Urban Climate xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

Seasonal characteristics of black carbon aerosol mass concentrations and influence of meteorology, New Delhi (India)

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A R T I C L E I N F O

Keywords:
Aerosol
Black carbon
Vehicle emission
Biomass burning
Delhi
Aethalometer

A B S T R A C T

This study investigates seasonal variability in black carbon (BC) aerosol mass concentrations at New Delhi, a monsoon-influenced urban agglomeration located at the edge of the Indo-Gangetic Plain and the Aravalli hills. Incessant measurement of BC has been carried out using Aethalometer AE-42 with the PM2.5 selective inlet. The BC concentrations show significant seasonal, diurnal and hourly variations. The hourly concentrations show a persistent peak distribution during the observation period with different magnitudes. There are two sharp peaks; first one in the morning between 8:00 and 11:00 h and the second one at night between 21:00 to 23:00 h. The morning high concentration peaks are more pronounced in all the observed months. The hourly and weekly analysis of BC concentrations indicates a significant contribution of vehicle emission, showing a definite pattern with the volume of traffic flow. Though, seasonal variation reveals that the local meteorological conditions directly influence it. Mean BC concentrations during summer; monsoon and post-monsoon seasons are 6.33, 4.95 and 17.4 μg m^{-3}, respectively. The correlation coefficient of BC concentrations with temperature and relative humidity (RH) indicates that temperature and RH influence the boundary layer dynamics which in turn result into diurnal and seasonal variability in BC concentrations at the ground level.

1. Introduction

Aerosol particles present in the air absorb solar radiation and significantly vicissitude the surface radiation budget, particularly in the urban areas. Aerosols are predominantly contributed by the anthropogenic activities in the urban areas. Hence, a study on aerosols has received considerable attention due to its adverse impact on microclimate and air quality. Black carbon (BC) aerosol in the atmosphere is largely aided by combustions of fossil fuel, biomass burning, and forest fires. Aerosol particulates suspended in the air are very minute in size and directly, affect scattering and absorptions of atmospheric radiation (Aruna et al., 2013) and significantly influence the earth's radiation budget (Bond et al., 2013; Raju et al., 2011; Tiwari et al., 2016).The BC concentrations in the lower atmosphere adversely affect air quality, visibility, and micro-climate (Apte et al., 2011; Safai et al., 2007). Aerosol absorbs light in the visible spectrum (Fialho et al., 2006); and also being considered as a crucial factor in the rise of global temperature (Bond et al., 2013; Das and Jayaraman, 2011; Nair et al., 2012; Panicker et al., 2008; Raju et al., 2016; Ramanathan et al., 2005).

The influence of BC aerosols depends on the strength of their originating source due to a shorter lifespan in the atmosphere (Das and Jayaraman, 2011). Particularly, in the urban environment, dust particles and carbonaceous aerosols get mixed in the air, and are

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https://doi.org/10.1016/j.uclim.2017.12.002
Received 29 June 2017; Received in revised form 14 November 2017; Accepted 8 December 2017

mainly composed of two fractions of organic carbon (OC); semi-volatile and elemental carbon (Jeong et al., 2004; Lal et al., 2015). BC is the most efficient and significant absorber of solar radiation over a wide spectral range in comparison to other aerosols, which is used for source apportionment. Though, a large uncertainty is noticed in the aerosol estimation regionally due to strong seasonal variation in BC concentrations. The regular measurements of BC concentrations are still limited to a few urban, and isolated locations in the India (Aruna et al., 2013, 2014a; Babu, 2002, 2004; Babu and Moorthy, 2001; Badarinath et al., 2007; Budhavant et al., 2012; Dumka et al., 2013; Joshi et al., 2016; Kumar and Kumari, 2015; Kumar et al., 2012; Latha et al., 2004; Madhavi Latha and Badarinath, 2003; Tripathi et al., 2007).

Aerosol BC concentrations in the urban locations are mainly contributed by the vehicle-industrial and emissions from biomass burning for domestic uses. Traffic congestion in Delhi is thought to be significantly related to diurnal and weekly variations in the BC concentrations (Apte et al., 2011; Latha et al., 2004; Srivastava et al., 2012a; Yerramsetti et al., 2013).The BC aerosol characteristics of Delhi are strongly associated with vehicular emission, surface meteorology and boundary layer dynamics (Srivastava et al., 2012a, 2012b; Tiwari et al., 2012, 2013, 2015). Diurnal variations in temperature and relative humidity also influence the BC concentrations (Das and Jayaraman, 2011). The presence of dust particles in the lower atmosphere during pre-and post-monsoon seasons was directly examined to the aerosol mass concentrations (Aruna et al., 2013; Joshi et al., 2016; Raju et al., 2016); biomass burning of crops residue (Srivastava et al., 2012a) and prevailing meteorological conditions (Kompalli et al., 2013; Kumar et al., 2012; Latha and Badarinath, 2005; Raju et al., 2011; Ramachandran et al., 2015; Safai et al., 2007). Correlation of BC concentrations and changing atmospheric optical depth (AOD) has also been established under changing atmospheric temperature (Δt) that directly influence boundary layer (Babu et al., 2011; Safai et al., 2012; Sreekanth and Kulkarni, 2013). The concentrations of BC and its variability are also related with monsoonal circulations over the Indo-Gangetic Plain (IGP) region (Babu, 2004; Kompalli et al., 2010; Manoj et al., 2011). Apart from the meteorological parameters, vegetation cover significantly affects the micro-scale environment in the urban areas (Duarte et al., 2015). Studies on the adverse impact of air pollution on human health in Delhi region have indicated that the poor air quality is one of the main causal factors for cardiovascular and respiratory diseases (Gurjar et al., 2010; Banerjee et al., 2012). In addition, the cardiovascular mortality is more than that caused due to the respiratory diseases in Delhi (Banerjee et al., 2012). In south Delhi, Nagpure et al. (2014) reported an overall increasing trend in respiratory as well as in cardiovascular mortality due to suspended particulate matter that is mainly produced by vehicular emissions. Against the backdrop of studies mentioned above, objectives of the present study is to analyze the hourly, diurnal and seasonal characteristics of black carbon mass concentrations; and influence of local meteorological condition and variability thereof.

2. Measurement site meteorological condition

BC aerosols are measured at JNU Campus New Delhi; located 28°32′23.30″N 77° 9′59.15″E, at 265 m altitude (amsl), over the northern flank of Aravali ridge and southern edge of the Indo-Gangetic plain (Fig. 1). The measurement site is located in the south part of Delhi, surrounded by dense residential colonies, predominantly a hub of services and commercial activities. It is also important to note that the site is bounded by major roads that commonly experience high traffic congestion during morning and evening hours. Also, the NH 8 to the northwest is one of the busiest roads in the National Capital Region (NCR). To the west of the city is the Thar Desert, a major source of fine dust particles. In the north and east of the site, there is Indo-Gangetic plain, used for intensive agriculture; and one of the major source of aerosol produced due to the burning of the crops residue. Apart from this, an industrial enclave with major thermal power plants substantially adds to the aerosols from the southern side of the site.

Climate of Delhi is characterized as monsoon-influenced humid subtropical to semiarid, with a high degree of variability in temperature and precipitation. The city's meteorological condition is more subjugated to its continental situation, and by the vicinity of the Thar Desert and the Himalaya; instigating to extreme weather conditions. Five distinct seasons are characterized in Delhi based on the meteorological parameters; that are spring (March–April), summer (May–June), monsoon (July–September), autumn (October–November) and winter (December–February). These seasons have a distinct temperature, relative humidity, and wind pattern. Based on the observation of the Indian Meteorological Department (IMD), New Delhi, the mean monthly temperature is highest (33.1 °C) during the summer months, but some hot spells experience up to 46 °C (Fig.2a). Lowest temperature (3 °C) is recorded in December and January months. In the monsoon months, relative humidity (RH) is about 69% that is highest while the lowest RH is up to 29% recorded during the autumn season. In the summer months, this is about 36%. Thus, RH ranges between 29 and 69%. Approximately, 85% rainfall occurs during the Indian Summer Monsoon (ISM) in some concentrated spells and also in a small amount during the winter season from the Westerlies. An average annual rainfall in Delhi (Safdarjung) is 762 mm received in 40 rainy days during 1981–2010 (IMD, n.d.).

The aerosol species characterization is based on the GOCART model for the Asian region, showing a discrete relationship with different seasons (Chin, 2003; Chin et al., 2002; Ginoux et al., 2001). Aerosols are directly influenced by the prevailing wind direction over Delhi. During the summer season, the wind direction is from WNW to ESE. Hence, the fine dust particles are blown from the Thar Desert towards Delhi, increasing the contribution of dust particles up to 69% of the total aerosols (Fig. 2b). However, the reversal of wind direction (from ESE to WNW) is observed due to the onset of ISM that causes rainfall. Dust particles settled down on the ground due to rain, causing a decrease in dust contribution to the total aerosols (Fig. 2e & f). Moreover, the onset of ISM is one of the major reason for extending boundary layer dynamics that reduces the atmospheric optical depth (AOD) by augmenting the ventilation process. Fig. 2b shows a high AOD index during monsoon while the lowest is observed in the winter season. Fig. 2c and d show the seasonal characteristics of aerosols index and aerosols mass concentrations (g/cm^2) over Delhi that was derived using MODIS aerosols L2 (Terra), ver.051 corrected AOD-land 550 nm and POLDER-3 aerosol over land L2, ver.JK aerosols index dataset.