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Assessment of particulate matter variation during 2011–2015 over a tropical station Agra, India

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HIGHLIGHTS

- Daily average and seasonal variations of RSPM and SPM were analysed over a period of 2011-2015 at Agra.
- Back Trajectory analysis was done to analyse the aerosol pathways associated with air mass transport.
- Wavelet analysis was employed to assess the periodicity in the time series data.
- Role of transported pollution at study site Agra has been analysed seasonally.

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ABSTRACT

Air quality over Agra is deteriorating and causing a serious threat to people residing in the city as well as to World heritage site- Tajmahal. In the present study, daily average concentrations of Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) were analysed over a period of 2011–2015 at four stations in Agra city, namely: Taj, Itmad-Ud-Daula, Rambagh and Nunhai. The concentrations are above threshold values when compared to specify standards for a healthy environment (by India, US, WHO, EU and China - Class I and Class II) for all the seasons except monsoon and the values are highest in the month of November and lowest in the month of August and September. Variation of RSPM and SPM were found to be positively correlated with each other with values of 0.76 (Taj), 0.72 (Itmad-Ud-Daula), 0.69 (Rambagh), 0.77 (Nunhai). The study illustrates that the levels of SPM and RSPM are not showing any decreasing trend over Agra even after closing of industries and taking other precautions inside the city by Government of India. The study clearly identifies that local control of pollution sources are not enough and pollution is being transported from nearby regions to keep the daily pollution value higher than threshold. Source regions of transported pollutants over Agra have been analysed by using Weighted Potential Source Contribution Function (WPSCF) for both SPM and RSPM. Wavelet analysis of monthly averaged values of RSPM and SPM data sets has shown the existence of semi-annual and annual periodicity over the study region.

1. Introduction

The presence of foreign particles, gases and other pollutants in the air in such concentration which is harmful to living entities and environment is termed as air pollution (WHO Online Ref.; Schmale et al., 2014). Constituents like Nitrogen dioxide, Ozone, Sulphur dioxide, Respirable Suspended Particulate Matter (RSPM) and Suspended Particulate Matter (SPM) are considered to be as main atmospheric pollutants and play an important role in affecting the human health, global environment and climate change (Schmale et al., 2014). Globally the proportions of these constituents are increasing rapidly due to increased vehicular pollution, urbanization, population, and industrialisation (Karagulian et al., 2015). Size and chemical composition of particulate matter (PM) have strong influence on the human health and environment, altering radiation budget by absorption and scattering (Ram and Sarin, 2012, Meena et al., 2014; Pipal et al., 2014c, Chitranshi et al., 2015).

Agra, heritage city of India is situated in the state Uttar Pradesh of India. It is the place where one of the seven wonders of world – Taj Mahal is situated. Assessment of air quality and aerosol load over Agra has always been an issue of prime concern by researchers

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and policy makers and it has been observed that values of aerosol loading is mostly higher than threshold values (e.g. Central Pollution Control Board (CPCB) report 2006; Safai et al., 2008; Kulshrestha et al., 2009; Singh et al., 2010; Dey et al., 2012; Pipal et al., 2014a; Meena et al., 2014; Chitranshi et al., 2014; Saini et al., 2014). It has been found that this increased PM concentration is affecting the monument adversely (Hicks and Kumari, 1987; Bergin et al., 2015). To provide a cleaner environment to public and to protect Taj Mahal, Government of India has taken strict measures in the past decade. Major actions being taken up for cleaner environment involves (i) usage of natural gas for the production processes, (ii) Continuous monitoring of existing industries which use coal or coke near the city boundary and no permission to new industries which use coal and coke inside the city area, (iii) Shut down of all the brick industries within a radius of 20 km of Agra city, (iv) Fitting scrubbers to diesel driven vehicles and use of low sulphur content diesel, (v) Restriction on usage of cars within a radius of 2 km from the monument to protect Taj Mahal, (vi) Use of battery driven/electric cars for the tourists (CPCB report, 2006).

The present study aims at assessment of SPM and RSPM concentration in Agra over a period of 2011–2015, and focused on finding an answer to the question: “Whether the measures implemented by Govt. of India on a local scale are improving air quality over Agra city?” We have analysed temporal (diurnal and seasonal) variation of RSPM and SPM concentration over Agra at four stations: Taj, Itmad-ud-Daula, Rambagh and Nunhai, over a period of 2011–2015, collected by Central Pollution Control Board (CPCB), Govt. of India. National Oceanic and Atmospheric Administration (NOAA) Hybrid Single Particle Lagrangian Integrated Trajectories (HYSPLIT) model (Draxler and Hess, 1998), which has been proven to provide a good model for back trajectory analysis (e.g. Fleming et al., 2012; Cheng et al., 2013; Chandra et al., 2014; Pipal et al., 2014c; Yadav et al., 2014) is employed in the present study to estimate long-range aerosol transport pathways to Agra. Source regions of transported pollutants over Agra have been analysed by using Weighted Potential Source Contribution Function (WPSCF) for both SPM and RSPM. Dispersion runs for cases during study period over the study regions are performed for understanding the dispersion patterns advecting over site. Use of wavelet analysis in the present study explores if there is any periodicity existing in the variation of RSPM and SPM over the study region.

2. Study area and data description

Agra (27.12° N, 78.17° E, 169 m above MSL), well known for one of the wonders of the world: Tajmahal, is situated in the state of Uttar Pradesh, India. Agra is a tropical, semiarid region with hot scorching summers and cold winters. The year has been divided into four seasons in the present study as pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February). The city is densely populated with the population density of 433 persons/km^2 (Census, 2011). River Yamuna is flowing through Agra city and Taj Mahal is situated on the west bank of Yamuna (Pipal et al., 2014a). Agra is surrounded by the Thar Desert from west to north-west (spatial distance ~ 300 km), and major cities including New Delhi in the north-west (spatial distance ~176 km), Firozabad in the east (spatial distance ~ 35 km), Mathura (spatial distance ~ 50 km), Hathras (spatial distance ~ 45 km), and Etah (spatial distance ~ 72 km) in the north-westerly to north-easterly direction.

CPCB has four monitoring stations in the city, namely: Taj (27.175° N, 78.0422° E), Itmad-Ud-Daula (27.1929° N, 78.031° E), Rambagh (27.2054° N, 78.0383° E) and Nunhai (27.2023° N, 77.78031° E). The location of Agra and zoomed on to four sites is shown in Fig. 1. Nunhai and Rambagh are highly industrialized areas, contributing to a remarkable growth in the concentration of pollutants. Various activities that contribute to air pollution over Agra other than vehicular emissions includes emissions from rubber processing, glass, and ferrous casting industries, biomass burning (Meena et al., 2014, Dayal et al., 2010).

The daily average concentration of RSPM (also can be called as $PM_{2.5}$) and SPM (also can be called as PM_{10}) at four sites: Taj, Itmad-Ud-Daula, Rambagh and Nunhai, collected by CPCB over a period of 2011–2015 are used in the present study. Wind data (3 hourly) from National Climate Data Centre (NCDC) (http://www.ncdc.noaa.gov/) has been used for analyzing wind roses to get a picture of wind speed and direction variation over Agra during period of study.

Back Trajectory and dispersion analysis has been performed using National Centres for Environment Prediction (NCEP)/National Centre for Atmospheric Research (NCAR) GDAS (Global Data Assimilation System) 1^{O} data and HYSPLIT 4 model June 2015 release (svn:761) (Stein et al., 2015; Draxler, 1999; Draxler and Hess, 1997). GDAS 0.5° data is missing vertical velocity and it has been found out recently by Su et al. (2015) that GDAS 1° data is better in computing back trajectories compare to GDAS 0.5° data because of this reason. Hence we have used GDAS 1° data only in present study. Therefore our model configuration for trajectory runs can be summarized as follows: Model version: HYSPLIT 4 model June 2015 release (svn:761), with Input data: GDAS 1^{O} data, Run time: −48 h for each 6 h interval, Model domain: not fixed with boundaries. Trajectories are allowed to go the extent they can move in the global domain, Trajectories computation method: Isentropic trajectories, Model altitude for trajectory computation: 500 m above ground layer (AGL), and Model top for trajectory computations: 10000 m AGL.

For dispersion runs also, we have used GDAS 1° data. The model has been allowed to use a deposition of 0.1 cm/s with a release top of 50 m AGL and release bottom at 0 m AGL. We have assumed that a unit mass has been released for 1 h at 12 UTC of the day and 24 h backward dispersion has been computed with averaging period of 6 h with top of averaged layer at 100 m AGL. For dispersion case studies, we have run online version of HYSPLIT (Rolph, 2016).

3. Methodology

3.1. Weighted Potential Source Contribution Function (WPSCF)

Back trajectory analysis was done over Agra for the four seasons to analyse the aerosol pathways from different sources at an altitude of 500 m above the ground level using HYSPLIT 4 model (Draxler and Hess, 1998). 48 h air mass isentropic back trajectories at Agra at an interval of 6 h (i.e. 00, 06, 12 and 18 UTC of every day) have been computed to analyse the long-term transport of aerosols from different regions. There are various methods for analysing back trajectory statistics, popular ones including- Concentration Weighted Trajectory (CWT) and Potential Source Contribution Function (PSCF). Both are trajectory statistical methods and it has been found by ensemble average correlation coefficient study that PSCF calculations are better than CWT (Kabashnikov et al., 2011). It is also found that both PSCF and CWT analysis are good in identifying the major source regions but performing different in identifying the moderate sources (Xin et al., 2016). The PSCF value for a given grid cell can be calculated by endpoints of trajectories in that grid cell. PSCF can be defined as (Han et al., 2007, Xu and Akhtar, 2010):

$$\mathrm{PSCF}(i,j) = (a_{i,j}/b_{i,j}) \quad (1)$$

$b_{i,j}$ and $a_{i,j}$ are the total number of back trajectory endpoints falling