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Impact of meteorological parameters on the development of fine and coarse particles over Delhi

Dinesh Kumar Trivedi *, Kaushar Ali, Gufran Beig

Indian Institute of Tropical Meteorology, Pune 411 008, India

HIGHLIGHTS

- Distribution of air particulate matters' concentration during December, 2010-November, 2011 has been examined over Delhi.
- Role of meteorological parameters on the development of particulate matters has also been investigated.
- Usually, diurnal variation shows two maxima with one during day and other during night.
- There is highly significant relation between PM_{10} and $PM_{2.5}$ on intra-seasonal scale but no relation on inter-seasonal scale.
- Meteorology has played important role on the observed seasonality in the concentration of PM_{10} and $PM_{2.5}$.

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ABSTRACT

Measurements of ambient particulate matters (viz., PM_{10} and $PM_{2.5}$) were made with an hourly sampling frequency at Indian Institute of Tropical Meteorology (IITM), New Delhi Branch (a residential area) during a period from December 2010 to November 2011. The data so generated were analyzed to understand frequency distribution of their concentrations and the impact of meteorological parameters on the distribution of particulate matters on different time scales. It is found that the particulate matters with cut off aerodynamic diameter of 10 μm (PM_{10}) preferentially occurred in the concentration range of 301–350 μg/m^3 during winter and post-monsoon, 251–300 μg/m^3 during summer and 51–100 μg/m^3 during monsoon season. The particulate matters with cut off aerodynamic diameter of 2.5 μm ($PM_{2.5}$) preferentially occurred in the concentration range of 201–250 μg/m^3 during winter and 51–100 μg/m^3 during the remaining seasons. The concentration of particulate matters (PM_{10} and $PM_{2.5}$) remained always above the National Ambient Air Quality Standards (NAAQS) except during monsoon season.

Annual distribution of the concentration of particulate matters showed seasonality with maximum in winter and minimum in monsoon season. Diurnal variation of PM_{10} and $PM_{2.5}$ showed bimodal distribution with one maximum in the forenoon and the other at around mid-night. The observed seasonality and diurnal variability in the distribution are attributed mainly to the meteorology.

1. Introduction

Urbanization on increased scale has resulted in mobilizing common public as well as government agencies to increase anthropogenic activities in major cities, especially in developing countries. These activities have been adding air pollutants on accelerated scale to the existing air quality. Vehicular movement on roads is one of the major activities of concern with regard to air pollutants' emission. Sizeable numbers of vehicles moving on the roads are old, possess inadequate infrastructure and use fossil fuel of low quality. Emission of gaseous as well as particulate pollutants from such vehicles may be uncontrollable. Other major anthropogenic activities are establishment of small to large scale industries, thermal power plants, etc. and the sources of pollutants' emission are combustion of coal, biomass, bio-fuel and fossil fuel. Although particulate matters emitted from anthropogenic activities form only a small fraction of the natural emission, but its potentiality to pollute air is well recognized.

Many scientific studies have linked particulate matters' breathing to a series of significant health problems including aggravated asthma, increase in respiratory symptoms like coughing and difficult or painful breathing, chronic bronchitis, decreased lung function, cardio-vascular disease, and premature death. Recently, many studies have shown statistically significant and robust association between respiratory health and inhalable particulate matters (Lippmann, 1989; Dockery et al., 1992, 1993; Monn et al., 1995; Pope et al., 2002; Valavanidis et al., 2013). Many epidemiological studies since the last two decades conducted around the world have found association between ambient particle

* Corresponding author at: Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pashan, Pune 411008, Maharashtra, India. Tel.: +91 20 25904222; fax: +91 20 25865142.
E-mail address: trivedi@tropmet.res.in (D.K. Trivedi).

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concentration and excess in daily mortality and morbidity (Pandey et al., 2013; Reyna et al., 2012; Tie et al., 2009; Katsouyanni et al., 1997).

Apart from health hazards, aerosols play vital role on climate through their impact on radiative balance and aerosol–cloud interaction. Many studies in the recent decades have shown significant impact of tropospheric aerosols on climate (Mitchell, 1971). Charlson et al. (1991) made an estimate of cooling effect of sulfate aerosols, and concluded that sulfate cooling may be comparable to anthropogenic greenhouse warming over the northern hemisphere. On the other hand, absorption of solar radiation by black carbon and some organics increase atmospheric heating and tend to amplify greenhouse warming of the atmosphere (Bond et al., 2013; Ramanathan and Feng, 2009). Also, atmospheric aerosols affect the climate indirectly by acting as cloud condensation nuclei and thereby affecting cloud microphysical and radiative properties (Spracklen and Rap, 2013; Twomey, 1977).

Atmospheric aerosols are highly dynamic. They have large spatio-temporal variability. Adequate understanding of spatio-temporal variability of particulate matters (coarse and fine particles) and their sink mechanisms are needed to know their impact in health hazards, particularly in urban areas, and climate change. Air pollution is suppressed or enhanced by the meteorology of the location. It is known that stable air is associated with near surface pollution buildup while unstable air is associated with near surface pollutant cleansing. The importance of air pollution has attracted many studies in the recent decades towards understanding the spatio-temporal distribution and the effect of meteorology on the evolution of particulate matters (Ali et al., 2012, 2013; Gugamsetty et al., 2012; Colbeck et al., 2011; Dubey and Pervez, 2008; Xu et al., 2008). However, most of the works on air pollution for Delhi region are either limited to a short period or with no emphasis on the impact of meteorology. Delhi is the seventh most populous megacity in the world, where more than 100,000 petrol and diesel consuming vehicles add annually to the roads (Department of Transport, Delhi, 2007). Apart from this, the area has several small to large industrial establishments and thermal power plants. Hence, the present research work is aimed at portraying particulate pollutants' scenario in Delhi and understanding how the prevailing meteorology of the region contributes to this scenario in individual seasons, namely winter (December–January), summer (April–May), monsoon (July–August) and post-monsoon (October–November) of the year 2011.

2. Measurement technique and data

Commonwealth Games (CWG-2010) was one of the biggest recent sports events in Delhi, India. During the CWG-2010, many international athletes joined the sports events and the air quality was a major concern to which several efforts were taken up by the Indian Government and researchers. A sustainable program named "SYSTEM OF AIR QUALITY FORECASTING AND RESEARCH (SAFAR)" was built exclusively for CWG-2010 covering Delhi-NCR (http://safar.tropmet.res.in/). Under the aegis of this program, network of Air Quality Monitoring Stations (AQMS) were set up across Delhi which continued to monitor criteria pollutants over Delhi even after the GAME was over. The present study is based on measurements of the concentration of PM_{10} and $PM_{2.5}$ over Indian Institute of Tropical Meteorology, New Delhi Branch (28°37′ N, 77°12′ E, 217 m amsl). Meteorological parameters like wind speed, air temperature, relative humidity, planetary boundary layer height, soil moisture and vertical velocity for Delhi region were taken from the National Center for Environmental Prediction (NCEP) final analysis.

PM_{10} and $PM_{2.5}$ were continuously monitored using Beta Attenuation Monitor (BAM-1020; Met One Instruments, Inc., USA) which uses industry-proven principle of beta ray attenuation. The measurement principle involves emission, by a small 14C (carbon-14) element, of a constant source of high-energy electrons known as beta rays through a spot of clean glass fiber filter tape. These beta rays are detected and counted by a sensitive scintillation counter to determine a zero reading. The BAM-1020 automatically advances this spot of tape to the sample nozzle where a vacuum pump then pulls a measured and controlled amount of dust-laden air through the filter tape loading it with ambient dust. This dirty spot is placed back between the beta source and the detector thereby causing an attenuation of the beta ray signal which is used to determine the mass of the particulate matter on the filter tape and the volumetric concentration of particulate matter in the ambient air. Though the measurement technique for both kinds of particulate matters is same, the equipment measuring $PM_{2.5}$ utilizes an additional inlet which allows only the particles with cut off aerodynamic diameter of 2.5 μm and hence this set of equipment measures $PM_{2.5}$ particulate matters only. The instrument measures concentration of ambient aerosols with a resolution of 0.1 μg/m^3 and lower detection limit of around 1 μg/m^3. Span check of the instrument is automatic and is verified hourly (Kindly see BAM-1020 Operation Manual for more details).

Data on meteorological parameters for Delhi are extracted from the National Center for Environmental Prediction (NCEP) final (FNL) analysis. These data represent values of the meteorological parameters averaged over one grid box area around the observational site at Delhi and are assumed to produce reasonable values for a point in the grid box on seasonal scale. It may be noted that NCEP FNL Operational Global Analysis data are on 1° × 1° grids prepared operationally every six hours. This product is from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources, for many analyses.

3. Results and discussion

3.1. Seasonal distribution of PM_{10} and $PM_{2.5}$

Fig. 1 shows distribution of PM_{10} for different seasons based on its daily average concentration. It is found that the concentration range from 105.4 to 624.4 μg/m^3 during winter, 100.7 to 442 μg/m^3 during summer, 22.8 to 235.8 μg/m^3 during monsoon and 105 to 583.1 μg/m^3 during post-monsoon. Average concentrations in individual seasons are 335 ± 117, 221.6 ± 77.1, 89 ± 46.6 and 315.7 ± 118.3 μg/m^3 during winter, summer, monsoon and post-monsoon respectively (hereinafter standard deviation is 1σ). Similar plots for $PM_{2.5}$ are shown in Fig. 2. It is seen in the figure that daily average concentration of $PM_{2.5}$ range from 80.7 to 470.1 μg/m^3 during winter, 40.6 to 144.7 μg/m^3 during summer, 16 to 124.7 μg/m^3 during monsoon and 53.1 to 407.8 μg/m^3 during post-monsoon. The seasonal average values are 221.1 ± 94.7, 86.4 ± 26.8, 58.5 ± 25.2 and 199.7 ± 94.2 μg/m^3 during winter, summer, monsoon and post-monsoon seasons respectively. Above figures reveal that particulate levels are highest in winter and lowest in monsoon season. The result dictates of major role of boundary layer lowering due to favorable weather conditions namely cooler air temperature and low humidity during winter and below cloud scavenging during monsoon season. Particulate matters' concentration in the post-monsoon season is initially nearly as low as observed during monsoon. It rises with the passage of days and takes about three weeks to reach in the vicinity of the average concentration observed in the post-monsoon season. Lower values of PM_{10} and $PM_{2.5}$ in the beginning of the post-monsoon season show signature of withdrawal phase of the southwest monsoon that sometimes lasts till the first week of October. Also, the average concentration of particulate matter obtained in post-monsoon season is comparable to that obtained in winter season. This may be because of climatologically similar meteorological parameters prevailing in the major parts of these two seasons.

3.2. Frequency distribution of PM_{10} and $PM_{2.5}$ concentrations during different seasons

Season wise frequency distribution of daily average PM_{10} concentrations in intervals of 50 μg/m^3 is shown in Fig. 3. The distribution shows peak concentration range at 301–350 μg/m^3 in winter (~19% occasion) and post-monsoon (~18% occasion), 251–300 μg/m^3 in summer (~28% occasion), and 51–100 μg/m^3 in monsoon season (~61% occasion).