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Ambient particulate matter and carbon monoxide at an urban site of India: Influence of anthropogenic emissions and dust storms☆

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ABSTRACT

Continuous measurements of $PM_{2.5}$, PM_{10} and CO were conducted at an urban site of Udaipur in India from April 2011 to March 2012. The annual mean concentrations of $PM_{2.5}$, PM_{10} and CO were 42 ± 17 μg m^{-3}, 114 ± 31 μg m^{-3} and 343 ± 136 ppbv, respectively. Concentrations of both particulate and CO showed high values during winter/pre-monsoon (dry) period and lowest in the monsoon season (wet). Local anthropogenic emission and long-range transport from open biomass burning sources along with favourable synoptic meteorology led to elevated levels of pollutants in the dry season. However, higher values of $PM_{10}/PM_{2.5}$ ratio during pre-monsoon season were caused by the episodes of dust storm. In the monsoon season, flow of cleaner air, rainfall and negligible emissions from biomass burning resulted in the lowest levels of pollutants. The concentrations of $PM_{2.5}$, PM_{10} and CO showed highest values during morning and evening rush hours, while lowest in the afternoon hours. In winter season, reductions of $PM_{2.5}$, CO and PM_{10} during weekends were highest of 15%, 13% and 9%, respectively. In each season, the highest $PM_{2.5}/PM_{10}$ ratio coincided with the highest concentrations of pollutants (CO and NO_X) indicating predominant emissions from anthropogenic sources. Exceptionally high concentrations of PM_{10} during the episode of dust storm were due to transport from the Arabian Peninsula and *Thar* Desert. Up to ~32% enhancements of PM_{10} were observed during strong dust storms. Relatively low levels of O_3 and NO_x during the storm periods indicate the role of heterogeneous removal.

1. Introduction

In recent years, the concentrations of airborne particulate matters (PMs) and gaseous pollutants have notably increased due to the rapid urbanization, increasing economic growth, emissions from biomass burning and fossil-fuel combustion over South Asia (Carmichael et al., 2009; Adhikary et al., 2007). Most of the urban cities of the world are facing serious air quality problem because of increased emissions of PMs and related environmental hazards from anthropogenic activities (Elbayoumi et al., 2013). Typically, the mass concentrations of PM are a composite mixture of inorganic and organic constituents which covers a wide particle size range with an aerodynamic diameters ranging from a few nanometers to tens of micrometers. PMs are emitted from both natural and anthropogenic sources as primary particle (i.e. they are directly emitted into the atmosphere) or formed by secondary processes (i.e. by transformation of emitted precursor's gases) (Fuzzi et al., 2015). The major anthropogenic sources of PMs are the incomplete combustion of bio and fossil-fuels. Other sources include agriculture residual burning, municipal solid waste treatment, construction activities and emissions from paved and unpaved roads. The elevated concentrations of PMs are not only an air quality issue of the cities, but also have regional and global effects (Obaidullah et al., 2012; Delfino et al., 2005). High levels of $PM_{2.5}$ are responsible for adverse health effects like respiratory and cardiovascular diseases. Several studies have reported the adverse impacts of chronic exposure to the high levels of PMs (e.g., Pope et al., 2009). $PM_{2.5}$ is associated with more adverse health effects than larger particles (Wilson and Suh, 1997). In addition to this, PMs play direct and indirect roles in climatic processes including precipitation (Stevens and Feingold, 2009), cloud formation (Wang et al., 2011), and contribute to the earth radiation budget

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(Ramanathan et al., 2007).

Carbon monoxide (CO) is one of the insidious gaseous pollutants in the ambient air. It plays a significant role in the atmospheric chemistry by removing hydroxyl radical (OH) (Hofzumahaus et al., 2009), which defines the existence of several greenhouse gases (GHG) like methane (CH_4) and ozone (O_3). O_3 is a primary precursor of highly reactive hydroxyl (OH) radicals and determines the oxidizing capacity of the atmosphere (Sharma et al., 2013). CO is emitted from incomplete combustion of fuels, forest fire, agricultural wastage burning as well as oxidation of hydrocarbons and used as a good tracer for long-range transport of pollutants (Jaffe et al., 2004). The long-range transport of CO from the source region can significantly degrade the air quality at the downwind locations (Cooper et al., 2004). NOx is mainly emitted from fossil fuel combustion (Lelieveld and Dentener, 2000). Interestingly, the weekend-effect of primary pollutants (i.e. $PM_{2.5}$, PM_{10} and CO) is an important phenomenon to assess the impact of traffic at urban locations. The study site is mainly influenced from vehicle exhaust emissions. In urban regions, anthropogenic emissions are reduced on weekends (Saturday-Sunday), hence ambient concentrations PMs and trace gases are less than weekdays. The year round measurements of PMs and CO at urban sites of South Asia are still limited compared to East Asia, North America and Europe. The level of trace constituents is controlled by a variety of surface and atmospheric processes (Sahu et al., 2016a, 2016b). In India, studies of $PM_{2.5}$ and PM_{10} have been reported at different urban regions of Delhi (Marrapu et al., 2014; Tiwari et al., 2015a,b; Ali et al., 2013; Ali et al., 2015; Beig et al., 2013), Agra (Kulshrestha et al., 2009), Kanpur (Sharma and Maloo, 2005), Lucknow (Pandey et al., 2012), Patiala (Awasthi et al., 2011), Udaipur (Yadav et al., 2014a). Most of the studies have been reported for the urban/semi-urban sites located in the Indo-Gangetic Plain (IGP). The Indo-Gangetic plain (IGP) is most populated river basin, where more than 600 million populations are living (Srivastava et al., 2012; Tripathi et al., 2006). The measurements of PMs and trace gases along with meteorological parameters at different sites of India have been conducted by the Ministry of Earth Sciences (MoES), Indian Institute of Tropical Meteorology, Pune under the Modeling Atmospheric Pollutants and Networking (MAPAN) plan. The causes of seasonal and diurnal variations in PMs and CO are poorly understood in the western part of India. The present study is based on the continuous measurements of particulate matters and trace gases in Udaipur, western India during 2011–2012. The framework or policies to control PMs and CO needs long-term and continuous observations of pollutants in rapidly developing regions. Understanding of seasonal variations of PMs and CO and relations with meteorological parameters are important to assess the roles of important emission sources and atmospheric processes. This study will be important to design the control measures in urban sites of western India. Although beyond the scope of this paper, time resolved measurements of PMs and CO are important to investigate exposure levels in view of the standard limits recommended by different agencies. The relationship between PMs and their dependence on trace gases have been investigated. The impact of windblown dust on the level of PMs and trace gases during the episodes of dust storm has been also presented. We have investigated the diurnal pattern, seasonal variation and weekend-effect.

2. Material and methods

2.1. Topography, emission and meteorology

The study site (24.58°N, 73.68°E and 598 m ASL) in Udaipur city is located in the campus of Mohanlal Sukhadia University (Fig. 1a). The site is encircled by the inhabited colonies and it's close to the national highway (NH). Many industrial units are located in the east and north outskirts of the city. Emissions from vehicular traffic and residential cooking activities are major sources of air pollutants near the observational site. Rajasthan state transport corporation has been reported that the number of vehicles in Udaipur is increasing at the rate of 15–20% per year (http://rsrtc.rajasthan.gov.in). In addition to vehicular and industrial sources, the emissions from agriculture residual burning, municipal solid waste treatment, use of diesel generator, use of bio-fuel and LPG (residential cooking), construction activities are other sources of air pollution at Udaipur. The common sources of $PM_{2.5}$, PM_{10} and CO include bio- and fossil-fuel combustion, industrial processes and biomass burning. However particularly for PM_{10}, windblown dust, road dust suspension, building construction, lime kilns, slab polishing are important non-combustion sources.

The climate of Udaipur is semi-arid with maximum temperatures of 40–45 °C during the pre-monsoon days and lowest of 1–5 °C during winter days. The episodes of dust storms originated from *Thar* desert and Arab countries can influence the site during the pre-monsoon season. In the present study, the analysis has been performed separately for four different seasons of pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February). The back trajectories data have been used to track the origin and transport pathway of air masses in different season during the study period. Isentropic back trajectories data have been calculated using the Japanese 25- year Reanalysis (JRA-25, 6 h, 1.25° × 1.25°) (Onogi et al., 2007; Sahu et al., 2013). The advection algorithm used in back-trajectory calculation is similar which is described in (Draxler and Hess, 1997). The back trajectories were calculated for a total run time of 168 h (7 days) at 500 m of altitude with a time step of 5 min for this study.

2.2. Instrumentation and data analysis

One year measurements of fine ($PM_{2.5}$) and coarse (PM_{10}) particles with 1 h resolution were carried out using a Met one Instrument Model BAM-1020 (Beta Attenuation Monitor) from April 2011-March 2012. The BAM-1020 provides the mass concentration (in unit of μg m^{-3}) of airborne PMs using the principle of beta ray attenuation. The BAM 1020 filter tape loading diagram is shown in Fig. 1b. At the start of each sample hour, Carbon-14 (^{14}C) element emits a constant source of high energy electrons known as beta rays through a spot of clean filter tape. These beta particles are detected and counted by a sensitive scintillation counter to determine a zero reading. A vacuum pump pulls a measured and controlled amount of air sample through the filter tape, loading it with the dust laden. Consequently, the dust loaded filter tape (polluted spot) is placed between the source and the detector. The attenuation of the beta particle signal is used to determine the mass of PM on the filter tape. The absorption of beta ray by substance can be described by the following equation:

$$I = I_0 e^{-\mu x}$$

$$x = -\frac{1}{\mu} \ln\left[\frac{I}{I_0}\right]$$

'I_0' is the measured beta ray flux (counts) across clean filter tape, while 'I' is the flux (counts) across aerosol loaded filter tape. 'μ' is the beta ray absorption cross section (m^2 kg^{-1}). The absorption cross section 'μ' depends only on the mass of the absorbing species and not on its chemical composition and x is the mass density of the absorbing matter (kg m^{-2}). The absorption cross section is experimentally determined during the calibration process. Once 'I' and I_0

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