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# Characterizations of Carbonaceous Aerosol in South and East Asia: A review from 2007 to 2014

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## Abstract

The variations of carbonaceous aerosols in particulate matter (mostly in PM10 and PM2.5) were reviewed in South and East Asia during the period of 2007 to 2014. The selected countries in South and East Asia are Bangladesh, China, India and Nepal. The carbonaceous aerosols consist of organic carbon (OC) and elemental carbon (EC) and combination of two is known as total carbon (TC). Anthropogenic or biogenic sources and atmospheric oxidation of volatile organic compounds and subsequent gas-to-particle conversion processes are the major sources of carbo-naceous aerosols. This paper is reviewed the numerous studies, which were carried out in various hotspot locations (namely residential, industrial, traffic intersections, rural, indoor environment etc) of selected countries in Asian con-tinent. OC/EC ratio in Bangladesh (Dhaka) varied from 0.78 to 1.3. OC/EC ratio in China (Chongqing, Xi'an, Xink-en, Pearl River Delta regions) varied from 1.13 to 6.92. OC/EC ratio in India (Delhi, Agra, and Mumbai) varied from 0.15 to 16.2. OC/EC ratio in Nepal (Kathmandu, Kathmandu valley) varied from 2.7 to 2.86. OC/EC ratio is gener-ally varies with seasons. Most of the country OC/EC ratio exceeded 2, indicating the formation of secondary organ-ic carbon (SOC). SOC is one of the major contributors of OC and its contribution varied from 18 to 61% in the se-lected locations. In Dhaka city, Bangladesh) EC concentrations were alarmingly high due to operation of diesel based power plants. The concentrations of OC in PM10 and PM2.5 varied from 15 to 33% and 26 to 46% respective-ly. Similarly the concentrations of EC in PM10 and PM2.5 varied from 3 to 10% and 9 to 10% respectively. The mor-phology study of particulate matter suggested that the origin of carbonaceous aerosols were mostly from combus-tion processes only. This work elucidates the characteristics, sources of carbonaceous aerosols in South and East Asia.

**Keywords**: Particulate matter, Carbonaceous aerosols, Organic carbon, Elemental carbon, South and East Asia.

## Introduction

The carbonaceous fractions are becoming matter of great concern in the world. Carbonaceous aerosols are the major component of particulate matter (PM) is usually classified as to Organic Carbon (OC) and Elemental Carbon (EC) {also known as Soot or BC} (NCAP Report-2013, India). OC refers to the molecule containing carbon hydrogen bond and represents a large variety of organic compounds and classified as aliphatic, aromatic compounds, acids etc.EC is a pure carbon or soot. EC is a primary pollutant resulting from the incomplete combustion of carbonaceous fuels e.g. diesel, wood and does not undergo any chemical transformation while OC can be either released directly into atmosphere from anthropogenic and biogenic sources i.e. Primary OC or formed within the atmosphere through gas to particle conversion of volatile organic compounds through photochemical reactions i.e. (SOC). Coal combustion, biomass burning and vehicular exhaust are the major sources of carbonaceous aerosols. SOC evolves as a result of condensation of low vapor pressure volatile organics. The various studies suggested that (OC/EC) ratio generally exceeded 2.0, indicates the presence of SOC in the ambient air. SOC is influenced by photochemical activity (for example low wind velocity, high temperature and intense solar radiation). The direct determination of SOC is rather difficult due to complexity of the OC reaction pathways. Nevertheless, it is possible to use an indirect method for assessment of SOC. SOC can be calculated by estimated by following formula on the basis of (OC/EC) ratio **(Castro *et al., 1998*)** as:

$$OC_{sec} = OC_{total} - (OC/EC)_{minimum} * EC$$

The minimum ratio of OC/EC is used to estimate SOC.

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The present paper reviews the work carried out by various researchers in this area in South and East Asia.

The primary objective of the paper is to comply the characterization of carbonaceous aerosols and its sources in selected Asian countries.

## Methodology for measurement of OC and EC

OC and EC were measured by various methods which are discussed below.

**1. Carbon Analyzer (Atmoslytic Inc., USA)**
OC and EC in most the countries were analyzed by Carbon Analyser (Atmoslytic Inc., USA) by IMPROVE thermal optical reflectance protocol (TOR) (Chow et al. 2001; Fung et al. 2002). The principle of the analyzer is based on preferential oxidation of organic carbon and elemental carbon at different temperatures. The principal function of the analyzer is to pyrolyse the sample and then to char the organic carbon compounds into elemental carbon. The method analyzes for organic carbon fractions (OC1, OC2, OC3 and OC4 at 140, 280, 480 and 580$^0$C), pyrolysed carbon fraction (OP) and elemental carbon fractions (EC1, EC2 and EC3 at 580, 740 and 840$^0$C), respectively. The IMPROVE protocol software defines OC as OC1+ OC2+ OC3+ OC4+OP, EC as EC1+ EC2 + EC3 - OP and TC as OC + EC.

**2. C-mat 5500 carbon analyzer (Strohlein, Germany).** For measurement of OC concentrations, OC was volatilized at 650$^0$C under nitrogen and catalytic converted to $CO_2$, while EC was brunt to $CO_2$ at 650$^0$C under oxygen. The formation of $CO_2$ was determined with a NDIR detector. The concentrations of OC and EC concentrations strongly depended on the condition of the operational OC/EC splitting.

**3. Aethalometer (Magee Scientific, USA)**
Aethalometer (Magee Scientific, USA) having flow rate of 2 lpm. The instrument provides the real time data of BC in the air stream.

**4. MicroAeth Model AE-51(Magee Scientific, Berkeley, CA)**
Real time indoor BC concentrations can be estimated using a MicroAeth Model AE-51(Magee Scientific, Berkeley, CA) which was set at a flow rate of 50mL/min.

**5. Transmission OCEC Lab Instrument (Sunset Laboratory, Forest Grove, USA, Model 2000)**
The samples were analyzed in two stages.

***Stage I:*** An aliquot was quartz filter paper was initially heated stepwise up to temperature of 870$^0$C in a non-oxidizing He atmosphere, and then cooled at 550$^0$C.

***Stage II:*** Then again heated at 870$^0$C in an oxidizing atmosphere (98% He + 2% $O_2$).
The evolved carbon at each temperature step is oxidized to $CO_2$ and then reduced to $CH_4$ for quantification with flame ionization detector. The transmittance of light from He-Ne laser, through the filter punch, is continuously monitored and used for settings the OC/BC split line.


***Fig.1- Map showing monitoring locations in South and East Asia.***

**Bangladesh**
Bangladesh is one of the most popular and developing country in South Asia located between 20°34′ to 26°38′ N and. 88°01′ to 92°42′ E. It has a border on the west, north, and east with India, on the southeast with Myanmar, and the Bay of Bengal is to

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the south. The several studies regarding the carbonaceous aerosols in ambient air were carried out in Dhaka city, Bangladesh the most populous city in Bangladesh and the tenth-largest city in the world, with a metropolitan area of 12 million inhabitants. The concentrations of OC and EC (in $\mu g/m^3$) were measured in two hotspot locations in Dhaka city i.e. Amin Bazar and Farm Gate. The selected locations are influenced by heavy duty vehicles, brickfield clusters, boats driven by residual oil. Particulate matter samples were collected at by Air Metric MiniVol sampler (developed by USEPA) for monitoring of $PM_{2.5}$. The samples were collected in both type of filter paper (teflon and quartz) for analysis purposes. The MinVols were programmed to sample at 5 lpm through particle size separator and then through 2 µm pore teflon and quartz filters. Samples were analyzed for OC; EC and TC concentrations with the help of DRI (Desert Research Institute) Model 2001 using IMPROVE TOR protocol.

**Begum *et al.*, 2011** estimated $PM_{2.5}$, OC, EC and TC concentrations in two selected locations i.e. Amin Bazar and Farm Gate. The concentration of $PM_{2.5}$ in Amin Bazar location varied from 11-328 $\mu g/m^3$ which was alarmingly high as compared to National Ambient Air Quality Standards) NAAQS of Bangladesh (65$\mu g/m^3$) The average concentrations of OC and EC in $PM_{2.5}$ accounted for 46±11% and 33±12%. in $PM_{2.5.}$ EC and TC concentrations varied from 28.5-55.2 and 55.9-95.1 $\mu g/m^3$. The average EC/TC ratio was 0.56 during the study period.

The Farm Gate location is representing the mixed use area. The location is consists of commercial and industrial hub and connected through several road intersections. EC and TC concentrations at Farm Gate location varied from 16.1- 32.1and 40.1-70.6 $\mu g/m^3$ respectively. The average EC/TC ratio was recorded as 0.43 during the study period. Dhaka city EC/TC ratio varied from 0.43-0.56 in two major locations.

**Begum *et al.*, 2012** demonstrated OC and EC concentrations in $PM_{2.5}$ in the same hot spot locations of Dhaka city, during the year 2012. Amin bazaar location average OC and EC concentrations accounted for 47.3 and 41.4 $\mu g/m^3$ respectively. OC/EC ratios at Amin bazaar varied from 0.25-2.34 during the study period, which indicated the presence of secondary organic carbon (SOC). The average SOC concentrations in $PM_{2.5}$ varied from 0.47-27.1 $\mu g/m^3$ with an annual average concentration of 4.61±5.26 $\mu g/m^3$. The annual average concentrations of SOC to the total OC accounted for 41±17% while for total $PM_{2.5}$ mass as 19±10%. It was concluded that OC/EC ratio in Dhaka city varied with temperature during the study period. The concentrations of carbonaceous aerosols during winter season were higher as compare to summer season as a result of volatilization being increased at the lower temperatures.

The concentrations of OC and EC were significantly correlated with $PM_{2.5}$, wind speed and temperature. Furthermore, local sources were also responsible for increased PM concentrations during the study period. The most probable sources of contaminations were as brick kilns and diesel based power plants, vehicular exhaust, biomass burning, coal combustion etc.

**China**

China is located in East Asia, the world's most populous country, with a population of over 1.35 billion. The several studies were carried out in various locations (Chongqing, Xi'an, Xinken, Pearl River Delta regions etc) during the period of 2007 to 2014.

**Di Ye *et al.*, 2007** demonstrated the characterization and concentrations of OC and EC (in $\mu g/m^3$) at nine urban sites and one urban background site in Chongqing, China during two intensive observations campaigns in 2006. $PM_{10}$ samples were collected using medium volume samplers (TH-150CIII, China) operated at a flow rate of 100L/min. These samples were collected on Whatman quartz micro- fiber filters (QM/A). Elemental Analyzer (EA) technique was used to measure OC and EC concentrations in $PM_{10}$. The annual average concentrations of OC and EC at urban sites were estimated as 57.5±20.8, 8.3±3.9 $\mu g/m^3$ while at urban background sites it accounts for 21.7±9.7 and 3.1±1.8$\mu g/m^3$ respectively. The concentrations of OC and EC $PM_{10}$ at urban nine sites were almost three times higher than those for urban background site in both the seasons. The study also suggested that OC concentrations in autumn were found to be about 1.5 times higher than that in spring. EC concentrations were not varied significantly with seasons. The higher OC concentrations in autumn might be due to more favorable conditions (i.e. higher temperature and more intense solar radiation for photochemical activity). Correlation between EC and $PM_{10}$ was ($r=0.45$, $p<0.05$) and between OC and $PM_{10}$ was ($r=0.82$, $p< 0.01$). The concentrations of possible SOC ($\mu g/m^3$) at nine located estimated by EC tracer method. The average SOC concentrations in spring and autumn were 26.7 and 39.4 $\mu g/m^3$ respectively which was accounted for 48.9 and 61.9 % of OC

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total. OC and EC concentrations were significantly correlated with each other in both the seasons (autumn and spring) implying the similar emission sources such as coal combustion. The higher emissions of OC and EC at urban sites at Chongqing, China were influenced by traffic or industrial emission or coal combustion.

**CAO Junji *et al.*, 2008** investigated chemical characterization of carbonaceous aerosols (carbonate carbon, OC and EC) at Xi'an (33.3° N, 108.9°E), China near Asian dust source regions in spring 2002. $PM_{2.5}$ samples were collected on 47 mm Whatman quartz microfiber filters (QM/A) at a flow rate of 5 lpm. The samples were collected during dust storm (DS) and non dust storm (NDS) by Mini volume samplers (Airmetrics, USA). A total 31 aerosol samples (DS 6 samples for three dust storm events and NDS 25 samples) were collected during the study period. The average % of total carbon (OC+EC+CC) in $PM_{2.5}$ during NDS (22.6%) periods was much higher than DS event (13.6%). The average OC and EC concentrations measured 8.2-63.7 and 2.4-17.2 $\mu g/m^3$ respectfully at Xi'an, China. OC-EC correlation during DS event was good ($R^2$=0.76, n=6) while stronger correlation was in NDS period ($R^2$=0.90, n=25). The average ratio of OC/EC during DS event was 5 and an NDS event was 3.3.The concentrations of CC mainly entered from Asian dust. However it was observed that even in the near atmospheric Asian dust source regions, atmospheric OC and EC concentrations were controlled mainly governed by local emission rather than the transport of Asian dust.

**Shen *et al.*, 2010** estimated traffic related emission at a heavy- traffic roadside in the month of April, 2008 at Xi'an, China. $PM_{10}$ and its chemical composition were observed during heavy traffic periods (morning rush hours, noon, and evening rush hours) PM10 samples were collected on 90mm ϕ quartz micro-fiber filters (Whatman QMA, England) using a medium volume sampler (KC-120H, Qingdao Laoshan Electric CO., Ltd., China) operated at a flow rate of 100 L/min. OC and EC concentrations were analyzed using IMPROVE TOR protocol. $PM_{10}$ concentrations ranged from 337.9-718 $\mu g/m^3$ with an average value of 569.2$\mu g/m^3$. The ratio of OC/EC during the three traffic periods were approximately equal and average ratio was 3.2.The level of eight carbonaceous fractions suggested a predominant contribution from gasoline exhaust.

**Gnauk *et al.*, 2008** estimated the size-segregated particle chemical composition in Xinken, Pearl River Delta, China during October, 2004. The size-segregated particulate samples were collected using Micro-Orifice Uniform Deposit Impactor (MOUDI, model No.110, MSP, USA). The flow rate of the sampler was 301min/liter. The samples were collected of 10 stages of particulate sizes (18, 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18, 0.1 and 0.056um). The concentrations of OC and EC were measured using a C-mat 5500 carbon analyzer (Strohlein, Germany). Stage 1 (range of particle upto 0.1 um) OC and EC concentrations were 2.4% and 1.4% of their stages total mass. Stages 2-6 (range of particle 0.1 to 1.8 um) OC and EC concentrations were 71.2% and 85.6% of their stages total mass. Stages 7-10 (range of particle 1.8 to 18 um) OC and EC concentrations were 26.4% & and 13% of their stages total mass. The OC/EC ratios in all stages mostly varied from 1 to 2.7. OC and EC concentrations were maximum in stages 2-6 (range of particle 0.1 to 1.8 um) and lowest in stage 1(range of particle 0.056 to 0.1 um). The sources of OC emission were from biogenic sources (primary) or due to troposphere chemical reactions. EC concentrations contributed from local dust only.

**Lai *et al.*, 2010** demonstrated the characteristics of residential indoor carbonaceous aerosols during the summer time in Guangzhou, Pearl River Delta. The fine particulate matter ($PM_{2.5}$) samples were collected at 1.5m above the ground in order to simulate the breathing zone and to avoid potential interference of particle re-suspension. The collected samples were classified into 5 types eg., urban residence with smoker, urban residence without smoker, roadside residence, newly remodeled residence and suburban site. The samples were analyzed for OC and EC with the help of DRI Model 2001 using TOR protocol. The average indoor $PM_{2.5}$, OC and EC concentrations were 47.4, 12.5 and 4.4 $\mu g/m^3$ respectively, indicating 24.4% of OC and 9.9% of EC to indoor $PM_{2.5}$ mass. The average OC/EC ratio was 2.5. The highest concentrations of $PM_{2.5}$, OC and EC were 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 were observed in urban with smoker type residence due to contribution of indoor emission sources and poor ventilation condition in the kitchen. The highest EC concentration was observed in the road side residence, indicating the outdoor traffic emissions. The urban residence without smoker and newly remodeled residence had similar $PM_{2.5}$, OC and EC concentrations. Suburban site had the lowest concentrations of $PM_{2.5}$, OC and EC concentrations. The pattern followed in the various types of indoor environment represented as urban residence with smoker > urban residence without smoker > roadside residence > recently remodeled residence > suburban

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site. The concentrations of various carbon fractions indicating that smoking, cooking, poor ventilation and indoor microenvironments are the major emission sources in indoor air pollution.

**India**

The Republic of India (21.0000° N, 78.0000° E) is a country in South Asia. It is the seventh-largest country by area, the second-most populous country with over 1.2 billion people, and the most populous democracy in the world. Bounded by the Indian Ocean on the south, the Arabian Sea on the south-west, and the Bay of Bengal on the south-east, it shares land borders with Pakistan to the west, China, Nepal, and Bhutan to the north-east; and Burma and Bangladesh to the east. In the Indian Ocean, India is in the vicinity of Sri Lanka and the Maldives. In addition, India's Andaman and Nicobar Islands share a maritime border with Thailand and Indonesia. The several studies regarding the carbonaceous aerosols in ambient air and its impact on climate change were carried out in Delhi, Agra, Mumbai and other cities also.

**Ramanathan *et al.*, 2011** 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 1to 9 September 2010 in 18 of 35 households In addition 24 h 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 0.57 L/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 to 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 to 1070µg/m$^3$ with a mean value of 62±61µg/m$^3$. Outdoor BC concentrations during morning cooking hours varied from 3 to 390µg/m$^3$ with a mean value of 24±39 µg/m$^3$. During evening cooking hours BC concentration varied from 3 to 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 to 50µg/m$^3$ on the highway crossing whereas BC ranged from 3 to 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 to 8.4 (mean value of 5.3±1.6); the corresponding EC concentration varied from 14 to 200 µgm$^{-3}$. Similarly, OC/EC ratio of outdoor samples varied from 2.8 to 8.7 (mean value of 4.9±1.5); the corresponding EC concentration varied from 6.3 to 25 µgm$^{-3}$.

**Sharma *et al.*, 2014** 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 93.4-328.8µg/m$^3$ with minimum average during monsoon (134.68µg/m$^3$) and maximum average during winter (213.09µg/m$^3$) and an annual average of 177±49.5 µg/m$^3$. Annual concentration of OC has varied from 9.7 to 69.0 µg/m$^3$ with an average value of the order of 26.77 µg/m$^3$ (~15% of $PM_{10}$ mass), whereas, mass concentration of EC has varied from 1.8µg/m$^3$ to 13.0 µg/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 (29.33 µg/m$^3$; ~16% of $PM_{10}$ mass) and monsoon (14.72 µg/m$^3$; ~11% of $PM_{10}$ mass). Similarly, EC has followed the similar pattern with maximum in winter (9.64 µg/m$^3$; ~4% of

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$PM_{10}$ mass) and minimum in monsoon (3.35 µg/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 to 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.

**P. Mandal *et al.*, 2013** demonstrated the contribution of carbonaceous aerosols in at urban cum industrial area of Delhi, India in the year 2011. $PM_{10}$ samples were collected by APM 541 samplers (Envirotech Pvt. Ltd., India) on Micro fiber quartz filter at a flow rate of 1m$^3$/h. Carbon fractions were analyzed by IMPROVE TOR protocol. The concentration of $PM_{10}$ varied from 95.9-453.5 µg/m$^3$ with an annual average of 280±126.10 µg/m$^3$. The annual average % of OC, and EC in $PM_{10}$ were estimated as 32.75%, and 9.47% respectively. OC concentration varied from 28.8-159.4 µg/m$^3$ with annual average of 93.03± 44.72 µg/m$^3$. EC values ranged from 7.5-44 µg/m$^3$ with an annual average of 27.30±13.35 µg/m$^3$. The strong correlation was observed between total carbon (TC) and $PM_{10}$ ($R^2$=0.99). Correlation between EC and OC was found to $R^2$=0.79, 0.72 during pre monsoon and winter seasons. The concentrations of $PM_{10}$, EC and OC were found as: post monsoon > winter > pre monsoon > monsoon. The average OC/EC ranged between 3.02-3.96 during the study period.

**Mandal et al., 2014** estimated $PM_{2.5}$ fraction andconcentrations of OC and EC in $PM_{2.5}$ at urban cum industrial area of Delhi, India in the year 2011. $PM_{2.5}$ samples were collected by APM 541 samplers (Envirotech Pvt. Ltd., India) on Micro fiber quartz filter at a flow rate of 1m3/h. Carbon fractions were analyzed by IMPROVE TOR protocol. The annual average concentration of $PM_{2.5}$ in the year 2011 was 145µg/m$^3$ in which OC and EC concentrations were 41.12 and 13.25 µg/m$^3$ respectively. The strong correlation (R2) was observed between OC and EC i.e. 0.83 and 0.79 for pre monsoon and winter seasons respectively. The annual average OC/EC accounts for 3.28. The annual average % of OC was recorded as 75% of TC. SOC contribution towards OC was 60.34% of total OC. The high concentrations of $PM_{2.5}$, OC and EC were attributed to vehicle exhaust, coal combustion, and biomass burning.

**Pachauri *et al.*, 2013** estimated characteristics and sources of carbonaceous aerosols in $PM_{2.5}$ during wintertime (November 2010 to February 2011) in Agra. $PM_{2.5}$ samples were collected using APM 550 sampler (Envirotech Pvt., Ltd) at a constant flow rate of 16.6 lpm on 47mm quartz fiber filter at traffic, rural and campus sites. The average $PM_{2.5}$ concentrations were estimated as 308.3±51.8 µg/m$^3$ at traffic site, 91.8±17.3 µg/m$^3$ at rural and 140.8±22.3 µg/m$^3$ at campus site. The concentration of $PM_{2.5}$ was significantly higher as compared to national ambient air quality standard of Central Pollution Control Board (24 hourly average 60 µg/m$^{3)}$. The average concentrations of OC were 86.1±5.2 µg/m$^3$, 30.3±12.9 µg/m$^3$, 44.5±18.5 µg/m$^3$ at traffic, rural, and campus sites respectively, while EC concentrations were found to be 19.4±2.4, 4.0±1.5, 5.0±1.4 µg/m$^3$ at traffic, rural and campus sites. The Average concentrations of all the parameters ($PM_{2.5}$, OC, and EC) varied in following pattern as: traffic site > campus site > rural site. OC /EC ratios at campus site, rural site and traffic site were 8.1, 7.4, and 4.4 respectively. SOC concentrations were found to be 18%, 24.7% and 60.7% of total OC at traffic, rural and campus sites respectively. Good OC/EC correlation ($R^2$) was measured at traffic, rural and campus sites as 0.87, 0.94 and 0.79 respectively. Relatively high concentrations of $PM_{2.5}$, OC, and EC indicated higher vehicular emissions and re-suspended of road dust, whereas comparatively lower concentrations at rural and campus sites indicating the biomass burning as major source of carbonaceous aerosols.

**Satsangi *et al.*, 2010** monitored carbonaceous aerosols in total suspended particulate matter (TSP) at suburban site in Agra using low volume sampler at a flow rate of 4 lpm at a suburban site, Dayalbagh, Agra during the period of January to October 2009. OC and BC concentrations were measured using Transmission OCEC Lab Instrument (Sunset Laboratory, Forest Grove, USA, Model 2000). The average TSP concentration was 273±179.9 µg/m$^3$. The highest TSP concentration was recorded in summers and lowest in monsoons. The average OC and BC concentrations were 60.9±40.5 µg/m$^3$ and 7.5±4.6 µg/m$^3$ respectively. The correlation coefficient is found to be 0.79 which indicates the major fraction of OC and BC originates from common sources. On an average, contribution of carbonaceous aerosols in TSP was 25.2%. The daily average OC/BC ratio varied from 5.2 to 16.2 with an average of 8. Such high ratios indicate that biomass burning may be the major contributor of carbonaceous aerosols at selected sites.

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**Elizabeth *et al.*, 2009** determined the comparison of indoor and outdoor $PM_{2.5}$ concentrations and the contribution of OC and EC in $PM_{2.5}$ during the year 2007 -2008. The sampling were carried out at two hotspot sites residential (Khar) and industrial (Mahul) in Mumbai city, India by using Air Metrics MiniVol and DRI thermal optical analyzer measured OC, EC and TC. The average $PM_{2.5}$ concentration at industrial site accounts higher value than residential (88.89±39.12 > 69.75±27.02 µg/m$^3$) due to more vehicular and industrial emissions. The indoor/ outdoor ratio for $PM_{2.5}$ was 0.8 and 0.78 in their respective sites. The average OC concentration at residential site accounts higher value than industrial site (32.73±15.09>25.03 µg/m$^3$) due to emissions from vehicular exhaust, cooking and poor ventilation system. Average EC values were about same at both the sites (approx. 7.65±4.11 µg/m$^3$). Excellent correlation was found at industrial site (r=0.67, 0.85 and p<0.01) among $PM_{2.5}$ with OC and EC respectively. At residential sites good correlation (r=0.52, 0.53 and p<0.05) between $PM_{2.5}$ and EC indoors with EC outdoors indicates penetration of outdoor air affecting inside air quality as site was close to freeway. OC/EC ratios at outdoors at residential and industrial site 5.31 and 3.99 respectively.

**Nepal**

Nepal (26.5333° N, 86.7333° E) is located in South Asia, with an area of 147,181 square kilometers and a population of approximately 27 million. Nepal is the world's 93rd largest country by land mass and the 41st most populous country. It is located in the Himalayas and bordered to the north by the People's Republic of China, and to the south, east, and west by the Republic of India. Specifically, the Indian states of Uttarakhand, Kathmandu is the nation's capital and largest metropolis. High population growth, dramatic land use changes and socioeconomics transformation have bought the paradox for rapid urbanisation and environmental consequences in Nepal. The study of carbonaceous aerosols and its effect on climate changed were carried out at two important cities (Kathmandu, Kathmandu valley) in Nepal.

**Manandhar *et al.* 2011** estimated Indoor and Outdoor particulate concentrations in Kathmandu valley at selected residential dwellings during May 2010. $PM_{10}$ samples were collected by Mini Volume PM Sampler (3156, Airmetrics) for 12 hours at the flow rate of 5 lpm on 47mm quartz fiber filter. Carbon fractions were analyzed through IMPROVE TOR protocol using DRI Model 2001 thermal/optical carbon analyzer.

Indoor $PM_{10}$ concentration varied from 243.6±453.3 to 103.6±29.1 µg/m$^3$ at different selected sites and varied as: urban roadside < urban background < urban hospital < urban residential < valley background. These high concentrations were attributed to biomass burning. The average outdoor $PM_{10}$ values varied from 60.6±36.1 to 199.2±38.5 µg/m$^3$ and varied as: valley background > urban background> urban hospital > urban residence > urban roadside. The average I/O ratio was recorded as 2.1±0.045 with highest at urban background and lowest at urban roadside. The average OC indoor concentration was found as 51.5±37.2 µg/m$^3$ with higher value at valley background and lowest at urban background. The outdoor OC concentration was 30.1±3.4 µg/m$^3$ with highest at urban roadside and lowest at urban background. Indoor and outdoor EC concentrations were higher at valley background (54.9±38.3 and 10.4±1.5 µg/m$^3$) and less at urban background (5.6±1.9 µg/m$^3$) and urban roadside (2.4±3.4 µg/m$^3$) respectively. The major sources of ambient carbonaceous aerosols were vehicle exhaust and re-suspension of dust.

**Sharma *et al.* 2012** measured the contribution of black carbon (BC) aerosols from vehicles and industry in Kathmandu valley, Nepal during strike days and working days during the period of May 2009 to May 2010 using an Aethalometer (Magee Scientific, USA) having flow rate of 2 lpm. The instrument provides the real time data in the air stream. During strike days (no vehicles were on road and all industries were completely closed), BC emissions were observed from domestic activity and BC ranged from 3.03 – 11.9 3µg/m$^3$. During working days, BC values ranged from 5.45-22.3 µg/m$^3$ with an average value of 10.91µg/m$^3$ indicating the vehicular and industrial emissions. The Contribution of BC aerosols by vehicles and industries were approximately 50%.The diurnal trend of BC aerosol in working day and strike days is nearly similar but during peak hours BC concentration on a working day was nearly two folds of strike days. A distinct inverse correlation was observed between BC and wind speed, indicating the major important role of micrometeorological parameters (wind speed, rain etc.)

**Surface Morphology of Particulate Matter**

Morphological characteristics (texture, edges and size) of ambient atmospheric particles were studied to determine their origin through SEM/EDX technique (Pachauri *et al.*, 2013) and (LI *et al.*, 2008). At traffic

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sites particles indicated to have branched aggregates of carbonaceous matter. Diesel exhaust emissions were characterized with amorphous branched clusters of carbonaceous spherules while petrol exhaust show co-aggregates of nanometer sized EC particles (50-100nm). At rural sites particles resembles clustered and branched. These soot particles were dominated by chain like aggregates of carbon bearing spheres (Fig. 2). At suburban sites individual particle was classified as: carbon rich particles and minerogenic particles. Carbon rich particles have nearly spherical morphology and porous surface configuration which facilitates the surface deposition of OC functional groups. Various studies have reported that morphology of carbonaceous particle originated from combustion processes varied from soot chains to complex structure. It also depended on type of fuels, burning condition, and atmospheric reactions (Cong *et al.*, 2009, Posfai and Buseck, *et al* 2010; Tumolva *et al.*, 2010). SEM/EDX technique of particle represented the dominance of clusters or aggregates of carbon particles at traffic and rural sites where as campus site carbon rich particles were of irregular shape (Fig 3).

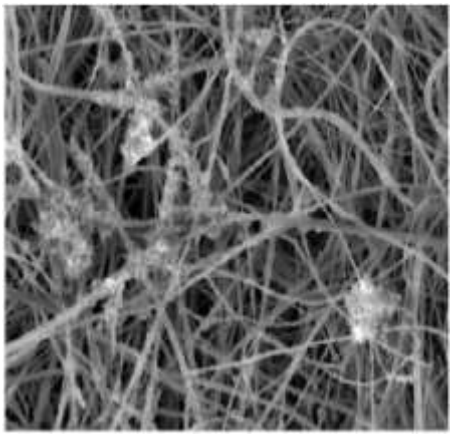

***Fig.2- Branched clusters of soot particles***

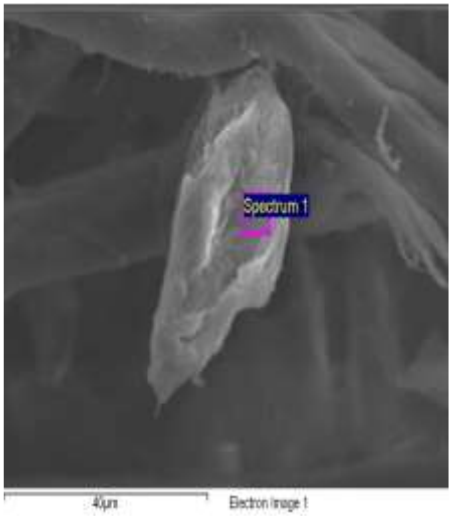


***Fig.3- Irregular shaped Minerogenic particle***

## Conclusion

A brief review on sampling locations, methodology for collection and analysis of OC and EC samples in their respective sizes of PM during the period of 2007 to 2014 in selected Asian countries were discussed in the paper. It was observed that traffic intersection and urban cum industrial areas are the major contributor of carbonaceous aerosols while biomass burning in rural areas are the major contributor of carbonaceous aerosols. The utilization of cooking gases, poor ventilations of building and vehicular emissions on roads are the major contributor of carbonaceous aerosols in residential areas. The selected locations (except Bangladesh) in South and East Asia, percentage of OC and EC in $PM_{10}$ and $PM_{2.5}$ ranged from 15 to 33% and 3 to 9.5% and 26 to 46% and 9 to 10% respectively. EC concentrations at Dhaka city, Bangladesh were abnormally high due to operation of diesel based power plants. The contribution of SOC in South and East Asia varied approximately 18 to 61% of total OC concentrations. Therefore, it is necessary to pay more attention to emission control at the sources.

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