while the plucked string instrument has a delta function excitation. A way of combining both might be to conceive a violin with a jawari, in which case the *Y* displacement would be as shown in Figure 8 *c*. This waveform is for a device that combines sudden impulse of the plucked string with that of continuous excitation by a bow.

We have analysed the effect of a jawari on a sonometer. In the absence of the jawari, the signal resembles a damped harmonic oscillator. However, as the jawari is introduced, the boundary condition is modified to periodically modulate the length of the string. The modulation frequency of the boundary condition for a particular mode is the same as the oscillation frequency. Combining many such modes, the experimentally observed lobe of the time series could be successfully replicated. The periodic modulation of the boundary condition causes the generation of FM sidebands, which interfere with the higher-order modes in the frequency spectrum to generate the beats observed in the time series of the sonometer with the jawari.

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Variation of black carbon concentration associated with rain events at a tropical urban location

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Mass concentration of black carbon (BC) near the surface (within the planetary atmospheric boundary layer) was measured using a seven-channel aethalometer at Kolkata, a metropolitan city in the Indian tropical region, during the period from June 2012 to May 2013. The diurnal variation of BC concentration shows a prominent increase in the morning and evening hours, an usual feature seen over continents. However, an anomalous feature of the BC variation is observed subsequent to rain events. On normal days, the BC mass concentration during noon and early afternoon hours remains around 8000 ng/m^3 at Kolkata. However, after the occurrence of isolated thundershowers, interestingly, the BC concentration increases (rather than decreasing due to washout) and at times reaches above 20,000 ng/m^3 during noon and early afternoon hours. This increase is found to be associated with the formation of local temperature inversion within the atmospheric boundary layer during and after the occurrence of rain, which would suppress or inhibit vertical mixing and dispersion in contrast to non-rainy days. Results are presented to indicate the above-mentioned behaviour of BC concentration.

Keywords: Black carbon concentration, diurnal variation, rain effect, temperature inversion, tropical urban location.

ATMOSPHERIC black carbon (BC) is an important aerosol species in climate change studies and has significant impacts on human health. It strongly absorbs the solar radiation over a wide spectral band[1–3] contributing to atmospheric warming. BC is emitted during incomplete combustion[4,5]. There is a rapid increase in fuel demand with increase in the daily energy needs for domestic, industrial and transport sectors. This change in fuel utilization has caused a historical change in BC emission in the past decades[6]. The presence of significant amount of BC in the clouds may 'burn off' the clouds[7,8]. However, it has a cooling effect at the surface, which affects the temperature profile in the troposphere and consequently the microphysical structure of the cloud as well as the rainfall mechanism[9,10]. Usually BC particles are hydrophobic and are less scavenged by precipitation. BC particles may be

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transformed into hydrophilic being coated with sulphate (SO_4^{2-}). Hence they can behave as cloud condensation nuclei (CCN) and be removed by precipitation[11,12]. BC emission from India due to fossil fuel, biomass burning and biofuel combustion is a significant fraction of total global emissions[6,13]. It has been reported from different parts of India that BC shows a definite pattern of diurnal as well as seasonal variations[9,14,15]. It has also been reported that the diurnal variation of BC is influenced by the associated boundary layer dynamics[6]. In the present study we have studied the normal trend of diurnal and seasonal variations of BC concentration near the Earth's surface at Kolkata, a metropolitan city located near the land–sea boundary in the tropical region, using the ground-based BC observations. We have focused on an anomalous behaviour of diurnal variation of local BC concentration associated with rain events. The main aim is to study the role of meteorological conditions associated with rainfall on the behaviour of BC concentration at the surface level. Since the amount of BC emission is high at an urban location like Kolkata and a strong summer monsoon is active over this tropical location, any departure from normal BC variation due to rain should be a major concern in modelling BC variation at locations like the present one.

A seven-channel aethalometer (AE 31; Magee Scientific Company, USA) is continuously being operated in Kolkata to measure the mass concentration of BC. This instrument draws ambient air through a cyclone inlet at a selected constant flow rate of 4 l min^{-1}, and measures BC at 5 min interval. The BC particles present in the air are deposited on the quartz filter tape of the instrument and the consequent change in transmittance of the filter tape is measured to estimate the BC concentration. BC mass concentration is determined using the following equation

$$BC = (\Delta ATN/\sigma) \times A/V,$$

where ATN is the attenuation of light through the filter tape, σ the specific attenuation cross-section (m^2/g), A the spot area of the filter tape and V is the volume of air passing through the filter. Absorption of light transmitted at seven wavelengths, viz. 370, 470, 520, 590, 660, 880 and 950 nm is recorded. The 880 nm wavelength is used for standard BC measurement[16,17] as BC from fossil fuel sources is the major absorber of light at 830 nm and other aerosols have minimum absorption at this wavelength[4,6,18].

BC concentration estimated by the aethalometer has uncertainties as reported in the literature. To overcome these, two calibration factors are incorporated to the aethalometer attenuation measurement. One of these is the C-factor which is taken into account due to the multiple scattering of transmitted wavelength by the quartz filter tape. The value of C is taken as 1.9 (ref. 16). The second one, the R-factor, is known as shadowing effect which is introduced due to the loading of light-scattering particles along with BC on the filter tape[19,20]. For unloaded filter tape, the value of R is unity. Shadowing effect is significant for pure soot particles and insignificant for mixed aerosols[19].

The temperature profile data used in the present study are obtained using ground-based microwave radiometer profiler. The multi-frequency radiometer (RPG-HATPRO) measures brightness temperatures (BRT) at 14 different frequency channels spreading over two frequency bands and having frequency ranges 22.24–31.40 GHz and 50–59 GHz. The higher seven-channel frequency band is utilized to monitor the temperature profile. Atmospheric temperature data, used for the present study, are obtained from the BRT measurements by means of a retrieval algorithm based on linear and nonlinear regression techniques.

The rain rate data at the ground have been collected using a Joss-type ground-based disdrometer operated at the same site. Along with rain rate measurement, it is capable of sensing drop sizes in the range 0.3–5.5 mm with an accuracy of 5% and a time resolution of 30 sec.

An automatic weather station (AWS) is running at the same location. AWS wind speed data are used for the present study. AWS consists of a weather-proof enclosure containing the data logger, rechargeable battery and the meteorological sensors. It has an anemometer for measuring wind speed.

We have used the BC data during the months of June 2012 to May 2013 for the present study. June to September it is known as Indian summer monsoon season. A good amount of rainfall occurs during these months over India. In Kolkata, on an average around 150 cm rainfall occurs during monsoon season. October and November are considered as post-monsoon season. During December to February it is winter and from March to May it is pre-monsoon season in India. We have carried out our observations throughout the year and introduced the BC concentration data of these seasons in our study.

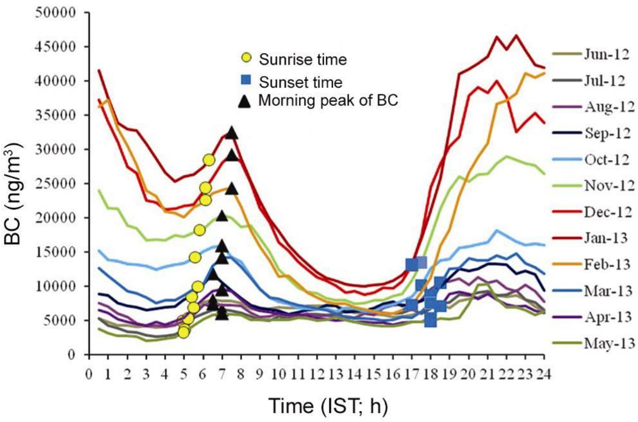

Figure 1. Diurnal variation of black carbon concentration from June 2012 to May 2013. Sunrise and sunset times are mentioned on the curves. Time is in IST (UTC + 5 : 30). The morning peak time varies with the sunrise time.

The average diurnal variation of BC for each month from June 2012 to May 2013 is examined at the present site (Figure 1). Prominent morning and evening peaks are observed in the diurnal variation of BC concentration. During December–February the morning peak is found around 0730 IST, whereas it shifts to around 0630 IST during July–September. For the rest of the months the morning peak is observed within 0630–0730 h IST. The evening peak hour varies around 2030 to 2230 h IST. In winter months the peak is observed comparatively later. The above-mentioned feature of BC concentration is associated with the diurnal change in atmospheric boundary layer dynamics[17,21,22]. In the morning hours, BC concentration increases due to the combined result of fumigation effect in the boundary layer just after the local sunrise[8,23] and an increase in anthropogenic activities. The timing of fumigation effect changes with the seasonal variation of the sunrise time and hence the morning peak shifts correspondingly[24] (Figure 1). BC concentration gradually decreases during local noon (1139 IST) and reaches at its minimum value at about 1300–1400 h IST when thermal convection is the strongest and the local atmospheric boundary layer (ABL) is the deepest. The gradual increase in the convective activity within the ABL during noon and afternoon hours results into a rapid dispersion of BC from the ground level[25]. This causes lower concentration of BC during noon and afternoon hours throughout the year. ABL gradually becomes shallower after sunset[26,27] and the nocturnal layer forms closer to the surface. This acts as a capping inversion confining the surface-based pollutants (including BC), which leads to the build-up and increase of BC concentration near the surface region[6]. Usually the anthropogenic activities reduce as the night progresses, which leads to the reduction in BC concentration at midnight and early morning. It is evident that the average morning (28,859.9 ng/m^3) and evening (41,426.4 ng/m^3) peak values during the winter season are much higher than the morning (8,369.1 ng/m^3) and evening (10,502.8 ng/m^3) peak values during the monsoon season (Figure 2). BC concentration during afternoon hours does not show significant seasonal change, whereas there is a prominent seasonal variation of morning and evening peak values of BC concentration (Figure 3). Average values of BC concentration during monsoon are low due to wet removal of BC particles from the atmosphere by the extensive rainfall[21,28], and change in air mass from continental to marine, which is comparatively cleaner.

Detailed studies of the diurnal variation of the individual days revealed that noon or early afternoon peaks in the diurnal variation of BC occur on a number of days in which isolated rain events occurred during noon and afternoon hours. Figure 4 *a* and *b* shows a sudden increase in BC concentration during noon hours after the occurrence of rainfall on 22 June 2012 and 2 August 2012 respectively. This increase in BC concentration during noon hours has not been reported so far. We have found 51 cases during the entire monsoon season, where BC concentration shows an increase after isolated rain events during noon and afternoon hours. A statistical analysis was carried out to obtain the percentage of cases where BC concentration has considerably increased after rain events (Figure 5). It is found that the significant increase of BC during the noon and afternoon hours is associated with the occurrence of rain events in noon time. It is evident that the average values of BC during the noon or early afternoon hours for those rainy days are higher than the overall noon or early afternoon hour average value of BC during the entire monsoon season (Figure 6).

To study this sudden increase in BC concentration near the surface during afternoon hours, some relevant parameters like wind speed or temperature profile within the atmospheric boundary layer are examined. From AWS data we observed the local diurnal wind speed variation as it causes change in the concentration of BC near the surface. It is reported that ventilation effect within the boundary layer reduces with the decreasing wind speed and it leads to an increase in BC concentration near the ground[14]. Some examples showing that the increase in

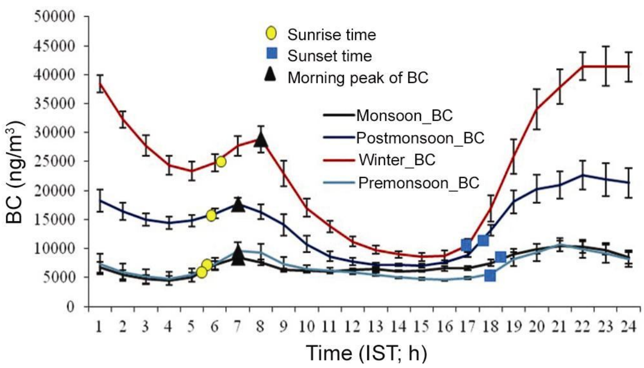

Figure 2. Mean diurnal variation of BC concentration (with standard deviation) in different seasons. Sunrise and sunset times are mentioned on the curves. Time is in IST (UTC + 5 : 30).

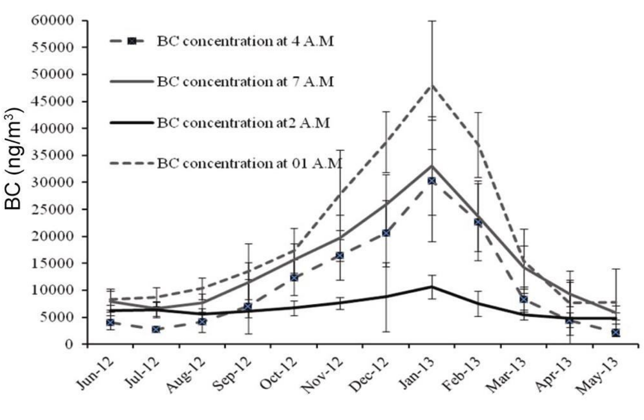

Figure 3. Monthly variations of diurnal maximum and minimum values of BC concentration.

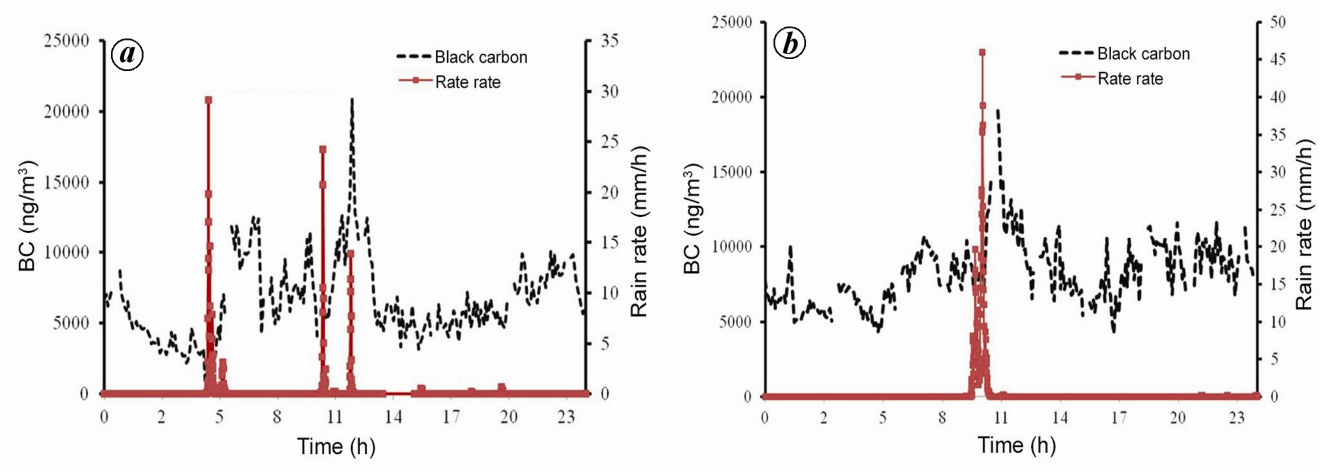

Figure 4. Diurnal variation of BC concentration on (***a***) 22 June 2012 and (***b***) 2 August 2012 along with the rain event.

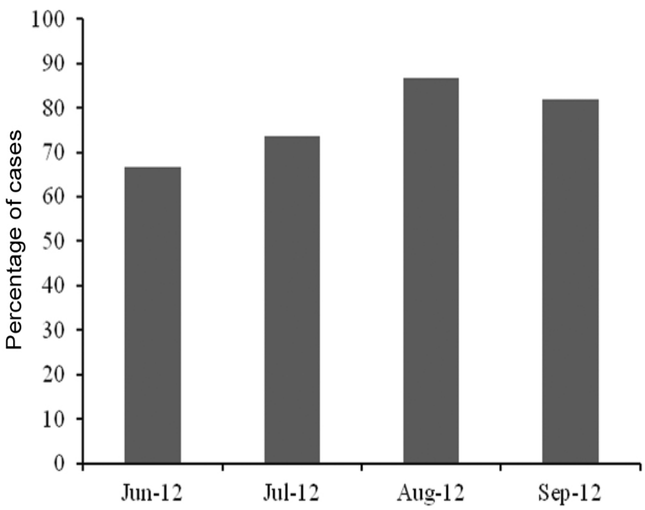

Figure 5. Percentage of cases where BC concentration has increased after rain events during the entire monsoon season (June to September 2012).

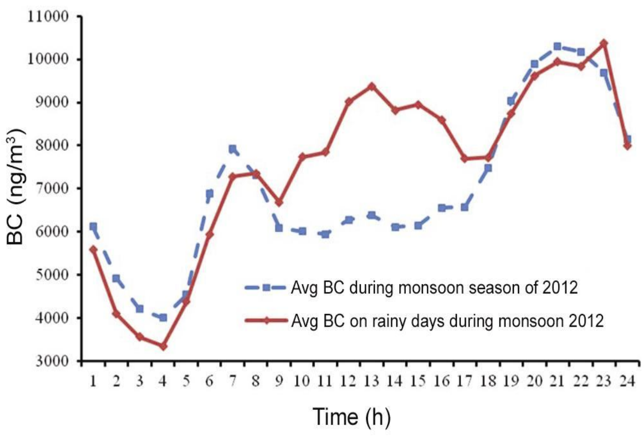

Figure 6. Comparison between average diurnal variation of BC only on rainy days and that during entire monsoon season (June to September 2012).

wind speed affects BC concentration are given in Figure 7. Our observations indicate that wind speed often falls abruptly after the rain events (Figure 8) and the decrease of local wind speed consequent to rainfall causes an increase in BC concentration near the surface level (Figure 9).

We also studied boundary layer temperature profile as it influences the ABL dynamics[25] and consequently the concentration of BC near the ground. From radiometric observations we examined the temperature profiles within the ABL before, during and after the rain events. The temperature profiles show significant changes during and after the rain (Figure 10). The red lines in Figure 10 *a* and *b* show prominent inversions in the temperature profile during rain events and black lines show the presence of inversions 45 min after the occurrence of rain events at noon time on 22 June 2012 and 2 August 2012 respectively. On the other hand, temperature profiles before the occurrence of rain, indicated by blue lines, do not exhibit any inversion in ABL.

From our observations at Kolkata it is evident that the diurnal pattern of BC concentration is significantly influenced during monsoon season. The average level of BC concentration is lower in the monsoon months, but the immediate effect of rain is dominant to affect the diurnal pattern. BC concentration near the ground anomalously increases during noon and afternoon hours related to the occurrence of rain events. The temperature inversion within the ABL during or after the rain events hinders the normal convection process within the ABL after the rain events and this may trap the suspended particles near the surface. Additionally, the wind speed often decreases after the rain events, which results in lesser dispersal of BC causing an increase in BC concentration near the earth's surface subsequent to the occurrence of rain events. This causes a departure of the diurnal variation of BC from its normal pattern. As rainfall affects the

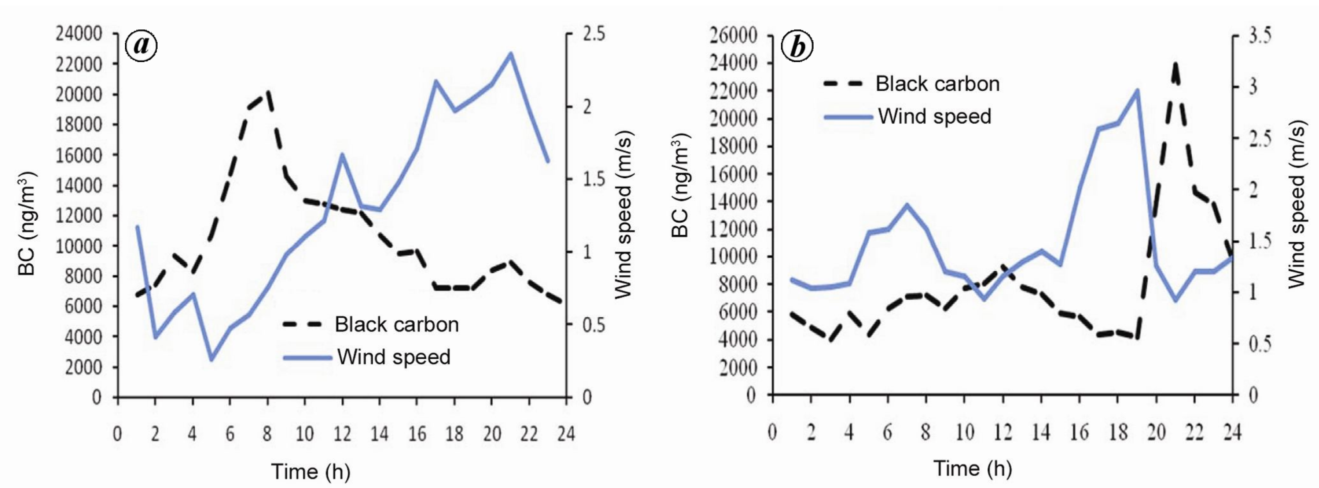

Figure 7. Diurnal variation of BC along with diurnal variation of wind speed on (***a***) 8 June 2012 and (***b***) 9 June 2012.

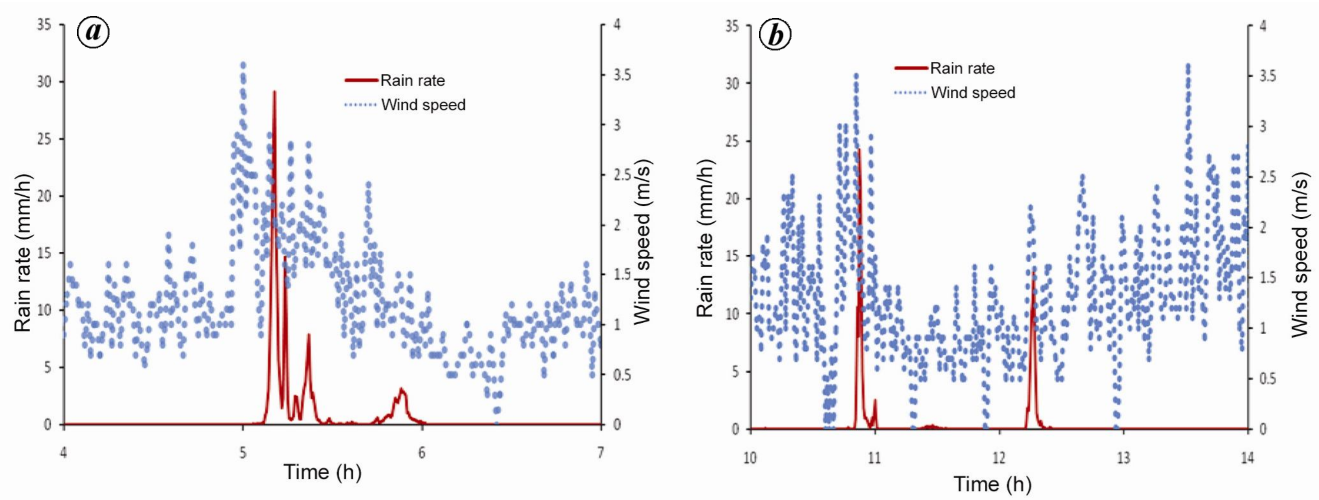

Figure 8. Sudden fall of wind speed consequent to the rain events (***a***) in the morning hours and (***b***) at noon hours on 22 June 2012.

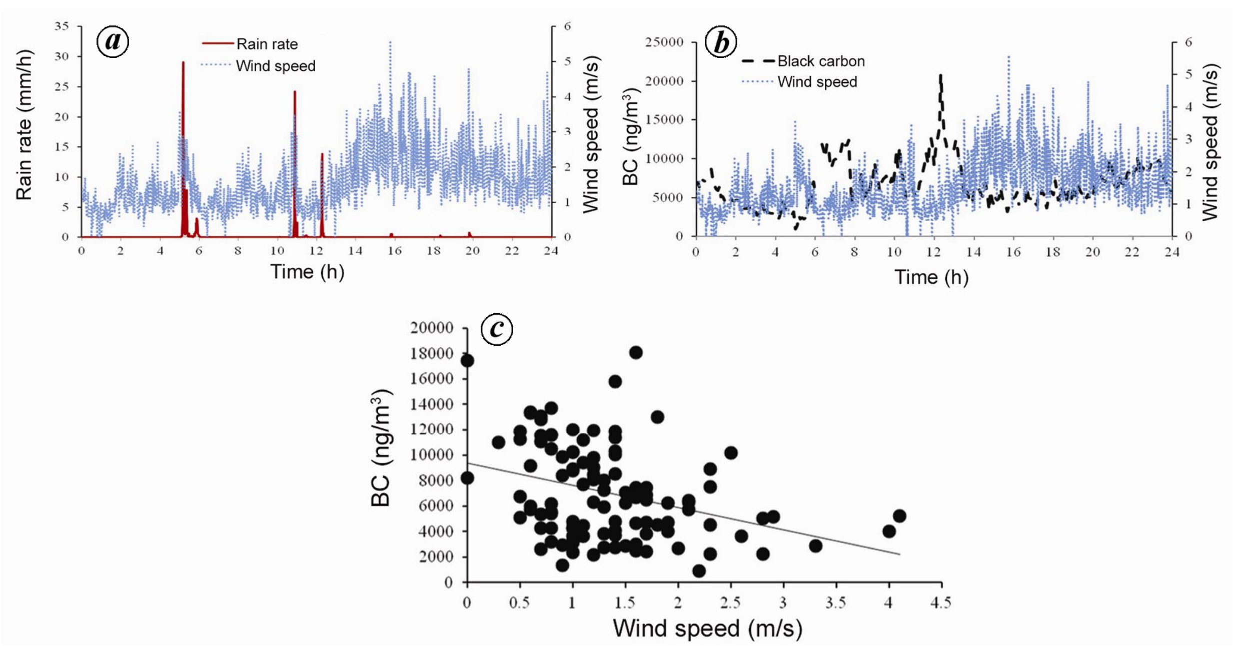

Figure 9. ***a***, Sudden fall of wind speed consequent to the rain events on 22 June 2012. ***b***, Diurnal variation of BC along with the diurnal variation of wind speed on 22 June 2012. ***c***, Increase in BC (from pre-rain value) versus decrease in wind speed (from pre-rain) for different events.

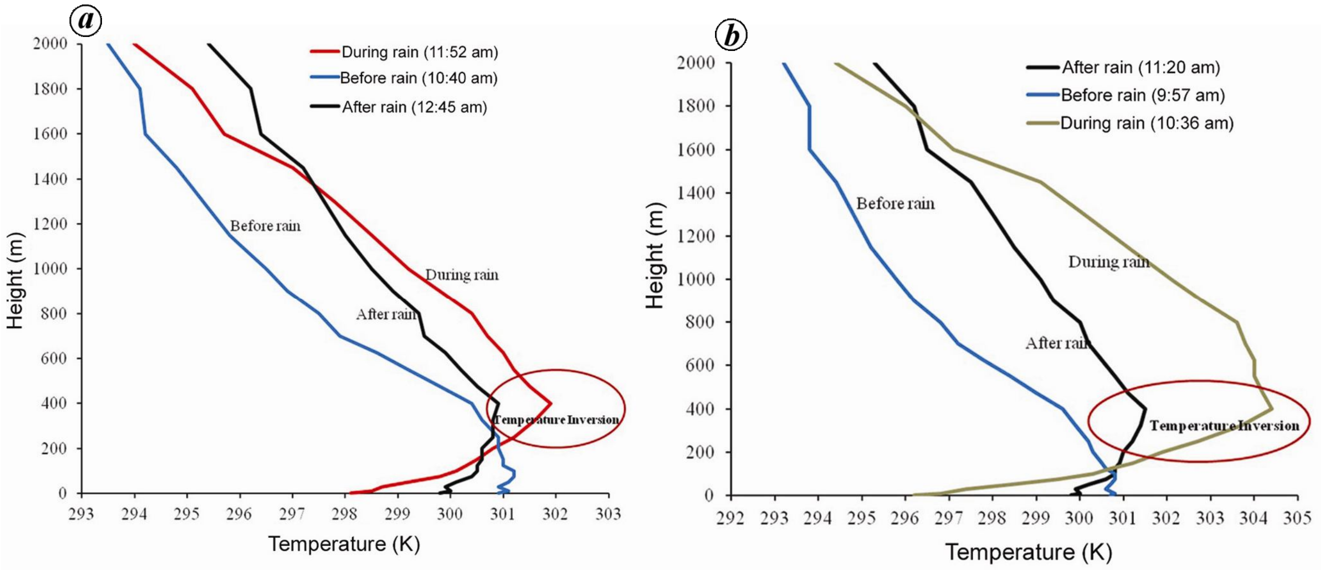

Figure 10. Temperature inversion during and after rain on (***a***) 22 June 2012 and (***b***) 2 August 2012.

behaviour of BC concentration near the surface, any BC emission during or just before the rain events will have a more dominant impact on near-surface environment compared to BC emission in no rain condition at tropical urban locations like the present one.

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Forecasting the distribution of heavy metals in soil and groundwater near municipal solid waste dumpsites using linear regression

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The levels of heavy metals are measured at different dumpsites with different distances and directions under the jurisdiction of Greater Municipal Corporation of Hyderabad for ascertaining the soil and groundwater quality and forecasting as a part of integrated municipal solid waste (MSW) management study. The datasets indicate a steady decrease in the concentrations of ions and heavy metals in groundwater with distance from the MSW dumpsites. Similar trends are observed for the levels of heavy metals in soil at dump sites around the MSW dumpsite. In this study, we have used both linear and quadratic regression to predict water and soil constituents. As the datasets on the components of solid waste and groundwater are limited, the desired level of forecasting accuracy could not be achieved. However, for some components the results are promising. This study suggests that improvement can be achieved by removing the outliers from the dataset. If the errors are large for a component, it would mean that we need a better way of separation of this component from the waste.

Keywords: Groundwater, heavy metals, municipal solid waste, soil.

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POLLUTION is one of the major public health concerns in many large cities worldwide. However, in many cases only little attention has been given to this issue, particularly in developing countries. Example is the case of Hyderabad, where municipal solid waste (MSW) dumpsites are not scientifically maintained. One of the main activities leading to this problem includes unorganized dumping and burning of MSW which contains high levels of heavy metals. Such activities tend to increase the elemental background levels in the surrounding soil and groundwater, driving to adverse temporal variations of heavy metal levels in soils. Anthropogenically derived chemicals are an important source of environmental pollution[1,2]. They contribute to the load of pollutants in urban run-off/leachate. In some areas close to MSW dumpsites, concentration of pollutants has reached levels which are toxic to humans and other living organisms[3–5]. Therefore, the measurements of the fluxes of pollutants from the atmosphere in urban environments can aid in the assessment of soil and groundwater quality and can be used to determine temporal and seasonal variability of pollution sources.

Soil constitutes part of vital environmental, ecological and agricultural resources that have to be protected from further degradation as an adequate supply of healthy food needed for the world's increasing population. Heavy metals can affect both the yield of crops and their composition[6]. Thus the elemental status of a cultivated land has to be determined to identify yield-limiting deficiencies of essential micronutrients of plants grown on polluted soils.

Some heavy metals are essential in trace amounts, namely Zn, Cu and Mn for plants and in addition, Co and Ni for animals[7]. Not much information is available on the toxicity of several metals, including Cd on either plants or animals. On the other hand, high concentrations of metals become toxic to plants and possibly are dangerous to human health. The three metals, Pb, Hg and Cd and the metalloid arsenic have all caused major human health problems in various parts of the world[8]. A number of cases of health problems related to environmental Cd poisoning have been reported. Some of the metals are phytotoxic and some are toxic to both plants and animals through their entry into the food chain[8,9]. Recent studies