (88.2)
Daily mean $^0C(^0F)$	14.3 (57.7)	16.8 (62.2)	22.3 (72.1)	28.8 (83.8)	32.5 (90.5)	33.4 (92.1)	30.8 (87.4)	30.0 (86)	29.5 (85.1)	26.3 (79.3)	20.8 (69.4)	15.7 (60.3)	25.1 (77.2)
Average low $^0C(^0F)$	7.6 (45.7)	10.1 (50.2)	15.3 (59.5)	21,6 (70.9)	25.9 (78.6)	27.8 (82)	26.8 (80.2)	26.3 (79.3)	24.7 (76.5)	19.6 (67.3)	13.2 (55.8)	8.5 (47.3)	19.0 (66.2)
Record low $^0C(^0F)$	-0.6 (30.9)	1.6 (34.9)	4.4 (39.9)	10.7 (51.3)	15.2 (59.4)	18.9 (66)	20.3 (68.5)	20.7 (69.3)	17.3 (63.1)	9.4 (48.9)	3.9 (39)	1.1 (34)	-0.6 (30.9)
Average precipi-tation mm (inches)	19 (0.75)	20 (0.79)	15 (0.59)	21 (0.83)	25 (0.98)	70 (2.76)	237 (9.33)	235 (9.25)	113 (4.45)	17 (0.67)	9 (0.35)	9 (0.35)	790 (31.1)

Source : NOAA; Indian Meteorological Department (record high and low up to 2010)

Table II: Spatial and Temporal Variation of RPM in the Ambient Air of Delhi

Month	Industrial		Commercial		Residential		Total-Delhi	
	2006	2011	2006	2011	2006	2011	2006	2011
Jan	295±21	336±123	220±116	366±158	253±71	260±116	768	962
Feb	287±59	227±69	182±44	280±117	196±42	166±87	665	673
Mar	225±33	200±55	147±61	267±69	149±58	165±23	521	632
Apr	284±155	228±63	208±87	291±54	227±108	225±108	719	744
May	206±81	216±47	163±98	358±115	180±77	135±49	449	709
Jun	121±31	118±42	117±76	221±94	129±96	88±47	367	427
Jul	79±17	88±27	45±8	87±24	87±34	59±15	211	234
Aug	75±19	98±27	49±12	91±28	48±14	63±27	172	252
Sep	114±39	99±29	66±18	101±26	67±9	53±11	247	253
Oct	266±97	231±31	208±108	296±118	164±82	165±103	638	692
Nov	224±71	426±102	149±55	400±155	185±77	242±57	558	1068
Dec	264±83	433±133	211±82	449±107	197±86	405±124	672	1287

Table III: Category of Ambient Air Quality Based on Air Quality Index (Q)

Index Value	Category
≤10 - 25	Clean air
26 – 50	Light air pollution
51 – 75	Moderate air pollution
76 – 100	Heavy air pollution
>100	Severe air pollution

Table IV: Category of Air Pollution Based on Air Quality Index (Q) based on RPM

Seasons	Industrial		Commercial		Residential	
	2006	2011	2006	2011	2006	2011
Winter	Severe air pollution					
Summer	Severe air pollution					
Monsoon	Heavy to severe air pollution	Severe air pollution	Heavy air pollution	Severe air pollution	Heavy air pollution	Moderate air pollution
Post-Monsoon	Severe air pollution					
Annual Mean	Severe air pollution					

Table V: Category of Ambient Air Pollution Denoted by Exceedence Factor Based on RPM Annual Mean

Seasons	2006			2011		
	Industrial Area	Commercial Area	Residential Area	Industrial Area	Commercial Area	Residential Area
Annual Mean	245	147	176	225	266	167
Exceedence Factor (EF) & Pollution Status	2.45 Critical Pollution	1.47 High pollution	1.76 Critical pollution	2.25 Critical pollution	2.66 Critical pollution	1.67 Critical pollution

Table VI: Heavy Metal Concentration (24-H Average) in ambient Air of Delhi

	Cd		Zn		Ni		Fe		Pb		Cr	
	2006	2011	2006	2011	2006	2011	2006	2011	2006	2011	2006	2011
Jan	0.001	0.006	O.44	0.475	0.001	0.003	0.0071	0.527	0.002	0.197	0.001	0.005
Feb	0.001	0.000	0.23	1.365	0.001	0.027	0.68	0.142	0.15	0.002	0.001	0.001
Mar	0.001	0.003	3.40	0.203	0.001	0.005	0.90	0.516	0.100	0.141	0.007	0.005
Apr	0.004	0.003	2.145	0.039	0.004	0.005	1.788	0.978	0.097	0.162	0.004	0.008
May	0.001	0.001	0.001	1.341	0.003	0.009	0.178	1.114	0.037	0.065	0.002	0.006
June	0.001	0.005	0.001	0.304	0.001	0.008	0.029	0.562	0.004	0.076	0.001	0.005
July	0.001	0.003	0.001	1.236	0.001	0.003	0.165	0.080	0.004	0.030	0.001	0.001
Aug	0.004	0.002	3.765	1.646	0.006	0.006	0.129	0.119	0.002	0.048	0.004	0.002
Sep	0.008	0.008	0.001	2.008	0.011	0.004	0.001	0.161	0.052	0.110	0.001	0.002
Oct	0.001	0.005	0.001	0.256	0.002	0.009	0.001	0.696	0.057	0.209	0.001	0.006
Nov	0.007	0.007	0.001	1.763	0.003	0.012	0.063	0.615	0.058	0.193	0.001	0.006
Dec	0.013	0.015	3.160	0.162	0.011	0.012	0.561	0.599	0.261	0.386	0.016	0.008
Av. ±SD	0.003 ± 0.003	0.005 ± 0.004	1.10 ± 1.542	0.9± 0.73	0.004 ± 0.004	0.027 ± 0.044	0.375 ± 0.537	0.51 ± 0.335	0.108 ± 0.151	0.135 ± 0.11	0.003 ± 0.004	0.005 ± 0.003

Table VII: Ranges of Heavy Metals in the Air of Delhi and Other Areas in India

	Cd	Zn	Ni	Fe	Pb	Cr
Delhi ambient air	0.0028 - 0.005	0.9 - 1.096	0.0038 - 0.027	0.375 - 0.51	1.108 - 0.135	0.003 - 0.005
Coal mine area of Dhanbad [9]	0.03 - 0.07	0.16 - 2.55	0.002 – 0.02	1.43 – 28.48	0.024 - 0.32	0.11 - 0.42
Lucknow [15}	--	0.0189 – 0.0999	0.0224 – 0.0525	0.506 – 2.434	0.023 – 0.249	0.0032 – 0.012
Lucknow, Annual Average [11]	--	0.0588 – 0.286	0.00336 – 0.036	677.24 – 3.645	0.0087 – 0.0867	0.024 – 0.0888
Moradabad (UP) Max conc in Ind. Area [13]	0.20 (heavy density traffic area)	21.24	0.03	18.43	2.72 (heavy density traffic area)	0.41
Raipur [14]		0.01 – 0.32	0.01 – 0.05	1.44 – 4.91		

Table VIII: Percentage of Heavy Metal Content in RPM Concentration

Months	2006			2011		
	HM	RPM	HM%	HM	RPM	HM%
Jan	0.452	256	0.160	1.213	321	0.378
Feb	1.063	222	0.479	1.537	224	0.686
Mar	4.409	174	2.534	0.873	211	0.414
Apr	4.042	240	1.684	1.195	248	0.482
May	0.222	150	0.148	2.536	236	1.075
June	0.037	122	0.030	0.96	142	0.676
July	0.173	70	2.471	1.353	78	0.453
Aug	3.91	57	6.860	1.823	84	2.170
Sep	0.022	82	0.027	2.293	84	2.730
Oct	0.063	213	0.030	1.181	231	0.511
Nov	0.133	186	0.072	2.596	356	0.729
Dec	4.022	224	1.796	1.182	429	0.276
Annual average			1.358			0.882

(HM: heavy metal)

Table IX: Correlation Coefficient among RPM-Total-Delhi (RPM-AT) and Trace Metals

	RPM-AT	Cd	Zn	Ni	Fe	Pb	Cr
RPM-AT	1						
Cd	0.039	1					
Zn	-0.0277	0.3407	1				
Ni	-0.1888	0.8829	0.3426	1			
Fe	0.4288	0.0538	0.4914	0.0122	1		
Pb	0.5056	0.6148	0.4128	0.4517	0.4743	1	
Cr	0.2336	0.6639	0.7351	0.5476	0.3539	0.7884	1

Table X: Standard / Guideline for Heavy Metal Concentration in Ambient Air for Protection of Public Health

Metal	Average of Samples (24-hour; µg/m3)		Range of samples (24-hour; µg/m3)		Standard/ Guideline (annual average; µg/m3)	References
	2006	2011	2006	2011		
Cadmium (Cd)	0.0028	0.005	0.001 - 0.013	0.00-0.015	0.005	[18]; [19]
Zinc (Zn)	1.096	0.90	0.001- 3.765	0.039- 2.008	Non-available	
Nickel (Ni)	0.0038	0.027	0.001- 0.011	0.003- 0.027	0.020	[18]; [19]; [20]
Iron (Fe)	0.375	0.51	0.001- 1.788	0.08- 1.114	Non-available	
Lead (BP)	0.108	0.135	0.002- 0.261	0.002- 0.386	0.500	[21]; [22]
					1.000	[20]
Chromium (Cr)	0.0033	0.005	0.001- 0.016	0.001- 0.008	Non-available	

Table X1: Ambient Air Quality Status based on Exceedence Factor For Heavy Metals in Ambient Air

Metal	Exceedence Factor (EF) and Pollution Status	
	2006	2011
Cadmium (Cd)	0.56 Moderate pollution	1.00 High pollution
Nickel (Ni)	0.19 Low pollution	1.35 High pollution
Lead (Pb)	0.108 - 0.216 Low pollution	0.135 - 0.27 Low pollution