ASSESSMENT OF BC CONTENT IN THE ATMOSPHERE EMITTED AS A CHIEF CONSTITUENT OF DIESEL EXHAUST IN AND AROUND MATHIKERE AREA, BANGALORE, INDIA

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Abstract: One of the dominant components of light absorbing aerosols in the atmosphere that significantly alters the earth's radiative balance is Black carbon (BC). It is known to be a large climate forcer and hence for research related to climate change, quantification of BC emissions from various sources to the earth's atmosphere holds primary importance. It has been established that vehicular emissions in urban areas contribute to BC release as diesel particulate matter (PM) formed as an outcome of incomplete diesel combustion. In the present endeavour, a case study has been carried out in Mathikere area of Bangalore, India which is an urban location to monitor the BC concentration in the atmosphere following a direct and continuous measurement technique in order to access the diurnal variations in relation to impact of vehicular emissions during the month of June. The diurnal variation patterns showed a similar trend with a bi-peak diurnal pattern i.e. twice daily maximum in BC concentration in the morning and in the evening and these timings easily coincided with the morning and evening traffic rush hours. On most of the days, the evening peak of BC level was found to be more pronounced than the morning peak. This may be due to increased activity of heavy duty vehicles transporting various materials over long distances which usually start their journey in the evening hours and cover long distances throughout the night. Moreover, another significant reason can be that the wind speed was weaker during night-time as compared to day-time. Moreover, the current study was conducted during the month of June which experiences slight intermittent rainfall from SW monsoon usually during the evening hours and precipitation could have also led to longer BC residence time in the atmosphere after sunset. While the decrease in BC level was gradual, the recovery was almost immediate with resumption of higher traffic. Thus, the analysis suggests that the diurnal variation pattern is mainly a result of vehicular emissions. This study has practically proven that the exhaust from vehicles significantly adds to the ambient BC concentration at urban locations and hence in order to curb the negative impacts of BC particles on the environment, there is an urgent need to analyze the ecological standards of fuels and vehicles on roads and switch to alternative means of fuel with low or minimum BC emissions.

Keywords: Black carbon, vehicular emissions, BC content variations, residence time.

I. INTRODUCTION

Among the carbonaceous aerosols, Black carbon (BC) being a dominant constituent of diesel exhausts as well as wood smoke strongly absorbs sun rays in the earth's atmosphere over a broad range of visible wavelengths (Talukdar at al., 2015). Chemically inert BC particles tend to have a long lifetime in the earth's atmosphere; more than 1 week in the troposphere (Babu and Moorthy, 2001) and can be transported over long aerial distances (Moorthy and Babu, 2006; Wolff, 1984; Raghavendra Kumar, 2011) owing to their hydrophobic nature and occurrence in sub-micron size range (Raghavendra Kumar, 2011). Longevity of BC particles, coupled with their strong absorption capability of light over wide spectral ranges vividly make them distinct contributors to radiative forcing of the atmosphere along with green-house warming (Babu et al., 2002; Satheesh et al., 2003; Chung and Seinfeld, 2005). It is known to be the second largest contributor to global warming after CO_2 (Ramanathan and Carmichael, 2008). BC particles significantly influence the regional and global climate by perturbing the monsoon circulation (Jacobson, 2001; Dumka and Moorthy, 2010; Ramanathan and Carmichael, 2008; Tiwari et al., 2013) and by causing a significant fraction of net aerosol radiative forcing (Jacobson, 2001; Andreae et al., 2005; Naseema Begum et al., 2008; Kharol et al., 2012). Black carbon can also become cloud condensation nuclei (CCN) on account of being coated with hydrophilic materials, and thereby contribute to indirect forcing of earth's climate (Lohmann et al., 2000; Ackerman et al., 2000).

In recent decades the gradual increase of anthropogenic aerosols such as BC is a matter of great scientific interest because of its impact on climate and environmental quality (Wolf and Hidy, 1997; Naseema Beegum et al., 2008; Talukdar at al., 2015). It can lead to severe health hazards too like cardiopulmonary diseases as it can easily enter during inhalation and get deposited in the respiratory system because of its fine sub-micron size (Raghavendra Kumar, 2011). Quite recently, it has been demonstrated as Category I Carcinogen by World Health Organization (WHO) and has been associated with occurrence of lung cancer etc.

Though it has been established that the major producers of BC aerosol particles in urban areas include vehicle (mainly diesel) exhausts, industries, thermal power plant and domestic uses (Kharol et al., 2012), the chief source has been reported to be the incomplete combustion of fossil fuels that are significantly more effective in warming the atmosphere than those produced by biomass burning (Ramana et al., 2010). In India, fossil fuel burning accounts for around 25% BC release (Venkatraman et al., 2002). The area under the present study being in an urban location, combustion of fossil fuel in terms of vehicular emissions can be assumed to be one of the most predominant sources of

BC here. Hence, an attempt was made to draw a relation between higher values of BC with higher intensity of traffic in the area. Another significant emission of BC from wood smoke can be ruled out in the present area under study.

II. LOCATION OF THE STUDY AREA

The study area is located near the Centre for Atmospheric and Oceanic Sciences (CAOS), Indian Institute of Science, Mathikere, Bengaluru, India. This area has an approximate distance of 1200 meters from the nearby New BEL Road and about 1700 meters from the C.V. Raman Road. The latitude and longitude of study area is 12º 96' N and 77º 58' E respectively.

III. MATERIAL AND METHODS

The basic aim was to analyze the variations in the concentration of Black carbon emission in the area over a period of one month. The measurement of BC was done by using **Aethalometer™** which is designed for automated operation and is capable of providing real-time measurement of Black Carbon aerosol particles. It is a self contained instrument where the sample gets collected as a spot on roll of quartz fiber filter tape; providing a means to measure the rate of change of optical transmission through a spot on the filter on which aerosol sample is being continuously collected, thereby presenting a method of converting this to a calculation of concentration of optically absorbing material i.e. BC in the sampled air stream. Further, the transmitted light intensities through 'sensing' portion of filter which is designed to collect the aerosol sample, also passes through a 'reference' portion of the filter so that it is possible to keep a check on the stability of the optical source. Here, the light source utilized is high intensity LED lamps emitting at 880 nm and 370 nm and thereby, the obtained optical measurements automatically get converted to BC concentrations and the final results get recorded in the built-in diskette drive. Thus, on the front panel of the instrument, the calculated BC concentration is displayed.

The **Aethalometer™** principle is based upon measurement of extinction or attenuation of a light beam transmitted through the filter while the filter itself is busy collecting the BC aerosol sample. It is possible for the investigator to access the BC content of the aerosol deposit at each measurement time depending upon the values of attenuation for a particular combination of filter and optical components. When there is increase in the aerosol BC collected from the air stream at a certain period of time, it generates an increase in optical attenuation from that period to the next recording period. When this increment is divided by the volume of air sampled during that time, one can measure the value of mean BC concentration in the sampled air stream during that juncture. When rural areas are under examination, the instrument time period is generally set as 1 hour while in case of urban locations, the time period is usually set as 5 minutes. Since the area under present study is located in urban background, the time base for the instrument was set as 5 minutes. The air flow rate was 3.8 litres per minute. The obtained results were interpreted to draw suitable conclusions.

IV. OBSERVATIONS AND RESULTS

Several temporal plots were prepared on weekly basis using hourly daily BC values. Finally, a monthly plot was outlined using mean values of daily BC. Careful scrutinization of these temporal plots was carried out to analyze any possible relation between higher values of BC with heavy traffic in and around the study area. The temporal plots have been presented and analyzed in detail as follows:

PLOTTING BC AND UV CONCENTRATION Vs TIME

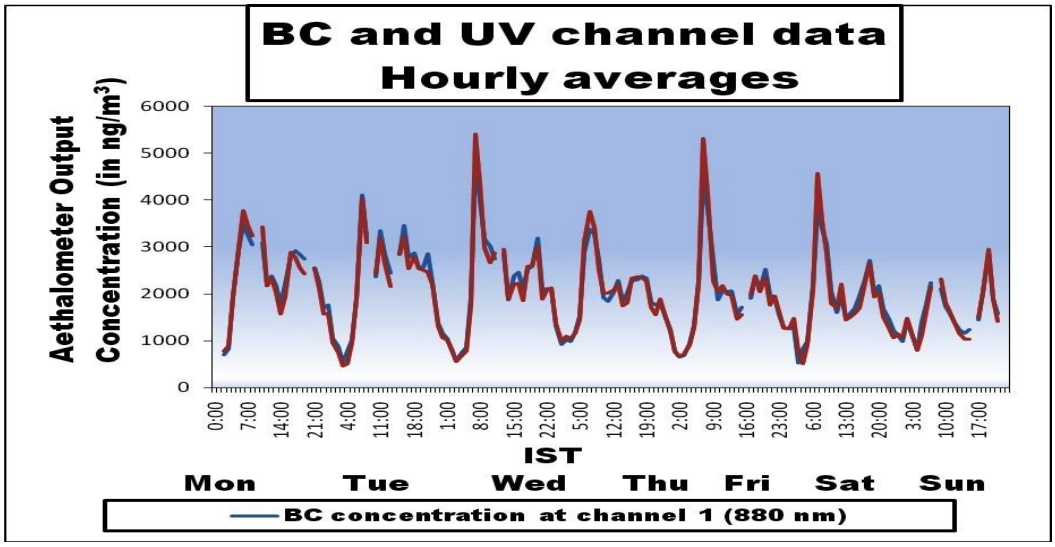

Figure.1. Temporal patterns (10/06/2013 to 16/06/2013)

Analysis based on the plot:

Theoretically, diesel combustion activity leads to increase in levels of BC. One week temporal pattern has been illustrated in figure 1. The peaks in BC are found to occur during the time when traffic intensity is high. Almost on all the week days, peak values are observed firstly between 7 a.m. to 11 a.m. or 12 noon. Then, there appears to be a drop in BC value until the values again show a higher trend from 5 p.m. to 8 or 9 p.m. This can be correlated with the usual office hours of the day when there are possibly more number of public and private vehicles on road. Considering the BC values on Sunday, no such significant peaks are seen as traffic is comparatively low on that day. However, a slight increase can be observed during evening time which may be attributed to people going out for recreation.

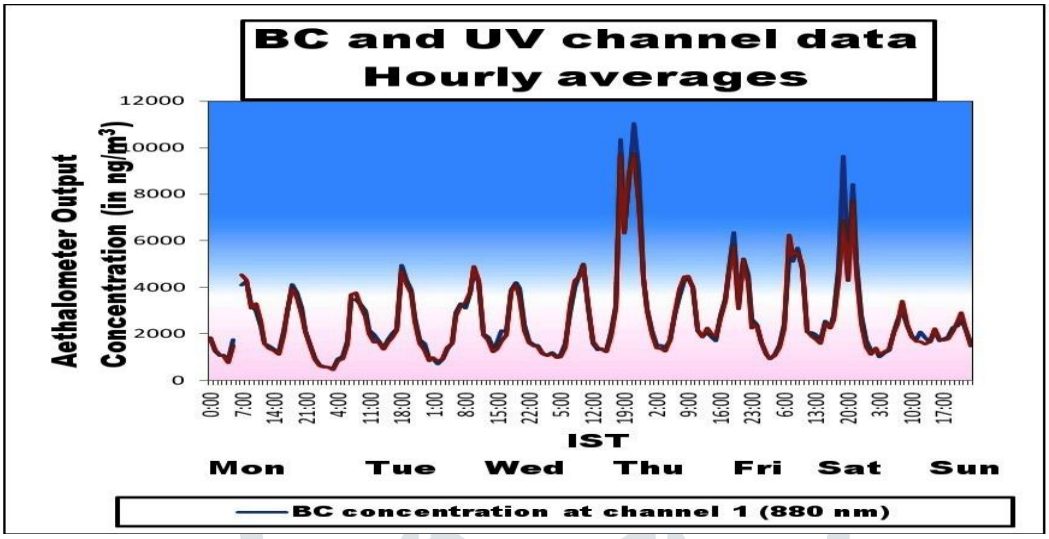

Figure.2. Temporal patterns (17/06/2013 to 23/06/2013)

Analysis based on the plot:

On plotting the BC and UV concentration values from 17th to 23rd June, almost a constant pattern can be seen except on Thursday and Saturday. On other days of the week, two peaks are observed during each day. The first peak is usually encountered during the morning hours, that is between 7 a.m. and 11 a.m. and the 2nd peak is between 5 or 6 p.m. to 8 or 9 p.m. which can be correlated with office hours in general. An unusually high peak can be observed on Thursday evening. The BC and UV values go up to an extreme of 10,000 to 11,000 ng. This indicates that some significant activity might have taken place on the road that evening which had resulted in enormous number of vehicles or created a traffic congestion that sustained for a long time leading to large emissions of BC through diesel exhausts that polluted the air up to late hours of the night. A similar peak though slightly lower can be observed on Saturday night within the same week. The peak lies between 6 p.m. and 12 a.m. This high peak gives us the hint that during those hours of the night, a lot of people must have gone out (leading to increase in traffic) and involved themselves in merry making as the next day was a holiday. Just like the previous week, there are not much significant peaks on Sunday.

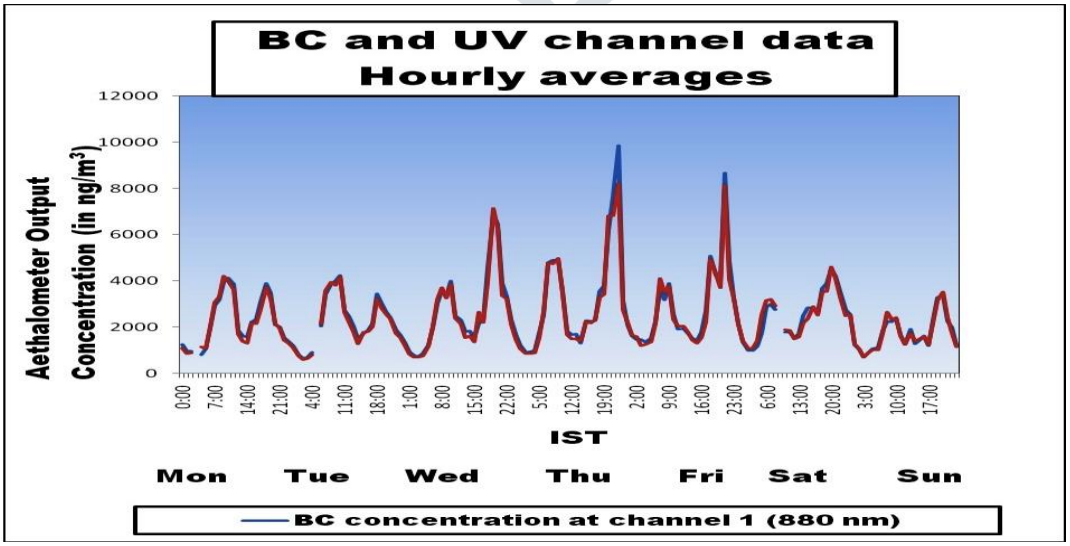

Figure.3. Temporal Patterns (24/06/2013 to 30/06/2013)

Analysis based on the plot:

The BC and UV concentration versus time plot for the period between 24th June and 30th June bears resemblance with the previous week plot. Everyday, two peaks can be observed which match with the daily office timings. A relatively higher peak is encountered during evening hours of Thursday and Friday. The peak again shows a higher extreme on Saturday night. No remarkable peaks can be observed on Sunday except a slightly higher trend in the evening for some time.

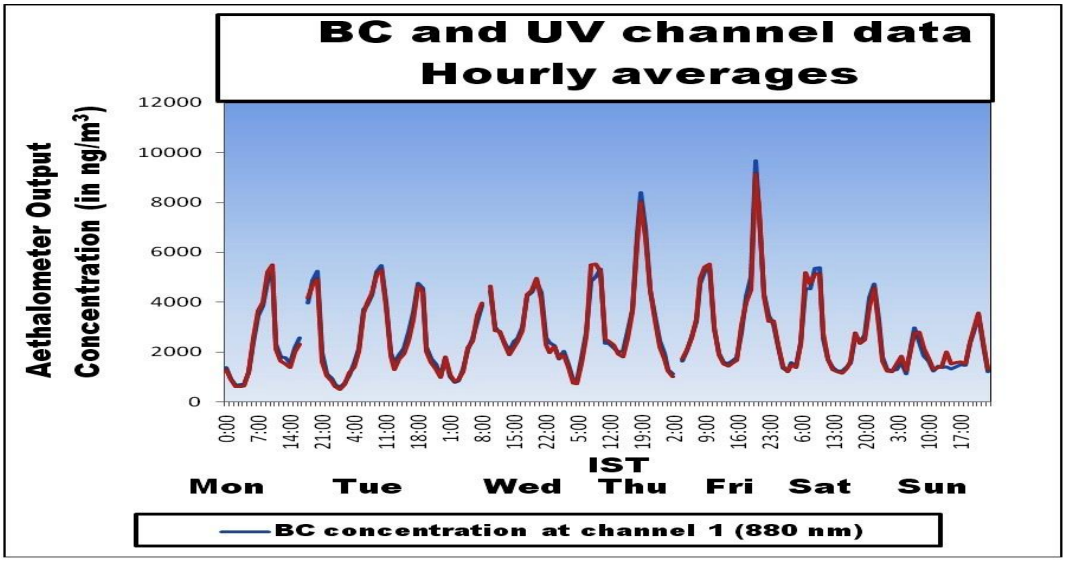

Figure.4. Temporal Patterns (01/07/2013 to 07/07/2013)

Analysis based on the plot:

The BC and UV concentration values show similar trends like the previous weeks. During each working day of the week, two peaks can be seen. One is usually between 7 a.m. to 10 or 11 a.m. and the other is between 6 p.m. to 8 or 9 p.m. These timings coincide with the usual office hours of the days. A comparatively higher peak is noted on Thursday and Friday evenings. One significant similarity can be noted down here: the evening hours of Thursdays during the previous two weeks as well as the present week, show higher concentration of BC and UV values. This indicates that due to some particular reason, there is heavy rush on the roads during these days probably leading to a traffic jam which in turn shoots up the BC and UV concentration values. On closely studying the hourly averages of BC and UV concentration values for this week, another remarkable issue was brought to light. During the previous three weeks, the concentration values generally go down up to 1000 to 1500 ng between 11 a.m. to about 2 p.m. on working days leading to a sharp decline after the occurrence of the morning peaks. However, during Wednesday and Thursday of the present week, the concentration values continued to remain high up to 2000 to 2700 ng even during the usual declining concentration hours of BC and UV i.e. between 11 a.m. to 2 p.m. This can be attributed to the movement of heavily loaded vehicles inside the institute campus transporting raw materials required for the ongoing construction activity here. As usual, no high peaks are depicted on Sunday though a slight increase is indicated in the evening hour.

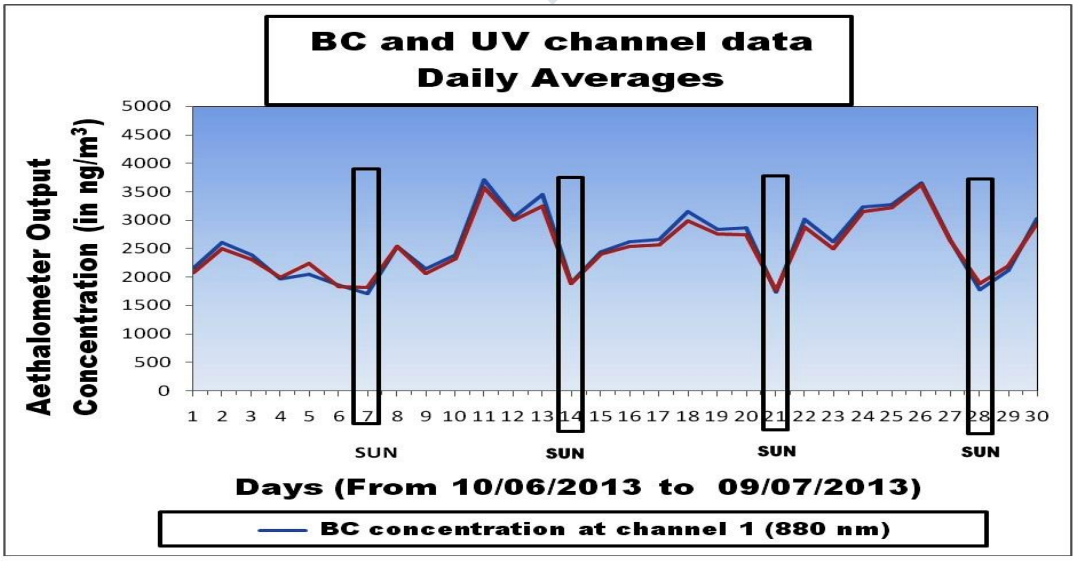

Figure.5. Temporal Patterns over a period of one month (10/06/2013 to 09/07/2013)
(Sundays are highlighted with black boxes)

Analysis based on the plot:

It was expected that Sunday being a non working day, there would considerably be less traffic on road. Hence, the concentration of BC and UV values should be lower on average than during the other days. The above figure displays mean daily BC and UV data collected by the Aethalometer™ during a period of one month i.e. from 10/06/2013 to 9/06/2013. The Sundays have been highlighted using black boxes. The figure clearly depicts that on every Sunday, the peaks show a decline in concentration. The minimum average daily values are encountered on Sundays that go as low as 1700 ng. The maximum average daily values go as high as 4000 ng.

Based on all the above temporal patterns, a suitable relation can be drawn between BC concentration and diesel exhausts. BC being one of the main constituents of diesel exhausts, increases with increase in intensity of traffic and vice – versa. The plots depict that BC concentration attains its peak during the office hours of the day which is between 7 a.m. to 11 a.m. during morning when people usually leave for office and 6 p.m. to 8 or 9 p.m. when people return to their respective places. Sundays display no significant peaks indicating lower traffic on road.

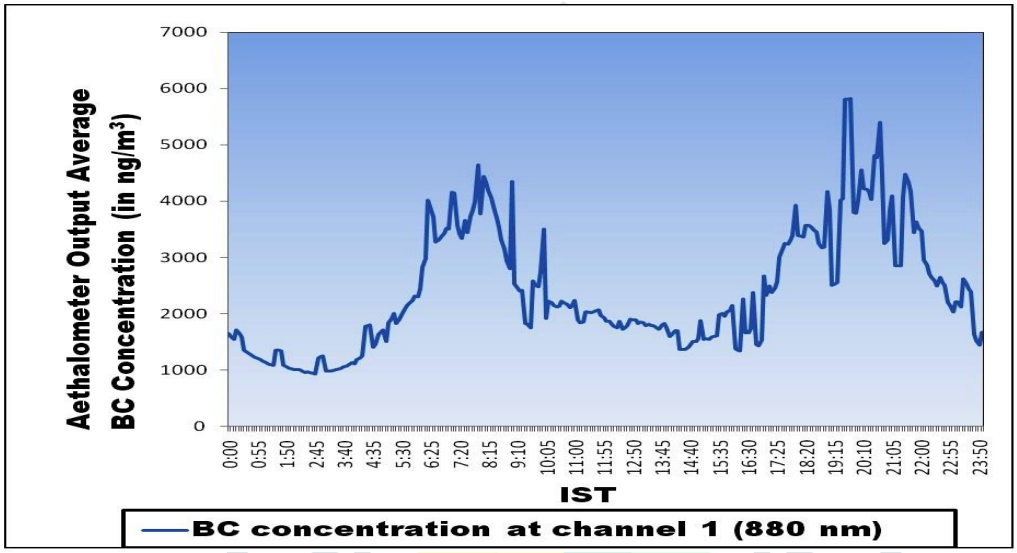

Figure.6. Plot of Mean Diurnal BC Variation over one month (10/06/2013 to 09/07/2013)

V. DISCUSSION AND INTERPRETATION

This study presents a novel approach of direct and continuous measurement of BC concentration through Aethalometer™ in fresh diesel engine tailpipe emissions in a typical urban ambient site in proximity to a busy roadside.

In all the above displayed temporal plots, the **diurnal variation of BC** in all the four weeks showed a similar trend with a **bi-peak diurnal pattern** i.e. twice daily maximum in BC concentration in the morning between 7:00 to 10:00 and in the evening between 18:00 to 21:00 IST. These timings easily coincided with the morning and evening rush hours. BC concentration reached its minimum value between 12:00 and 15:00 h. A similar build of BC occurred during the evening rush hours followed again by a gradual decrease in the late night to early morning hours. Thus, the analysis suggests that the diurnal variation pattern is mainly a result of vehicular emissions. However, BC concentrations decreased gradually from morning to noon also due to convective pumping of pollution to the free troposphere. While the decrease in BC level was gradual, the recovery was almost immediate with recommencement of higher traffic. On most of the days, the evening peak was found to be more pronounced than the morning peak. This may be due to increased activity of heavy duty vehicles transporting various materials over long distances which usually start their journey in the evening hours and cover long distances throughout the night. Moreover, another significant reason can be that the wind speed was weaker during night-time than during the day-time (Naseema Begum et al., 2008). As a result, the accumulated BC got drifted at a slower pace leading to higher concentration during measurement. Moreover, the fact that in the absence of heavy rainfall, BC particles have extensive lifetime in the atmosphere ranging from 1 week to 10 days has been established through several studies. One such similar impact study at Thiruvananthapuram dealing with induction of BC into the atmosphere postulated that impact of BC takes more than a week to become normal (Babu and Moorthy, 2001; Madhavi Latha et al., 2004). Thus, the current study conducted in Bengaluru during the month of June where slight intermittent rainfall is usually experienced in the evening hours from SW monsoon (Rao, 1976), could have also led to longer BC residence time in the atmosphere after sunset.

Hence, this study has practically proven that the exhaust from vehicles significantly adds to the ambient BC concentration at the urban location of Mathikere area, Bengaluru, India. Though a sudden decrease is noticed in the BC concentration with slight cut-off in the potential source component of diesel exhaust due to traffic reduction, the total impact associated with it is experienced much later owing to the finite atmospheric residence time of BC. Thus, there is an urgent need to analyze the ecological standards of fuels and vehicles on roads and evaluate policies for emission reductions from existing vehicle (especially diesel) fleet and look for alternative means of fuel with low or minimum BC emissions.

VI. ACKNOWLEDGEMENT

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