# STUDY ON CARBONACEOUS SPECIES AND CARBONYLS AT MULTINATIONAL FOOD COURT (INDOOR ENVIRONMENT) IN DELHI, INDIA

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*by*

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# Abstract

Atmospheric aerosols are gaining considerable importance in present-day scenario in urban areas in India due to growing anthropogenic activities as well as in terms of their effects on human and climate. Recent interest has centered on particulate matter and chemical species, particularly carbonaceous fractions as they act as both air pollutants and climate agents. The precise sources and chemical composition of carbonaceous species till now are not well known in India. Atmospheric aerosols are released in both indoor and outdoor environment. Aerosol released indoors is approximately one thousand times more likely to reach people's lung than a pollutant released outdoors. The present study aims at indoor air quality during the winter season at selected Multinational Food Courts (MFC's) in Delhi, India. Assessment of outdoor air quality is carried out for investigation on sources of pollutants. The study included the assessments of concentrations of particulate matter ($PM_{10}$), organic carbon (OC), elemental carbon (EC), total carbon (TC) and carbonyl compounds. The meteorological parameters e.g., temperature, wind speed, wind direction and relative humidity were also collected during the study period. The study revealed the indoor air quality of MFC's in Delhi during the winter season and probable sources of pollutants. Study revealed that the concentrations of $PM_{10}$, OC and EC at MFC – Rohini West stand higher in comparison with MFC – Netaji Subhashh place. I/O of $PM_{10}$, OC, EC and TC were 1.35, 1.1, 1.14 and 1.1 respectively; indicating sources of pollutants lying Indoor. Analysis on Carbonyl compounds revealed that Acetaldehyde and Acetone contribute 31% each of all fifteen compounds identified. Recommendations were made to reduce the concentration levels of pollutants at indoor environment.

**Keywords**

Particulate matter; Organic carbon; Elemental carbon; Total carbon; Carbonyl compounds; MFC.

Air pollution is a potential problem being faced in urban areas compared to rural areas. Economic expansion, increased population and industrial activities and automobiles subjected to exponential growth are imposing threat to human health in urban areas. Long term reduction of productivity and ultimately overall deterioration of economic condition can be observed due morbidity and mortality caused by air pollution.

A comprehensive approach was already made in designing policies and implemented the monitoring and management system that is required to identify major sources of outdoor air pollution to restore air quality by corrective measures (in major urban centers). Interest is to be centered on indoor air quality, for healthy sustenance of human life. The major reason being, the time spent in a day at indoor environment.

Contributing towards the economical growth Industrial development accompanies with environmental issues. Injudicious settlement of an industry can pose serious threat to ecosystems, besides increasing vehicular population. Amongst emission of variety of pollutants from unique sources particulate matter draws more attention. Depending on the assessed penetration of particulate matter into lungs they were traditionally classified in 'coarse particles' ($PM_{10}$) and 'fine particles' ($PM_{2.5}$). Coarse particulates found near roadways and dusty industries where as fine particulates emitted from forests fires, industrial combustions etc.

Particulate matter, a complex matrix: accommodating numerous species under favorable meteorological conditions. The major component in particulate matter was being carbonaceous species. Carbonaceous species usually classified into organic carbon, elemental carbon.

Primary organic carbon (POC) is formed during combustion processes. Coarse primary organic aerosol can also be produced by mechanical processes with pollen, vegetable debris, organic matter form soil etc. as in association. Secondary organic carbon (SOC) is formed through gas to particulate conversion of volatile organic compounds. However, the study on SOC is beyond the scope of this study. Apart from the particulate matter and carbonaceous species, carbonyls (aldehydes and ketones) were covered in this study.

Delhi, capital city of India located at 28.61˚N Latitude and 77.20˚E Longitude, is considered as the most polluted and second most populated city in the world with metropolitan population making 25 million as of 2014 [1]. Air pollution (During 2013 – 14, Particulate Matter ($PM_{10}$) concentration level increased by 44% is causing death of about 10,500 every year in Delhi.

Health survey conducted by Central Pollution Control board (CPCB), New Delhi and All India Institute of Medical Sciences (AIIMS), New Delhi during 1997 – 98 revealed that several medical symptoms were predominant among the residents of Delhi due to air pollution (Annexure – 1). Regulations and guidelines for Indoor air quality were formulated by regulatory authorities like Unites States Environmental Protection Agency (US EPA), Occupational Safety and Health Administration (OSHA), World Health Organization (WHO), Canadian Government, American Society of Heating Refrigerating and Air-conditioning Engineers (Annexure – 2).

This report comprises a comprehensive detail on the $PM_{10}$, OC, EC, TC and Carbonyls at the Multinational Food Court (MFC) during the winter season (December'14 to February'15). The major source of $PM_{10}$, OC, EC and TC was attributed by cooking activity and influence of outdoor environment.

## 1.1. Objective of the study
- Sampling and measurement of $PM_{10}$ at MFC's during winter season
- Assessment of OC, EC and TC at MFC from $PM_{10}$ monitored.
- Sampling and assessment of carbonyls, due to the cooking activity at the same during winter season.
- Sampling and measurement of $PM_{10}$ at outdoor environment.
- Comparative analysis of indoor and outdoor environments with respect to $PM_{10}$ and carbonaceous species (OC, EC and TC).

This chapter encompasses the literature published earlier on Indoor Air Quality (IAQ) especially at food courts. The related work carried on carbonaceous species and carbonyls in India and abroad was also highlighted in this chapter.

**Roe *et al.,* 2005** [2] investigated on concentration of pollutants from commercial cooking in United States. The cooking styles of which total charbroiling, fry (deep), fry (flat griddle), fry (clamshell griddle), charbroiling (under fried) and charbroiling (conveyorized) and concentration of pollutants in each style were highlighted. $PM_{10}$ concentration among the different styles of cooking was 85500tones/year, NA, 15700tones/year, NA, 60300tones/year and 8500tones/year respectively.

**Shun Cheng Lee *et al.,* 2001** [3] characterized four different restaurants both at indoors' and outdoors' for air quality, as a limited data is available on IAQ at restaurants in Hong Kong, China. Amongst four restaurants 'western canteen', mean concentration of $PM_{10}$ was 39 ± k9.3µg/m$^3$ with a range of 35.3 - 55.1µg/m$^3$ and 99.8 ± 9µg/m$^3$ with a range of 78.5 - 153.3µg/m$^3$ at indoor and outdoor respectively. Similarly, formaldehyde (HCHO) concentration was 17.7 ± 1.9µg/m$^3$ with a range of 17 - 55µg/m$^3$, and 15.5 ± 3.1µg/m$^3$ with a range of 9 - 18µg/m$^3$ at indoor and outdoor respectively.

**R. Kumar *et al.,* 2008** [4] Cooking in India and fuels used have a great impact on indoor air quality. Liquefied Petroleum Gas (LPG) and Biomass were the predominant fuels used for cooking purposes in India. Investigation revealed that $PM_{10}$ emissions from LPG and Biomass were 710µg/m$^3$ and 744µg/m$^3$. Results depicted that $PM_{10}$ emission from Biomass fuel was higher in comparison with LPG.

## 2.1. Carbonaceous species

Literature survey highlighted on Organic Carbon (OC), Elemental Carbon (EC) and Total Carbon (TC); Work carried out earlier in the European continent and many countries in Asia including India are reported.

**L. M. Castro *et al.,* 1999** [5] in the present study analyzed the aerosol samples from Urban, rural and coastal areas in Europe for carbonaceous content by thermal optical transmission

method. Total eight sites were selected for monitoring in which four sites were in urban area, three in rural background and one site in remote area. It has been found that carbonaceous matter (total carbon) concentrations are highest in urban areas and minimum in remote areas. Enrichment in organic carbon (OC) was observed for remote and rural locations in comparison to urban locations. Result suggest that in summer there is increased formation of secondary organic carbon (SOC) because of more favorable conditions for gas-particle conversion of VOCs as a result of photochemical activity. SOC can reach significant levels in summer periods as a consequence of semi volatile primary organic carbon (POC) evaporation at higher temperatures. OC /BC ratio obtained at urban sites (Birmingham, Oporto, Coimbra, Aveiro) ranges from 1.1 - 1.3 during a year while at rural sites it is found to be 1.5. In Averio (Portugal), at coastal and rural sites OC/BC was 1.5. However in winter it is found to be 2.6 while in other seasons as 1.5.

**Di Ye et al., 2007** [6] analyzed over $PM_{10}$ samples simultaneously at nine urban sites and one Urban background site and concentrations of elemental carbon (EC) and organic carbon(OC) in $PM_{10}$ were analyzed using an elemental analyzer as well as correlation between OC and EC were investigated in detail. Annual average concentration of $PM_{10}$ at Urban sites found to be $268.7 \pm 97.5 \mu g/m^3$ exceeding the limits according to Chinese NAAQS while at urban background site it was found to be $130.6 \pm 55.6 \mu g/m^3$ : much less as compare to urban site. Similarly average OC and EC concentration at nine urban sites was found to be $57.5 \pm 20.8 \mu g/m^3$ and $8.3 \pm 3.9 \mu g/m^3$ respectively, while at urban background site it was recorded $21.7 \pm 9.7 \mu g/m^3$ and $3.1 \pm 1.8 \mu g/m^3$ respectively. Also seasonal variation was noticed in which OC concentrations in autumn were higher than those in spring while EC showed very little distinction between seasons. On an average, total carbonaceous aerosol (TCA) accounted for 33.2% in spring and 35% in autumn of $PM_{10}$ mass. Correlation between EC and $PM_{10}$ was moderate (r = 0.45, p < 0.05) and between OC and $PM_{10}$ was good (r = 0.82, p < 0.01). OC/EC ratio exceeding 2.0 indicates the presence of secondary organic carbon (SOC). Estimated SOC concentrations were $26.7 \mu g/m^3$ and $39.4 \mu g/m^3$ and accounted for 48.9% and 61.7% of TCA in spring and autumn respectively.

**Thomas Gnauk et al., 2008** [7] conducted a study in which size segregated particle samples were collected in October 2007 at Xinken site, China on the mouth of Pearl River. A total of eight daytime and night time size segregated samples classified into continental and coastal trajectories were analyzed for mass concentration, organic and elemental carbon (OC/EC), alkenes, polycyclic aromatic hydrocarbons (PAHs). Comparisons of day and night time as

well as continental and coastal samples were carried out for every component in all considered particle size classes. $PM_{18}$ was found to range from 58.9 to 127.4$\mu$g/m$^3$. Total carbon (TC) fraction of PM mass was found to be between 12% and 18%. Mean size distribution of OC and EC was found to be in the range $Dp_{aer}$= 0.056 – 18$\mu$m. Mean size of OC, EC and TC over 15 runs were calculated as 7.3, 6.2, 13.5$\mu$gC/m$^3$ respectively. OC/EC in different size classes was found to be mostly greater than one with maximum of 2.7 in coarse mode while measurement at sites being strongly dominated by traffic resulted in an OC/EC ratio near 0.3 in fine particle size other than technological processes, soot producing processes, fossil fuel burning, private burning of electric cable. EC fraction in fine particle size ranges about 80%. OC from biogenic sources are major source of primary coarse particle.EC in $PM_{10}$ showed higher daytime concentration due to higher soot emissions from traffic, industry, etc. Similarly higher daytime OC concentration in different size ranges from, mainly in coastal samples may be due to new particle formation, volatilization of sea spray. Ultrafine particles account for 2.4 % of total OC and 1.4 % of total EC accumulation mode particles for 71.2 % OC and 85.6% EC and coarse particles for 26.4% OC and 13% EC.

**LI Xuxiang *et al.,* 2008** [8] determined the characteristics of carbonaceous aerosols (Carbonate Carbon, Elemental Carbon and Organic Carbon) in Xi'an, China near Asian dust source regions in spring 2002. Samples were collected during both DS (dust storms) and NDS (non dust storms) periods over 28 days. Lowest value of CC recorded was 0.1$\mu$g/m$^3$ and highest value was 15.8$\mu$g/m$^3$. It was noticed that CC concentrations were high during dust storms periods. Average value of CC during DS events was 7.8$\mu$g/m$^3$ and 1.8$\mu$g/m$^3$ during NDS events. OC concentration ranges from 8.2 - 63.7$\mu$g/m$^3$ while EC concentration ranges from 2.4 - 17.2$\mu$g/m$^3$. Average EC concentrations during DS events (9.8$\mu$g/m$^3$) are nearly same as those in NDS (9.8$\mu$g/m$^3$) while average OC concentrations in DS events was 40.9$\mu$g/m$^3$ and 31.8$\mu$g/m$^3$ in NDS. OC – EC correlation ($R^2$=0.76, n=6) was good in DS periods while stronger in NDS period ($R^2$ = 0.90, n = 25). Average percentage of total carbon (CC = OC = EC) in $PM_{2.5}$ during NDS events was 22.6% higher than 13.6% during DS periods. EC, CC and OC accounted for 16.4%, 12.9% and 70.7% of TC in DS events respectively. Average ratio of OC/EC was 5.0 in DS events and 3.3 in NDS periods. Percentage of water soluble OC (WSOC) in TC accounted for 15.7% and ranges from 13.3 - 22.3% during DS events. Distribution of eight carbon fractions implies that local emissions such as motor vehicle exhaust were dominant contributors to carbonaceous particles.

**Abba Elizabeth Joseph et al., 2009** [9] measured the indoor and outdoor $PM_{2.5}$ concentration simultaneously at two sites residential (Khar) and industrial (Mahul) in Mumbai city, India during summer, post monsoon and winter season for a week during 2007-2008. $PM_{2.5}$ was monitored using the metrics Minivol and DRI thermal optical analyzer was used for measuring OC, EC and TC. Average $PM_{2.5}$ concentrations at residential sites were found to be $88.89 \pm 39.12 \mu g/m^3$ and $69.75 \pm 27.02 \mu g/m^3$ exceeding the limit of $40 \mu g/m^3$ as per Indian NAAQS, 2009. OC concentration was $32.76 \pm 15.09 \mu g/m^3$ and $24.5 \pm 8.58 \mu g/m^3$ and EC concentration was $7.76 \pm 5.17 \mu g/m^3$ and $6.6 \pm 5.38 \mu g/m^3$ respectively. At industrial sites average $PM_{2.5}$ concentrations were $96.84 \pm 24.53 \mu g/m^3$ and $76.58 \pm 28.05 \mu g/m^3$ exceeding the limit of $40 \mu g/m^3$ as per Indian NAAQS 2009. Average OC concentrations were $29.09 \pm 16.32 \mu g/m^3$ and $19.25 \pm 9.5 \mu g/m^3$ while average EC concentrations were $7.61 \pm 3.79 \mu g/m^3$ and $3.61 \pm 2.95 \mu g/m^3$. At industrial site excellent correlation among $PM_{2.5}$ with OC and EC ($r = 0.67$, $r = 0.85$, $p < 0.01$) is due to common combustion sources like vehicles. At residential site good correlation between $PM_{2.5}$ and EC indoors with EC outdoors ($r = 0.52$ and $r = 0.53$, $p < 0.05$) indicates penetration of outdoor air affecting inside air quality as site is close to freeway. OC/EC ratio outdoors at R and I site were greater than two with an average ratio of 5.31 and 3.9 implying presence of Secondary organic carbon (SOC).

**Rodrigo Segual A. et al., 2009** [10] determined the primary organic aerosol (POA) and secondary organic aerosol (SOA) fractions from total mass of $PM_{2.5}$ particulates was recorded in Urban atmosphere of Santiago City during 2002-2005. To accomplish this elemental carbon (EC) and organic carbon (OC) determinations developed by automatic monitoring stations were installed at three sites. Seasonal fluctuations of EC and OC were observed showing that autumn-winter concentrations (April-September) are higher than spring-summer (October-March). Reason being the presence of permanent subsidence and thermal inversion layer and mixing height are around 400m in winter time and around 1000m in summer. OC and EC represent significant component in $PM_{2.5}$ which reaches from 19 - 26% in mass. However OC is dominant component accounting at least 80% of total carbon. Results show that highest mean OC and EC concentration occur at urban site influenced by local primary emissions from nearby industrial, international airport. Lowest OC and EC concentrations occur at the site which was exclusively residential area. OC/BC ratio at all three sites were recorded greater than two indicating presence of Secondary Organic Carbon (SOC). SOC concentrations were determined by EC tracer method and they were reaching up to 20% of total organic aerosol matter.

**S.C. Lai et al., 2010** [11] conducted a study in which nine residences located in Guangzhou were selected to characterize indoor fine particles ($PM_{2.5}$), OC, EC during summer time. Nine residences were classified into 5 types, Urban without smoker, Urban with smoker, newly remodeled urban, roadside and sub Urban. Average indoor $PM_{2.5}$ concentration was 47.4 $\mu g/m^3$ exceeding limit consisting 12.5$\mu g/m^3$ of OC and 4.4$\mu g/m^3$ of EC i.e. 24.6% and 9.9% of indoor $PM_{2.5}$ respectively. Higher $PM_{2.5}$, OC and EC concentrations were observed in urban residences with smokers as 48.9 - 95.2$\mu g/m^3$, 10.5 ± 2.6 to 34.5 ± 6.1$\mu g/m^3$ and 5.3 ± 1.4 to 3.1 ± 1.6$\mu g/m^3$ respectively indicating poor condition of ventilation in kitchen. Roadside concentrations were 45.3 - 55.4$\mu g/m^3$, 11.4 ± 2.1$\mu g/m^3$, 7.6 ± 3.7$\mu g/m^3$ respectively (indoor sources and outdoor penetration). Urban residences without smokers and recently remodeled residences had similar $PM_{2.5}$, OC and EC concentrations. Sub-urban residences has lowest $PM_{2.5}$, OC concentrations (32.1$\mu g/m^3$ and 6.9 ± 1$\mu g/m^3$) while EC concentrations was lower than roadside residences (4.5 ± 1$\mu g/m^3$). OC/EC has maximum value of 1.1 at urban residence with smoker and minimum at sub-urban and roadside residence site. Average OC/EC at outdoor is found to be 2.5. Eight carbonaceous fractions by thermal optical reflectance (TOR) method were determined namely $OC_1$, $OC_2$, $OC_3$, $OC_4$, OP, $EC_1$, $EC_2$, $EC_3$. Among these fractions $OC_2$, $OC_3$ and $EC_1$ were most abundant fractions found.

**Animesh Kumar et al., 2010** [12] collected 24 hour integrated samples of $PM_{10}$ and $PM_{2.5}$ in a kerb site in a major Indian Urban community impacted by diesel automobile exhaust emissions during May 2005 to January 2006. EC concentrations were found to be 14.4 - 48.8$\mu g/m^3$ with minimum during June and maximum during October whereas OC concentration was found to be 1.7 - 9.2$\mu g/m^3$ with maximum during September and minimum during June. OC/EC was found to be 0.09 - 0.31 with an average of 0.15. Over all correlation coefficient between OC and EC as monthly average found to be $R^2 = 0.86$, between $PM_{2.5}$ and EC $R^2 = 0.24$, between $PM_{2.5}$ and OC was $R^2 = - 0.17$ i.e. negative. Overall EC and OC concentration accounted for 20 - 48% and 3.6 - 9.2% of $PM_{2.5}$ respectively.

**Aparna Satsangi et al., 2010** [13] monitored the carbonaceous aerosols at sub urban site, Dayal bagh Agra from January to October 2009. Average Total suspended particulate (TSP) concentration ranged from 79 - 658$\mu g/m^3$ with a mean of 273 ± 179.9$\mu g/m^3$ exceeding Indian NAAQS of 40$\mu g/m^3$. Highest TSP was recorded in months of March, April and lowest in monsoon. Concentration of OC ranges 20.4 - 147.4$\mu g/m^3$ while EC ranged from 1.4 - 20.3$\mu g/m^3$. Average concentration of OC and EC were 60.9 ± 40.5$\mu g/m^3$ and 7.5 ± 4.6$\mu g/m^3$

respectively. OC and BC contribute 22% and 3% of TSP respectively. Correlation coefficient (R) between OC and BC is 0.79 (P > 01). Daily average OC/EC ratio varies between 5.2 and 16.2 with an average of 8.1. OC concentration is always greater than BC as OC is obtained from primary origin as well as secondary sources while EC has only primary origin. High concentrations of OC and BC are contributed by increasing heating sources such as fuel wood burning, coal burning and other biomass burning and meteorological conditions (calm condition and lower temperature) that cause stagnation of pollutants. Highest OC concentration was recorded in April as 133.9μg/m$^3$ and lowest in July as 19.6μg/m$^3$.

**Zhenxing Shen et al., 2010** [14] studied the traffic related emissions at a heavy-traffic roadside in Xi'an at the end of April 2008 to survey exposure levels of freshly emitted CO, Chemical composition (OC, EC, PAHs) of $PM_{10}$ and Ozone during daily heavy traffic periods (morning, noon and evening traffic rush hours). OC and EC in $PM_{10}$ samples were analyzed with IMPROVE (Interagency Monitoring of Protected Visual Environment) thermal optical protocol (TOR) as well as eight carbonaceous fractions were determined ($OC_1$, $OC_2$, $OC_3$, $OC_4$, OP, $EC_1$, $EC_2$, $EC_3$). $PM_{10}$ concentration ranged from 337.9 - 718μg/m$^3$ with an average value of 569.2μg/m$^3$ exceeding limit as per Chinese NAAQS. This would have been enhanced due to slow decrease in mixing layer height towards sunset. Average OC and EC levels were 53μg/m$^3$ and 17μg/m$^3$. Ratio of OC/EC during three rush periods were in the range of 2.8 - 3.3, with mean value of 3.2. Average concentrations of $OC_2$, $OC_3$, $OC_4$ and $EC_1$ were relatively abundant in study, while $OC_1$, OP, $EC_2$ and $EC_3$ were at lower level; indicating predominant contribution from gasoline exhaust.

**Manandhar A. et al., 2011** [15] estimated the indoor and outdoor particulate concentration and its chemical composition in six monitoring stations and selected residential dwellings were studied in May 2010 in Kathmandu Valley. Six stations were strategically located viz - Urban roadside, urban hospital, urban residential, urban background and valley background. Particulate concentration was for 12 hours from 8 a.m. to 8 p.m. IMPROVE TOR protocol was used for carbon analysis. Eight carbon fractions were studied namely $OC_1$, $OC_2$, $OC_3$, $OC_4$, OP, $EC_1$, $EC_2$, $EC_3$. Indoor and Outdoor $PM_{10}$ concentration was also determined. Air sampling locations, both indoor and outdoor were at respiratory level i.e. 1.5 m above ground. Indoor $PM_{10}$ concentration varies as: Urban roadside < Urban background-TU < Urban hospital < Urban residential < Urban background - Bhaktpur < Valley background ranging from103.6 ± 29.1μg/m$^3$ to 373.1 ± 330.8μg/m$^3$; Major reason being biomass burning from cooking. Average outdoor $PM_{10}$ concentration varies from 60.6 ± 36.1μg/m$^3$ to 199.2 ±

$38.5\mu g/m^3$ in following order: Valley background > Urban background – TU > Urban background – Bhaktpur > Urban hospital > Urban residential > Urban roadside; Major source being vehicle exhaust and re-suspension dust. Average Indoor/Outdoor (I/O) ratio range from $0.05 \pm 0.5$ to $4.2 \pm 0.04$ in following order: Urban roadside < Urban residence < Urban background – TU < Urban hospital < Valley background < Urban background – Bhaktpur. I/O ≤ 1, sources of $PM_{10}$ are from outdoors especially from diesel motor vehicle exhaust. Average OC indoor concentration was found to be $51.5 \pm 37.2\mu g/m^3$ and varies as follows: Urban background – TU < Urban hospital < Urban residential < Urban roadside < Urban background – Bhaktpur < Valley background. It ranges from $18.7 \pm 3.5\mu g/m^3$ to $103.7 \pm 118.3\mu g/m^3$. Outdoor OC concentration varies from $20.3 \pm 1.2\mu g/m^3$ to $54.6 \pm 4.6\mu g/m^3$ with an average of $30.1 \pm 3.4\mu g/m^3$ with: Urban background – TU < Urban hospital < Urban background – Bhaktpur < Valley background < Urban residential < Urban roadside. Average Indoor EC concentration was $21.4 \pm 18.9\mu g/m^3$ and ranges from $1.87 \pm 0.48\mu g/m^3$ to $3.6 \pm 0.69\mu g/m^3$ with highest at valley background and lowest at Urban background – Bhaktpur. Average outdoor EC concentration was $2.7 \pm 0.91\mu g/m^3$; with highest at valley background $(4.25 \pm 0.22\mu g/m^3)$ to lowest at urban roadside $(1.81 \pm 0.04\mu g/m^3)$. Average value of OC/EC was estimated at 3.01 indicating importance of secondary organic carbon. Strong correlation between OC and EC $(R^2=0.88)$ in outdoor environment and $(R^2=0.89)$ in indoor environment was found.

**Bilkis A. Begum *et al.,* 2011** [16] conducted a study in Dhaka to explore the sources of carbonaceous material in airborne particulate matter. Sampling was performed from 3 Jan to 14 Jan, 2010 at traffic hot spot site, Farm Gate. Long term PM data – April 2000 to March 2006 and April 2000 to March 2010 in two size fractions ($PM_{2.2}$ and $PM_{2.2-10}$) obtained from two air quality monitoring stations. Data was analyzed and compared with sampling results. During sampling daily $PM_{2.5}$ and $PM_{10}$ values were higher than 24 h average concentration of $65\mu g/m^3$ and $150\mu g/m^3$ (Bangladesh NAAQS) respectively. Ratio of $PM_{2.5}/PM_{10}$ observed that average $PM_{2.5}$ mass was about 78% of $PM_{10}$ mass whereas 63% of $PM_{2.5}$ was $PM_1$. BC contributed about 16% to $PM_{2.5}$ and showed decreasing trend over the years. $PM_1$ fractions were found to be the major contributors of carbonaceous fraction. IMPROVE TOR protocol was used to analyze the carbon fractions. Emission from gasoline vehicles attributed to $PM_1$ and given the high abundance of $EC_1$ and $OC_2$. Contribution from diesel vehicles to $PM_1$ was minimal as indicated by low abundance of $OC_1$ and $EC_2$. Overall observation was conducted

that vehicles exhaust and brick kiln has significant contribution to particulate matter related air pollution.

**Kyung Hwan Kim et al., 2011** [17] estimated the atmospheric carbonaceous components, particularly char and soot in ultrafine particles (UFPs; $Dp < 0.1\mu m$) and fine particles (FPs; $Dp < 2.5\mu m$), four times during one year in Saitama City, Japan, to observe the concentrations of elemental carbon (EC) and the relationship between the EC concentrations in UFPs and FPs, and to examine the possible emission sources of char and soot that constitute UFPs and FPs in a roadside environment. It was found that EC accounts for 33 - 37% of total carbon (TC) in FPs, whereas EC accounts for 12 - 20% of TC in UFPs. Both char-EC and soot-EC account for similar proportions of the total EC concentration in UFPs, while soot-EC accounts for only a small amount of the total EC in FPs. Positive and negative correlations between OC and soot-EC were observed for UFPs and FPs, respectively. The observed positive correlation in the case of UFPs possibly reflects the compactness (high density) of UFPs coated with condensed material, such as unburned fuel or lubricating oil emitted by motor vehicles, whereas the negative correlation in the case of FPs possibly indicates that whether or not the spaces between primary soot particles in FPs can be filled depends on the engine load of diesel vehicles operated near the sampling site. The positive and negative correlations were stronger for UFPs ($R^2 = 0.69$, $n = 29$, $p < 01$) and FPs ($R^2 = -0.62$, $n = 29$, $p < 01$) when the data collected at wind speeds greater than 2.5 m/s were excluded. The different morphological characteristics of the particles observed by transmission electron microscopy also support the observed correlations between OC and soot- EC. The possible emission of char or char-like particles from motor vehicles was shown and discussed in this study.

**Rehman I. H. et al., 2011** [18] carried out field measurements simultaneously inside rural households, ambient air and vehicular emissions from highway in a rural area in the Indo-Gangetic-Plains region of India to establish the role of both solid biomass based cooking in traditional stoves and diesel vehicles in contributing to high BC, EC, OC and solar adsorption in the month of October 2009. Indoor BC sampling was conducted in two periods, initially during the period of 27 September to 29 November 2009 in randomly selected 35 households. Next samples were carried out during the period of 1 - 9 September 2010 in 18 of 35 households. In addition, 24hr indoor BC samples were collected using cell-phone based monitoring system (BC_CBM). Miniaturized Aerosol filter Sampler (MAS) in BC CBM system draws air at flow rate of 0.57L/min and deposit particulate matter on quartz filter.

Some of these filters collected were analyzed for EC and organic carbon (OC) concentrations using thermal-optical EC/OC analyzer (Sunset Laboratory Inc., Forest Grove, OR) employing NIOSH TOT protocol. Real time outdoor BC concentration was measured continuously from November 2009 using Aethalometer Model AE42. Indoor BC concentrations during morning cooking hours (05:00 to 08:00) varied from ~3 - 1970μg/m$^3$ with a mean value of 54 ± 7μg/m$^3$. During evening cooking hours (17:00 to 19:00) BC concentration varied from ~3 - 1070μg/m$^3$ with a mean value of 62 ± 61μg/m$^3$. Outdoor BC concentrations during morning cooking hours varied from 3 - 390μg/m$^3$ with a mean value of 24 ± 39μg/m$^3$. During evening cooking hours BC concentration varied from 3 - 180μg/m$^3$ with a mean value of 26 ± 18μg/m$^3$. Similar diurnal variation in outdoor and indoor BC concentration suggests strong influence of indoor cooking on outdoor BC concentration. BC measurements were recorded from 19 – 27 November 2009 at a traffic junction intersected by highway. Diesel driven transport trucks and passenger buses dominated the traffic. The BC concentration at the highway location during the non-cooking hours is a factor of 3 to 5 larger than the village center BC. The BC concentrations ranged from 20 - 50μg/m$^3$ on the highway crossing whereas BC ranged from 3 - 15μgm$^{-3}$ in the village. OC/EC ratio was considered as a function of EC concentration in indoor and outdoor samples. The OC/EC ratio of indoor samples varied from 2.9 - 8.4 (mean value of 5.3 ± 1.6); the corresponding EC concentration varied from 14 - 200μg/m$^3$. Similarly, OC/EC ratio of outdoor samples varied from 2.8 - 8.7 (mean value of 4.9 ± 1.5); the corresponding EC concentration varied from 6.3 - 25μg/m$^3$.

**Bilkis A. Begum** *et al.,* **2012** [19] collected the air particulate matter samples using Air metrics samplers from 11 – 17 January 2012 and 19 – 27 January 2012 at Amin bazaar and Farm gate sites respectively. Sampling time was from 8 a.m-4 p.m. these samples were analyzed for organic and elemental carbons (OC and EC). At Amin bazaar site concentration of EC varies from 28.5 – 55.2μg/m$^3$ while that of TC varies from 55.9 - 95.1μg/m$^3$ and average EC/TC ratio was found to be 0.56 during 11-17 Jan. At Farm gate sites EC concentration varies from 16.1 - 32.1μg/m$^3$. TC concentration from 40.1 - 70.6 μg/m$^3$ and average EC/TC ratio was found to be 0.43. Also seven carbonaceous fractions $OC_1$, $OC_2$, $OC_3$, $OC_4$, $EC_1$, $EC_2$ and $EC_3$ were studied. Overall, it is estimated that diesel, gasoline, coal/wood combustions are major source for air quality deterioration.

**Bilkis A. Begum** *et al.,* **2012** [20] concluded the results from one year monitoring of $PM_{2.5}$, organic carbon (OC) and black carbon (BC) concentrations for an urban traffic-influenced site, the Farm Gate in Dhaka, Bangladesh. The measurements were based on sampling using

two Air Metrics simultaneously operating samplers. The concentrations of OC and BC concentrations in $PM_{2.5}$ varied from $5 - 96\mu g/m^3$ and $4 - 48\mu g/m^3$, respectively. The concentrations of $PM_{2.5}$ varied from $11 - 328\mu g/m^3$. The annual particulate organic matter (POM) accounted for $46 \pm 11\%$ in $PM_{2.5}$ whereas BC stayed at $33 \pm 12\%$. The effects of meteorological conditions on the variability of OC and BC concentration were examined and the contribution of secondary organic aerosol to the total OC was calculated. The concentrations of OC and BC relative to the total $PM_{2.5}$ are high and have good correlation with wind speed and temperature. The OC/BC ratio correlated with wind speed, temperature and sulfur concentration. Based on these relationships, it can be concluded that both local and regional sources of OC and BC are important. The local sources are traffic, coal and biomass burning. Distant sources include areas where there is extensive agricultural burning.

**Sharma R. K. *et al.,* 2012** [21] identified the black carbon (BC) aerosol at an interval of every five minutes at Pulchowk Campus, Lalitpur Nepal from May 2009 to May 2010 using seven channels Magee Scientific AE-31 Aethalometer. In this paper, the data of six continuous strike days and working day are analyzed to identify the actual portion of BC contributed by vehicles and industries in the total concentration of BC aerosol. During six continuous strike days, $1 - 6$ May 2010 all the industries were completely shut down and there were no vehicles plying on the road. Therefore, BC emission by vehicles and industries was considered as zero and only domestic activity was assumed as main source. In working day the mean value of BC aerosol was $10.91\mu g/m^3$ in a range between $5.45\mu g/m^3$ and $22.3\mu g/m^3$ while on the first day of strike, it was between $3.03\mu g/m^3$ and $11.9\mu g/m^3$ with the mean value of $6.31\mu g/m^3$. On the last day of the strike, the variation of BC aerosol from minimum to maximum was ranging between $1.90 - 11.59\mu g/m^3$ having mean value as $5.07\mu g/m^3$. The contribution of BC aerosol by vehicles and industries was found to be about 50%. The diurnal trend of BC aerosol in one working day and strike days is nearly similar but the peak hour concentration of BC on a working day was nearly two folds of strike days. Further, a clear inverse relationship between BC and wind speed was also found.

**Papiya Mandal *et al.,* 2013** [22] investigated carbonaceous aerosols in $PM_{10}$ fraction monthly in the industrial area of Delhi in 2011. $PM_{10}$ ranged from $95.9 - 453.5\mu g/m^3$ with an annual average concentration of $280 \pm 126.10\mu g/m^3$ exceeding the limit of $60\mu g/m^3$ (Indian NAAQS).OC ranged from $28.8 - 159.4$ $\mu g/m^3$ with an annual average of $93.03 \pm 44.72$ $\mu g/m^3$. EC ranged from $75.5 - 44\mu g/m^3$ with an annual average of $27.30 \pm 13.35\mu g/m^3$. Strong correlation between total carbon and $PM_{10}$ ($R^2 = 0.99$) and between OC and EC during

pre monsoon and winter seasons ($R^2$ = 0.79, 0.72) was observed indicating similar sources for both OC and EC. Concentrations of PM10, OC, and EC during the study period were in the following order: Post monsoon > winter > Pre-monsoon > Monsoon. Annual average percentage of total carbonaceous aerosols, OC and EC in $PM_{10}$ were estimated at 61.87, 32.7 and 9.47 respectively. Monthly average (OC/EC) ratio was obtained in the range 3.02 - 3.96 indicating the formation of secondary OC. Analysis of carbon fractions indicated multiple emission sources e.g. motor vehicle exhaust, industrial emission and biomass burning.

**Tripti Pachauri et al., 2013** [23] $PM_{2.5}$ samples were collected at traffic, rural and campus sites in Agra during Nov 2010 to Feb 2011and characterized for carbonaceous aerosols. $PM_{2.5}$ concentration ranged from 210.8 - 381.7μg/m$^3$ with an average of 308.3 ± 51.8μg/m$^3$ at traffic site, 72.9 - 118.2μg/m$^3$ with an average of 91.8 ±17.3 μg/m$^3$ at rural site and 101.3 - 163.9μg/m$^3$ with an average of 140.8 ± 22.3μg/m$^3$ all exceeding the limit of 40μg/m$^3$ (Indian NAAQS).

Average concentration of OC was 86.1 ± 5.2μg/m$^3$, 30.3 ± 12.9μg/m$^3$, 44.5 ± 18.5μg/m$^3$ at traffic, rural and campus site respectively while that of EC concentration were found to be 19.4 ± 2.4μg/m$^3$, 4 ± 1.5μg/m$^3$, 5 ± 1.4μg/m$^3$ at same. OC/EC ratios were found to be 8.1 at campus site, 7.4 at rural and 4.4 at traffic site; indicating the presence of secondary organic carbon (SOC) at all the sites. SOC concentration were found to be 15.3 ± 6.3μg/m$^3$, 8.2 ± 5.8μg/m$^3$ and 28.8 ± 15.8μg/m$^3$, accounting for 18%, 24% and 60.7% of total OC at traffic, rural and campus sites, respectively.

A good OC – EC correlation with correlation coefficient (R) of 0.87, 0.94, and 0.79 at traffic, rural and campus site suggested presence of common dominant sources for OC and EC. Also a significant correlation was observed between soluble $K^+$ and OC at rural ($R^2$=0.63) and campus ($R^2$=0.53) sites as compared to traffic site ($R^2$=0.35). This may be attributed to increased biomass burning emission at rural and campus site. Surface morphology of the particles was analyzed by scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM/EDX). Result indicated chain like aggregates of carbon bearing spheres at traffic and rural sites while at the campus site carbon rich and mineral dust particles were dominant ones.

**Papiya Mandal et al., 2014** [24] investigated carbonaceous Aerosols in $PM_{2.5}$ fraction; monthly in industrial area of Delhi in 2011. Results show annual average concentration of $PM_{2.5}$ of 145μg/m$^3$ (NAAQS) in which organic C is 41.12μg/m$^3$ and elemental C is founded

to be $13.25\mu g/m^3$. Correlation ($R^2$) between OC and EC in pre-monsoon and winter season were found to be 0.83 and 0.79. OC/EC of $PM_{2.5}$ ranged from 2.71 - 5.29 with an annual average of 5.28. Annual average concentration of OC was 75% of TC. Annual average concentration of OC was 60.34% of total OC. OC and EC were higher in post monsoon and winter season indicating that meteorological condition were a main governing faster. Emission sources were vehicle exhaust, coal combustion, biomass combustion etc.

**Richard Toro Araya** *et al.,* **2014** [25] conducted a study for 6 years (2002 - 2007) in which concentrations of fine PM and organic carbon (OC) and elemental carbon (EC) were measured continuously in capital of Chile. Contributions of carbonaceous aerosols to the primary and secondary fractions were estimated at 3 different sampling sites and in warm and cool seasons. Concentrations of OC, EC and $PM_{2.5}$ exhibited minima in spring-summer (Sep - Feb) i.e. warm seasons (44 ± 18%) and maxima in winter-autumn (March - Aug) i.e. cool seasons (53 ± 41%). Greater contribution of TCA to $PM_{2.5}$ was greater for cool seasons may be attributed to more significant emission sources of carbonaceous aerosols and meteorological factors (low temperatures and low wind speed, low mixing height).

Mean OC and EC concentration in $PM_{2.5}$ were highest in urban industrial area and lowest in urban-suburban areas. Minimum values of EC/OC ranges were observed from 1.2 ± 0.02 to 1.92 ± 0.05 in cool season and from 1.15 ± 0.03 to 1.43 ± 0.04 in warm seasons. Annual average concentration of secondary organic carbon (SOC) and its contribution to ambient OC were estimated at $1.6\mu g/m^3$ (25.2%), $1.3\mu g/m^3$ (23.7%) and $1.6\mu g/m^3$ (28.8%) in warm seasons and $3.2\mu g/m^3$ (29.6%), $4.2\mu g/m^3$ (26.8%) and $6.8\mu g/m^3$ (37.6%) in cool seasons at all 3 sites. Also the impact of $PM_{2.5}$ and carbonaceous fraction on human health is studied and it was found to be related with premature death and adverse cardiovascular effects.

**S. K. Sharma** *et al.,* **2014** [26] studied the variation of OC, EC in $PM_{10}$ in Delhi at an urban site of Indo Gangetic Plain, India in 2010. $PM_{10}$ samples were collected (every Wednesday on weekly basis; 4 – 5 samples in a month) on quartz fiber filters by using Particle Sampler (APM460NL, Make: M/s. Envirotech, India). Ambient air was passed through Whatman Quartz Micro fiber filter (QM-A) at a flow rate of 1.12 $m^3/min$. Analysis of OC, EC have been carried by OC/EC carbon analyzer (Model: DRI 2001A, USA) following the USEPA method 'IMPROVE Protocol' with negative pyrolysis areas zeroed. $PM_{10}$ concentrations

varied from 93.4μg/m$^3$ - 328.8μg/m$^3$ with minimum average during monsoon (134.68μg/m$^3$) and maximum average during winter (213.09μg/m$^3$) and an annual average 177 ± 49.5μg/m$^3$.

Annual concentration of OC has varied from 9.7 - 69.0μg/m$^3$ with an average value of the order of 26.77μg/m$^3$ (~15% of PM$_{10}$ mass), whereas, mass concentration of EC has varied from 1.8 - 13.0μg/m$^3$ with an average value of 6.17μg/m$^3$ (~3% of PM$_{10}$ mass). Concentration of OC in PM$_{10}$ has been recorded higher (36.05 μg/m$^3$; ~17% of PM$_{10}$ mass) in winter followed by summer (29.33μg/m$^3$; ~16% of PM$_{10}$ mass) and monsoon (14.72μg/m$^3$; ~11% of PM$_{10}$ mass). Similarly, EC has followed the similar pattern with maximum in winter (9.64μg/m$^3$; ~4% of PM$_{10}$ mass) and minimum in monsoon (3.35μg/m$^3$; ~3% of PM$_{10}$ mass). TC was recorded as ~18% of PM$_{10}$ mass during the study period. Concentrations of OC, EC and TC were found to be higher in winter and varied with the increase of aerosol loading. OC/EC ratio during the study period varied from 3.8 - 5.8 with an average value of 4.38 ± 2.36.

OC and EC concentrations at the study site are attributed by the combined effects of traffic emission, biomass burning, wood burning and crop residue burning. Positive linear trend ($R^2 = 0.53$) was observed between OC and EC.

**Kirpa ram *et al.,* 2008** [27] investigated on carbonaceous aerosols on northern and northwestern peaks of India, namely Mt. Manora and Mt. Abu. Aerosol contributes 20 - 50% of particulate matter of which OC contributing 90% of carbonaceous aerosols and 5 - 10% of EC. The variations in OC/EC from west to east in northern India encompassing Gangetic plain are 4 - 27 (Feb'05 to Jul'08), 5.4 - 17.8 (Jan'07 to Mar'08), 2.5 - 22 (Jan'07 to Mar'08) and 5.7 - 11.4 (Jan'07 to Mar'08) at Mt. Manora, Hisar, Kanpur and Allahabad respectively; is due to biomass burning on a large scale (which includes wood − fuel and post-harvest burning of agricultural waste)

## 2.2. Carbonyls

Literature survey was highlighted on carbonyls during different styles of cooking. Investigation on pollutant emission revealed that different style of cooking and cooking methods is the cause from the same food

**E. Kabir *et al.,* 2011** [28] investigation on pollutant emission form different style of cooking and cooking methods was also the cause from the same food. Carbonyls identified on steamed cabbage, brewed coffee and roasted coffee were Acetaldehyde, Propionaldehyde,

Butyraldehyde, Isovaleraldehyde, Methylethyl ketone and Methylisobutyl ketone. From steamed cabbage the order of carbonyl concentration was Acetaldehyde > Methyethyl ketone > Isovaleraldehyde > Propionaldehyde = Butyraldehyde > Methylisobutyl ketone. From brewed coffee the order of concentration was Acetaldehyde > Butyraldehyde > Methylethyl ketone > Propionaldehyde > Isovaleraldehyde > Methylisobutyl ketone. Similarly, from roasted coffee Acetaldehyde > Methylethyl ketone > Isovaleraldehyde > Butyraldehyde > Propionaldehyde > Methylisobutyl ketone. From the method of cooking, emission of Acetaldehyde from roasted coffee was observed to be the highest with 5233ppb.

This literature survey shows that investigation on carbonaceous species is limited to outdoor environment. Meager study was carried out on OC (Organic Carbon), EC (Elemental Carbon), TC (Total carbon) and Carbonyls in indoor environment. In this report an effort is made to concentrate on area where a meager investigation is carried in the past.

This chapter encompasses analysis technique of carbonaceous species and carbonyls besides the $PM_{10}$ measurement, highlighting the work area (location) and meteorology, where the monitoring is carried out during winter season. Methodology of statistical analysis (Principle Component Analysis) is carried out using SPSS 19.0 was included in this chapter.

## 3.1. Method for determination of $PM_{10}$, OC, EC, TC and Carbonyls

Determination of Particulate Matter concentration ($PM_{10}$), OC, EC, TC and Carbonyls are discussed under this head.

### 3.1.1. $PM_{10}$

$PM_{10}$ samples were collected by APM 800 samplers (Envirotech Pvt. Ltd., India) for 3 months (December 2014 to February 2015) on Whatman 37mm and Micro fiber quartz filter papers (deposition area of $\sim 8.553 cm^2$) on 2 to 3 hourly basis in food court with a flow rate variation of 2.4lpm to 3.0lpm. The filter papers were prebaked in a muffle furnace at 550°C for 6h to remove organic impurities and kept in desiccators for 24h before and after the sampling. The concentrations of $PM_{10}$ (in $\mu g/m^3$) were measured by gravimetric method using microbalance ('Sartorius' manufactured).

### 3.1.2. OC, EC and TC

OC and EC analyses are carried through Carbon Analyzer by Interagency Monitoring of Protected Visual Environment (IMPROVE) TOR (Thermal Optical Reflectance) protocol. The basic principle of analyzer is to oxidize organic carbon and elemental carbon at different temperatures to get their respective fractions. Pyrolyzing the sample and to char the OC Compounds into EC is the principle function of analyzer.

A program driven (Thermal Protocol) Thermal/Optical Analyzer, (The DRI Model 2001) (Figure 3.1) stores data automatically in hard drive via computer processor board which is PC Compatible, as the program begins parameter file is built with response times and signal lag times

In IMPROVE_A protocol, at one analysis condition program advance to next temperature level as FID signal returns to baseline (min. of 150seconds). Establishment of 580seconds, a maximum time limit is fixed per analysis to prevent baseline drift which prevents holding of sample indefinitely at one condition. This method requires at least a punch area of $0.5m^2$ approximately

Analyses sequence of in IMPROVE protocol is Organic Carbon (OC), Pyrolyzed carbon fraction (PY) and Elemental Carbon (EC). OC is further divided into OC1, OC2, OC3, OC4 whose analysis is carried at 140, 280, 480, 580°C respectively; similarly at 580, 740, 840°C, EC1, EC2, EC3 are analyzed respectively. Predefined OC by the IMPROVE protocol is; OC = OC1 + OC2 + OC3 + OC4 + PY, Similarly EC as; EC = EC1 + EC2 + EC3 – PY [29] [30].
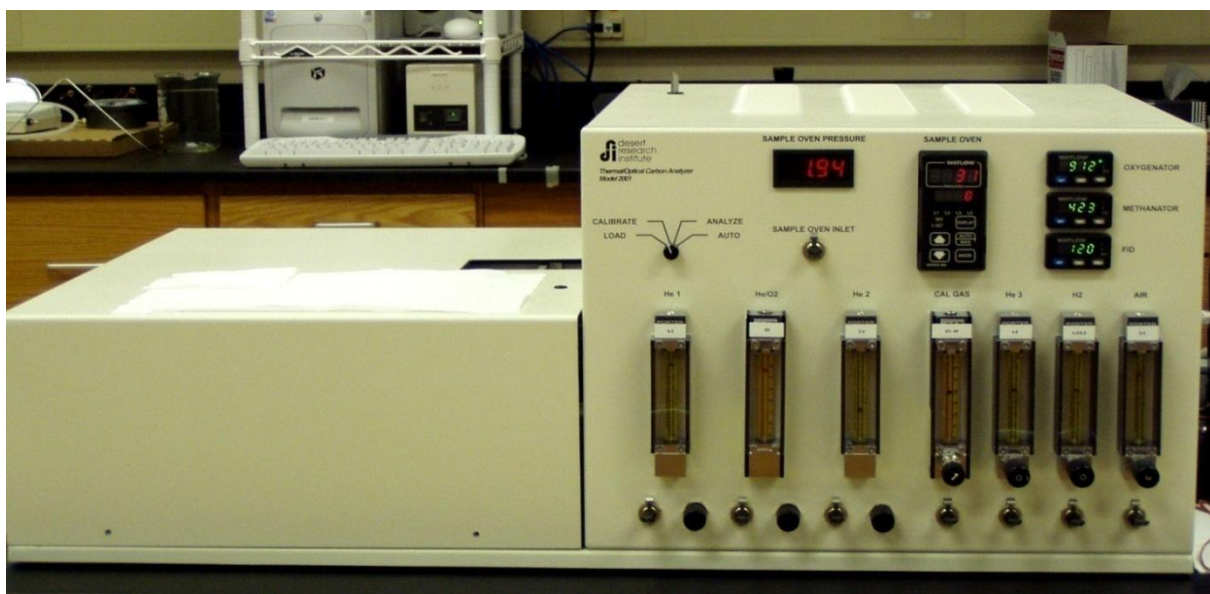


*Figure 3.1 DRI Model 2001 Thermal/Optical Carbon Analyzer*

### 3.1.3. Carbonyls

Sampling of carbonyls carried out using 'low flow air sampler' at a rate of 80mL/min for 3 to 4 hours at a particular site. Ozone scrubber is used to restrict the further reactions of carbonyls. After sampling cartridges (DNPH) were capped individually and stored at a temperature of 4°C until analysis. Sample was extracted using solid phase extraction method by 1.5 ml of Acetonitrile into a graduated volumetric.

Formaldehyde and 14 other carbonyl compounds (Table 3.1) were determined using reverse phase High Performance Liquid Chromatography (HPLC) with Ultraviolet (UV)

absorption detector at 360nm. Gradient of Acetonitrile and Water were used as eluents and Tetrahydrofuran was used as modifier.

*Table 3.1 Compounds identified in HPLC*

| Sl. No. | Compound | Sl. No. | Compound |
|---|---|---|---|
| 1 | Acetaldehyde | 9 | Hexanaldehyde |
| 2 | Acetone | 10 | Isovaleraldehyde |
| 3 | Acrolein | 11 | Propionaldehyde |
| 4 | Benzaldehyde | 12 | o – Tolualdehyde |
| 5 | Butyraldehyde | 13 | m – Tolualdehyde |
| 6 | Crotonaldehyde | 14 | p – Tolualdehyde |
| 7 | 2,5 – Dimethylbenzaldehyde | 15 | Valeraldehyde |
| 8 | Formaldehyde | | |

## 3.2. Monitoring site

Monitoring carried over for three winter months (Dec'14 to Feb'15) in North West Delhi at a two different outlets of same multinational food court (MFC). Location of MFC and instrument place was described in the figures 3.2 to 3.5. Rohini West, MFC is located towards road side – ground level, Netaji Subhash Place's MFC is located towards road side – mezzanine level. Period and frequency of indoor air monitoring at two selected stations can be depicted from the Table 3.2 with 41 monitoring days for three months.

*Table 3.2 Frequency of Monitoring*

| Place | Period | No. of Weekdays Monitored | No. of Weekends Monitored | Season |
|---|---|---|---|---|
| Rohini West | December'14 | 5 | 2 | Winter |
| | January'15 | 4 | 3 | Winter |
| | February'15 | 3 | 3 | Winter |
| Netaji Subhashh Place | December'14 | 6 | 2 | Winter |
| | January'15 | 3 | 3 | Winter |
| | February'15 | 3 | 4 | Winter |
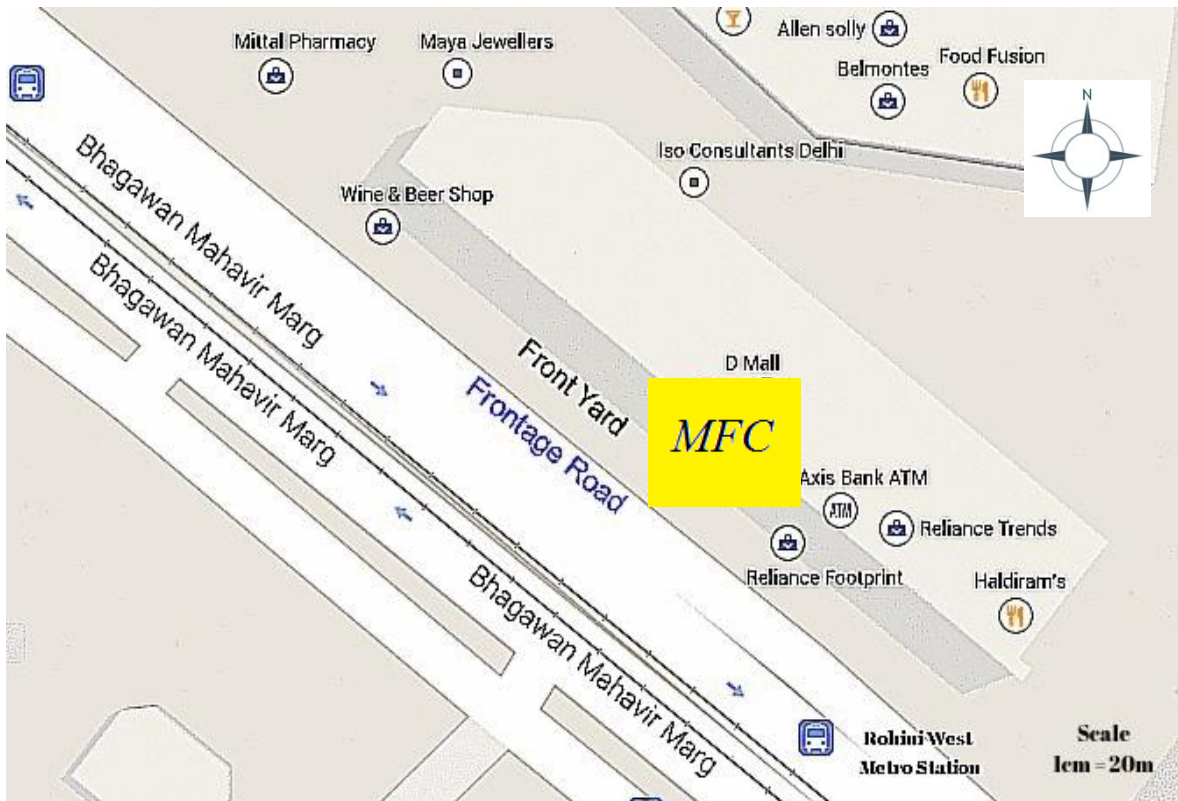
*Figure 3.2 Monitoring site (1) – Rohini West (Source: Google Maps)*
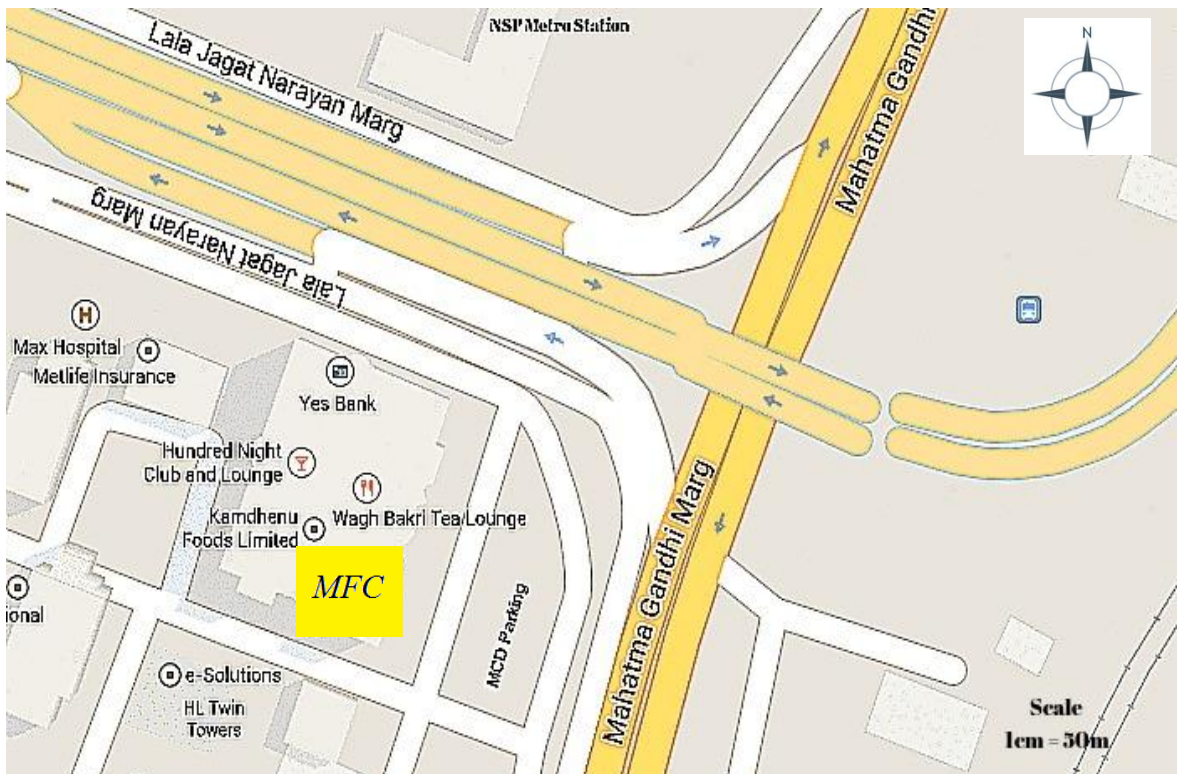


*Figure 3.3 Monitoring site (2) – Netaji Subhash Place (Source: Google Maps)*
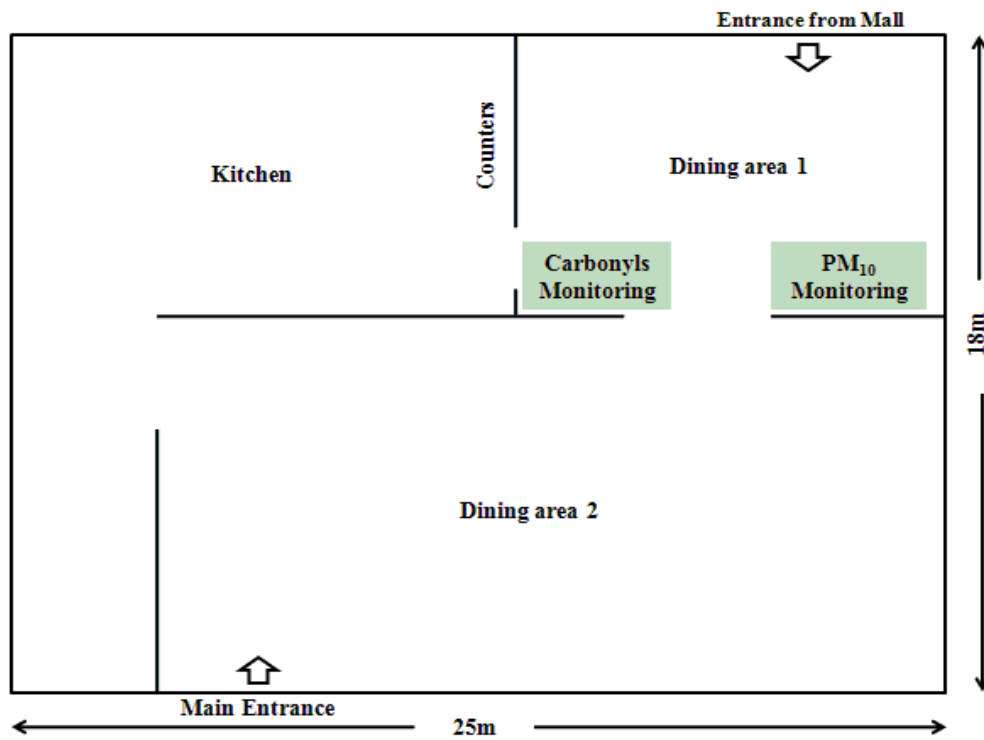
*Figure 3.4 Sketch of MFC at Rohini West (Not to scale)*
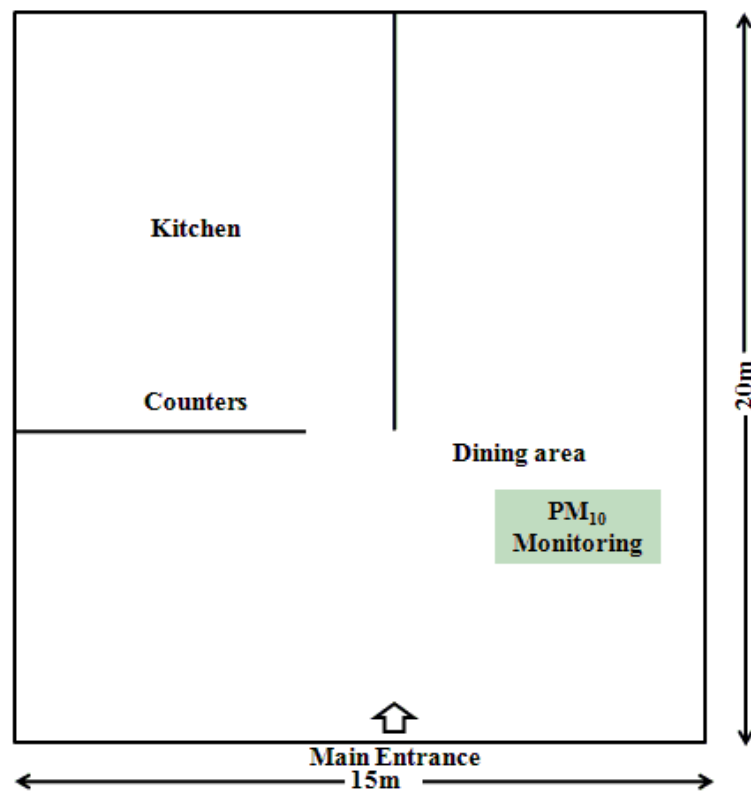


*Figure 3.5 Sketch of MFC at Netaji Subhash Place (Not to scale)*

## 3.3. Meteorology

Meteorological parameters play a key role in affecting the concentration of pollutant at a particular locality, predominantly wind speed and wind direction. Wind rose plots developed using WRPLOT software (Figure 3.6 to Figure 3.9). Wind rose plots depicts that direction of wind during monitoring period over Delhi was towards West and NW Direction. Hence NW district of Delhi is considered as the deposition area for pollutants.
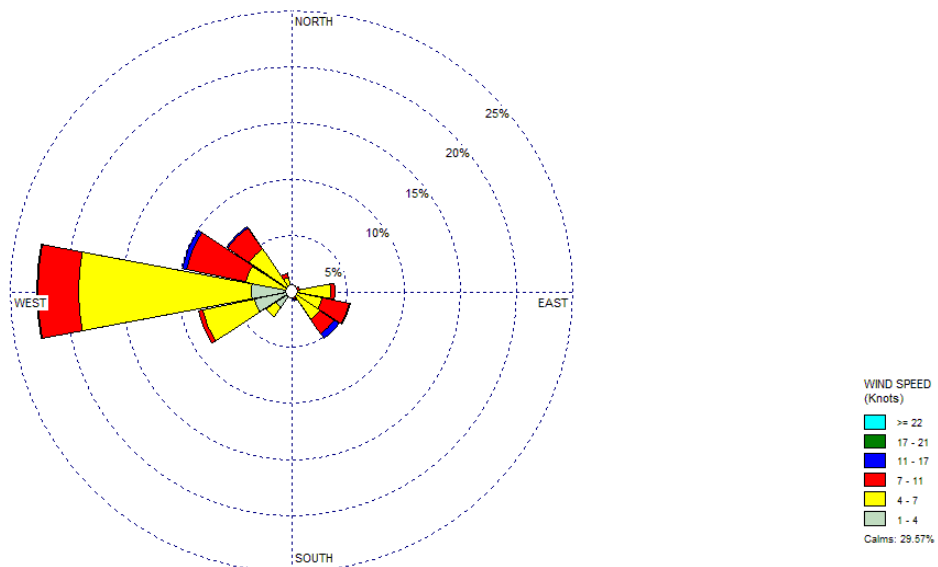


*Figure 3.6 Wind Rose Plot over Delhi (December 2014)*
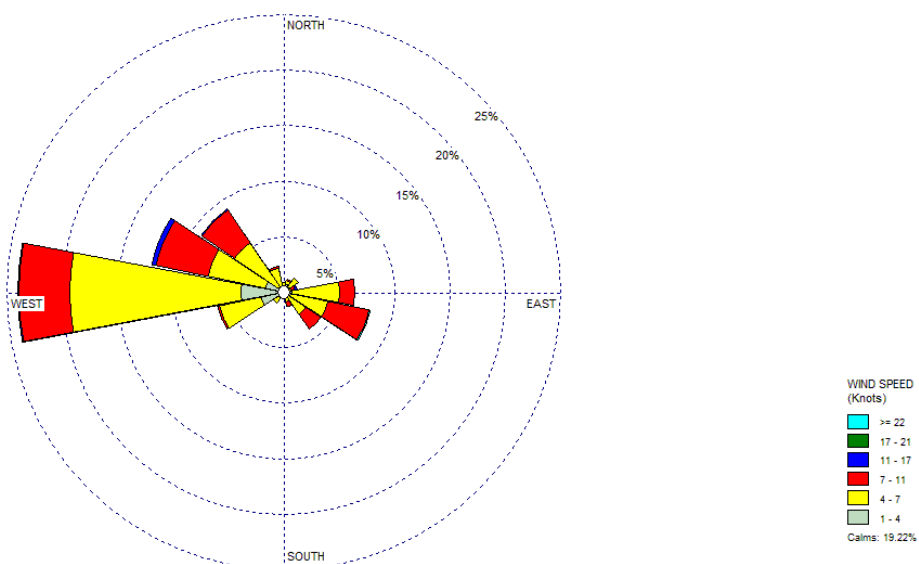


*Figure 3.7 Wind Rose Plot over Delhi (January 2015)*
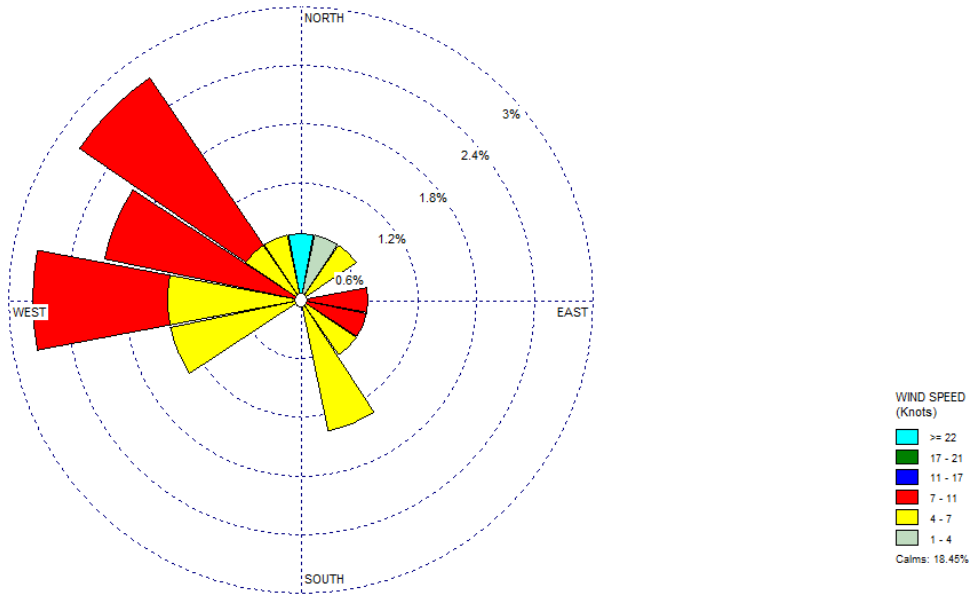
*Figure 3.8 Wind Rose Plot over Delhi (February 2015)*
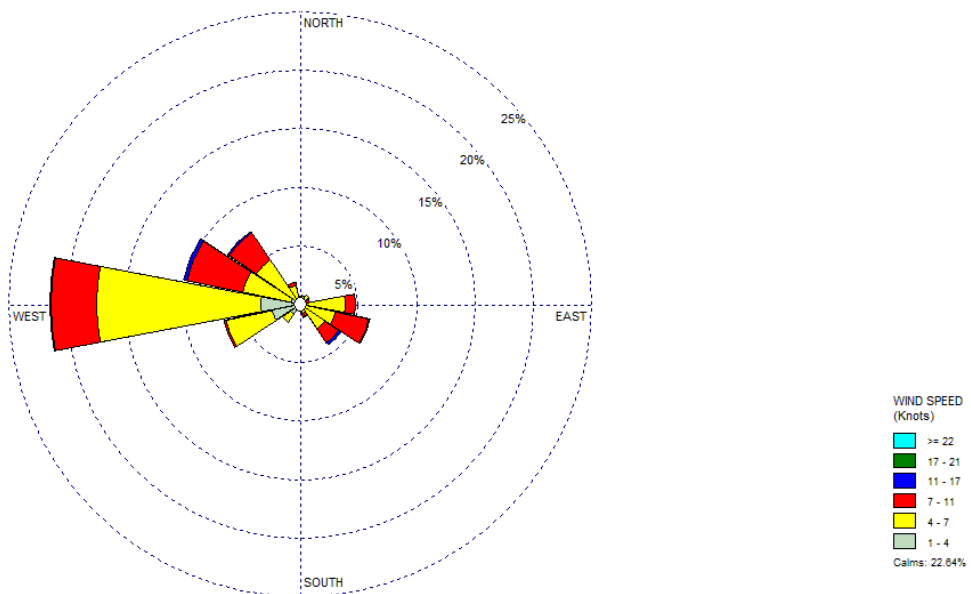


*Figure 3.9 Cumulative Wind Rose Plot over Delhi (December'14 to February'15)*

### 3.4. Precautions while monitoring

Following precautions were adopted while monitoring at the site;

1. Instrument was placed at the dining area of MFC, within the proximity of activities that were being carried out in kitchen.
2. Flow rate was maintained almost same for the time period of monitoring.
3. Carbonyls, instrument/cartridge was not exposed to particular source.

## 3.5. Principal Component Analysis [31]

Identification and quantification of $PM_{10}$, OC, EC, TC and Carbonyls was performed using PCA in SPSS 19.0. Factor score in PCA served as independent variable ($x_i$) against concentrations of compounds served as dependent variable ($y_i$).

$$y = \sum m_i x_i + b \ \ldots\ldots\ldots (1)$$

Normally standardized dependent and independent variables; and the influence of latter one on the former comparison done by regression coefficients. Normalized variable of equation (1) with intercept zero and regression coefficients B is represented as

$$z = \sum B_i X_i \ \ldots\ldots\ldots (2)$$

Standardized normal deviate of PM, OC, EC, TC and Carbonyls concentration in indoor air (dependent variable), partial regression coefficient $B_i$ and PCA factor score $X_i$ for source 'i' (independent variable) multiple linear regression equation is given by

$$T = \sum B_i \sigma_T FS_i + TM^* \ \ldots\ldots\ldots (3)$$

Where,

T: $PM_{10}$, OC, EC, TC and Carbonyl concentration (accordingly)

TM*: mean total $PM_{10}$, OC, EC, TC and Carbonyl concentration (accordingly)

$\sigma_T$: Corresponding standard deviation

$FS_i$ : Factor score for 'i' source

Mean contribution of source 'i' is given by

$$mean\ contribution\ of\ source\ i\ (\%) = 100 \ \frac{B_i}{\sum B_i} \ \ldots\ldots\ldots (4)$$

Contribution of source 'i' can be calculated as

$$Daily\ contribution\ of\ source\ 'i'\ \left(\frac{\mu g}{m^3}\right) = TM^* \ \frac{B_i}{\sum B_i} + B_i \sigma_T FS_i \ \ldots\ldots\ldots (5)$$

Where,

$\frac{B_i}{\sum B_i}$ : (regression coefficients for factor i) / (sum of all regression coefficients)

Results of the above study were highlighted in this chapter. Influence of meteorological parameters on concentration of pollutants, variation between indoor and outdoor concentrations, assessment of carbonyl compounds and their source apportionment were discussed.

## 4.1. $PM_{10}$ and Carbonaceous species

### 4.1.1. MFC at Rohini West

Higher concentration of 3278µg/m$^3$ and 527.31µg/m$^3$ of $PM_{10}$ and TC respectively were observed due to burning of the waste in open land adjacent to MFC (Table 4.1). It was also observed that wind speed and wind direction (Figure 3.7) greatly influenced the indoor concentration of $PM_{10}$ and TC, due to frequent opening of doors on that particular day to accommodate maximum customers.

*Table 4.1 Statistics of $PM_{10}$, OC, EC and TC at MFC – Rohini (West)*

|  | $PM_{10}$ ($\mu g/m^3$) | OC ($\mu g/m^3$) | EC ($\mu g/m^3$) | TC ($\mu g/m^3$) | OC/EC |
|---|---|---|---|---|---|
| **Weekdays** |  |  |  |  |  |
| Min | 2132 | 68 | 14 | 82 | 1 |
| Max | 3278 | 461 | 73 | 527 | 10 |
| Std. Dev. | 389 | 101 | 20 | 110 | 3 |
| Mean | 2725 | 175 | 36 | 211 | 6 |
| **Weekends** |  |  |  |  |  |
| Min | 1792 | 74 | 15 | 91 | 1 |
| Max | 3448 | 194 | 114 | 308 | 8 |
| Std. Dev. | 530 | 48 | 32 | 67 | 2 |
| Mean | 2740 | 147 | 46 | 194 | 4 |

The highest weekend $PM_{10}$ concentration of 3448µg/m$^3$ was recorded with a meager difference between OC and EC concentrations. The observed guest count (GC) (225) and influence of $PM_{10}$ from multiple outdoor emission sources – frequent opening of doors

(Figure 4.1). It was also observed that in a particular month's highest concentration of $PM_{10}$ was recorded on the day with highest guest count. The lowest concentration of $PM_{10}$ was observed might be due to the maximum recorded temperature (20˚C) and wind speed (7.1knots) in the month of January'15.

### 4.1.2. MFC at Netaji Subash Place

$PM_{10}$ and TC concentrations were in the downward trend from Dec'14 to Feb'15; according to change in weather conditions and guest count (Figure 4.2). Highest concentration of $PM_{10}$ was reported in December'14, $2796 \pm 161 \mu g/m^3$ on weekdays and $3212 \pm 494 \mu g/m^3$ on weekends (Table 4.2). The large variation in the concentrations of OC, EC is directly proportional to the guest count at MFC.

*Table 4.2 Statistics of $PM_{10}$, OC, EC and TC at MFC – NSP*

| | $PM_{10}$ ($\mu g/m^3$) | OC ($\mu g/m^3$) | EC ($\mu g/m^3$) | TC ($\mu g/m^3$) | OC/EC |
|---|---|---|---|---|---|
| **Weekdays** | | | | | |
| Min | 2347 | 99 | 11 | 116 | 3 |
| Max | 2976 | 318 | 61 | 364 | 12 |
| Std. Dev. | 161 | 76 | 17 | 88 | 3 |
| Mean | 2711 | 174 | 29 | 203 | 7 |
| **Weekends** | | | | | |
| Min | 1830 | 54 | 11 | 70 | 3 |
| Max | 3212 | 214 | 71 | 280 | 9 |
| Std. Dev. | 494 | 60 | 19 | 74 | 2 |
| Mean | 2708 | 141 | 31 | 171 | 5 |

### 4.1.3. Comparison

The highest concentration of $PM_{10}$, OC, EC and TC were observed at MFC Rohini (west) than the concentration at MFC in NSP. It can be depicted from the wind rose plot that the wind direction was dominated towards West during the monitoring period. Hence, NW District of Delhi might be considered as the major deposition area for wide range of pollutants. MFC of Rohini West falls exactly to the NW of MFC at Netaji Subash Place. Besides, MFC at Rohini being at ground level and MFC at NSP being at mezzanine level, the concentration of pollutants are a bit lower at the latter one.
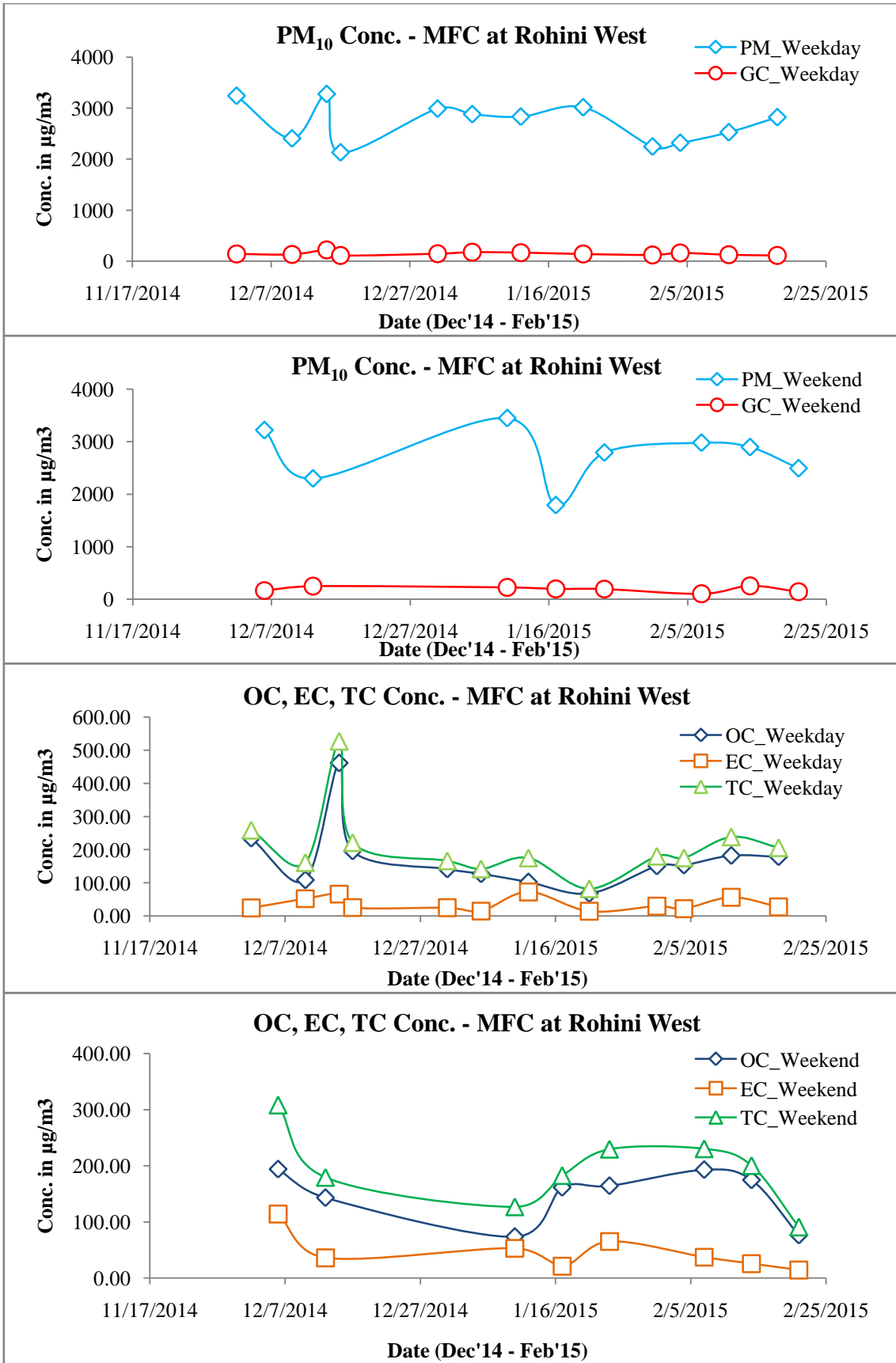
*Figure 4.1 weekday and weekend concentration of PM$_{10}$ and Carbonaceous Species – MFC at Rohini West*
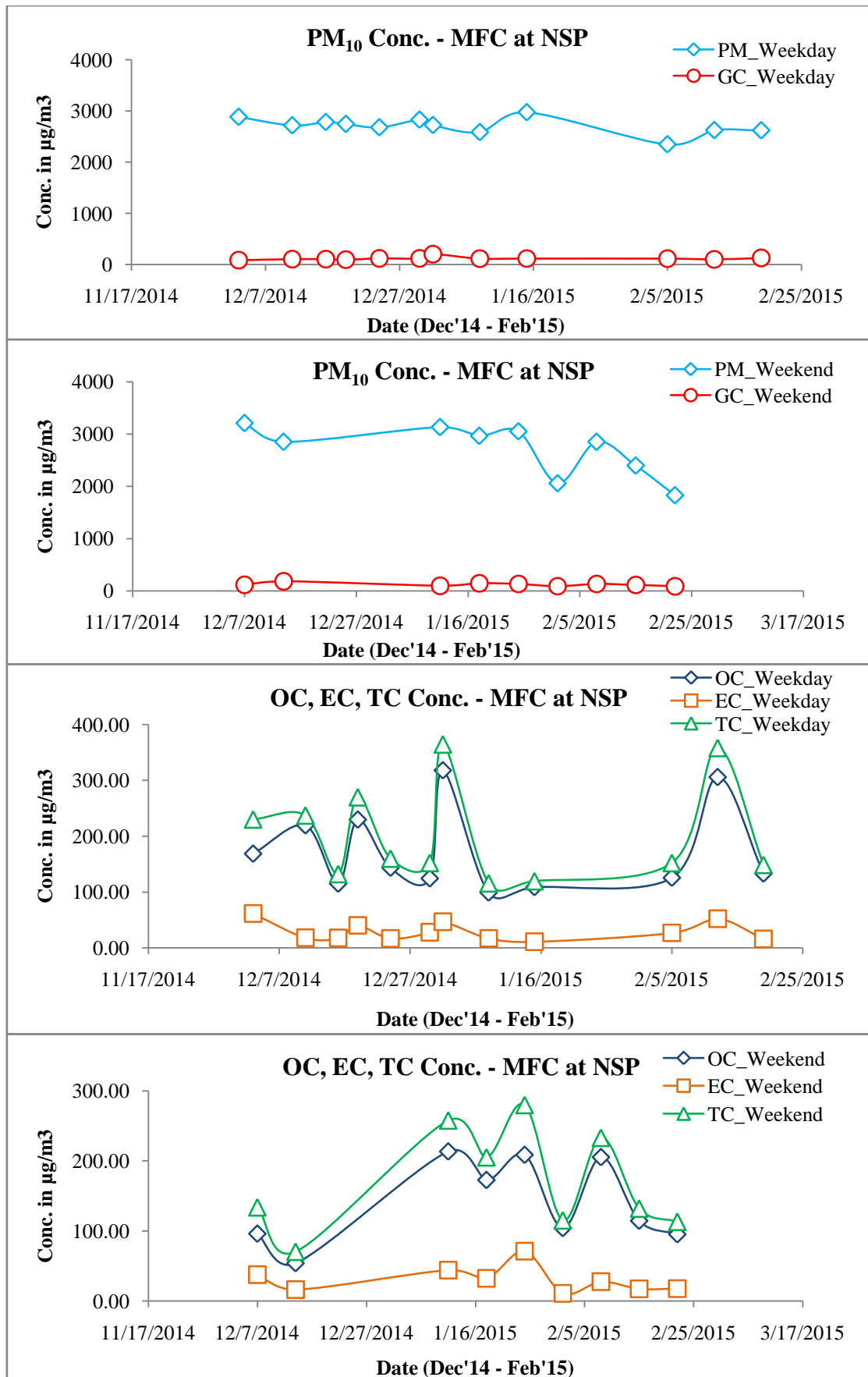
*Figure 4.2 weekday and weekend concentration of PM₁₀ and Carbonaceous Species – MFC at Netaji Subhashh Place*

*4.1.4. Indoor/Outdoor (I/O) Ratio*

Indoor – Outdoor ratio of $PM_{10}$, OC, EC and TC were 1.35, 1.1, 1.14 and 1.1 respectively (Table 4.3); Monitoring performed for Rohini Locality. Variation in the concentration of PM, OC, EC and TC were represented graphically (Figure 4). If Indoor – Outdoor ratio is greater than one which indicates the sources of air pollutants belong to indoor environment [32].

*Table 4.3 Indoor – Outdoor ratio of $PM_{10}$, OC, EC and TC*

| | $PM_{10}$ ($\mu g/m^3$) | OC ($\mu g/m^3$) | EC ($\mu g/m^3$) | TC ($\mu g/m^3$) | OC/EC | TC/PM (%) |
|---|---|---|---|---|---|---|
| **Indoor** | | | | | | |
| Mean | 1040 | 40 | 8 | 48 | 6 | 5 |
| Std. Dev. | 187 | 8 | 4 | 11 | 2 | 1 |
| Max | 1361 | 51 | 15 | 67 | 9 | 7 |
| Min | 826 | 31 | 5 | 35 | 3 | 3 |
| **Outdoor** | | | | | | |
| Mean | 768 | 37 | 7 | 43 | 6 | 7 |
| Std. Dev. | 187 | 8 | 4 | 11 | 2 | 1 |
| Max | 1101 | 52 | 12 | 59 | 7 | 11 |
| Min | 385 | 26 | 4 | 30 | 3 | 3 |
| **I/O (Mean)** | 1.35 | 1.10 | 1.14 | 1.10 | - | - |

Impact of organic carbon concentration either to indoor or outdoor environment are: biomass combustion, traffic, long range transport and secondary production [33]. Whereas, Elemental carbon enters atmosphere through incomplete combustion from traffic, industrial incineration [34]. Through frequent opening and closing of doors meager concentration of EC (as the door remains shut after the customers' arrival into the MFC) were observed resulting in higher OC/EC.

The guidelines established by the authorities were on gaseous pollutants but not on particulate pollutants except US EPA. No standards have been formulated yet in India. In comparison between the standards levied by authorities, it was observed that the results obtained from this study were beyond the permissible limit.
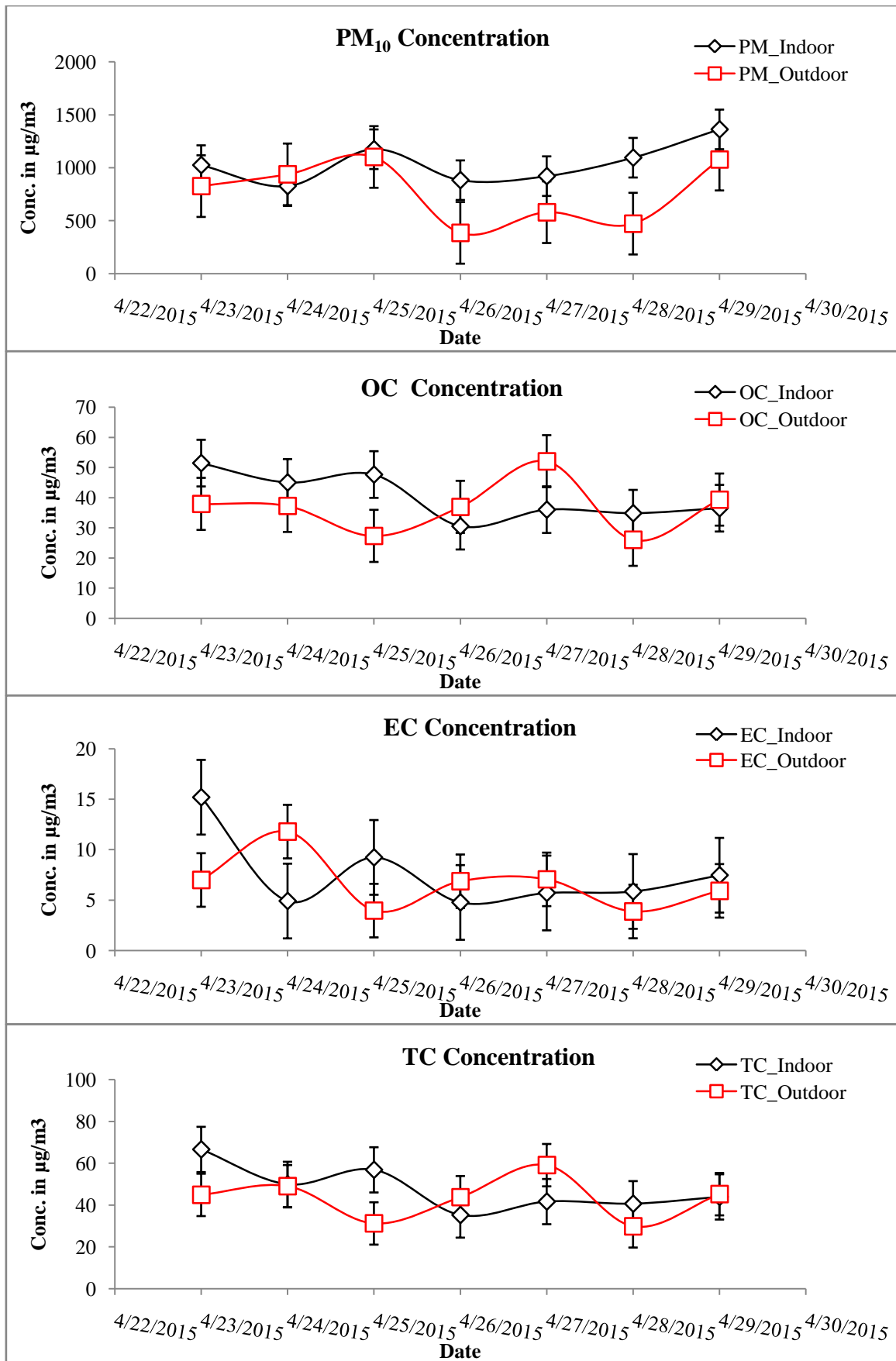
*Figure 4.3 A Comparison on I-O concentration of PM₁₀ and Carbonaceous Species*

## 4.2. Carbonyls

The results obtained from analyses of carbonyl samples are represented in Table 4.4. The maximum concentration amongst all compounds was Acetaldehyde during day time reporting $14.0 \pm 16.83 \mu g/m^3$ varied from 1.86 - $48.78 \mu g/m^3$. The night time concentration of Acetaldehyde was low in comparison to day time. The concentration of Acetone was recorded maximum amongst all carbonyl compounds during night time (i.e., $12.67 \pm 7.89 \mu g/m^3$ with a range varied from B.D.L. to $25.56 \mu g/m^3$).

Other carbonyl compounds concentration was identified meagerly in downward trend from December'14 till February'15 diurnally (Figure 4.4 and 4.5). Identification of formaldehyde in outdoor environment is greater than indoor environment. In the case of Acetaldehdye the scenario is vice versa [35].

*Table 4.4 Statistics of identified Carbonyls (diurnal variation) at MFC – Rohini West (Concentration in $\mu g/m^3$)*

| Compound | Day-time | | | |
|---|---|---|---|---|
| | Min | Max | Mean | Std. Dev. |
| Formaldehyde | 0.55 | 3.14 | 0.99 | 0.78 |
| Acetaldehyde | 1.86 | 48.78 | 14.00 | 16.83 |
| Acetone | 0 | 18.00 | 9.18 | 6.16 |
| Acrolein | 0 | 42.80 | 4.31 | 13.52 |
| Propanal | 0.57 | 7.84 | 2.12 | 2.55 |
| Butanol | 0 | 0.97 | 0.41 | 0.38 |
| Crotonaldehyde | 0.54 | 11.45 | 2.16 | 3.29 |
| Benzaldehyde | 0.40 | 1.42 | 0.89 | 0.32 |
| Isovaleraldehyde | 0 | 1.69 | 0.75 | 0.46 |
| Valeraldehyde | 0.62 | 1.73 | 1.15 | 0.39 |
| o-Tolualdehyde | 0 | 13.19 | 1.38 | 4.15 |
| m,p-Tolualdehyde | 0 | 0.39 | 0.06 | 0.13 |
| Hexanal | 0.42 | 10.55 | 2.68 | 2.91 |
| 2,5-Dimethylbenzaldehyde | 0 | 4.22 | 0.70 | 1.48 |
| Compound | Night-time | | | |
| | Min | Max | Mean | Std. Dev. |
| Formaldehyde | 0 | 2.83 | 1.12 | 0.92 |
| Acetaldehyde | 2.45 | 12.43 | 7.81 | 3.67 |
| Acetone | 0 | 25.56 | 12.67 | 7.89 |
| Acrolein | 0 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| Propanal | 0 | 1.84 | 0.90 | 0.60 |
| Butanol | 0 | 0.83 | 0.28 | 0.32 |
| Crotonaldehyde | 0.44 | 2.61 | 1.27 | 0.82 |
| Benzaldehyde | 0.41 | 3.75 | 1.17 | 1.01 |
| Isovaleraldehyde | 0.17 | 2.10 | 0.79 | 0.66 |
| Valeraldehyde | 0.54 | 3.91 | 1.44 | 1.12 |
| o-Tolualdehyde | 0 | 0 | 0 | 0 |
| m,p-Tolualdehyde | 0 | 0 | 0 | 0 |
| Hexanal | 0 | 4.88 | 1.89 | 1.80 |
| 2,5-Dimethylbenzaldehyde | 0 | 0.54 | 0.14 | 0.23 |



**Carbonyls Concentration - Day-time in MFC at Rohini West**
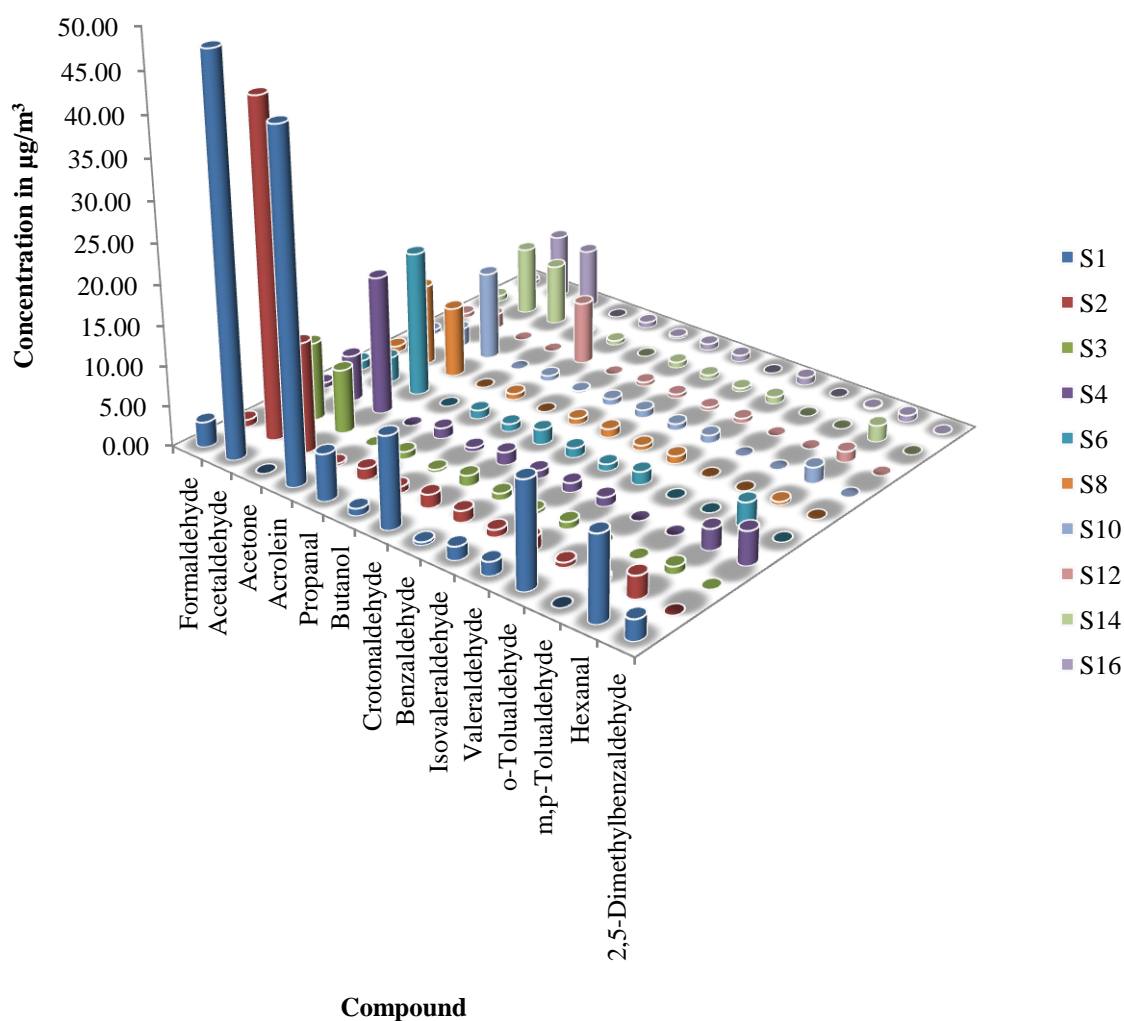
*Figure 4.4 Day-time variation (winter season) of carbonyl compounds*

# Carbonyls Concentration - Night-time in MFC at Rohini West
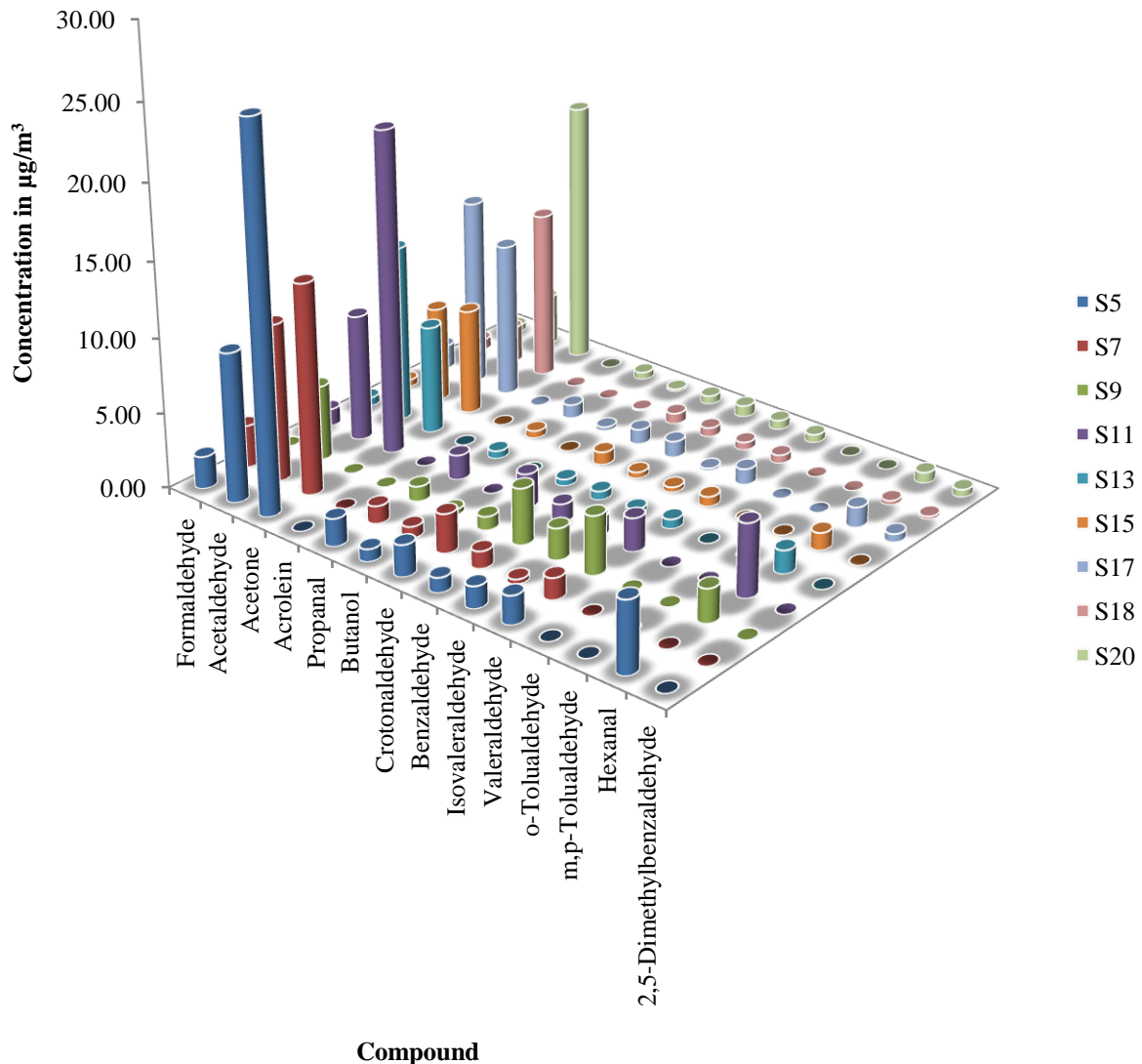


*Figure 4.5 Night-time variation (winter season) of carbonyl compounds*

The association of acetaldehyde levels is with the presence of smokers. MFC being a non smoking zone, low air exchange rate might be the other possible reason surrogated by carbon dioxide levels and absolute humidity [36]. The observed acetaldehyde concentration during day and night time is beyond the guideline specified by World Health Organization (WHO, 2005).

Acetone concentration might be due to the intrusion of soil vapors, detergents and cleansers [37]. MFC for its dignity to please customers, floor of MFC was wiped with cleansers; might be a possible reason for Acetone levels in indoor environment.

## 4.3. Carbonyls – Elucidation

PCA factors were identified for Carbonyls using 'Varimax' rotation with Kaiser Normalization (Table 4.5). Factors were selected on criteria with Eigen Value greater than 1. Four factors explained 83.515% variance of data. PC1 loaded with crotonaldehyde, o-Tolualdehyde, Acrolein, Hexanal, Formaldehyde, Acetaldehyde, Propanal, 2,5 – Dimethylbenzaldehdye and Butanol. PC2 loaded with Valeraldehyde, Benzaldehyde and Isovaleraldehdye.

*Table 4.5 PCA results (varimax rotation with Kaiser Normalization) at MFC – Rohini West. (Only factor loadings > 0.3 are shown. Loading > 0.5 are highlighted)*

| Compound | Principal Components | | | |
|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC4 |
| Crotonaldehyde | **.976** | | | |
| o-Tolualdehyde | **.949** | | | |
| Acrolein | **.949** | | | |
| Hexanal | **.877** | | | |
| Formaldehyde | **.758** | | .389 | |
| Acetaldehyde | **.721** | | | **.622** |
| Propanal | **.587** | | | |
| 2,5 – Dimethylbenzaldehyde | **.569** | | | |
| Butanol | **.531** | .314 | **.520** | .350 |
| Valeraldehyde | | **.964** | | |
| Benzaldehyde | | **.926** | | |
| Isovaleraldehyde | .431 | **.831** | | |
| Acetone | | | **.933** | |
| m,p-Tolualdehyde | | | | **.950** |
| Eigen Values | 6.131 | 2.555 | 1.607 | 1.400 |
| % of Variance | 43.790 | 18.248 | 11.479 | 9.997 |
| Cumulative % | 43.790 | 62.038 | 73.518 | **83.515** |

Carbonyl compounds at indoor environment were abundant in the order of **formaldehyde**, butyraldehyde, acetone + **acrolein**, **acetaldehyde**, *valeraldehyde*, propionaldehdye, *isovaleraldehdye* and *benzaldehyde*; detected in kitchens usually [38] [39]; of which compounds in bold are loaded under PC1 and compounds italicized were loaded

under PC2. Acrolein loaded in PC1 infers that the use of seed oil at MFC for potato fries frequently during day time [40].

Study carried out at two different locations of NW Delhi covering the MFC's was intended to represent a typical indoor environment. Air samples extracted from the food court were analyzed in the laboratory for $PM_{10}$ (by gravimetric method), OC, EC and TC (using DRI – Model 2001 – Thermal Optical Analyzer) and Carbonyls (using HPLC).

## 5.1. Conclusion

Site specific results obtained were discussed in the chapter IV. Following are the conclusions made;

The concentration of $PM_{10}$ at two monitoring sites was recorded very high. The Maximum concentration of $PM_{10}$ being 3278μg/m$^3$ and 3448μg/m$^3$ during weekdays and weekends at MFC – Rohini West. Similarly, the concentration of $PM_{10}$ at MFC – NSP was 2976μg/m$^3$ and 3212μg/m$^3$ during weekdays and weekends respectively. Expected higher concentrations, away from the trend were observed in both the places from 30 December 2014 to 2 January 2015, on the eve of New Year celebrations. Concentration of $PM_{10}$ was too high in comparison with the guidelines levied by authorities (US EPA). No standards or guidelines were established in India to control the increasing $PM_{10}$ concentration at indoor environment.

The percentage of Total Carbon (TC) in $PM_{10}$ was approximately 7% at both MFC's. The percentage distribution of organic carbon (OC) and elemental carbon (EC) in TC at MFC – Rohini West was 80% and 20% respectively. Similarly, at MFC – NSP the percentage of OC and EC in TC was 84% and 16% respectively. The major contributing factors for $PM_{10}$ at indoor environment were indoor activities as well as intervention of outdoor sources.

A large variation in the concentrations of carbonyls can be observed from the kitchen exhausts. The factors affecting the concentration levels of carbonyls might be style of cooking, size of the restaurant and ventilation rate of the exhaust. The percentage variation of carbonyl concentration at MFC – Rohini west over the winter season is shown in the Figure 5.1 from December 2014 till February 2015. The even contribution of Acetaldehyde and Acetone were observed at 31% each.
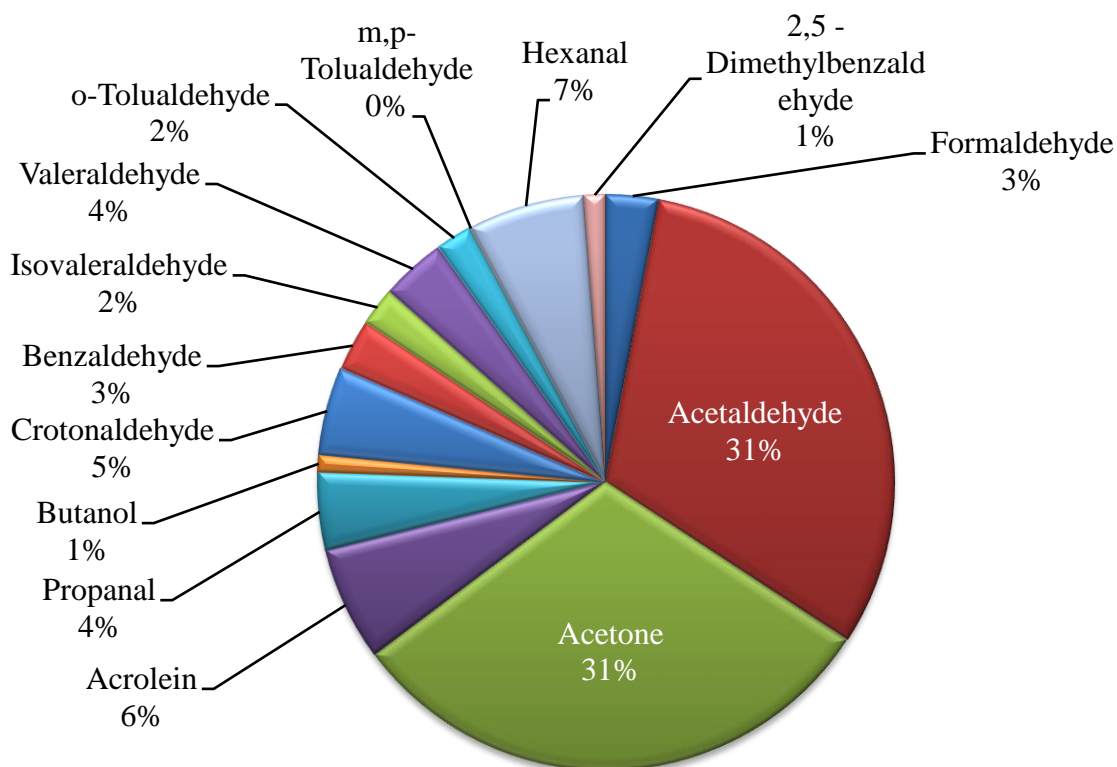
*Figure 5.1 Percentage Distribution of carbonyls during winter season (December 2014 – February 2015) at MFC – Rohini West*

## 5.2. Recommendations

Delhi classified under Koppen climatic condition, shows a great variation in temperatures during summer and winter seasons. The situation arises in the latter half of December, where temperature plunges to 2˚C vicinity demanding to turn off air conditioning indoors. The same is the case with MFC, assisting the rise in pollutant concentration levels. Winters favoring low dispersion of pollutants, both particulate and gaseous with low air exchange rate.

The persistence of pollutants for longer duration may worsen existing health issues. Indoor air pollution was ranked one among five threats to public health [41]. Research conducted by "The Plants for Clean Air Council" and "Wolverton Environmental Services" revealed that house-hold plants are capable enough in removing organic compounds from indoor air. Plants (household) besides producing aesthetic sense they also help in maintenance of cleaner air. Adding foliage plants helps in reducing 20% of PM accumulation on horizontal surface [42]. Research conducted by National Aeronautics and Space Administration (NASA) revealed the sources and solutions for different organic compounds (Annexure – 3) [43]. Plants species available which help in capturing high dust are tabulated below (Table 5.1)

*Table 5.1 High Dust capturing Plants species* [44]

| Type | Plant Species | |
|---|---|---|
| **Moderate** | **Herbs** | **Shrubs** |
| | Lilium species (Lily) | Bambusa species (Bamboo) |
| | Draceana species | Lagerstomiaindica (Crape Myrtle) |
| | Halianthusannuus (Sunflower) | Nerium indicum (Kaner Pink) |
| | Tegetespatula (Genda) | Codiumvarigatum (Croton) |
| | Pothusaureus (Money Plant) | Thevetiaperuviana (Kaner Yellow) |
| | | Wrightiaarborea (Dudhi) |
| | | Rosa indica (Rose) |
| | | Ipomea nil (Beshrum) |
| | | Tabermaemontanadivaricata (Chandani) |
| | | Acalyphahispida (Copper leaf) |
| | | Plumeria acuminate (temple Tree) |
| **High** | Colocasiaantiquorum (Elephants Ear) | Hibiscus rosasinensis (Gurhal) |
| | Celosia argentea (cock'scomb) | Bougainvillea glavara (Bougainvillea) |

The basic strategy identified by US – EPA to reduce the concentration levels of pollutants at indoor environment are source control, improved ventilation and use of air cleaners. $PM_{10}$ and carbonyl compounds emission from cooking sources are to be controlled by alternative and efficient style of cooking. Efficient Ventilation and air conditioning during winter season may be provided for better air exchange at good rate for indoor environment. Eco friendly cleansers are to be used to wipe floor to reduce the emission of carbonyl compounds.

# Scope for Future Study

Based on the investigation carried out on $PM_{10}$, carbonaceous species and carbonyls at indoor environment (Multinational Food Court – MFC), the following are the areas recommended for further study.

1. Continuous monitoring of air quality for $PM_{10}$, $PM_{2.5}$, $CO_2$, CO, Ozone at indoor and outdoor environment simultaneously.
2. Comparative study between MFC's at same locality with and without high dust absorbing plant species.
3. Outdoor intervention of pollutants at indoor environment.
4. Source profile identification of a pollutant.
5. Carbonyl emission for particular food at different style of cooking. (e.g. pollutant emission from potato when fried, deep fried, boiling etc.)
6. Study on efficient ventilation and air conditioning system during winter season.

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*Medical issues among the residents of Delhi at AIIMS due to Air Pollution* [45]

| 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 |

Standards or Guidelines set by the regulatory authorities are as follows:

**Canada Health – 1987 (First issue)**

|  | 24hr | 8hr | 1hr | Annual |
|---|---|---|---|---|
| **CO** | - | 11ppm | 25ppm | - |
| **Formaldehyde** | - | 0.05ppm | - | - |
| **$NO_2$** | - | 0.05ppm | 0.25ppm | - |
| **Ozone** | - | - | 0.12ppm | - |
| **$SO_2$** | - | 0.019ppm | - | - |

**World Health Organization (WHO) Guidelines (2009)**

|  | 24hr | 8hr | 1hr | Annual |
|---|---|---|---|---|
| **$PM_{10}$** | - | - | - | - |
| **$PM_{2.5}$** | - | - | - | - |
| **$SO_2$** | $20\mu g/m^3$ | - | - | - |
| **$NO_2$** | - | - | 0.1ppm | 04ppm |
| **CO** | - | 10ppm | 25ppm | - |
| **$CO_2$** | - | - | - | - |
| **Acetaldehyde** | $1.5 - 9 \times 10\text{-}7\ \mu g/m^3$ (Life time cancer risk at $1\mu g/m^3$) | | | |
| **Formaldehyde** | $100\mu g/m^3$ (30min) | | | |

**ASHRAE (Std 55)**

|  | 24hr | 8hr | 1hr | Annual |
|---|---|---|---|---|
| **CO** | - | 9ppm | - | - |
| **$CO_2$** | - | 1000ppm | - | - |

**OSHA (must not exceed during 8hr work shift) – 2011**

|  | 24hr | 8hr | 1hr | Annual |
|---|---|---|---|---|
| **$PM_{2.5}$** | - | $5mg/m^3$ | - | - |
| **$SO_2$** | - | 5ppm | - | - |
| **$NO_2$** | - | 5ppm | - | - |

| | | | | |
|---|---|---|---|---|
| **CO** | - | 50ppm | - | - |
| **CO$_2$** | - | 5000ppm | - | - |

## NAAQS (US) / EPA (2014)

| | 24hr | 8hr | 1hr | Annual |
|---|---|---|---|---|
| **PM$_{10}$** | 150µg/m$^3$ | - | - | 50µg/m$^3$ |
| **PM$_{2.5}$** | 65µg/m$^3$ | - | - | 15µg/m$^3$ |
| **SO$_2$** | 0.14ppm | - | - | 0.03ppm |
| **NO$_2$** | - | - | - | 0.05ppm |
| **Ozone** | - | - | 0.12ppm | - |
| **CO** | - | - | 35ppm | - |

## Australian Standards (NHMRC) – 2006

| | |
|---|---|
| **Formaldehyde** | 130µg/m$^3$ (Ceiling Limit) |
| **CO** | 9ppm (8hr average) |
| **Ozone** | 260µg/m$^3$ (1hr average) |

*Sources and solutions for organic emissions at indoors'*

| Compound | Source | Solution (Plants) |
| --- | --- | --- |
| **Formaldehyde** | foam insulation | Azalea |
| | Plywood | Dieffenbachia |
| | particle board | Philodendron |
| | Clothes | Spider plant |
| | Carpeting | Golden pothos |
| | Furniture | Bamboo palm |
| | paper goods | Corn plant |
| | household cleaners | Chrysanthemum |
| | water repellants | Mother-in-law's tongue |
| **Benzene** | tobacco smoke | English ivy |
| | Gasoline | Marginata |
| | synthetic fibers | Janet Craig |
| | Plastics | Chrysanthemum |
| | Inks | Gerbera daisy |
| | Oils | Warneckei |
| | Detergents | Peace lily |
| **Trichloroethylene** | dry cleaning | Gerbera daisy |
| | Inks | Chrysanthemum |
| | Paints | Peace lily |
| | Varnishes | Warneckei |
| | Lacquers | Marginata |