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Spatial and temporal patterns of air pollutants in rural and urban areas of India

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ABSTRACT

In this study, we analysed spatial and temporal patterns of Suspended Particulate Matter (SPM) concentrations across India. We have also assessed MODIS-derived aerosol optical depth (AOD) variations to characterize the air quality and relate it to SPM, NO_2 and SO_2 in different areas. In addition, the pollutant concentrations have been mapped using geospatial techniques. The results indicated significant differences in air pollutant levels across rural and urban areas. In general, districts of central and northern India had relatively higher SPM concentrations compared to southern India. Out of the top ten SPM polluted districts in India, nine were located in the state of Uttar Pradesh (UP). We observed significant correlations between the SPM and AOD at different sites. Although spatial and temporal patterns of NO_2 and SO_2 matched AOD patterns, the correlation strength (r^2) varied based on location. The causes and implications of these findings are presented.

1. Introduction

The presence of particulate matter in the atmosphere can be attributed to both natural as well as anthropogenic processes. The nature of aerosols found in the Indian region may be different from those reported in the other parts of the world (Kulshrestha et al., 2001, 1999; Kafatos et al., 2006). Previously, atmospheric aerosols in Indian region were reported to have significant amounts of soil dust and carbonaceous compounds affecting radiative properties of atmosphere (Kulshrestha et al., 2009; Parashar et al., 2005). High loadings and re-suspension of soil dust lead to high levels of suspended particulate matter (SPM) in the Indian region (Kulshrestha, 2013). The incidents of forest fires also contribute significantly to the emission of carbonaceous aerosols in the country (Vadrevu et al., 2012). Radiative effect of atmospheric aerosols is believed to be of the same magnitude as greenhouse gases (Andreae, 2001). Aerosol components such as black carbon (BC) (Babu et al., 2002), are known to have a warming effect on global climate due to absorption of radiation, whereas others such as, sulphate, organic matter (OM) and mineral matter, cause cooling in the atmosphere as they scatter radiation (Charlson et al., 1992, 1999). Fossil fuel consumption and vehicular emissions along with large industrial point sources add to elevated aerosol fluxes over northern and western India (Reddy and Venkataraman, 2002). The unique variation of energy use across different regions gives rise to temporal and spatial patterns of aerosols distribution over India affecting aerosol optical depth (AOD). AOD is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption between the point of observation and the top of the atmosphere. It is a measure of the integrated columnar aerosol load and the single most important parameter for evaluating direct radiative forcing (Kaufman et al., 1997). AOD can be determined from the ground through measurements of the spectral transmission of solar radiation through the atmosphere using rather simple and relatively inexpensive instruments pointed directly at the sun called sun-photometers or filter radiometers. Routine ground based AOD observations are of utmost importance for the calibration and validation of AOD retrievals from satellites (Chu et al., 2002; Ichoku et al., 2002).

In this study, we present the spatial and temporal variations in SPM over the Indian region. We report typical SPM values and MODIS-derived AOD, in different districts of India and compare levels of SPM in southern and northern India. Relationship between AOD and SPM has also been explored. In addition, we also assessed the relationship between AOD and other pollutants such as SO_2 and NO_2.

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2. Methodology

2.1. Study sites and pollution data

For analysis of the spatial distribution of SPM over the Indian region, eighty-nine districts were selected. These are the districts where ground monitoring of particulate matter is carried out by the Central Pollution Control Board (CPCB). AOD was derived for nineteen districts mostly from central and southern parts of the country. The number was brought down to nineteen from eighty-nine for the ease of calculations. The nineteen districts where AOD variations were studied were further classified as rural and urban. CPCB monitoring sites that are located in the cities were termed as urban. Sites without any important source of anthropogenic emissions in the neighbourhood (approximately 10 km buffer) were termed rural and are representative of the surrounding countryside. More specifically, out of the nineteen districts, four were classified as rural: Palakkad (Kerala), Dimapur (Nagaland), Rayagada (Orissa), Tirupathi (Andhra Pradesh) and the rest as urban. Rural sites are the places with relatively low population density and industrial activities. The other fifteen districts were classified as urban because of high industrial density contributing to a high level of emissions. A comparison between AOD, SO_2, NO_2 and other pollutants was also made at the rural and urban sites.

2.2. MODIS aerosol optical depth (AOD)

We used the MODIS Collection (MYD08_M3.051) 5.1 AOD at 550 nm for characterizing AOD variations. MODIS acquires daily global data in 36 spectral bands from visible to thermal infrared (29 spectral bands with 1 km 5 spectral bands with 500 m. and 2 spectral bands with 250 m. nadir pixel dimensions). The MODIS sensor is on-board the polar orbiting NASA-EOS Terra and Aqua satellites with equator crossing times of 10:30 and 13:30 Local Solar Time, respectively. Aerosol retrievals from MODIS data are performed over land and ocean surfaces by means of two separate algorithms described in literature (Kaufman and Tanre. 1998; Kaufman et al., 2005). The aerosol properties are derived by the inversion of the MODIS-observed reflectance using pre-computed radiative transfer look-up tables based on aerosol models (Remer et al., 2005; Levy et al., 2007). For this study, we specifically used the Level 3 monthly mean product from Aqua spanning different districts to understand spatial and temporal variations in relation to SPM. The data is available online and obtained from https://lpdaac.usgs.gov/lpdaac/get_data/wist etc.

2.3. Data analysis

In order to characterize aerosol distribution over the Indian region, SPM values for all three years viz. 2004, 2005, 2006 were obtained from the CPCB, Government of India (http://www.cpcb.in), and were mapped using ArcMap (version 9.3). Values for SO_2 and NO_2 were also obtained from CPCB for the year 2005 which were used to find out the correlation between other air quality parameters. In the analysis, air quality data was also correlated with the population densities of the districts (Fig. 8a,b) obtained from the population census (http://censusindia.gov.in/2011-prov-results/data_files/). Corresponding to SPM data for different districts, MODIS AOD data were obtained from LPDAAC website for analysing correlations (see Fig. 9).

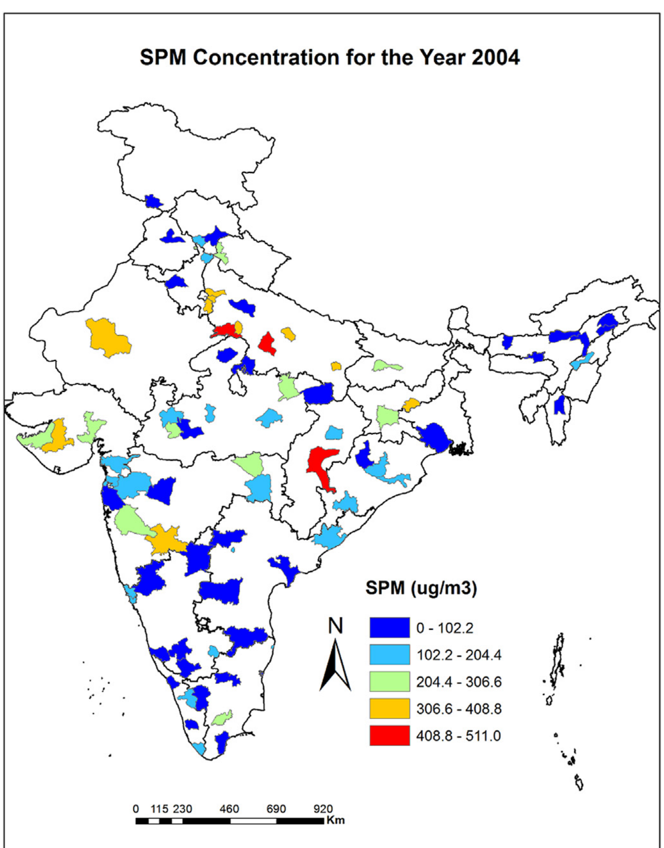

Fig. 1. Variation of SPM over Indian region for the year 2004.

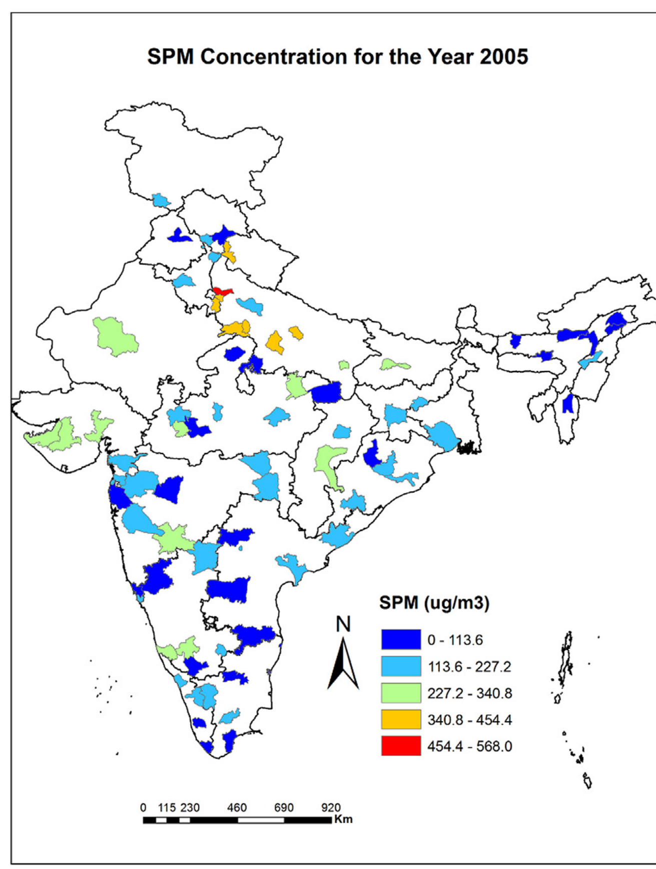

Fig. 2. Variation of SPM over Indian region for the year 2005.