



Gradients in PM_{2.5} over India: Five city study

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ABSTRACT

Keeping in view the growing interest in the air pollution attributed morbidity and mortality, this study investigates the levels of ambient fine particulate matter over the rapidly developing and agglomerating Indian cities. Despite several measures and pollution mitigation strategies being implemented over Delhi, it recorded the highest PM_{2.5} among all the study cities, across all the seasons, in all the times of the day. The annual mean ($\pm$ standard deviation) PM_{2.5} is found to be $\sim 37 \pm 17$, 51 ± 23 , 54 ± 36 , 80 ± 67 , 114 ± 86 over the cities of Chennai, Hyderabad, Mumbai, Kolkata and Delhi respectively. Winter season is the most hazardous among others, with almost all of its days exceeding the WHO threshold for daily mean PM_{2.5}. On annual and seasonal basis, the daily mean PM_{2.5} values exhibited a northward increasing trend. A gradual change in the shape of the PM_{2.5} diurnal variations is noticed with change in space and time. The demographic factors influencing the concentrations and the modulations by weather and other natural phenomena were thoroughly discussed. The statistics and analysis presented in the manuscript are highly useful for the policy makers to strategize their region-specific mitigation efforts.

1. Introduction

Ambient air pollution is one of the major contributor to Global Burden of Disease (GBD) and its stake has been increasing over last 25 years (Cohen et al., 2017). Among the ambient air pollutants, PM_{2.5} (here and in rest of the paper PM_{2.5} refers to the mass concentration of the air-borne pollutant particles having diameter less than 2.5 μm) is found to be strongly associated with human health (e.g. Pope III et al., 2002). Exposure to PM_{2.5} can lead to increased risk of various health disorders related to lung, cardio-pulmonary, cardiovascular and even mortality (Dockery et al., 1993; Ostro et al., 2008). In addition to the adverse health effects, PM_{2.5} is also responsible for its negative environmental, atmospheric and climatic impacts such as degradation of visibility, fog formation, altered cloud dynamics etc. Cohen et al. (2017) listed ambient PM_{2.5} as the fifth largest mortality risk factor for the year 2015 and estimated a 4.2 million PM_{2.5} attributable deaths. They attributed the raising levels of air pollution over low and middle-income countries as one of the potential reason for increasing trends in air pollution related deaths. Indian subcontinent, being one of the rapidly developing middle-income Asian countries, recorded 1.09 million PM_{2.5} attributable deaths per year according to Cohen et al. (2017). These attributable deaths and disability estimates require high spatially and temporally resolved accurate PM_{2.5} datasets.

Studies on atmospheric particulate matter (PM) are available across Indian sub-continent, mostly treating them as short-term atmosphere and climate forcers rather than air quality, environment and health degraders (e.g. Pillai et al., 2002; Sreekanth et al., 2007). Over the last decade, the alarming air quality situation and health concerns over India, caused by airborne PM, led to a variety of studies. They include (i) fixed station monitoring (e.g. Tiwari et al., 2012); (ii) emission inventory (Guttikunda and Calori, 2013); (iii)

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in-traffic exposures (Srimuruganandam and Nagendra, 2011; Apte et al., 2011); (iv) source apportionment (Kumar et al., 2001; Kar et al., 2010; Pant et al., 2015; Guo et al., 2017); satellite remote sensing of surface PM (Dey et al., 2012; Sreekanth et al., 2017); (v) exposure to fine particles and health response relationship (Tonne et al., 2017); (vi) air pollution trends (Gurjar et al., 2016); (vii) statistical modelling (Guttikunda et al., 2013) etc. Most of these studies are city and urban centric studies due to various reasons such as lack of infrastructural support and trained man power in rural areas. Also, clearly, there is a geographical bias with large number of air quality studies from northern part of India compared to that of South. Extensive air pollution studies were conducted around New Delhi (northern India), which the national capital city of India (Pant et al., 2015 and the references cited therein), might be due to its explosively polluted nature. Some of the limitations of the above mentioned studies are (i) being filter based studies, they lack information on the diurnal evolution of the PM; (ii) statistics and analysis based on PM_{10} (particulate matter having diameter less than $10\text{ }\mu\text{m}$) and SPM (suspended particulate matter), which are far less hazardous compared to $PM_{2.5}$ (iii) limited number of studies over southern part of India. In an attempt to overcome the listed shortcomings, the present study explores the comprehensive statistics on the $PM_{2.5}$ levels over five cities spanned across the length of the Indian sub-continent, using the real-time hourly $PM_{2.5}$. The temporal variations (at different scales) in $PM_{2.5}$ over the Indian megacities are showcased with discussion on the parameters influencing their levels.

2. Data and study locations

Open access to air quality data can support various individual and independent scientific and policy groups to combat and make informed decisions on tackling air pollution. Real time $PM_{2.5}$ concentrations from US diplomatic missions are made public over various cities in countries like China and India. Very few studies are available leveraging these data sets (San Martini et al., 2015; Mukherjee and Toohey, 2016; Sreekanth et al., 2017). BAM-1020 (Beta Attenuation Monitor; MetOne, USA), which is designated by the US EPA (Environmental Protection Agency) as Federal Equivalent Method (FEM) is used to measure the $PM_{2.5}$ under this monitoring program. More technical details on the instrument can be found at Chung et al. (2001) and Schweizer et al. (2016) and are not repeated here. Supplementary data on boundary layer heights are derived from MERRA-2 (Modern Era-Retrospective Analysis for Research and Applications) model. Further details on these datasets are presented in Sreekanth et al. (2017). Diurnal (daily) averages (24-h mean) of $PM_{2.5}$ and boundary layer heights are computed from the hourly observations, only if at least 75% (18 h) of the data is available in that particular day.

Nearly four years (Jan 2013–Oct 2016, 1400 days) of hourly $PM_{2.5}$ data over five India mega cities: New Delhi (DEL), Kolkata (KOL), Mumbai (MUM), Hyderabad (HYD) and Chennai (CHN) has been portrayed in the current study to understand its variability in time and space. The geographical locations of these megacities are shown in Fig. 1. DEL is having more number acceptable (as per the



Fig. 1. Geographical locations of the five India cities (study locations) laid on Google Earth.

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