TUTA/IOE/PCU
SAHR

Journal of the Institute of Engineering, Vol. 8, No. 3, pp. 105–113

Fax: 977-1-5525830

Variation of Black Carbon Aerosols on Six Continuous Strike Days of Kathmandu Valley: A Case Study

Ram K. Sharma[1*], Binod K. Bhattarai[1], Balkrishna Sapkota[1], Mohan B. Gewali[2], and Berit Kjeldstad[3]

[1] Pulchowk Campus Institute of Engineering, Tribhuvan University, Kathmandu, Nepal
[2]Central Department of Chemistry, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[3] Depart of Physics Norwegian University of Science and Technology, Trondheim, Norway

Abstract: Black carbon (BC) aerosols concentrations were measured using an aethalometer AE 31 at Pulchowk Campus, Institute of Engineering, Lalitpur, Nepal an urban location of Kathmandu valley. The monitoring was conducted from May 2009 to April 2010. In this paper only the data on 30th April (working day) and six continuous strike days (1- 6 May 2010) are analyzed to find out the actual mass of BC aerosols when vehicular and industrial emission was nearly zero. The daily average BC aerosols on these six days are 4.6, 3.0, 7.6, 7.0, 6.1 and 5.5 µg /m^3 respectively. Low concentration of BC aerosols in the earlier days is attributed to rain. The decreasing trend in the later days is due to dispersion of collected people from different parts of the country in the valley for the effective operation of strike. It has been found that the average BC aerosols concentration on strike days is (5.6 ± 1.16) µg /m^3 while it is (10 ± 4.9) µg /m^3 on 30th April, a regular working day. This indicates vehicles and industries emit about 44% of BC in Kathmandu. The average for the month of April, BC comes out to be 12 ± 4.4 µg /m^3 showing the contribution from vehicle and industry to be about 55%. Further, it has been observed that the hourly BC aerosols concentration in the strike days does not follow the typical diurnal variation as in the working days.

Keywords: Black Carbon, aethalometer, aerosol, diurnal.

Introduction

Black carbon (BC) and elemental carbon (EC) carbonaceous aerosols are produced by the partial combustion of fossil fuel, bio- fuel, wood, cattle dung and crops residue. They are spherical particles of about 50nm in diameter and with homogenous surface. Results also show that these particles aggregate with other aerosols, or with themselves, to form larger agglomerates in the micrometer range. The shape of these 50 nm black carbon spherical particles was found to be very similar to that of black carbon particles released from petroleum engines (Fengfu et al. 2006). These BC affect environment at local, regional and global level. A black carbon aerosol absorbs solar radiation and is the second largest contributor to global warming, after green house gases (Jacobson, 2002).

The two most important sources of BC are fossil fuel combustion and biomass burning (*Penner et al*. 1993; *Cooke and Wilson*, 1996). Solid bio-fuel combustion is the largest source of black carbon emission in India (*Venkataraman et al*., 2005). BC may also have regional climate impacts. High concentration of BC over India and China are responsible for a trend toward increasing flooding in the south (India) and drought in the north (China) (*Menon et al*., 2002). Significant amount of BC, if present, in the main clouds can lead to increased absorption of solar radiation that heats the atmosphere. The consequence of this is to burn off the clouds or to alter

the cloud life time and precipitation patterns (*Menon et al*., 2002, *Ackerman et al*., 2000). The atmospheric transparency reduced by high concentration of soot over India and China decreases agricultural productivity by 10-20 percent (*Chameides et al*., 1998). Black carbon strongly absorbs light and thereby degrades visibility (*Watson*, 2000). BC can also alter the earth's radiation balance (*Penner et al*., 1993; *Jacobson*, 2001). The climate effects of BC aerosol depend strongly on its physical and chemical properties as well as in its residence time and distribution in the atmosphere (*Jacobson*, 2001). Global warming due to black carbon may be as much as 0.3-0.4^{o} C (*Jacobson*, 2004; *Chung and Seinfeld*, 2005).

The main objective of the present work is to observe BC variation in working days as well as strike days. It is also attempting to find out the amount of BC aerosol from the vehicles and industries by comparing the amount of it released on working days and strike days. It has been assumed that in the working days the amount of BC is released by industrial, vehicular and domestic activities while in the case of strike it is only by domestic activities. An opportunity was capitalized to observe the above mentioned objects on complete strike days in Kathmandu from 1st to 6th May 2010.

Methodology

Kathmandu valley is located between 27°37'30" N and 27^{o}45'0" N latitude and 85^{o}15' 0" E and 85^{o} 22' 30" E longitude. The valley is about 1500 meters above sea level and covers about 340 sq.km.area. The cross section of the valley is about 20 km north to south and 30 km east to west. The valley has a bowl like structure surrounded by four major mountains namely Shivapuri, Phulchowki, Nagarjun and Chandragiri.

An aethalometer AE 31 manufactured by Magee Scientific USA is a seven wave length instrument. The aethalometer was deployed in second floor, in G block of Pulchowk Campus for monitoring BC. The aethalometer is an instrument that provides a real time read out of the concentration of BC or EC aerosol particles in air stream. In an interval of five minutes it shows BC concentration in the display screen. These data are automatically recorded in the flash card of the instrument. The instrument aspirates ambient air from an altitude of ~8m above the ground level using its inlet tube. Black carbon mass concentration is estimated by measuring the change in the transmittance of a quartz filter tape on to which particles impinge. The instrument was set into operation at a time interval of 5 minutes round the clock with a flow rate of 2 liters per-minutes (2LMP).

The optical attenuation method is applied in the measurement of black carbon by aethalometer.The optical method that it uses is a measurement of the attenuation of a beam of light transmitted through the sample when collected on a fibrous filter. When calculated, this quantity is linearly proportional to the amount of BC in the filter deposited. The Optical Attenuation ATN is defined as

$ATN = 100*\ln (I_o/I)$ (the factor of 100 is for numerical convenience)

I_o = Intensity of light transmitted through the original filter

I = Intensity of light transmitted through the portion of the filter on which the aerosol deposit is collected.

For a given mass of black carbon (BC), the optical attenuation at a fixed wavelength λ may be written as

$$ATN(\lambda) = \sigma(1/\lambda) * [BC]$$

where [BC] is the mass of black carbon, and σ (1/λ) is the optical absorption cross section (sigma) that is wavelength dependent, and which is referred to as 'Specific Attenuation.'

Aethalometer operates at one or more fixed wavelengths, and so the optical intensity functions are products of terms that may or may not be wavelength-dependent. The intensity of light detected after passing through a blank portion of the filter is

$I_o(\lambda) = IL(\lambda) * F(\lambda) * OC(\lambda) * D(\lambda)$ Where

IL (λ) is the emission intensity of the light source,

F (λ) is the spectral transmission function through the filter,

OC (λ) is the spectral transmission function through all the other optical components, and

D (λ) is the spectral response function of the detector.

If we now measure the optical transmission through an aerosol deposit on this filter, using the same light source and detector, the net intensity will be

$I = I_o(\lambda) * \exp-\{A(\lambda)\}$ where the absorbance is

$A(\lambda) = k(1/\lambda) * [BC]$

And [BC] is the amount of black carbon whose optical absorption is inversely proportional to the wavelength (http:// www.mageesci.com/Aethalometer book_2005.pdf).

Result and Discussion

Data collected using aethalometer AE 31 for 30th April (general working day) and 1st to 6th May (Strike days) is analyzed to observe the actual mass of black carbon aerosols contributed by vehicles and industries in this study. Strike days were typical since vehicles, industries, school and offices were not in operation during those days. In addition to this thousands of people (demonstrators) from different parts of the country were gathered in Kathmandu valley for strengthening the strike. This typical situation was capitalized to study the contribution on BC by domestic activities. The present study is focused on variation of BC aerosols due to general public and domestic activities.

In order to find the amount of BC emitted by vehicles and industries a comparison between diurnal trend of average BC on general working day and strike days were made. Out of the six consecutive strike days, highest daily average BC was recorded on 3rd May as 7.6 ± 4.9 μg /m^3 while the lowest on 2nd May as 2.9 ± 1.7μg /m^3. Figure 1 shows the average diurnal relation of BC on the strike days and working days in April. It can be seen from the figure that the trend of BC on both the types of days looks similar. However BC concentration was almost two fold higher on the normal days. The two peaks observed during the morning and afternoon represents the normal public activities. A highest hourly maximum value of 24 μg/m^3 was observed around 8:00 in April while the average value became about 9 μg/m^3 during the strike days. A short term

spikes exceeding 40 µg /m^3 have been reported in Karachi, Pakistan (Durkiewicz et al., 2009). BC value of 14.7 ± 9.5 µg /m^3 have been observed in Xian, China (Cao et al., 2009). Similarly daily average value of BC in range of 6-20 µg /m^3 had been reported at Kanpur City northern India (Tripathi et al., 2005) Therefore the average strike day value of BC observed in this study is lower than that in Pakistan , China and India whereas on working day it is between these cities.

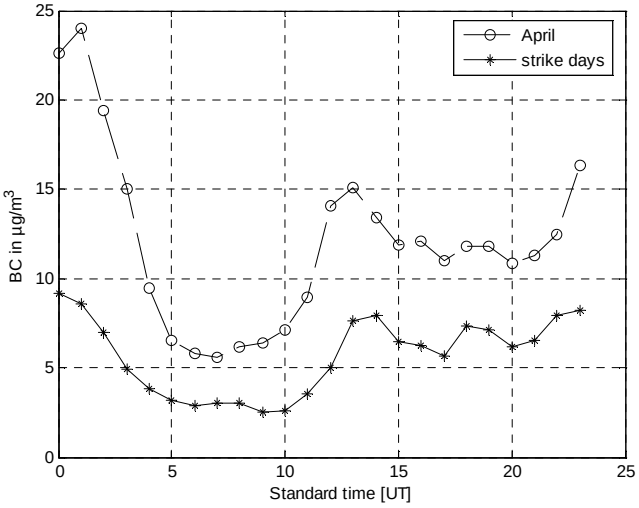

Figure 1: Diurnal variations of BC aerosol on strike days and normal working days in Kathmandu.

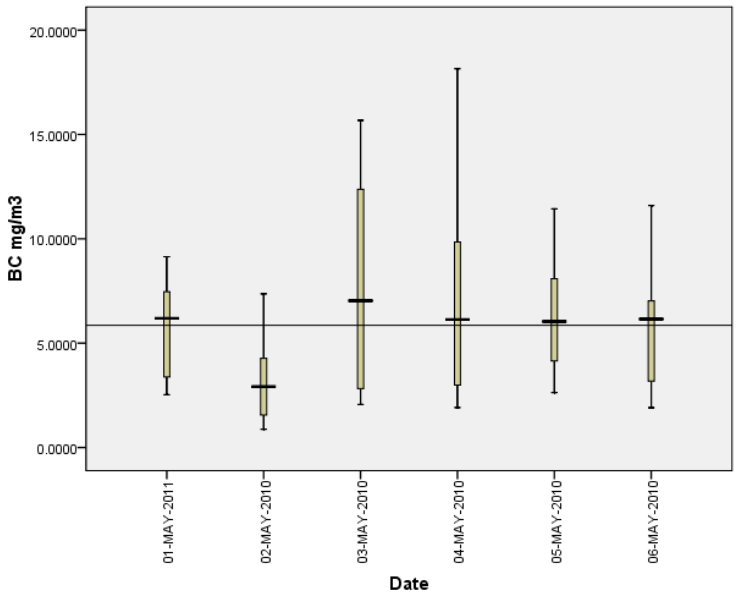

Figure 2: Box plot of BC aerosol for strike days showing its distribution.

A box plot was created to show the comparative statistical distribution of BC during the strike days under study. Average BC concentration was found to be 5.6 µg/m^3 with a median of 7.6 µg/m^3 on 3rd May 2010. Furthermore the mean and median BC level in Kathmandu lies almost very close to each other (Figure 2) on 1, 4, 5 and 6th May. However on 2nd and 3rd May there is significant difference between the mean and median. More than 75 % data of Black Carbon on 2nd May is less than the mean value. This is because of the rainfall on that particular day. Department of Hydrology and Metrology recorded a rainfall of 52.2 mm on that day. Generally the removal of pollution from the ambient air with rainfall depends on its intensity, duration and pattern. Although we don't have such detailed rainfall information, yet we can infer the relation of total rain with BC amount from this graph. In addition, the wind speed is between 0.5 and 3.6 m/s on 2nd May with the domination of westerly wind (Figure 3). The average wind speed on rest of the days lies within 0.5 to 2.1 m/s. It is because of the same reason BC aerosol is minimum in this day in comparison to the rest of day. Average wind speed is comparatively less on 3rd May and the direction of it is southerly (Table 1). Since Kathmandu is surrounded by hills more than 500 m from its basin the pollutants are trapped in the valley in the less wind speed. Pollutants over the valley get flushed out of the valley atmosphere by the westerly and south westerly winds (Dhaubhdel and Sapkota, 2002). As stated above since the direction of wind on 3rd May is southerly the BC is trapped and the concentration on this particular day is comparatively higher than other days (Figure 2).

Table 1: General description of wind on days under consideration in Kathmandu

Date	Calm Wind %	Active Wind %	Wind Direction Blowing from	Average wind Speed
May 1, 2010	34.78	65.22	WSW 0.5-2.5 m/s	0.85 m/s
May 2, 2010	16.67	83.33	West 0.5-3.6 m /s	1.09 m/s
May 3, 2010	29.17	70.83	South 0.5-2.5 m/s	0.81 m/s
May 4, 2010	24.0	76.00	SSW &WSW 0.5-3.6 m/s	0.78 m/s
May 5, 2010	27.08	72.92	South 0.5-2.5 m/s	0.69 m/s
May 6, 2010	29.17	70.83	South 0.5-2.5 m/s	0.70 m/s

Figure 4 shows the BC and wind speed on 2nd May. It is obvious from the figure that there is a negative relation between BC and wind. Increasing wind decreases the pollutants. The increase in wind speed increases the ventilation thereby dispersing the BC aerosols in the ambient air. Moreover the consequence of this dispersion decreases the observed BC aerosol concentration. It can be seen from figure 4 that when the wind speed reaches up to 1.3 m/s the BC drops down to about 1 µg /m^3 on that particular day. A scatter plot is made between the wind speed and the BC level in Kathmandu during the strike days (Figure 5). The plot shows that there is a negative correlation between these two parameters which supports wind disperses the BC present from the air. The correlation coefficient is low which indicates that there must be other meteorological parameters like vertical temperature gradient, rain fall, etc to flush out BC from the valley.

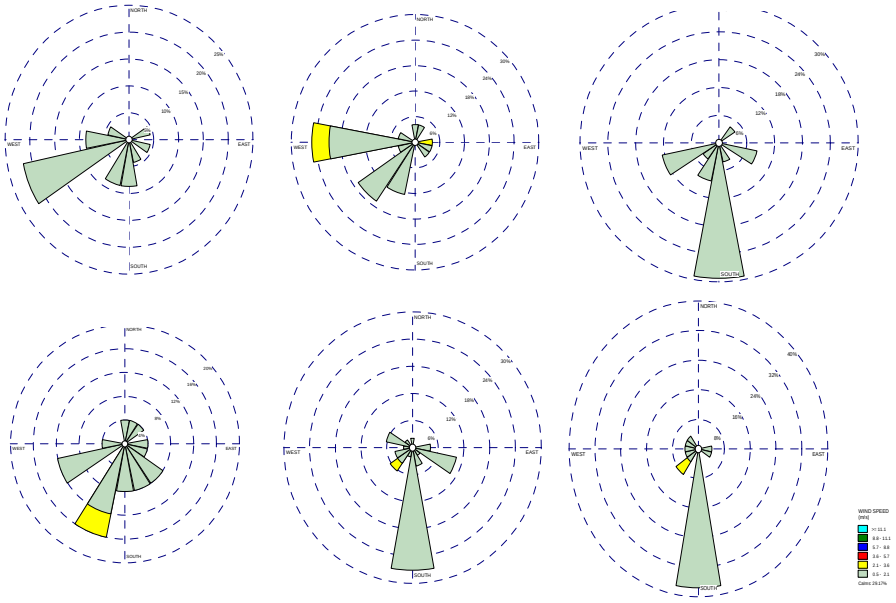

Figure 3: Wind rose for 1-6th May2010 (Clock wise 1-6th May)

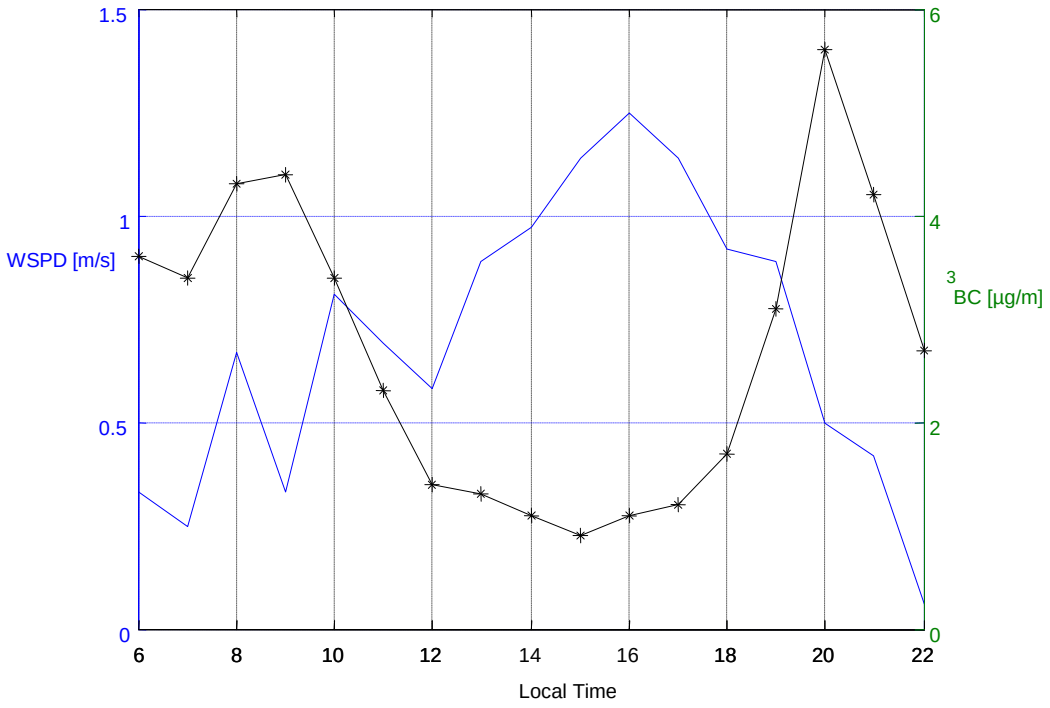

Figure 4: Diurnal BC aerosol and wind speed pattern on 2nd May
(BC- black line with asterisks; wind speed - blue solid line)

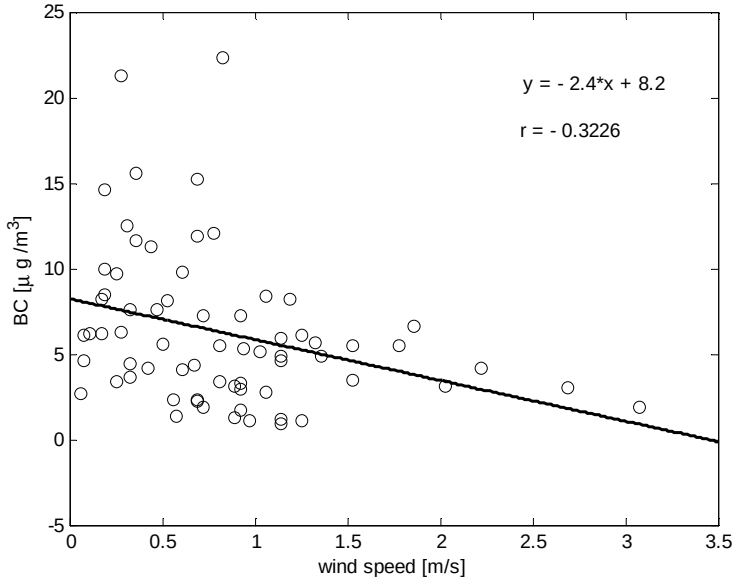

Figure 5: Scattered plots between Wind speed and BC for the strike days

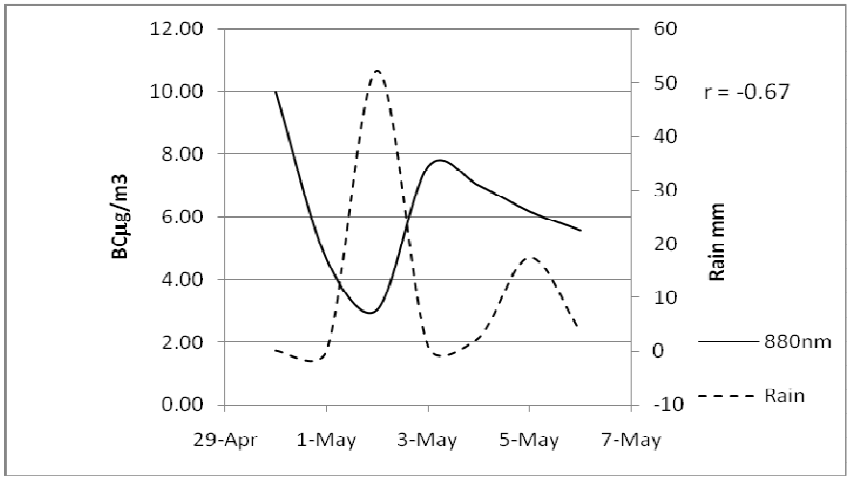

Figure 6: Relation between BC concentration and rain.

Figure 6 shows the variation of BC and rain in the observed days. It can be seen from the figure that rain has reduced the concentration of BC aerosol significantly on 2nd May as discussed earlier. A maximum (52.2 mm) rain was recorded in this particular day (http://www.mfd.gov.np). A mild rain was observed on 5th May as well. It is found that the rain has washed BC level on this day bringing the median value close to the mean. It is better to make an investigation of diurnal intensity of rain and BC but due to the unavailability of detail rain data this study has only shown its rough estimate. A negative correlation coefficient of 0.67 is observed between total amount of rain and BC level. Therefore it shows that total amount of rainfall is also a useful parameter for the study of washout of the pollutant.

Elemental carbon and Black Carbon

Aethalometer shows elemental carbon (EC) at 370 nm and black carbon (BC) at 880 nm (Magee, 2009). For the observed days the ratio of EC and BC is not very far from unity and lies within the range 0.83 to 0.98. It indicates the source of BC is nearly of same type. Moreover it also shows that only one type of combustible product is used for the production of carbonaceous aerosol.

Conclusion

The diurnal variation of BC aerosol is follows nearly same pattern in strike days as in working days but it is lowered by about 50%. The average BC level recorded during the strike days are 4.6, 3.0, 7.6, 7.0, 6.1, and 5.5 $\mu g /m^3$ respectively. These values of BC aerosols are because of the domestic activities of the people. The variation in BC aerosol is also influenced by different meteorological condition like rain and wind. Since people had collected in the valley for the movement the result can not conclude for the background BC level for the valley.

The wind profile of the observed days reflects high wind speed at about 4 PM local time and reduces BC aerosol around these hours. There is a negative correlation between wind speed and rain on BC. Therefore these metrological parameters play significant role in the reduction of BC aerosol from the air.

EC and BC ratio indicates their source is of similar type. The study suggests that the vehicular and industrial contribution on BC comes to be about 44% and 54% compared with single working day (30^{th} April) and monthly average (April).

Acknowledgement

The authors are thankful to Solar Radiation and Aerosols in Himalayan Region (SAHR) for providing the equipments. R. K. Sharma acknowledges SAHR for logistic support.

REFERENCES

[1] Ackerman A. S., Toon O. B., Stevens D. E., Heymsfield A. J., Ramanathan V. and Welton E. J., Reduction of tropical cloudiness by soot, *Science*., **288**(5468), 1042-1047, doi:10.1126/Science 288.5468.1042, 2000.

[2] Cao J., C. Zhu S., Chow J. C., Watson J. G., Han Y. M., Wang G., Shen Z. and An Z. S., Black carbon relationships with emission and meteorology in Xi'an, China, *Atoms.Res* **94**,194-202, 2009.

[3] Chameides W. L., Yu H., Liu S. C., Bergin M., Zhou X., Mearns L., Wang G., Kiung C. S., Saylor R. D., Luo C., Huang Y., Steiner A. and Giorgi F., Case study of the effects of atmospheric aerosols and regional haze on agriculture: an opportunity to enhance crop yields in China through emission controls, *Proc. Natl. Acad. Sci. U.S.A.* **96**, 13626-13633,1999.

[4] Chung S. H. and Seinfeld J. H., Climate response of direct radiative forcing of anthropogenic black carbon, *J. Geophys. Res*., **110**, D11102, 25PP, doi: 10. 1029 /JD005441, 2005.

[5] Cooke W. F. and J. Wilson J. N., A global black carbon aerosol model, *J. Geophys. Res*., **101**(D14), 19395-19409, 1996.

[6] Dhaubhadel R. and Sapkota B., Atmospheric turbidity over Kathmandu valley, *Atoms Environ*, **36**, 1249-1257, 2002.

[7] Dutkiewicz V. A., Alvi S., Ghauri B. M., Choudhary M. I. and Husain L., Black carbon aerosols in urban air in South Asia, *Atoms Environ*, **43**, 1737-1744, 2009.

[8] Fu F., Xu L. Ye W., Chen Y., Jiang M. and Xu X., Morphology of black carbon aerosols and ubiquity of 50-nanometer black carbon aerosols in the atmosphere, *China Particulogy*,**4**, 323-326, 2006.

[9] Ghedini N., Gobbi G., Sabbioni C. and Zappia G., Determination of elemental and organic carbon on damaged stone monuments, *Atoms Environ*, **34**, 4383-4391, 2000.

[10] Jacobson, M. Z., Control of fossil fuel particulate black carbon and organic matter, possibility the most effective method of slowing global warming, *J. Geophys. Res*., **107** (D19), 4410, doi: 10.1029/JD001376, 2002.

[11] Jacobson, M. Z., Climate response of fossil fuel and biofuel soot, accounting for soot's feed back to snow and sea ice albedo and emissivity, *J. Geophys. Res*., **109**, D21201, 15PP, doi: 10. 1029/JD004945, 2004.

[12] Jacobson, M. Z, Strong radiative heating due to the mixing state BC in atmospheric aerosols, *Nature*, **409**(6821), 695-697, 2001.

[13] Jones G. S., Jones A., Roberts D. L., Stott P. A. and Williams K. D., Sensitivity of global scale climate change attribution results to inclusion of fossil fuel black carbon aerosol, *Geophys. Res. Lett*., **32**, L14701, 4PP, doi: 10.1029/GL023370, 2005.

[14] Menon S., Hansen J., Nazarenko L. and Luo Y. F., Climate effects of black carbon aerosols in China and India, Science, **297**(5590), 2250-2253, doi: 10.1126/science. 1075159, 2002.

[15] Penner J. E., Eddleman H. and Novakov T., Towards the development of a global inventory for black carbon emissions, *Atmos. Environ*., **27**(8), 1277-1295, 1993.

[16] Tripathi S. N., Dey S., Tare V. and Satheesh S. K., Aerosol black carbon radiative forcing at an industrial city in northern India, *Geophys. Res. Lett.*, **32**, *L08802, doi: 10.1029/2005GL022515*, 2005.

[17] Venkataraman C., Habib G., *Fernandez* A. E., Miguel A. H., Friedlander S. K., Residential biofuels in south Asia: carbonaceous aerosol emission and climate impacts, *Science*, **307**, 1454, doi:10.1126/science 1104359, 2005.

[18] Watson J. G., Visibility science and regulation, *J. Air and Waste Manage. Assoc*., **52**, 628-713, 2002.