STUDY ON CARBONACEOUS SPECIES AND HEAVY METALS DURING AN EPISODIC POLLUTION EVENT IN DELHI, INDIA

A thesis submitted in partial fulfillment of the requirements for the award of degree of

MASTER OF TECHNOLOGY
in
ENVIRONMENTAL ENGINEERING

by

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Certificate

This is to certify that the thesis entitled ***Study on Carbonaceous species and Heavy Metals during an episodic pollution event in Delhi, India*** *is a bonafide record of work carried out by* **Ms. ANUSHREE BISWAS** bearing registered number **2K14/ENE/03** from November 2015 till June 2016 has been approved for submission for partial fulfillment of the award of Master of Technology in Environmental Engineering of Delhi Technological University.

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DECLARATION

I, hereby declare that the work being presented in the Project Report entitled "Study on Carbonaceous species and Heavy Metals during an episodic pollution event in Delhi, India'' is an original piece of work and an authentic report of our own work carried out during of 4th semester as a part of our major project.

The data presented in this report is a result of monitoring of air pollutants during the study period and is being utilized by us for the submission of our Major Project Report to complete the requirements of Master's Degree of Examination Environmental Engineering, as per Delhi Technological University curriculum.

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Abstract

Ambient respirable fraction was sampled for a seven day special observation period during the festival of lights- Diwali, in a residential area, Delhi, India. Every year this "festival of lights" releases toxic chemical species in the air degrading the quality of air. In recent years, carbonaceous fraction of particulate matter has gained large interest due to its significance in altering the air quality adversely and climate patterns. Delhi, the capital city of India, already reeling under the criticism of being in top rankings of world's most polluted cities is making staggering efforts to abate its air pollution. With such a title thrust to it, such an episodic pollution due to Diwali festivities in the winter months when the temperature and mixing heights are low, forces air quality to reach a new ebb. Among the analyzed species, Organic Carbon(OC) contributed to ~28% and Elemental Carbon (EC) ~14% with an increase in concentration by a factor of 2.27 and 2.02 times on Diwali day than the previous day. Although, contributions of secondary organic aerosols has not been investigated in this study, higher OC/EC ratio following after the days of Diwali suggests its contribution to OC concentration. Nine heavy metals (Al, Cr, Cu, Ba, Zn, Fe, Pb, Mn and Ni) also commensurate to PM_5 loadings. Fe, Pb, Cu and Mn hint their more use in the manufacture of firecrackers with seemingly less use of Zn, Ba and Al this time. The non-carcinogenic and carcinogenic risks due to short episodic pollution of Diwali has also been accounted. An increase of Hazard Index (HI) by~8% manifests the severity of Diwali metal pollution.

Keywords- Aerosols, Organic carbon, Elemental carbon, Heavy metals, Health risk assessment, Fireworks

Chapter-I

Introduction

The report of World Health Organization (WHO) 2014, reverberated harsh criticism from different countries for long forcing India to take major steps in its containment and abatement of Air Pollution. This anecdote has made us focus on a highly publicized word nowadays – Particulate Matter(PM). Particulate Matter is defined as an amalgam of solid and liquid particulates (OC/EC, heavy metals, cations and anions, PAH and bioaerosols) suspended in gaseous media (air). These particles find prominence in energy regulation activities of earth both in direct and indirect ways. For the proper functioning of different ecosystems, earth balances the incoming solar radiation from the sun in such a way that an equal amount of thermal and solar energy find their way back out of the earth's atmosphere. This is called the radiative budget of earth. Aerosols may be of homogenous or heterogenous nature with different sizes and shapes, upon which the amount of light scattered and reflected depends. This is known as the direct effect of aerosols on atmospheric processes. The indirect effect of aerosols is excercised by clouds which being 'seeded' by them alter the albedo and precipitation pattern.

Apart from plain conspicuous roles in clouds physics and chemistry, one another important aspect of it is its role in deteriorating health of humans and ecosystems. These particles ranging in sizes from smaller than 10μm to 100μm can have their residence time from few hours to days, weeks and years, travelling long distances as far as Arctic (Sadiq et al. 2015). These can corrode facade of buildings damaging surfaces and properties, impede growth of plants, disrupting mass agricultural production and food chains. PM_{10} (particulate matter with aerodynamic diameter < 10μm) and $PM_{2.5}$ (particulate matter with aerodynamic diameter < 2.5μm) have major spotlight focused on them on account of various chronic pulmonary diseases, cardiovascular diseases and lung cancer in humans(Dockery et al. 1989,1993;Pope et al. 1995,2006).

Organic carbon(OC) and elementary carbon (EC) / black carbon (BC), subset of PM have the universal presence especially in environments habituated by humans. Organic carbon finds its route from from both biogenic and non-biogenic sources(primary and secondary), consists of various hydrocarbons is the non absorptive part of particulate carbon markedly influencing the radiative budget of earth. Its role as clouds condensation nuclei is ascertained to be on par with sulfate aerosols which have been established to play potent roles as cloud condensation nuclei. Black carbon on the other hand is black, has higher molecular weight than OC, absorbs solar radiation contributing to the green house effect of earth's atmosphere. It is primarily emitted from anthropogenic activities like biomass burning, biomass cooking, fossil fuels, combustion in vehicles, industries and open incineration. OC and EC are found more abundantly in diameter < 1μm (Kleeman et al. 2000)and can become carrier of toxic substances, some being carcinogenic in nature(Diggs et al. 2011). These can lead to reduction of incoming incident light from 27-44% (Pratisnis et al. 1984) and 10-50%(Zhang et al. 2013).

Delhi, the capital city of India is currently under the scorching gaze of World Health Agencies due to its ranking amongst the most polluted cities of the world. So severe is its condition that during the winter months it has a knack of falling into severe category of AQI, India(Annexure-I) for most part of the months. Air pollution is responsible for a number of various medical symptoms and compromised health for residents of Delhi, revealed a study conducted by All India Institute of Medical Sciences (AIIMS) and Central pollution Control board (CPCB)(Annexure-II).Road dust, vehicular emission, domestic cooking and power plants spew inappreciable quantities of PM in the air. Adding to these sources is the Diwali festival, known as the "festival of lights". Every year it is celebrated with fireworks display during the post monsoon months of October or November, a time when the temperature begins its descent before the start of winters. This short episode of fireworks display expose us to a high concentration of heavy metal pollution-Ba, K, Sr, Mg, Na, Fe, Cu, Mn, Ni, Al and Pb which are used for its manufacture (Kulshrestha et al. 2004;Vecchi et al. 2008;Sarkar et al. 2010).The colours or the lights are attributed to different excitation levels of atoms of metals under different temperatures. The summary of general composition of fireworks is shown in **Figure 1.1**. Such an episodic event in calm winter months of Delhi when the temperature and mixing heights are low can cause profound health effects, carcinogenic and non-carcinogenic in nature.

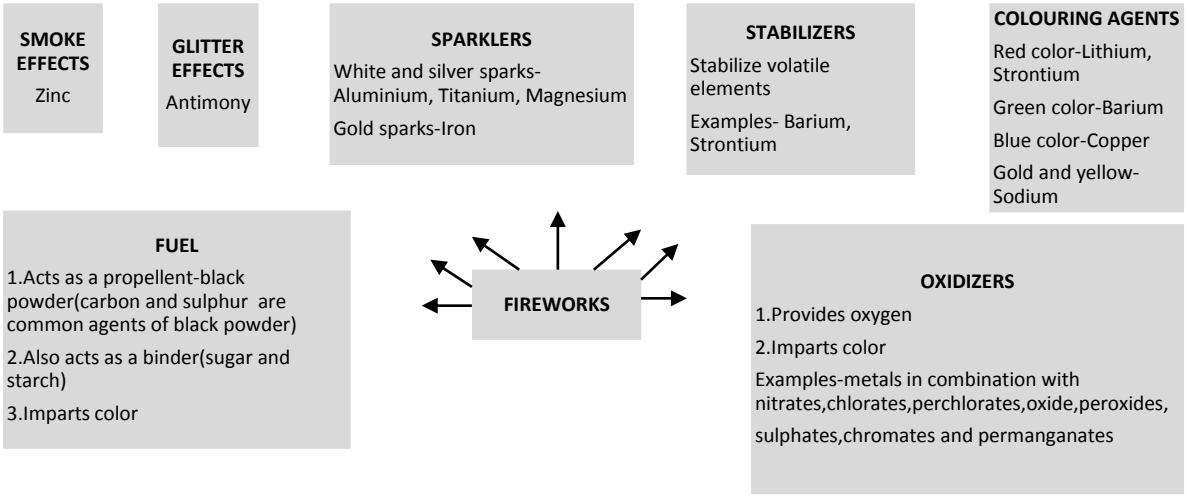

Figure 1.1Summary of General composition of Fireworks

In this present study, detailed quantification of PM_5(particulate matter with aerodynamic diameter < 5µm), OC, EC, TC and heavy metals (HM's) in a residential area during the Diwali week (8^{th} November'15 to 14^{th} November'15) has been summarized. To the best of our knowledge the nearest NAAQM station set up by CPCB from the present chosen location has not been in working condition for long, hence the need for monitoring.

1.1 Objectives of the study –

- Sampling and measurement of PM_5 during the Diwali week in a residential area.
- Assessment of OC, EC and Total Carbon(TC) from PM_5 sampled.
- Assessment of heavy metals from PM_5 sampled.
- Assessment of non-carcinogenic and carcinogenic risks from heavy metal pollution during the Diwali week.

Chapter-II

Literature Review

This chapter encompasses the literature published earlier on effects of particulate matter on climate, levels of particulate matter in Delhi, other states of India and related firework episodes in other parts of the world. Reviews on health hazards posed by particulate matter has also been covered.

Hamilton et al. 1992 discussed the effects of carbonaceous aerosols on environment and health. Organic carbon, which is a matter of some concern because of possible mutagenic and carcinogenic effects, is generally responsible for 60--90% of the carbon mass in airborne particulate matter. Particulate elemental carbon or PEC, also known as black carbon or graphitic carbon, has been linked to a range of adverse environmental effects. Its submicron mass median diameter means that it can penetrate deeply into the lung and deposit in the pulmonary region where it can slow the clearance mechanisms and also provide adsorption sites for toxic pollutants. Its light absorption properties are such that it may make a contribution to global heating by the absorption of solar radiation), to the reduction of atmospheric visibility and to the soiling of buildings, including historic monuments, by the deposition of PEC to the building surface.

Xin et al. 2016 investigated the aerosol direct radiative forcing in desert and semi-desert regions of northwestern China. Heavy loading of non-anthropogenic dust aerosols was in northwest China. There were remarkable seasonal variations of aerosol optical properties. A positive feedback has been formed between aerosol radiative forcing and the local wind and specific humidity, implying that dust aerosol absorption is substantial in northwestern China. Dust aerosols warmed the atmosphere–surface system in the northwest China. Aerosol direct radiative forcing was confirmed to heat the atmosphere (50–53 W/m^2) and cool the surface (− 39 to − 48 W/ m^2) above the analyzed desert. Radiative forcing in the atmosphere in spring and winter was 18 to 21 W/m^2 higher than other two seasons. Based on the dust sources around the sites, the greater the AOD, the more negative the forcing.

Kalluri et al. 2016 studied the direct radiative forcing properties of atmospheric aerosols over semi-arid region, Anantapur in India.. The mean values of AOD at 500 nm were found to be 0.47 ± 0.09, 0.34 ± 0.08, 0.29 ± 0.06 and 0.30 ± 0.07 during summer, winter, monsoon and post-monsoon respectively. The Angstrom exponent (α380–1020) value is observed maximum in March (1.25 ± 0.19) and which indicates the predominance of fine - mode aerosols and lowest in the month of July (0.33 ± 0.14) and may be due to the dominance of coarse-mode aerosols.. The highest monthly mean BC concentration is observed in the month of January (3.4 ± 1.2 μg m^{-3}) and the lowest in July (1.1 ± 0.2 μg m^{-3}).The estimated Aerosol Direct Radiative Forcing (ADRF) in the atmosphere is found to be + 36.8 ± 1.7 W m^{-2} ,+ 26.9 ± 0.2 W m^{-2} , + 18.0 ± 0.6 W m^{-2} and + 18.5 ± 3.1 W m^{-2} during summer, winter, monsoon and post-monsoon seasons, respectively.

Sadvarte et al. 2016 studied seasonal differences in aerosol abundance and radiative forcing in months of contrasting emissions and rainfall over northern South Asia. WRF-STEM simulations show larger BC and OC burden in Apr, SO_4 in Jul & Sep. Influence of agricultural field burning in Apr, incursion from East Asia in Sep. Aerosol atmospheric forcing of 32–48 W m^{-2}, lower in Sep than in Apr & Jul. Anthropogenic fraction of atmospheric forcing, 45–74% over Ganga plain and Tibet. BC transport to Tibet, at elevated levels, from S Asia in Apr & E Asia in Sep.

Jacobson 2001 studied that aerosols affect the Earth's temperature and climate by altering the radiative properties of the atmosphere. A large positive component of this radiative forcing from aerosols is due to black carbon –soot that is released from the burning of fossil fuel and biomass, and, to a lesser extent, natural ®res, but the exact forcing is affected by how black carbon is mixed with other aerosol constituents. From studies of aerosol radiative forcing, it is known that black carbon can exist in one of several possible mixing states; distinct from other aerosol particles or incorporated within them or a black-carbon core could be surrounded by a well mixed shell. But so far it has been assumed that aerosols exist predominantly as an external mixture. The mixing state and direct forcing of the black-carbon component approach those of an internal mixture is largely due to coagulation and growth of aerosol particles. This finding implies a higher positive forcing from black carbon than previously thought, suggesting that the warming effect from black carbon may nearly balance the net cooling effect of other anthropogenic aerosol constituents. The magnitude of the direct radiative forcing from black

carbon itself exceeds that due to CH_4, suggesting that black carbon may be the second most important component of global warming after CO_2 in terms of direct forcing.

Pratsinis et al. 1984 studied the source resolution of the organic component of the fine fraction of the ambient aerosol *(dp* < 3.5 *um)* by combining source information from the inorganic component with thermal analysis and local emission inventories. The primary and secondary carbon containing components were identified using a source fingerprint thermogram. The primary carbon emitted from automobiles was calculated using the ambient lead concentration and a recent estimate of the lead to carbon ratio for this source. The remaining primary carbon was apportioned to the other sources according to the local emission inventory. Source apportionment of the secondary component was performed by scaling the secondary carbon to a recent emission inventory for reactive organic gases (ROG) neglecting biogenic contributions and assuming equal potential for aerosol formation for the various ROG. The major source at both sites was automobiles which were responsible for 68% and 36% of the carbon containing component of the fine aerosol at Lennox and Duarte respectively. Industrial sources made a relatively higher contribution at Duarte, 26%, than at Lennox 12%. Good correlation was found between ozone and secondary carbon. However, a weaker correlation was found between sulfates and secondary carbon using an appropriate regression model. It was found that the carbon containing component was responsible for 27% and 44% of the incident light extinction at Lennox and Duarte, respectively.

Pant et al. 2016 investigated the present scenario and future directions for particulate matter in India. Given the high mortality burden associated with air pollution exposure in India, a deeper understanding of ambient pollutant levels as well as source strengths is crucial, both in urban and rural areas. Further, the attention needs to expand beyond the handful large cities that have been studied in detail. The relevance of exposures studies from the developed countries in developing countries is uncertain. There are a limited number of studies focused on exposure to PM and/or associated health effects in India, but it is evident that levels of exposure are much higher than those reported in developed countries. Most studies have focused on coarse aerosols, with a few studies on fine aerosols. Additionally, most studies have focused on a handful of cities, and there are many unknowns in terms of ambient levels of PM as well as personal exposure.

Kim et al. 2016 studied the adverse effects of airborne particulate matter on various skin diseases PM induces oxidative stress via production of reactive oxygen species.These processes lead to the increased inflammatory skin diseases and skin aging. In addition, environmental cigarette smoke, which is well known as an oxidizing agent, is closely related with androgenetic alopecia (AGA). Also, ultrafine particles (UFPs) including black carbon and polycyclic aromatic hydrocarbons (PAHs) enhance the incidence of skin cancer. Overall, increased PM levels are highly associated with the development of various skin diseases via the regulation of oxidative stress and inflammatory cytokines. Therefore, anti-oxidant and anti-inflammatory drugs may be useful for treating PM-induced skin diseases.

Kim et al. 2016 investigated relations between the association between prenatal and postnatal exposure to PM_{10} and children's weight from birth to 60 months of age. This birth cohort study evaluated 1129 mother-child pairs in South Korea. Children's weight was measured at birth and at six, 12, 24, 36, and 60 months. The average levels of children's exposure to particulate matter up to 10 μm in diameter (PM_{10}) were estimated during pregnancy and during the period between each visit until 60 months of age. Exposure to PM_{10} during pregnancy lowered children's weight at 12 months. PM_{10} exposure from seven to 12 months negatively affected weight at 12, 36, and 60 months. Repeated measures of PM_{10} and weight from 12 to 60 months revealed a negative association between postnatal exposure to $PM_{10}$and children's weight. Children continuously exposed to a high level of PM_{10} (> 50 μg/m3) from pregnancy to 24 months of age had weight z-scores of 60 that were 0.44 times lower than in children constantly exposed to a lower level of PM_{10} (≤ 50 μg/m3) for the same period. Furthermore, growth was more vulnerable to PM_{10} exposure in children with birth weight < 3.3 kg than in children with birth weight > 3.3 kg. Air pollution may delay growth in early childhood and exposure to air pollution may be more harmful to children when their birth weight is low.

Funasaka et al. 2007 studied concentrations of particulate matter (PM) and carbonaceous particulates in indoor and outdoor air at roadside private house-holds measured in Osaka, Japan. The particulate samples were collected on filters using a portable sampler capable of separating particles into three different size ranges: over 10 um, 2±10 um (coarse) and below 2 um (fine) in aerodynamic diameter. The filters were weighed and then analyzed for elemental carbon (EC)

and organic carbon (OC) by thermal oxidation using a CHNCORDER. The results showed that indoor PM concentration is considerably affected by EC and the EC in indoor air is signifcantly correlated to that in outdoor air, r=0.86 (n=30, p<0.001). A simple estimation from EC content ratio in diesel exhaust particles indicated that about 30% of indoor particulates of less than 10 um (PM_{10}) were contributed from diesel exhaust. Additionally, the size characteristics of outdoor PM at roadside and background sites were examined using Andersen Cascade Impactors.

Sarkar et al. 2010 studied the ambient respirable particles (PM≤10um, denoted by PM_{10}) were characterized with respect to 20 elements,16 polycyclic aromatic hydrocarbons (PAHs), elemental and organic carbon (EC and OC) during a major firework event—the "Diwali" festival in Delhi, India. The event recorded extremely high 24-h PM_{10} levels (317.2–616.8 ug/m^3, 6–12 times the WHO standard) and massive loadings of Ba (16.8ug/m^3 mean value), K (46.88 ug/m^3), Mg (21.38ug/m3), Al (8 ug/m^3) and EC (40.58ug/m^3). Elemental concentrations as high as these have not been reported previously for any firework episode. Concentration of Ba, K, Sr, Mg, Na, S, Al, Cl, Mn, Ca and EC were higher by factors of 264, 18, 15, 5.8, 5, 4, 3.2, 3, 2.7,1.6 and 4.3, respectively, on Diwali as compared to background values. It was estimated that firework aerosol contributed 23–33% to ambient PM10 on Diwali. OC levels peaked in the post-Diwali samples, perhaps owing to secondary transformation processes. Atmospheric PAHs were not sourced from fireworks; instead, they correlated well with changes in traffic patterns indicating their primary source in vehicular emissions. Overall, the pollutant cocktail generated by the Diwali fireworks could be best represented with Ba, K and Sr as tracers. It was also found that chronic exposure to Diwali pollution is likely to cause atleast a 2% increase in non-carcinogenic hazard index (HI) associated with Al, Mn and Ba in the exposed population.

Joly et al. 2010 evaluated the levels of $PM_{2.5}$ and their elemental content was carried out during the nine launches of the 2007 Montréal International Fireworks Competition. The highest $PM_{2.5}$ levels reached nearly 10 000 ug/m3, roughly 1000 times background levels. Elements such as K, Cl, Al, Mg and Ti were markedly higher in plume-exposed filters. This study shows that 1) persons in the plume and in close proximity to the launch site may be exposed to extremely high levels of $PM_{2.5}$ for the duration of the display and, 2) that the plume contains specific elements for which little is known of their acute cardio-respiratory toxicity.

Papiya mandal et al. 2011 assessed the variation in ambient air quality and ambient noise levels during pre-Diwali month (DM), Diwali day (DD) and post-Diwali month during the period 2006 to 2008. The use of fireworks during DD showed 1.3 to 4.0 times increase in concentration of respirable particulate matter (PM_{10}) and 1.6 to 2.5 times increase in concentration of total suspended particulate matter (TSP) than the concentration during DM. There was a significant increase in sulfur dioxide (SO_2) concentration but the concentration of nitrogen dioxide (NO_2) did not show any considerable variation.

Nandita D. Ganguly 2015 studied that the changes in humidity levels during the Diwali festivities over a period of 13 years at three Indian metro cities: Ahmedabad, New Delhi and Kolkata. A small short term increase in relative humidity even in the absence of transport of humid air from Arabian Sea and Bay of Bengal has been observed. The relative humidity levels were found to be exceeding the ambient levels during night and lying below the ambient levels during morning hours, indicating an increase in the survival rates of viruses responsible for the transmission of viral infections, as well as triggering immune-mediated ill- nesses such as asthma during Diwali.

Xin H et al. 2012 assessed the bioaccessibility and human health risks of As and heavy metals (Cu, Pb, Zn, Ni, Co, Cr, Cd and Mn) in total suspended particulates (TSP) and fine particulate matter (PM2.5) in Nanjing, China were investigated.The average mass concentration ratios of PM2.5 to TSP were 0.61 for Gulou sampling site and 0.50 for Pukou sampling site, respectively. Zn, Pb, Mn and Cu were the most abundant elements among thestudied metalloids in both TSP and PM2.5. The results of a simple bioaccessibility extraction test of thestudied metalloids varied among elements, with Cd, Zn, Mn, Pb and As showing the higher bioaccessibility.The carcinogenic risks of As, Cd, Co, Cr and Ni in both TSP and PM2.5 via dermal contact and inhalation exposure were within the acceptable level (<1*10-4) for both children and adults, but there was potential carcinogenic risk posed by Pb via ingestion to children and adults. The hazard index values for all of the studied elements suggested no non-carcinogenic health risks via ingestion and derma lcontact, but a potential non-carcinogenic health risk via inhalation to adults. Values of hazard quotient and hazard index indicated the non-carcinogenic risks from the studied metalloids to children via ingestion, dermal contact and inhalation pathways in Nanjing given the present air quality.

Kulshrestha et al. 2004 assessed concentration of metal during Diwali week. The burning of these fireworks leads to metal pollution in air. In this study, metal concentrations in ambient air were observed to be very high as compared to background values on previous days. For some metals the concentrations were observed to be higher than reported at industrial sites. The order of concentration of metals on the day of festival was observed to be in the order—K>Al>Ba>Mg>Fe>Sr>Na>Ca>Cu>Mn>As>V>Ni>Bi. Interestingly, the concentrations of Ba, K, Al and Sr went up to 1091, 25, 18 and 15times higher than the previous day of Diwali. This study indicated that burning of crackers and sparkles on Diwali is a very strong source of air pollution which contributes significantly high amount of metals in air.

Tsai et al. 2012 studied the firework displays during Taiwan's Lantern Festival in Kaohsiung harbor in Taiwan. Field measurements of atmospheric particulate matter (PM) were conducted on February 9-11th, 2009 during Taiwan's Lantern Festival in Kaohsiung City. Moreover, three kinds of fireworks powders obtained from the same manufacturing factory producing Kaohsiung Lantern Festival fireworks were burned in a self-designed combustion chamber to determine the physicochemical properties of the fireworks' particles and to establish the source profile of firework burning. Several metallic elements of PM during the firework display periods were notably higher than those during the non-firework periods. The concentrations of Mg, K, Pb, and Sr in $PM_{2.5}$ during the firework periods were 10 times higher than those during the non-firework periods. Additionally, the Cl^-/Na^+ ratio was approximately 3 during the firework display periods as Cl came from the chlorine content of the firework powder. Moreover, the OC/EC ratio increased up to 2.8. Results obtained from PCA and CMB receptor modeling showed that major sources of atmospheric particles during the firework display periods in Kaohsiung harbor were fireworks, vehicular exhausts, soil dusts and marine sprays. Particularly, on February 10th, the firework displays contributed approximately 25.2% and 16.6% of PM10 at two downwind sampling sites, respectively**.**

Vecchi et al. 2008 assessed the chemical–physical properties of airborne particles (elements, ions, organic and elemental carbon and particles size distributions) collected during a fireworks episode in Milan (Italy) are reported. Elements typically emitted during pyrotechnic displays increased in 1 h as follows: Sr (120 times), Mg (22 times), Ba (12 times), K (11 times), and Cu

(6 times). In our case study, Sr was recognised as the best fireworks tracer because its concentration was very high during the event and lower than, or comparable with, minimum detection limits during other time intervals, suggesting that it was mainly due to pyrotechnic displays. In addition, particles number concentrations increased significantly during the episode (up to 6.7 times in 1 h for the 0.5<d<1 um size bin). Contributions (e.g. Cu, elemental carbon and nitrogen oxides) to air pollution due to the large traffic volume registered during the same night were also singled out. The contribution of fireworks to the local environment in terms of PM_{10} mass, elements and chemical components was assessed with 4-h time resolution. PM_{10} mass apportioned by fireworks was up to 33.6 ugm^{-3} (about 50% of the total PM_{10} mass). Major contributors were elemental and organic carbon (2.8 and 8.1 ugm^{-3}, respectively) as well as metals like Mg, K, Sr, Ba, and Cu (0.4, 0.7, 0.07, 0.1, and 0.1 ugm^{-3}, respectively).

Wang et al. 2007 assessed the effects of the burning of fireworks on air quality in Beijing from the ambient concentrations of various air pollutants (SO^2, NO^2, $PM_{2.5}$, PM_{10} and chemical components in the particles) during the lantern festival in 2006. Eighteen ions, 20 elements, and black carbon were measured in $PM_{2.5}$ and PM_{10}, and the levels of organic carbon could be well estimated from the concentrations of dicarboxylic acids. Primary components of Ba, K, Sr, Cl^-, Pb, Mg and secondary components of $C_5H_6O_4^{2-}$, $C_3H_2O_4^{2-}$, $C_2O_4^{2-}$, $C_4H_4O_4^{2-}$, SO_4^{2-}, NO_3^- were over five times higher in the lantern days than in the normal days. The firework particles were acidic and of inorganic matter mostly with less amounts of secondary components. Primary aerosols from the burning of fireworks were mainly in the fine mode, while secondary formation of acidic anions mainly took place on the coarse particles. Nitrate was mainly formed through homogeneous gas-phase reactions of NO_2, while sulfate was largely from heterogeneous catalytic transformations of SO_2. Fe could catalyze the formation of nitrate through the reaction of a-Fe_2O_3 with HNO_3, while in the formation of sulfate, Fe is not only the catalyst, but also the oxidant. A simple method using the concentration of potassium and a modified method using the ratio of Mg/Al have been developed to quantify the source contribution of fireworks. It was found that over 90% of the total mineral aerosol and 98% of Pb, 43% of total carbon, 28% of Zn, 8% of NO_3^-, and 3% of SO_4^{2-} in $PM_{2.5}$ were from the emissions of fireworks on the lantern night.

Murty 2000 investigated hospital admissions due to Diwali toxicity and burns. In the year (1999) 251 fires were reported from various parts of Delhi city on Diwali. Out of these 176 were directly cracker related incidents, 36 were indirectly related 14 were vague calls. The centralized accidents and trauma services received 124 calls, 53 were related to fire, 38 road accidents, 15 medical emergencies and 11 cases of burns. At AIIMS hospital 48 eye injury cases were brought to RPC casualty, nine were of serious nature.

Pervez et al. 2015 collected $PM_{2.5}$ (particulate matter less than 2.5 um) samples, in a 8-week wintertime sampling program in two residential sites of Bhilai, India during the Indian Diwali festival in November 2012, were chemically characterized for 38 chemical species including eight speciated carbonaceous fractions (SCFs) of elemental (EC) and organic carbon (OC), twenty one metallic elements, and nine water soluble ionic species. The objectives were to investigate: 1) relative abundances of SCFs contained in $PM_{2.5}$ during the Diwali festival period compared to normal days, and 2) enrichment pattern of potential inorganic markers of firework emission in ambient $PM_{2.5}$ during the festival days. Eight-fold increase in $PM_{2.5}$ mass concentrations were measured during the Diwali festival days compared to concentrations occurring in normal days. Bursting of firecrackers in the residential streets have shown significant contribution to the emission markers (K, Mg, Zn, S, EC and OC) along with crustal markers (Ca, Fe, Al) in ambient $PM_{2.5}$ aerosol samples. Concentrations of water soluble ionic species were found to be 10 times greater than those found in normal days. Further, the anion/cation ratios were found to reach a factor of 2; indicating the acidic character of emissions resulting from fireworks. The relative abundance of SCFs and higher ratios of OC to EC during the Diwali episode suggested the significant formation of secondary organic carbon (SOC) aerosols.We estimate that aerosols emitted from firework bursting contribute up to 32% of total ambient $PM_{2.5}$ during the Diwali festival.

Izhar et al. 2016 assessed health risks related to exposure to toxic metals of PM_1 was assessed. Concentrations of 13 heavy metals, adsorbed to submicron particulate matter PM_1 were experimentally examined but only 12 metals were found at detectable levels inside IIT Kanpur campus in 2008-2009 for all months excluding June and October. A total of 90 samples collected for 8 h sampling time by a single stage round nozzle, grease impaction substrate based impactor type PM_1 sampler were analysed by ICP-OES (Inductively Coupled Plasma Optical Emission

Spectrometry). Results showed daily average PM1 concentration is 102.46 ± 35.9 mg/m^3 and metal concentration followed the trend: Ca > Fe > Mg > Zn > Pb > Cu > Cr > Ni > Se > Cd > V > As. Contamination level assessment using geo-accumulation index showed Ca, Fe and Mg exhibited non contamination whereas metals like Cr, Zn, As, Cd, Pb, Se, Ni and Cu exhibited ranges from moderate to extreme contamination. Ingestion is found to be the major exposure pathway for heavy metals. Non carcinogenic health risk assessment for Pb, Cd and Cr (HI > 1) signified strong chances of adverse impact on children whereas adults are well under safe limit. Cancer Risk for adults and children followed the same decreasing order, Cr(VI)>Cd > Ni > As > Pb. It was found to be higher than permissible limits(10^{-6}) for adults and children both.

Kumar 2013 studied that the deterioration of air quality in Indian megacities (Delhi, Mumbai or Kolkata) is much more significant than that observed in the megacities of developed countries. Densely packed high-rise buildings restrict the self-cleaning capabilities of Indian megacities. Also, the ever growing number of on-road vehicles, resuspension of the dust, and anthropogenic activities exacerbate the levels of ambient air pollution, which is in turn breathed by urban dwellers. Pollution levels exceeding the standards on a regular basis often result in a notable increase in morbidity and mortality. This article discusses the challenges faced by Indian megacities in their quest for sustainable growth, without compromising the air quality and urban way of life.

Pant et al. 2013 studied that road traffic is one of the main sources of particulate matter in the atmosphere. Despite its importance, there are significant challenges in quantitative evaluation of its contribution to airborne concentrations. This article first reviews the nature of the particle emissions from road vehicles including both exhaust and non-exhaust (abrasion and re-suspension sources). It then briefly reviews the various methods available for quantification of the road traffic contribution. This includes tunnel/roadway measurements,twin site studies, use of vehicle-specific tracers and other methods. Finally, the application of receptor modelling methods is briefly described. Based on the review, it can be concluded that while traffic emissions continue to contribute substantially to primary PM emissions in urban areas, quantitative knowledge of the contribution, especially of non-exhaust emissions to PM concentrations remain inadequate.

Pakade et al. 2015 studied the physico-chemical parameters as well as the heavy metal in agricultural soil samples collected from four different zones of Amritsar, Punjab (India). pH of different soil samples ranged from 7.4 to7.8 whereas in control pH was found to be 6.6. Alkalinity was observed in the range of 201-354 meq100g^{-1}. The content of nitrate (NO^{3-}) ranged from 0.25-0.33 mgKg^{-1} slightly less than control (0.38 mgKg^{-1}). A wide variation of metal concentration was observed in all studied samples. Fe (2809-5692 mgKg^{-1}) was found one of the predominant heavy metal in soil followed by Zn (73-320 mgKg^{-1}) Mn (154-194 mgKg^{-1}), Pb (7.7-118 mgKg^{-1}), Ni (9.67-24.32 mgKg^{-1}), Cu (8.4-24 mgKg^{-1}) and Cd (0.55-1.39 mgKg^{-1}). All the samples also induced significant genotoxicity in Allium cepa test system. The levels of all essential and toxic metals were compared well with other parts of the world.

Srinivas et al. 2015 investigated the sensitivity of interactive Weather-Chemistry model has been examined to predict the air quality (1 and 3 days in advance) of Indian mega city Delhi during two identical extreme events of Diwali in 2012 and 2013 in this study. Analysis is conducted 3 days prior to 3 days later of Diwali day for both events to verify the rapid changes in fine particulate matter ($PM_{2.5}$) due to widespread display of Diwali fireworks. The model successfully predicted the variability in $PM_{2.5}$ during 2012 for the entire period of analysis withreasonable accuracy. Although model performed reasonably well until Diwali day in 2013 but it was unable to simulate rapid built up of $PM_{2.5}$ (1500 mg^{-3} hourly average) during post Diwali day as it failed to capture unusual mid-night steep temperature gradient followed by a record lowering of boundary layer height.

Pope et al. 2006 reviewed six substantial lines of research that have been pursued since 1997 and helped elucidate our understanding about the effects of PM on human health. There has been substantial progress in the evaluation of PM health effects at different time-scales of exposure and in the exploration of the shape of the concentration-response function. There has also been emerging evidence of PM-related cardiovascular health effects and growing knowledge regarding interconnected general pathophysiological pathways that link PM exposure with cardiopulmonary morbidity and mortality. Despite important gaps in scientific knowledge and continued reasons for some skepticism, a comprehensive evaluation of the research findings

provides persuasive evidence that exposure to fine particulate air pollution has adverse effects on cardiopulmonary health. Although much of this research has been motivated by environmental public health policy, these results have important scientific, medical, and public health implications that are broader than debates over legally mandated air quality standards.

Tiwari et al. 2009 investigated that the concentrations of PM_{10}, $PM_{2.5}$ and their water-soluble ionic species were determined for the samples collected during January to December, 2007 at New Delhi.The annual mean PM_{10} and $PM_{2.5}$ concentrations (± standard deviation) were about 219 (± 84) and 97 (±56) μgm^{-3} respectively, about twice the prescribed Indian National Ambient Air Quality Standards values. The monthly average ratio of $PM_{2.5}/PM_{10}$ varied between 0.18 (June) and 0.86 (February) with an annual mean of 0.48 (±0.2), suggesting the dominance of coarser in summer and fine size particles in winter. Thedifference between the concentrations of PM_{10} and $PM_{2.5}$, is deemed as the contribution of the coarse fraction (PM10~2.5). The analyzed coarse fractions mainly composed of secondary inorganic aerosols species (16.0 μgm^{-3}, 13.07%), mineral matter (12.32 μgm^{-3}, 10.06%) and salt particles (4.92 μgm^{-3}, 4.02%). PM2.5 are mainly made up of undetermined fractions (39.46 μgm^{-3}, 40.9%), secondary inorganic aerosols (26.15 μgm^{-3}, 27.1%), salt aerosols (22.48 μgm^{-3}, 23.3%) and mineral matter (8.41 μgm^{-3}, 8.7%). The black carbon aerosols concentrations measured at a nearby location to aerosol sampling site, registered an annual mean of ~14 (±12) μgm^{-3}, which is significantly large compared to those observed at other locations in India. The source identifications are made for the ionic species in PM_{10} and $PM_{2.5}$. The results are discussed by way of correlations and factor analyses. The significant correlations of Cl^{-}, SO_4^{2-}, K^{+}, Na^{+}, Ca^{2+}, NO^{3-} and Mg^{2+} with $PM_{2.5}$ on one hand and Mg^{2+} with PM_{10} on the other suggest the dominance of anthropogenic and soil origin aerosols in Delhi.

Tiwari et al. 2013 confirmed that Black carbon (BC), which is one of the highly absorbing capacities of solar radiation, reduces albedo of atmospheric aerosol. BC along with fine particulate matters ($PM_{2.5}$), which play crucial role in climate and health,was monitored online for an entire year of 2011 at an urban megacity of Delhi, situated in the northern part of India. Daily mass concentration of BC varies from 0.9 to 25.5 μg m−3, with an annual mean of 6.7±5.7 $\mu g\ m^{-3}$ displayed clear monsoon minima and winter maxima; however, $PM_{2.5}$ concentration was

ranging from 54.3 to 338.7 μg m^{-3}, with an annual mean of 122.3±90.7 μg m^{-3}. During summer and monsoon, the BC concentrations were found less than 5 μg m−3; however, the highest concentrations occurred during winter in segments from b5 to >10 μg m^{-3}. In over all study, the BC mass concentration was accounted for ~6% of the total $PM_{2.5}$ mass, with a range from 1.0% to 14.3%.

Gupta et al. 2016 investigated that the concentration, spatial distribution and source of 13 PM_1 bound trace metals (Fe, Cu,Mn, Cr, Zn, Cd, Ni, K,Mg, Na, Ca, Pb and V) and adverse health effects of 5- PM_1 bound trace metals (Mn, Zn, Ni, Cr and Cd) collected during foggy and non-foggy episodes are presented. Twenty-four samples from each period (foggy and non-foggy episodes)were collected from Kanpur, a typical densely populated city and the most polluted representative site in the Indo-Gangetic plain of India, andwere analyzed for carcinogenic (Ni, Cr and Cd) and non-carcinogenic metals (Mn and Zn). The average mass concentration of PM_1 during foggy and non-foggy episodes was found to be 160.16 ± 37.70 and 132.87 ± 27.97 μg/m3. Source identification via principle component analysis suggested that vehicular emission and anthropogenic, industrial and crustal dust were the dominant sources in this region. During both episodes the decreasing order of hazard quotient (Hq) for adult and children was as Mn , Cr, Cd, Ni, Zn. In a non-foggy episode the hazardous index (Hi) values of these 5 trace metals were found to be ~3.5 times higher than a foggy episode's exposed population, respectively. In a foggy episode, due to the exposure to total carcinogenic trace metals (Ni, Cr and Cd) present in the ambient air, 95% probability total incremental lifetime cancer risks were ~687 cancer cases and ~402 cancer cases per million in the adult population and children population respectively. These cancer cases were ~1.6 times higher than a nonfoggy episode's exposed population.

Sadiq et al. 2015 investigated that East Asia, North America and Europe are the world largest emitters of anthropogenic black carbon (BC). Generally, a change in BC emissions tend to linearly influence BC concentrations over both source and nearby downwind regions even taking into account the effect of BC-induced climate perturbations. Aerosol optical depth (AOD) and the net radiative flux perturbation at top of atmosphere (TOA) tend to preserve a similar linear relationship to local BC emission changes, with a robust signal confined only to the source areas. However, the response of temperature in most places is inconsistent to BC emission changes.

Though the presence of BC in the atmosphere absorbs solar and terrestrial radiation which has a tendency to warm the atmosphere, the perturbed atmospheric circulation induces substantial meridional exchanges of warm and cold air masses, which overpasses the warming tendency of BC exerted on the atmosphere. This indicates that reducing/increasing regional BC emissions immediately ameliorate/deteriorate local air quality proportionally, but the associated effects on climate perturbation may lack a clear trend within the initial 10- year time span.

Ariya et al. 2006 reviewed that organic substances have been recognized as active cloud condensation and ice formation nuclei for several decades. In some regions of the world, these organic compounds (OC) consist predominantly of suspended matter mass, which can have local (e.g. toxicity, health hazards) and global (e.g. climate change) impacts. However, due to the complexity of their chemical nature, the significance of organic molecules in driving physical and chemical atmospheric processes is still very uncertain and poorly understood. It seems that classical Kohler theory does not adequately describe the hygroscopic behaviour of predominantly identified organic CCN such as pure dicarboxylic acid particles. Factors such as surface tension, impurities, volatility, morphology, contact angle, deliquescence, and the oxidation process should be considered in the theoretical prediction of the CCN ability of OC and the interpretation of experimental results.

This literature survey tries to give a general idea of the behavior of particulate matter under different circumstances. It gives a fair share of idea that aerosol science is a complex arena and given its presence in vast amounts in the atmosphere, the overall effect is anything but simple. This necessitates it to be studied in both spatially and temporally collected data over small and large time periods, generating an overall overview.

Chapter-III

Methodology

This chapter encloses the methodology adopted for sampling and chemical speciation of particulate matter. The meteorological data influencing the concentrations of particulate matter has also been collected. Health risk assessment models adopted for this study have also been discussed.

3.1 Method for determination of PM_5,OC,EC,TC and Heavy metals

Determination of concentration of particulate matter (PM_5**)**, organic carbon (OC), Elemental carbon (EC) and Heavy metals are discussed in this portion.

3.1.1 PM_5

The sampler used for the study was APM801 (Envirotech Pvt. Ltd.) with a flow rate of 2 L/ Min. It was kept at a height of 4 m above the ground level maintaining the required distance needed for building and trees not to pose as as an obstacle for sampling,although, a heavy traffic road at a distance of 600 m could not be avoided .The samples were collected on Whatman 37 mm Micro fibre quartz filter paper with a deposition area of ~8.533 cm^2 requlary for 7 days (1^{st} day, 2^{nd} & 3^{rd} days- pre diwali, 4^{th} day- Diwali day, 5^{th}, 6^{th} & 7^{th} day- Post diwali days) from 8/11/15 to 14/11/15 for 3 hours (7 pm – 10 pm). The sampling time so chosen, was to arrest the PM 5 loadings in peak hours as people burst crackers only for a few hours. Also, because the Supreme Court of the country had issued directives not to burst crackers after 10 pm till 6 am. The quartz filter papers were prebaked in a muffle furnace at 550^0 C for 6 hours and kept in dessicator for 24 hrs before and after sampling to avoid interference of organic impurities. Gravimetric method was employed to measure PM 2.5 conc. (μglm^3) with the help of "Sartorius Microbalance" (accurate upto 6 digits).

3.1.2 OC, EC and TC

The determination of carbonaceous fraction of OC (OC1 + OC2 + OC3 + OC4) and EC (EC1 + EC2 + EC3 + EC4) have been made through DRI model 2001(**Figure 3.1**) thermal optical carbon analyzer by Thermal optical reflectance (TOR)- IMPROVE_ A method. This

analyzer uses preferential oxidation at different temperatures to identify carbon compounds as OC1, OC2, OC3, OC4, EC1, EC2 and EC3 at temperatures of 140^0 C, 280^0 C, 480^0 C, 580^0 C,580^0 C, 740^0C, and 840^0C, respectively.TC can be calculated by summation of all subcarbonaceous fraction of OC and EC. Filter punches of 0.5 cm^2 from each QFF's are subjected to a non-oxidzing Helium (He) atmosphere for OC component detection; 2% O_2/ 98% He for EC components. The main advantage of this analyzer is that it provides for correction of pyrolysis charring of OC component to EC, which otherwise would give misguided results if not checked. A computer connected to the analyzer displays the on going process in the form of graph; peaks depicting identification of a component based on temperature.

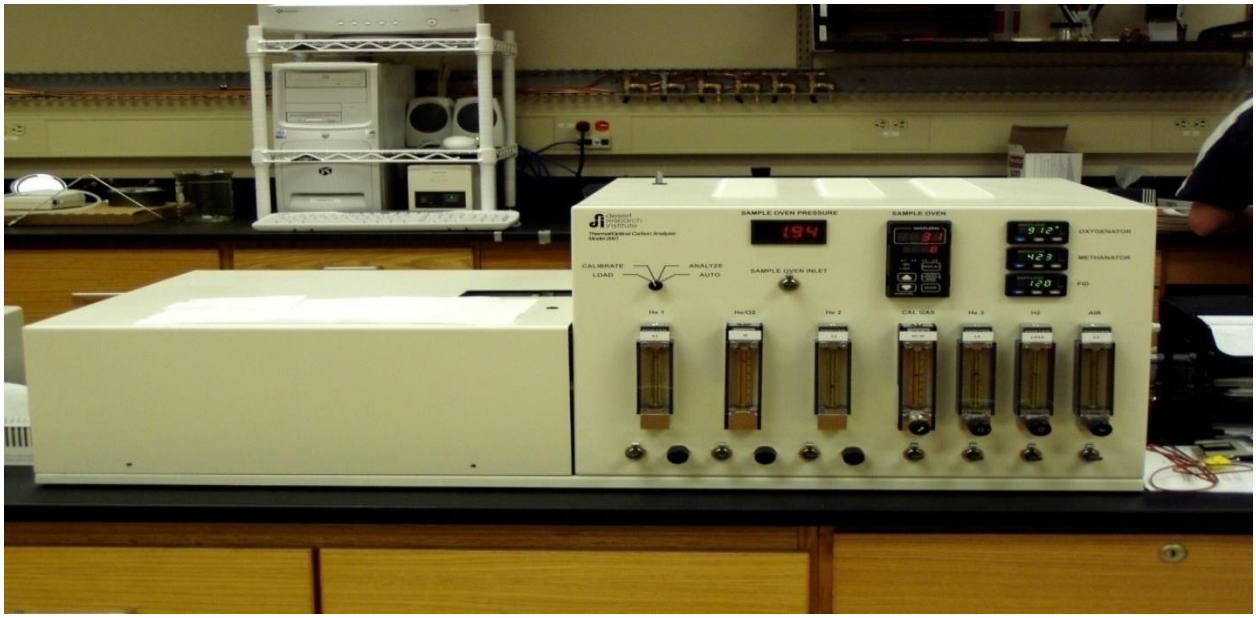

Figure 3.1 DRI Model 2001 Thermal/Optical carbon Analyzer

3.1.3 Heavy metals

Analysis of heavy metals was carried out in ICP-OES (Teledyne Leeman,Model – Prodigy Spec)(**Figure 3.2**).Small known weights of sampled Quartz filter paper were subjected to acid digestion(5ml HNO_3+ 2ml H_2O_2) on a hot plate inside a fume hood and refluxed at 50~70˚C. The excess acid is boiled off during the digestion with the final result being a wet dry filter paper. These are then subjected to heating in the same process with 10ml of 5% HNO_3 until a wet dry filter paper is achieved. After cooling this solution, 10ml of 5% HNO_3 is again

added and allowed to stand for 30 minutes. This step is essential for the diffusion of acid from filter paper into the solution. The solution is then passed through a Whatman 2µm pore size PTFE syringe filter. The volume is made upto 25ml by rinsing with 2% HNO_3. Field blanks are prepared in a similar way and both polluted and unpolluted samples are subjected to elemental analysis in ICP-OES.

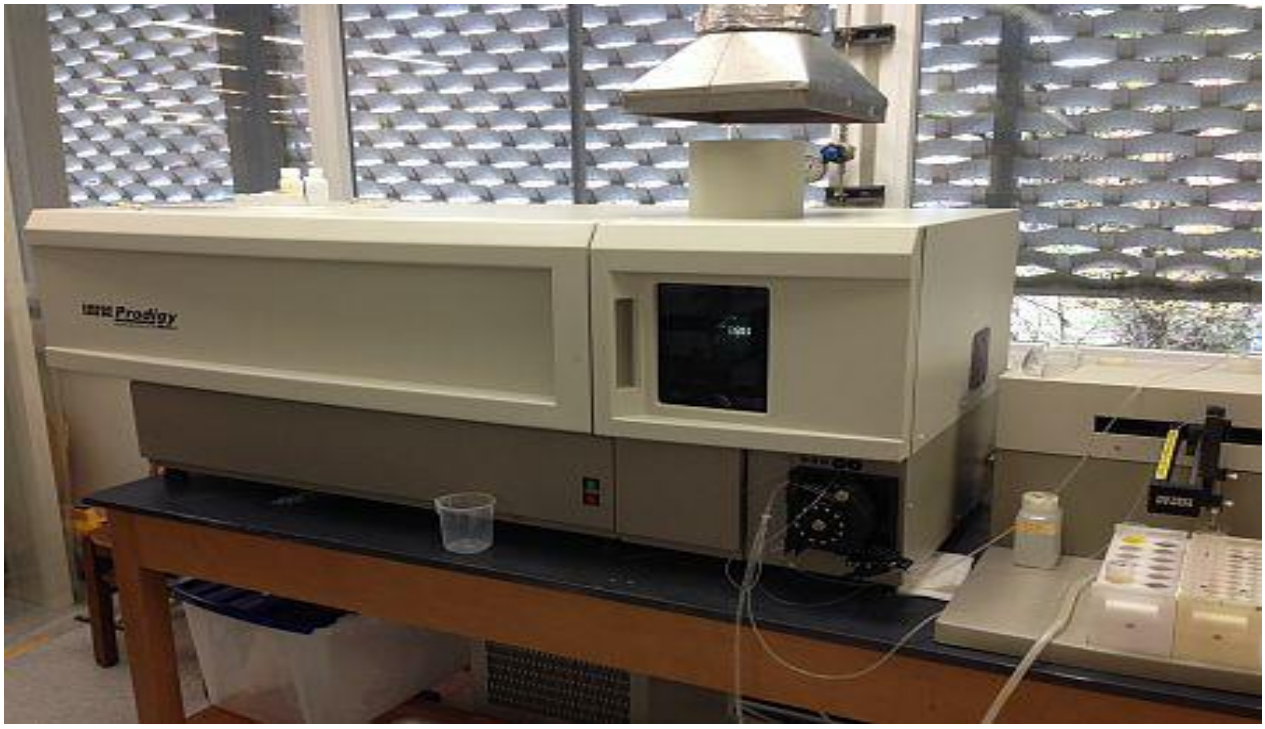

Figure 3.2 Teledyne Leeman ICP-OES, Model-Prodigy Spec

3.2 Health Risk Models

The health risk assessment of this study is based on the US EPA model (US EPA 1997).Airborne respirable particulate matter can reach the lungs and gas exchange regions of lungs most easily through inhalation. The average daily dose of a chemical through inhalation is given by-

$$ADD=(C*IR*EF*ED)/(BW*AT)$$

Where, ADD=average daily dose in $mgkg^{-1}day^{-}1$, C= concentration of metal in PM 5 in mgm^{-3}, IR=Inhalation rate in m^3/day which in this study is 7.63(children) and 20(adults),EF=Exposure frequency in days /year, ED=Exposure duration in years which in this study is 6(children) and 24(adults),BW=Body weight in kg which in this study is 15(children) and 70(adults) and AT=Average lifetime(ED*365days/year).All the values have been taken from risk assessment reports of US EPA.(US EPA 1989,2004b,2007,2011).

The Hazard Quotient(HQ) is defined by,

$$HQ=ADD/RfD$$

Where, RfD known as reference dose is defined as the safe threshold dose of exposure of an individual to a chemical on a daily average basis such that it will not cause any detrimental non-cancerous effect on the individual. These values have been formulated by the US EPA and can be found on the integrated risk information system(IRIS) of the US EPA.If HQ>1 for a metal, it suggests, deleterious non-carcinogenic effect on the population in concern. HQ<1 means, the average daily dose is less than the Rfd of the metal implying, it would not pose non-carcinogenic harm.

The health index (HI) is defined by,

$$HI=\Sigma_{i=1 \text{ to } n} HQ$$

HI is the summation of all health quotients of all metals through different pathways (which in this study is inhalation) to give an overall evaluation of increase in chronic non cancerous diseases due to metal contamination. HI>1 suggests adverse non-carcinogenic effect. HI<1 suggests it would not pose non-carcinogenic effect(US EPA 1993).

3.3.1 Excess Cancer Risk

Exposure to probable, likely and definite carcinogens may likely increase the chances of causing cancer in humans.No safe threshold values exist for carcinogens. Even the tiniest fraction or smallest concentration may promote cancer in the body in any form .Excess cancer risk (ECR) measures the increased probability of an individual developing cancer, if, exposed to any classified carcinogen during his lifetime. It is given by the formula-

$$ECR=(C*ET*EF**ED*IUR)/AT$$

Where C=Concentration of carcinogenic metal in $\mu g/m^3$, ET=Exposure time which in this study is 3 hrs/day, AT= average time for carcinogens which is (70 years*365days/year*24hrs/day) for both child and adult(US EPA 1989),IUR=Inhalation unit risk in $(\mu g/m^3)^{-1}$.IUR is an estimate of the increased cancer risk from inhalation exposure to a concentration of 1 µg/m3 for a lifetime. The IUR can be multiplied by an estimate of lifetime exposure (in µg/m3) to estimate the lifetime cancer risk. The values of IUR have been taken from IRIS system and other studies(Hu et al. 2012).All other parameters hold the same meaning and value as described in equation of average daily dose of inhalation.

3.3 Monitoring site and Metorology

Delhi (28^0 39^0 N, 77^0 13^0 E) 160 kms south of Himalayas, approximately 216 above m.s.l is part of NCR, an urban agglomeration. It constitutes ~2.9 % of the total area of NCR, which covers an area of ~51, 109 Km^2 encompassing the states of Haryana, Uttar Pradesh and Rajasthan. According to the last census data in 2011, Delhi had a population of 16.3 million, with present population of nearly 18 million as of 2015. It experiences an annual rainfall intensity of 670 mm, with monsoon months (July-Sept) receiving 80% out of it. Maximum temperatures can soar as high as 46^0 C in summers (May-June) and minimum temperature can go down to 1^0 C (December-January). Chiefly, north and north westerly winds blow throughout the year except in monsoon when easterly and south easterly winds are predominant. Calm winter months with inversion conditions is typical of Delhi climate. For this study, sampling was conducted in a residential area in Rohini, situated in North west region of Delhi. North West Delhi houses two industrial areas, namely- Badli industrial area and Bawana industrial area, latter being a larger unit. These units consists of an array of variety of industries dealing in manufacture of automobile spare parts, household electronic equipments, computer hardware, ball bearings, paints, dyes, adhesives, stationery and metal alloy industries and many more.

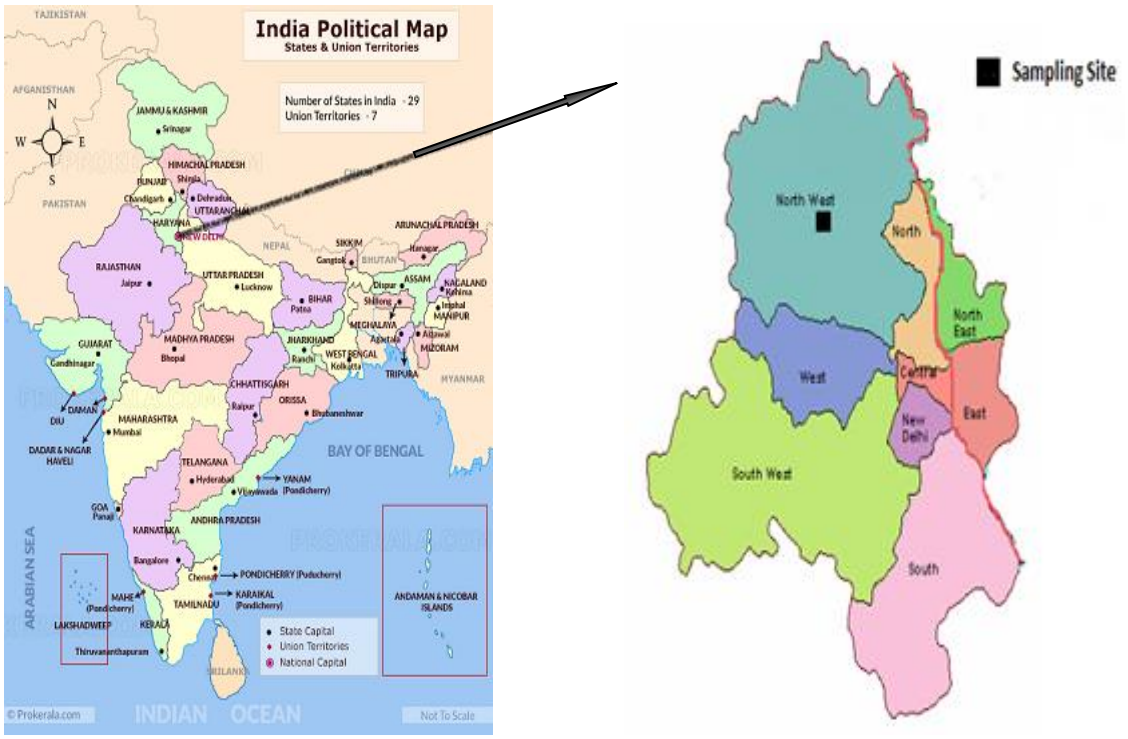

Figure 3.3.1 Location of study site on the map of Delhi

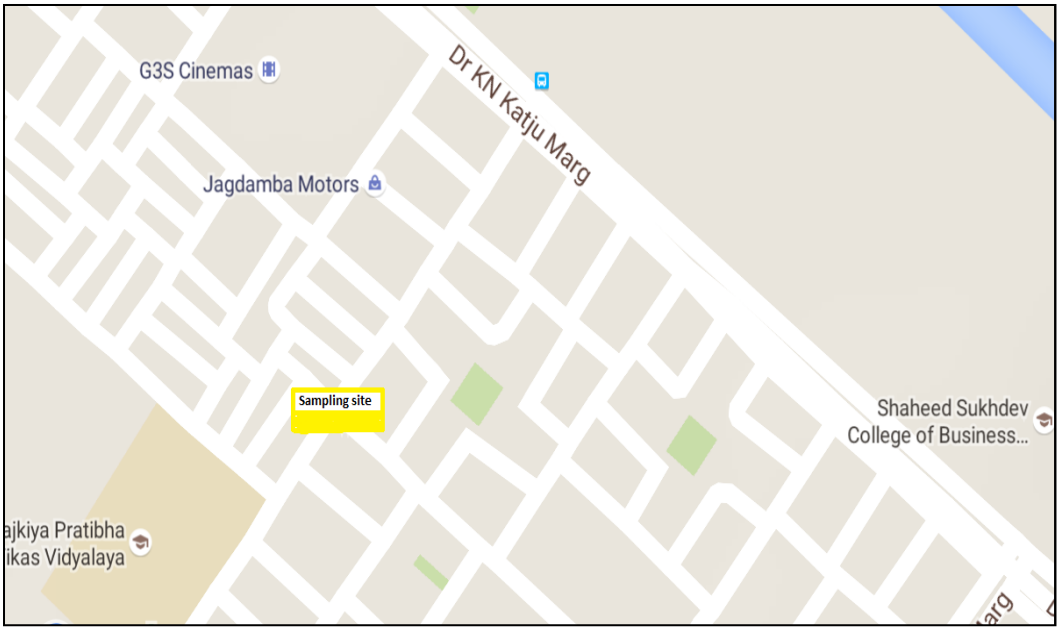

Figure 3.3.2 Location of Monitoring site (Source: Google Maps)

The meteorological data- Temperature, Relative Humidity,Wind Speed, Rain and Wind direction prevailing during the study period with the sampling time, duration and days are shown in Table 3.3.

Table3.3 Meteorological parameters with sampling time, duration and days. WS: Wind Speed; RH: Relative Humidity; W.D-I: Observations taken at 7:21 hrs; W.D-II: Observations taken at 14:21hr

Sampling Days	Sampling time	Duration (hr)	Mean Temp (°C)	Mean RH%	WS (m/s)	Rain (mm)	W.D-I	W.D-II
8th Nov,2015	7:00PM-10:00PM	3	21.5	59	0.03	0	NW	N
9th Nov,2015	7:00PM-10:00PM	3	20.5	59	0.04	0	C	NNE
10th Nov,2015	7:00PM-10:00PM	3	21.6	61	0.02	0	C	N
11th Nov, 2015-DIWALI	7:00PM-10:00PM	3	22.1	56	0.02	0	C	NW
12th Nov,2015	7:00PM-10:00PM	3	22.05	55	0.08	0	NW	NW
13th Nov,2015	7:00PM-10:00PM	3	20.95	58	0.05	0	C	NW
14th Nov,2015	7:00PM-10:00PM	3	21.6	59	0.05	0	C	NW

(Source: Indian Agricultural Research Institute (IARI), New Delhi.

website: http://iari.res.in/?option=com_content&view=article&id=402&Itemid=322)

Chapter IV

Results and Discussions

This section attempts to delineate the results of this short study.concentrationof different pollutants (PM_5 mass, carbonaceous aerosols and heavy metals) under the effect of meteorology of the region, their rise and decline trend during the Diwali week, source apportionment of heavy metals with the help of correlation matrix and assessment of health risks due to Diwali heavy metal pollution has been discussed.

4.1 PM_5 and Carbonaceous species

By definition, PM_5 should be a little higher on the side of $PM_{2.5}$concentrations roughly in a $PM_{2.5}/PM_5$ ratio of 0.77-0.91(Audrey Ann Backes 2014). $PM_{2.5}/PM_{10}$ ratios dominantly exist in 0.65-0.8 ratios from anthropogenic sources (Zhou et al. 2016; Sugimoto et al. 2015). In order to check if our study is in line with the others, studies carried on $PM_{2.5}$ and PM $_{10}$concentrationsentrations have been cited. **Table 4.1** shows the statistics of PM_5, total carbon (TC) which is the sum total of OC (OC1 + OC2 + OC3 + OC4) and EC (EC1 + EC2 + EC3 + EC4), OC and EC concentrations observed in this study. Invariably, the maximum concentrations for the pollutants is on Diwali day. Earlier studies conducted have recorded breaknecking $PM_{2.5}$ concentrations of 1509.19 $\mu g/m^3$ (Pervez et al. 2015) and 1500($\mu g/m^3$) (Srinivas et al.2015) on Diwali day.

Table 4.1 Statistics of PM_5,OC, EC and TC during the Diwali week

	PM_5 ($\mu g/m^3$)	**OC ($\mu g/m^3$)**	**EC ($\mu g/m^3$)**	**TC ($\mu g/m^3$)**	**OC/EC**
Min	404	106	29	142	2
Max	922	264	130	394	4
Std. Dev.	175	61	35	95	1
Mean	589	149	65	214	2

As shown in **Figure 4.1.1** the three hourly average concentrationsfor PM_5 is found to be higher during the Diwali week, with maximum on Diwali day.The higher level of PM_5 in the capital can

be attributed to the existence of a thick blanket of smoke over the entire city even before the Diwali week. This disconcerting status was largely due to crop burning in the neighbouring states of Punjab and Haryana. Farmer of these states have a ritual habit of clearing the paddy stubble every year post monsoon mostly in the last two weeks of October to 3rd week of November filling the air fumes of CO_2, CO unburnt carbon , SO_x, NO_x. Also, on the 5th and 6th Nov, 2015, the capital experienced slight rain showers which rather than clearing off the pollutants (Tiwari et al. 2014) ensued its build up primarily because of low temperature, low mixing height& calm and low wind speeds. This may account for the high concentrations of PM_5 on 8th Nov which is the 1st day of study.People start off early festivities one day prior to Diwali day accounting for rise in concentrations by a factor of 1.1 on the third day than its previous day. Diwali day sees a phenomenal rise of 1.79 times. Post Diwali day has only a dip of 0.77 times even with comparatively higher wind speeds than Diwali day suggesting formation of secondary aerosols. Last two consecutive days have a dip of 0.56 times and a rise of 1.37 times respectively. It should be taken into account that the sampling site is nearly 600m from a heavy traffic road. Consequentially, inputs of road dust and vehicular pollution imply transgress of PM_5 concentrations.

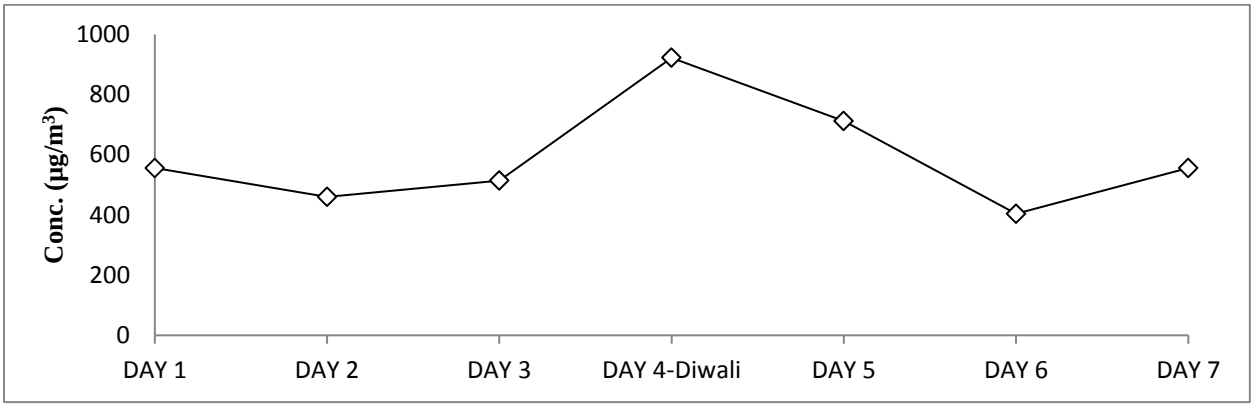

Figure 4.1.1 PM_5concentrationsentrations during Diwali week

The total carbon (TC) pursues the same rise and decline trend as PM_5 concentrations in addition to higher values**(Figure 4.1.2**). The average contribution of TC to PM_5 pollution is 35% and max contribution is 43 % on Diwali Day **(Figure 4.1.3**). Pervez et al. 2015 reported an average contribution of 33% to $PM_{2.5}$ loadings. This study does not cover measurement of

inorganic chemical constituents- metallic elements (K, Ca, Mg,Na,Li) and ionic species (SO_4, NO_3^- Cl^-)which can enrich the PM_5 concentrations in addition to carbonaceous species.

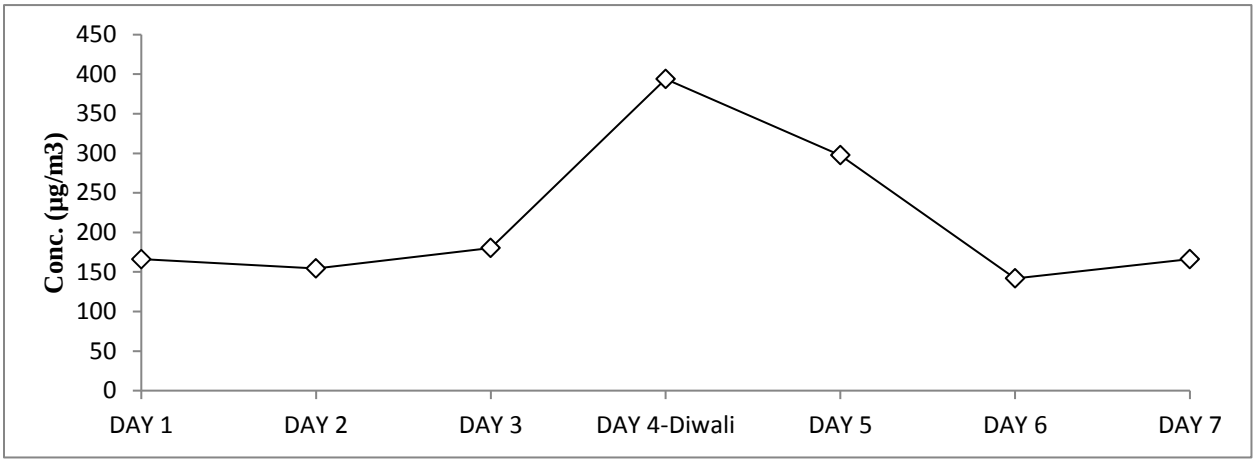

Figure 4.1.2 TC during Diwali week

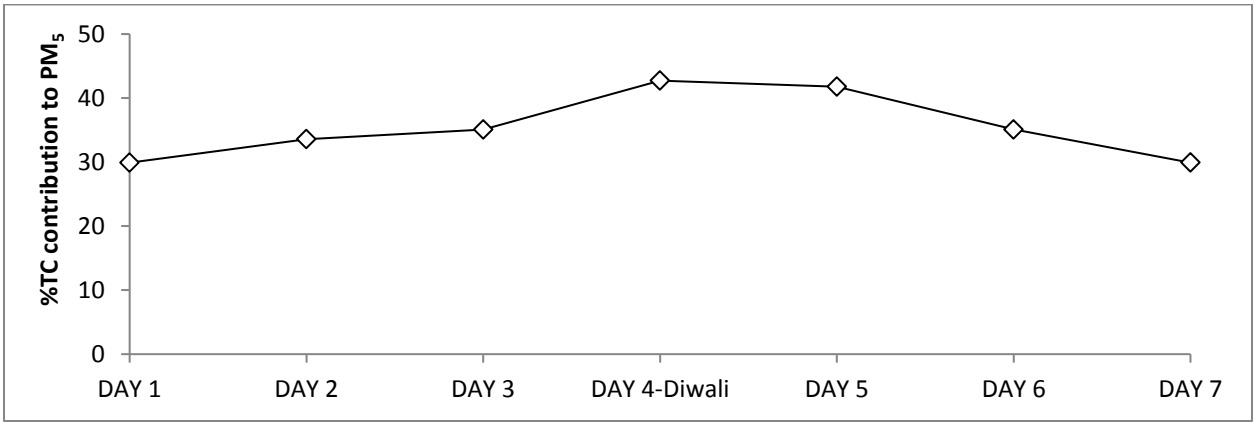

Figure 4.1.3 TC contribution to PM_5 during Diwali week

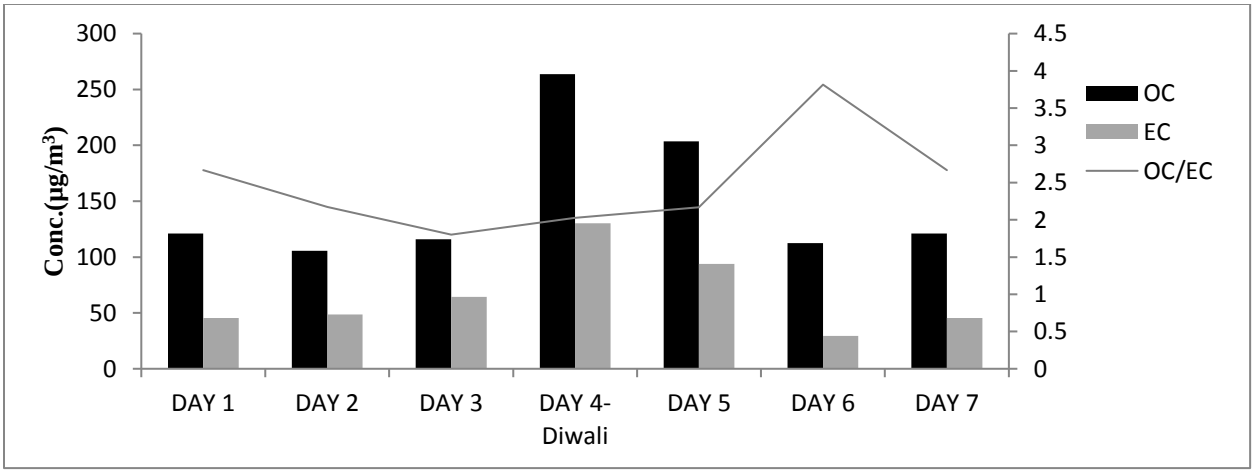

Figure 4.1.4 OC,EC and OC/EC ratio during Diwali week

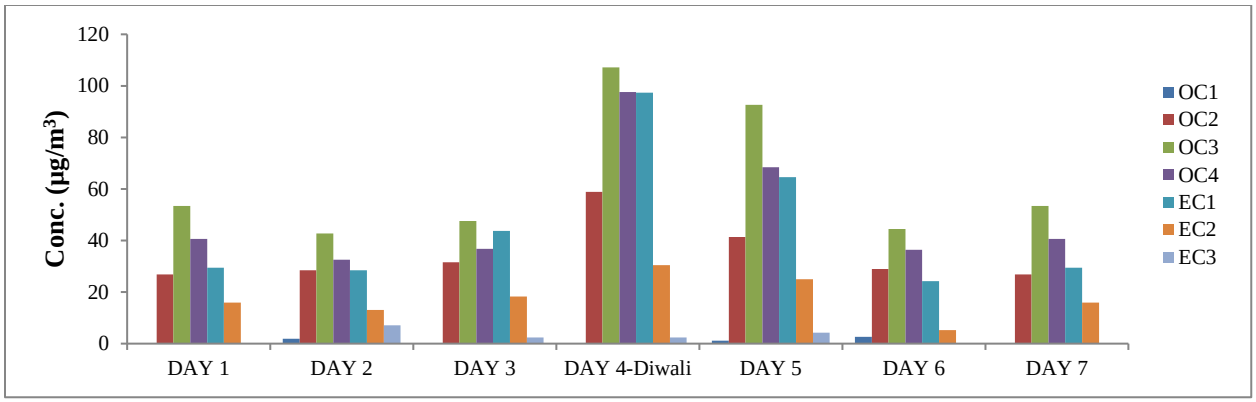

Figure 4.1.5 Apportionment of sub carbonaceous fraction of OC and EC during Diwali week

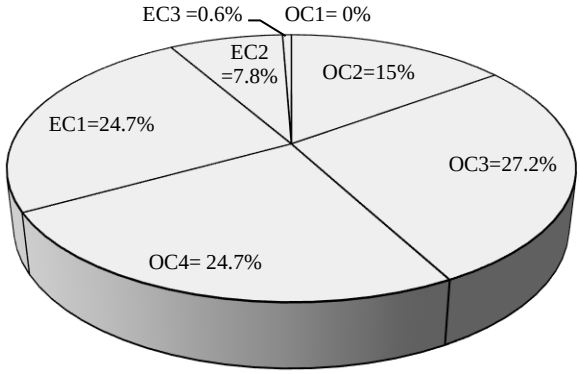

Figure 4.1.6 Enrichment of sub carbonaceous fraction of OC and EC to TC on Diwali day

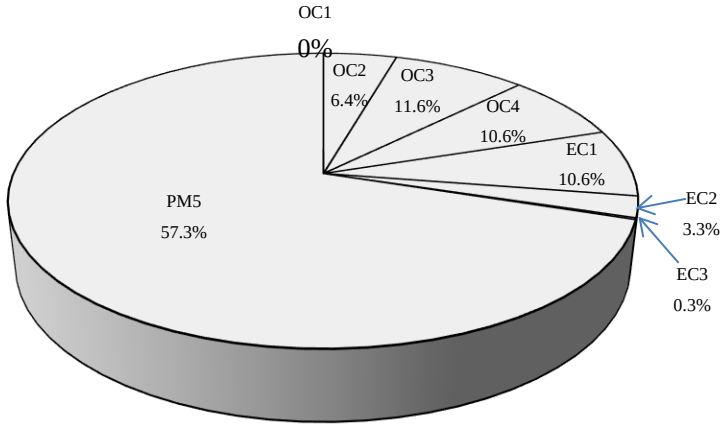

Figure 4.1.7 Enrichment of sub carbonaceous fraction of OC and EC to PM_5 on Diwali day

OC and EC manifest a similar pattern of rise and fall (**Figure 4.1.3)** in concentrations just like PM_5 and TC except for EC which shows an increment on 2nd day of the study. OC concentrations reveal 2.27 fold increase on Diwali day than its previous day which is in line with earlier studies. Sarkar et al. 2010 reported 1.29 times on Diwali day than its previous day for PM_{10} mass. For, FIFA World cup 2006, Milan, Vecchi et al. 2008 observed 1.6 fold increase for PM_{10} mass. Pervez et al. 2015 study reported 7 fold increase for $PM_{2.5}$ mass. In our study, post Diwali day has a concentration of 203.60 ug/m^3, 1.29 times less than Diwali Day which could be attributed to formation of secondary organic carbon aerosols (SOC's), measurement of which is not taken in this study. However, earlier studies have confirmed its participation under similar conditions of low speeds sometimes conducing to 50% of total organic carbon (Pervez et al. 2015). **Figure 4.1.4** shows apportionment of sub-carbonaceous fractions of OC and EC. Among the temperature resolved sub carbonaceous fractions of OC, on the day of Diwali, OC1 contributes 0%, OC2 ~15% OC3 ~27.2% and OC4 ~24.7% to TC (**Figure 4.1.5**). Towards, PM_5 Mass concentrations on Diwali day, OC1 contributes 0%, OC2 ~6.4%, OC3 ~11.6%, OC4 ~10.6% (**Figure 4.1.6**)

Charcoal is used as a binder in fireworks which seems a plausible reason for EC ambient concentrations. In our study, EC concentrations on Diwali day increased 2.02 folds compared to previous day. Sub carbonaceous fraction of elemental carbon EC1 contributes ~24.7%, EC2 ~7.8% and EC3 ~0.6% to TC on Diwali day(**Figure 4.1.5**).For PM_5 Diwali day concentrations EC1 contributes ~10.6%,EC2 ~3.3 % and EC3 ~0.3% (**Figure 4.1.6**) EC absorbs shortwave radiation strongly, enhances climate warming, disturbing the radiation balance of earth (Jacobson et al. 2001) and influences the cloud albedo (Liousse et al. 1996). OC/EC ratio has been shown to successively increase from Diwali day till two days after Diwali again suggesting formation of SOC's.

Overall, OC contributed to 28.6% and EC 14.2% to PM_5 Diwali day concentrations. Vecchi et al. 2008 reported 16.9-20.3% (OC) and 2.7 -4.0% (EC) in Milan, 2006 to PM_{10}; Tsai et al, 2012 reported 14.43% (OC) and 4.76 % (EC) in Taiwan's lantern festival, 2009 to $PM_{2.5}$; Pervez et al. 2015 found 25-47% (OC) and 2.2-2.6% (EC) to $PM_{2.5}$ on Diwali Day, Bhilai, India. An important aspect of this study is, seeing that people burn crackers only for a short duration of time mostly between 3-4 hrs range and since the emission markers show a comparitvely higher

residence time in the atmosphere than near to the firework launching site after the firework show,for assesment of personal exposure, data should be integrated over a short period which this study captures. Short episodic pollution have been reported to be related to upper and lower respiratory ailments (Murty 2000) along with increased incidences of cardiovascular diseases (Pope et al. 2006).

4.2 Heavy metal (HM)-Elucidation

A plausible account for levels and sources of heavy metal concentrations during the entire week has been attempted with the help of a correlation matrix. **Table 4.2.1**.shows the statistical analysis of HM and **Fig.4.2.1,4.2.2,4.2.3** shows the quantification of HM during Diwali week and **Table 4.2.2**. gives the correlation matrix among different metals.

Table 4.2.1 Statistics of Heavy Metals (HM) during the Diwali week

	Al	Cr	Cu	Ni	Mn	Pb	Fe	Zn	Ba	Total HM's	HM/PM_5
Min	1.20	0.62	2.14	0.68	0.48	0.86	39.12	8.83	14.63	74.10	0.18
Max	1.26	0.87	6.09	3.29	2.06	5.36	58.69	14.17	23.08	107.49	0.12
Std.Dev.	0.02	0.09	1.57	0.91	0.59	1.61	6.42	1.98	3.21	11.12	0.06
Mean	0.74	0.74	3.83	1.94	1.32	2.86	46.46	11.48	18.23	88.09	0.15

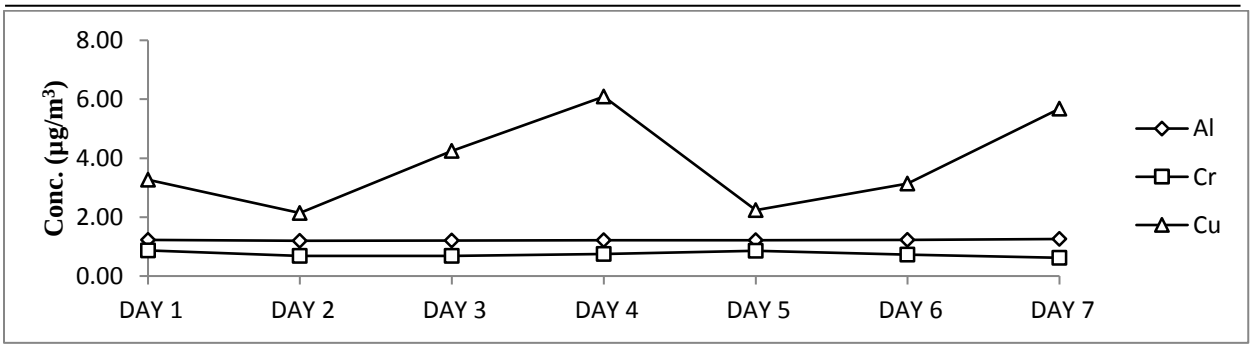

Figure 4.2.1 Al,Cr &Cuconcentrationsentrations during Diwali week

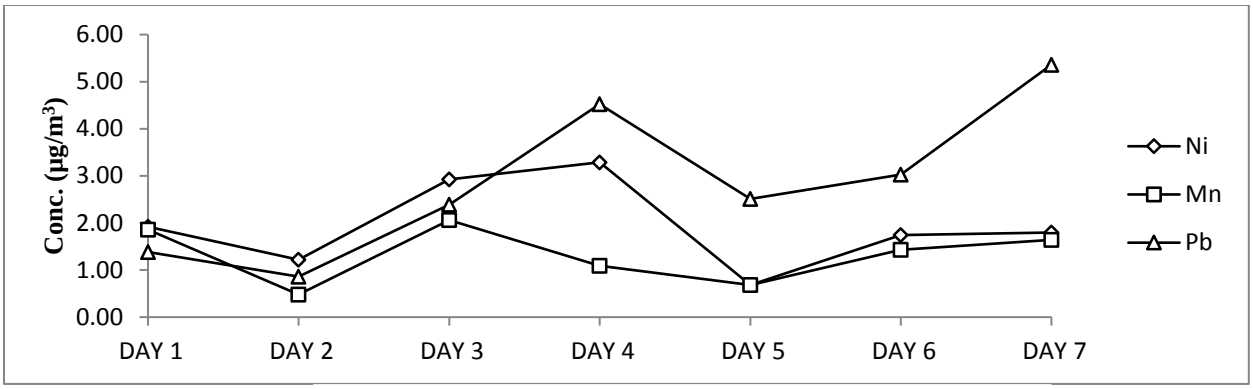

Figure 4.2.2 Ni,Mn & Pbconcentrationsentrations during

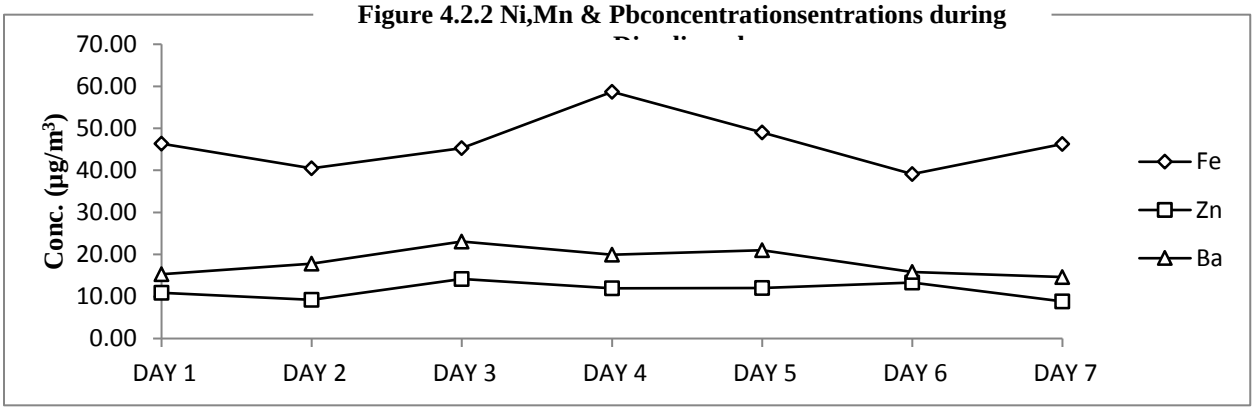

Figure 4.2.3 Fe,Zn & Baconcentrationsentrations during Diwali week

Table 4.2.2 Correlation among different HM's during Diwali week

	Al	Cr	Cu	Ni	Mn	Pb	Fe	Zn	Ba
Al	1.000								
Cr	-0.175	1.000							
Cu	**0.462**	-0.423	1.000						
Ni	-0.076	-0.423	**0.765**	1.000					
Mn	**0.447**	-0.128	**0.445**	**0.540**	1.000				
Pb	**0.685**	-0.409	**0.843**	0.376	0.208	1.000			
Fe	0.025	0.269	**0.625**	**0.511**	-0.054	**0.500**	1.000		
Zn	-0.310	0.231	-0.040	0.390	0.348	-0.084	0.056	1.000	
Ba	-0.604	0.094	-0.041	0.278	-0.109	-0.151	0.349	**0.605**	1.000

Prior to discussing the levels, a background discussion of various uses of different metals has been done. Oxides of Mn and Pb can be used in the making of fireworks identifying with the role of oxidizers. The use of other metals-Al,Fe,Zn,Cu and Ba in the firework industry

has been briefly described in **Figure 1.1**. After the complete prohibition of leaded gasoline concentrations of Pb in exhaust fumes has markedly reduced but it continues to pollute in lesser significant form from industries and biomass burning. Pb and Mn are used in paints,glass and battery industries etc. Al,Fe, Mn and Ba are among the abundant metals of crustal origin.One of the lesser known and researched contributor to vehicular particulate pollution is the brake dust. Particulates are dispersed in the air by abrasion of brakes and tyres. Even the normal movement of tyres on the roads causes significant concentrations of metals to be emitted. Fe, Ba, Cu and Zn are some of the major offenders in this category. These metals find plenty of usefulness in the automobile industry. Barium is considered as the tracer for brakedust (Pant 2013). Ni,Cr and Zn are common metals finding extensive application in electroplating, paints, dyes etc.

In our study, the concentration of Al is almost invariably the same throughout the whole week. It shows significant correlations with Mn suggesting its crustal origin and with Cu and Pb suggesting origins from biomass burning. The significant wind direction during the week was NW outlining the contributions of biomass burning from the states of Punjab and Haryana which lie on the north west side of Delhi. Agricultural soils are loaded with heavy metals like Pb,Cu and Mn from these two states (Pakade et al. 2014).Cu showed strong correlation with Pb,Fe,Mn,Al and Ni. Pb,Fe,Mn,Al are components of firework and Ni can be found in crop soils (Pakade et al. 2014; Bhatti et al. 2016). Ni and Cr are generally not used in the manufacture of firecrackers and are largely come from industrial emissioins. Mn showed positive associations with Al,Cu,Ni hinting crustal origin, biomass burning and association with firecrackers. Ni-Mn associations could also be from industries. Pb exhibited strong correlations with Cu ,Fe, Al pointing its association with fireworks and biomass burning. Ni-Fe strong correlation could be explained by their use in electronics industry. Ba and Zn are positively correlated to each other due to their vehicular pollution.

In general, Fe,Cu,Pb and Mn seem to be related with firework emissions with supposedly less use of Al,Zn and Ba in firework preparation this time. Fe, Cu, Pb and Mn contribute 6.3%,0.6%,0.4% and 0.1% respectively to PM_5 on Diwali day. Fe, Cu and Pb show an upward swing in concentrations on Diwali day than its previous day by factor of 1.29, 1.43 and 1.89 respectively. On Diwali day, Zn and Ba have reduced by a factor of 0.84 and 0.86 than the preceding day. An explaination for this would be decreased vehicular traffic on Diwali. For

the most part, offices are closed on Diwali and in order to avoid burn injuries from firecrackers people tend to stay at there own homes and celebrate. The concentrations of Mn on Diwali day falls from its previous day concentrations but still the average of main three days of Diwali (day3,day4-Diwali and day5) remains higher than consecutive average of day2,day3 and day4-Diwali; day4-Diwali,day5 and day6).Our study has reported high concentrations of Cr, Cu, Ni, Mn, Pb, Fe, Zn and Ba than previous studies by a factor of 2.5,11,47,1.1,12.5,9.3,14.5 and 1.2(Sarkar et al.,2010) and 7.5,60.9,253,6.4,4.8,15,7.4 and 1.7(Perrino et al. 2011) carried out in 2009,Delhi for PM_{10}.

4.3 Assessment of health risks due to heavy metals

In order to consolidate the established non carcinogenic risks associated with heavy metal pollution we designed a study, wherein, we compared two situations-

Situation 1 assumes no Diwali festivities during the Diwali week. For this study,it has been hypothesized that people burst crackers only on the day of Diwali,one day preceding it and one day succeding it. Therefore, average of concentrations of day 1 and day 2 has been taken as the background concentrations for the whole week in the absence of Diwali. Although, the average concentrations of day1 and day2 is quite high for being considered as background for the whole week, we rationalize our hypothesis on the basis of published reports which presented the data that in the year 2015, November saw 73% of its days in severe category of AQI attributed to $PM_{2.5}$ concentrations (CPCB 2014-15). One of the major reasons was crop burning on massive scale in the neighbouring states of Punjab and Haryana which compounded Delhi's air quality problem further. The polluted winds bring with them heavy metals accumulated in crops and agricultural soils of these states. Studies have shown these soils and crops to be enriched with Cr, Cu, Cd, Co, Pb, Fe, Zn, Mn, and Ni(Pakade et al. 2014; Bhatti et al. 2016).Heavy metals from anthropogenic sources tend to be found more in $d<2.5\mu m$ size and from natural origin $2.5\mu m<d<10\mu m$ (Canepari et al. 2008).In our study, $d=5\mu m$ is a mixture of both of these. For situation 1, Exposure frequency (EF^a) has been taken as 7 days/year.

Situation 2 involves Diwali celebrations during the Diwali week which occurred in actual. Here, the background concentrations will be considered for EF^b= 4days/year. Average

concentrations of Diwali day, one day before it and one day after it i.e 3rd,4th and 5th day will be considered for EF^c= 3 days/year.

By comparing these two situations , we will be able to quantify the elevated levels of health risks during the Diwali week linked with heavy metal pollution. The results are shown in **Table 4.3.** Reference dose **(**Rfd) value for iron has not been formulated since it is an essential element required for the growth and development of the human body.All levels of HQ are less than 1 for three days of Diwali for all metals for both adults and children.But the cumulative effect of all metals i.e the HI calculated is greater than 1 for children than adults. This implies children being at greater non carcinogenic risk. Ba and Mn seem to contribute to HI the most.Due to fewer studies conducted on effects of barium inhalation there is unsubstantial evidence of actual effects due to inhalation. However, it has been

Table 4.3 Increase in non carcinogenic Health Index (HI) due to heavy metal Diwali pollution

		Situation 1 FOR 7 DAYS		Situation 2 FOR 4 DAYS		FOR 3 DAYS	
METALS	**RFD**	**HQ-ADULT**	**HQ-CHILD**	**HQ-ADULT**	**HQ-CHILD**	**HQ-ADULT**	**HQ-CHILD**
Al	1.43E-03	0.0046	0.0083	0.0027	0.0047	0.0020	0.0035
Cr	2.86E-05	0.1485	0.2643	0.0848	0.1510	0.0627	0.1116
Cu	4.02E-02	0.0004	0.0007	0.0002	0.0004	0.0002	0.0004
Ni	2.00E-02	0.0004	0.0008	0.0002	0.0004	0.0003	0.0005
Mn	1.43E-05	0.4483	0.7981	0.2562	0.4561	0.2096	0.3733
Pb	3.52E-03	0.0017	0.0031	0.0010	0.0018	0.0021	0.0037
Zn	3.00E-01	0.0002	0.0003	0.0001	0.0002	0.0001	0.0002
Ba	1.43E-04	0.6343	1.1293	0.3625	0.6453	0.3505	0.6240
	HI	1.24	2.20	0.71`	1.26	0.63	1.12

suggested to cause muscle weakness and paralysis (ATSDR-CAS#: 7440-39-3). Manganese inhalation might affect nervous system(US EPA Air Toxics web site).The overall risk from all metals is higher in situation 1 indicating non-carcinogenic risks even of background levels. And, with Diwali celebrations on the upswing the HI increased by ~8% for adults and children respectively during the Diwali week.A previous study reported an increased HI of 2% for

PM_{10}(Sarkar et el.,2010) during Diwali.This manifests the objectionable nature of Diwali celebrations calling for emergency steps to be taken at the policy makers level and our own to control Diwali pollution.

4.3.1 Excess Cancer Risk(ECR)

The excess cancer risk has been calculated for the concentrationsfor the whole week and for Diwali day. Among the metals detected Ni,Pb and Cr(VI) are definite, probable and definite human carcinogens respectively. Chromium exists in two valence states, III and VI in the ratio 1:6 in the enviroment. From the toxicological point of view, Cr (III) is not considered as a carcinogen, only Cr (VI) is a human carcinogen. As reported in earlier studies (US EPA 2004a,b) the concentrations of Cr (VI) in this study has been taken as $1/7^{th}$ of the total Cr concentrations. The results of ECR are shown in **Table 4.3.1 and Table 4.3.2 .**Values greater than 10^-6 - 10^-4 are considered to be of considerable risk and may stimulate cancer in its various forms(US EPA 2012). All our values are under permissible limit for both adult and children category for Diwali week and for Diwali day. ECR values follow the same trend of decreasing risk in the order Cr(VI)>Ni>Pb under adult and children category. The total ECR value is also well under harmful concentrations implying safe environment in terms of carcinogens, for the individuals residing in the study area.

Table 4.3.1 Assessment of excess cancer risk due to carcinogenic heavy metals during the Diwali week

METALS	Concentrations (µg/m^3)	IUR(µg/m3)$^{-1}$	ECR ADULTS	ECR CHILDREN
Cr(VI)	0.11	0.012	1.55E-07	3.786E-08
Ni	1.94	0.00024	5.46E-08	1.36E-08
Pb	2.86	0.000012	4.02E-09	1.589E-09
		Total ECR	2.13E-07	5.33E-08

Table 4.3.2 Assessment of excess cancer risk due to carcinogenic heavy metals on Diwali day

METALS	Concentrations (µg/m^3)	IUR(µg/m3)$^{-1}$	ECR ADULTS	ECR CHILDREN
Cr(VI)	0.11	0.012	1.50E-07	3.76E-08
Ni	3.29	0.00024	9.27E-08	2.31E-08
Pb	4.52	0.000012	6.36E-09	1.58E-09
		Total ECR	2.49E-07	6.23E-08

Chapter-V

Conclusions

This short study captures the episodic pollution caused due to Diwali festival celebrated every year in India. Although, the festival embodies the prosperity of people, it also calls upon itself the dangers related to health and climate commensurated with high PM_5 loadings from OC,EC and heavy metals.

Conclusions:

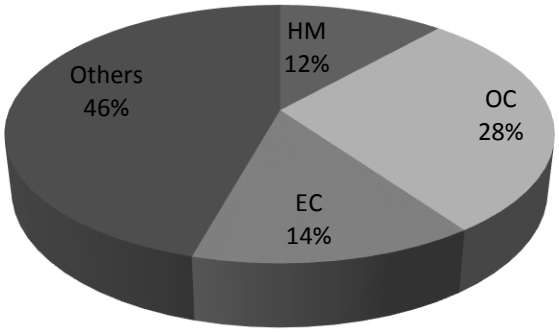

Figure 5.1 Component contribution to PM_5 on Diwali day

In this study,OC contributed ~28.6% and EC ~14.1% to PM_5 on Diwali day, showing a rise of 2.27 times and 2.02 times respectively than previous day. OC/EC ratio has been shown to successively increase from Diwali day till two days after Diwali suggesting formation of Seconadary Organic Carbon aerosols. Rise in particulate pollution has predominantly increased heavy metal pollution. Compared to studies conducted 5-6 years ago, in this present study, not only the Diwali day concentration increased but so has our background concentrations. This typically suggests the cumulative detrimental effect of anthropogenic activities which are largely to be blamed. Heavy metals seem to contribute to 11.6% to PM_5 mass loadings in this study for Diwali day.Among heavy metals, Fe,Pb and Cu show an upward trend on Diwali day by a factor of 1.29, 1.89 and 1.43 respectively. This increase could be mainly traced to use of these metals in manufacture of fireworks.Zn and Ba seem to be used in less quantities this time as they show a

decline in trend by 0.84 and 0.86 times; these being tracers for vehicular pollution are low on account of reduced traffic on Diwali day.This study also reveals the significant objectionable pollution by biomass burning in the neighboring states of Haryana and Punjab which is depicted by the strong correlation found among different metals which are reportedly found in high masses in agricultural soils of these states.

The health risk assessment model might have its uncertainities with respect to the values of different pararmeters and also because of our study hypothesis that crackers are burnt only for three days; still, it makes an attempt to predict the health hazards in a conclusive form. Although, people might consider themselves to be less exposed to cancer risks, the non carcinogenic risks observed in this study is quite high ~8%. It is advised to burst non polluting crackers, which if not possible, individuals should remain indoors.

Contribution of the author- It has been a sincere effort to understand a pollution event such as Diwali. With such a set of data as collected in this study, we aim to understand better about Diwali episodic pollution and what harm it can pose to individuals regarding their health.This study could serve as a basis for highlighting the increased concentrations of pollutants and dangers of lighting firecrackers for people staying in the study site.

Chapter-VI

Recommendations

Awareness and concerted efforts on our part can help reduce environmental and consequentially health degradation. Urban dwellings are often jam packed with closely spaced houses attributed to rise in population. Instead of bursting firecrackers in these congested areas, bursting them in large open spaces provides increased available volumes of air thereby giving pollutants a chance to get diluted and disperse rapidly. Not only, emissions from fireworks are a problem but the massive quantities of dry solid waste generated from packaging materials of fireworks and sweets also pose hazards. Reduction in the generation of these volumes which release toxic liquids, gases and particulates upon waste disposal could reduce the environmental burden and pollution.

Nowadays, some non polluting firecrackers available in the market are able to claim less pollution load inventory. Also, a different approach would be to have organized laser and artificial sound shows creating smokless and pollution free environments. Some of these novel ideas in the field of non polluting crackers claimed as patents are reported in **Annexure III**.

It has been well established that many plants have ingrained capabilities of dust capture (**Table 5.1**) (CPCB,2007).This process of 'phytoremediation' approached with some novel technological ideas such as the one shown in Figure can help control on site pollution.Figure shows a plant air purifier which sucks in the polluted air through low pressure created by a pump fitted inside the arrangement.This polluted air is drawn upwards into the filter bed where it is taken into the cellular structure of plants. A sensor attached to the filter bed signals the upflow of water into the filter bed as and when it dries up. In case of metals there exists "Hyperaccumulater plants" which have appreciable capacities to take in metals in their tissues.7 genera and 72 species and 3 genera and 20 species of Brassicaceae hyperaccumulate Ni and Zn respectively. Among,Thlaspi species Cd, Ni, Pb, and Zn can be hyperaccumulated by T.caerulescence ; Ni and Zn by T. goesingense, T. ochroleucum; Ni, Pb and Zn by T.

rotundifolium. Cd, Cr, Cu, Ni, Pb, and Zn can be reportedly hyperaccumulated by Indian mustard (Prasad et al. 2003)

In conclusion, these measures could prevent pollution to reach drastic levels from short episodic pollutions such as Diwali in the capital. Exposure to sudden high level of pollution can make the vulnerable population even more susceptible to compromised immunity and health. Joined efforts have to be made in order to combat the problem or else the fear of perpetual decline of air quality may continuously plague Delhi.

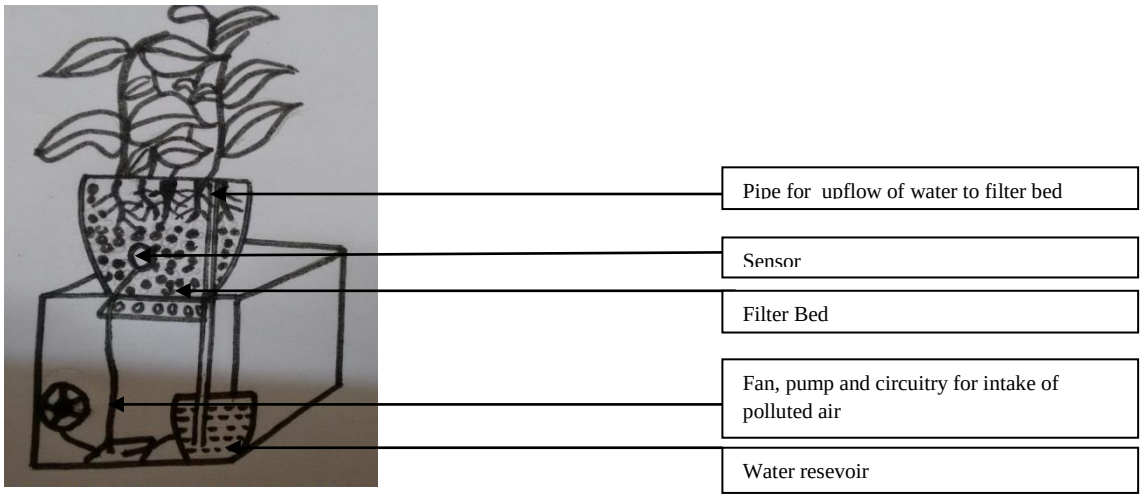

Figure 5.2 Plant Air Purifier

Table 5.2 High Dust capturing plant species

Type	Plant Species	
	Herbs	**Shrubs**
Moderate	Lillium species (Lily)	Bambusa species (Bamboo)
	Dracaena species	Lagerstroemia indica (Crape Myrtle)
	Helianthus annuus (Sunflower)	Nerium indicum (Kaner Pink)
	Tagetes patula (Genda)	Codium variegates (Croton)
	Pothos aureus (Money Plant)	Thevetia peruviana (Kaner Yellow)
		Wrightia arboriea (Dudhi)
		Rosa indica (Rose)

	Herbs	Shrubs
		Ipomea nil (Beshram) Tabernaemontana Divaricata (Chandani)
High	Colocasia antiquorum (Elephants Ear)	Acalypha hispida (Copper leaf)
	Celosia argentea (Cock'scomb)	Plumaria acuminate (Temple Tree)
		Hibiscus rosa sinensis (Gurhal) Bougainvilliea glavra (Bougainvilliea)

Chapter-VII

Scope for Future Study

Our study on investigation of Particulate matter (PM_5), its chemical speciation consisting of carbonaceous species and Heavy metals during a short episodic pollution of Diwali could be further explored and studied. Following are some recommended areas of study in order to understand the implications involving phenomenon of short episodic pollutions.

1. Continuous monitoring of quality of air for different fractions of Particulate matter and their chemical speciation, CO_2, CO and Ozone at outdoor environments.
2. Comparitive study of the same at indoor environments and estimating the outdoor intervention to indoors.
3. Study of PAH's and Cations and Anions component of Particulate Matter at the same locality during Diwali week.
4. Comparitive study in the same locality with and without planting some high dust absorbing plant species.
5. Comparitive study between rural and urban dwellings during Diwali week.
6. Comparitive study between areas using non polluting firecrackers and areas using general polluting firecrackers.

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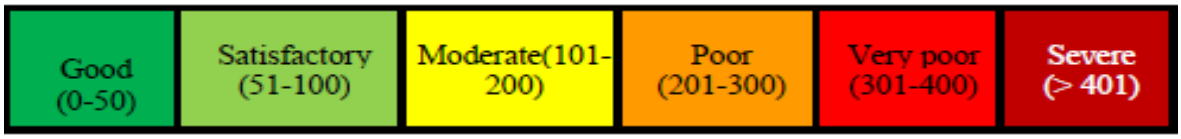
Annexure – I

Air quality index –India (CPCB-2014-15)

AQI Category	AQI Range
Good	0 – 50
Satisfactory	51 – 100
Moderate	101 – 200
Poor	201 – 300
Very Poor	301 – 400
Severe	401 - 500

Legend:



Health Statements for AQI Categories

AQI	Associated Health Impacts
Good (0–50)	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people
Moderate (101–200)	May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure
Very Poor (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe (401-500)	**May cause respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases. The health impacts may be experienced even during light physical activity**

Annexure – II

Medical issues among the residents of Delhi at AIIMS due to Air Pollution (CPCB Parivesh September, 2001)

Name of Medical Issue	Male N = 788	Female N = 533	Total N = 1321	%
Irritation of eye	354	233	587	44.4
Cough	224	157	381	28.8
Pharyngitis	138	81	219	16.5
Dyspnea	117	97	214	16.2
Headache	78	114	192	14.5
Nausea	50	82	132	10
Vomiting	44	79	123	9.3
Conjunctivitis	59	47	106	8
Abdominal pain	36	50	86	6.5
Respiratory problems	51	27	78	5.9
Rhinitis	23	21	44	3.3
Bronchitis	17	13	30	2.3
Burning of mouth and throat	8	3	11	0.8
Epistaxis	2	4	6	0.5
Depression	2	–	2	0.2
Non-smokers	–	–	–	87
Smokers	–	–	–	13

Annexure – III

Few Patents developed in the field of non-polluting elements to reduce pollution load during festivities related to noise and light.

Citing Patent	Filing date	Publication date	Applicant	Title
US5181775 A	Jul 12, 1991	Jan 26, 1993	Lan Ching Hwei	Non-polluting firecracker device
CN102872597 A	Sep 26, 2012	Jan 16, 2013	Wan Xinming	Air firecracker
CN102872597 B	Sep 26, 2012	Jul 16, 2014	Wan Xinming	Air firecracker
CN102553248 A	Mar 5, 2012	Jul 11, 2012	Chang	Electronic fireworks and crackers
US6364509 B1	Jun 30, 2000	Apr 2, 2002	J & J Creative Ideas	Sound responsive illumination device
US6749481 B1	Aug 25, 1999	Jun 15, 2004	Technocracker Private Limited	Sound producing apparatus
CN1110188 A	Apr 12, 1994	Oct 18, 1995	Chen Yanzhong	Cracker with spark discharger
CN201271501 Y	Sep 2, 2008	Jul 15, 2009	Take Part	Device for imitating Firecrackers
CN102631785 A	Nov 20, 2011	Nov 20, 2011	Ling Qiyuan	Air-pressure explosive electronic firecrackers
CN1321527 A	May 21, 2001	Nov 14, 2001	Wang Zhengfeng	Electronic fireworks with vivid effect

(Source: Google)