Atmospheric Environment 62 (2012) 551–561

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Application of SIM-air modeling tools to assess air quality in Indian cities

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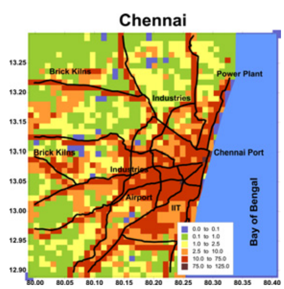
HIGHLIGHTS

- ► An overview of the SIM-air modeling system to assess urban air quality.
- ► A multi-pollutant emissions inventory for six cities in India.
- ► An analysis of sectoral contributions and health impacts of particulate pollution.
- ► A review of pollution control strategies and their implications.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 May 2012
Received in revised form
27 August 2012
Accepted 29 August 2012

Keywords:
Particulate pollution
Pune
Chennai
Indore
Ahmedabad
Surat
Rajkot
India
Emissions inventory
Dispersion modeling
Air quality management

ABSTRACT

A prerequisite to an air quality management plan for a city is some idea of the main sources of pollution and their contributions for a city. This paper presents the results of an application of the SIM-air modeling tool in six Indian cities – Pune, Chennai, Indore, Ahmedabad, Surat, and Rajkot. Using existing and publicly available data, we put together a baseline of multi-pollutant emissions for each of the cities and then calculate concentrations, health impacts, and model alternative scenarios for 2020. The measured annual PM_{10} (particulate matter with aerodynamic diameter less than 10 micron meter) concentrations in μg m^{-3} averaged 94.7 ± 45.4 in Pune, 73.1 ± 33.7 in Chennai, 118.8 ± 44.3 in Indore, 94.0 ± 20.4 in Ahmedabad, 89.4 ± 12.1 in Surat, and 105.0 ± 25.6 in Rajkot, all exceeding the annual standard of 60 μg m^{-3}. The PM_{10} inventory in tons/year for the year 2010 of 38,400 in Pune, 50,200 in Chennai, 18,600 in Indore, 31,900 in Ahmedabad, 20,000 in Surat, and 14,000 in Rajkot, is further spatially segregated into 1 km grids and includes all known sources such as transport, road dust, residential, power plants, industries (including the brick kilns), waste burning, and diesel generator sets. We use the ATMoS chemical transport model to validate the emissions inventory and estimate an annual premature mortality due to particulate pollution of 15,200 for the year 2010 for the six cities. Of the estimated 21,400 premature deaths in the six cities in 2020, we estimate that implementation of the six interventions in the transport and brick kiln sectors, can potentially save 5870 lives (27%) annually and result in an annual reduction of 16.8 million tons of carbon dioxide emissions in the six cities.

1. Introduction

Urban air pollution is a complex issue, fueled by multiple sources ranging from – vehicle exhaust, on-road resuspended dust due to vehicles, industrial flumes, construction dust, garbage burning, domestic cooking and heating, and some seasonal sources such as agricultural field residue burning, dust

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1352-2310/$ – see front matter
http://dx.doi.org/10.1016/j.atmosenv.2012.08.074

storms and sea salt (for coastal areas) (Shah et al., 1997; Fenger, 1999; Molina and Molina, 2004; Schwela et al., 2006; Speizer et al., 2008; Parrish and Zhu, 2009; Johnson et al., 2011). Accelerating growth in the transport sector, a booming construction industry, and a growing industrial economy are increasingly responsible for worsening air quality in Indian cities (CPCB, 2010). While city and national authorities are introducing steps to control ambient pollution, a lack of coherent policy as well as unplanned growth across sectors is exacerbating pollution levels in most Indian cities.

Studies that measure health impacts of pollution are effective in raising concern about air quality in India and serve as a call to action (Chhabra et al., 2001; Pande et al., 2002; HEI, 2004, 2010b; Wong et al., 2008; Balakrishnan et al., 2011). However, these are not specific in terms of identifying sources and their relative contributions to ambient pollution levels, much less the impact of various control strategies for a given city. For Indian states and cities, there are a few integrated models that collate information at the regional level (Shah et al., 2000; Balakrishnan et al., 2007; GAINS, 2010) and there are receptor modeling studies which identified source contributions (Balachandran et al., 2000; Chowdhury et al., 2007; Srivastava and Jain, 2007a,b; Srivastava et al., 2009; CPCB, 2010).

Often, studies cite lack of relevant and/or reliable data, lack of modeling and assessment capabilities, which hinder an accurate assessment of urban air quality and its management (Shah et al., 1997; Schwela et al., 2006; Johnson et al., 2011). In this paper, we present an overview of the SIM-air modeling tool and its application in six Indian cities – Pune, Chennai, Indore, Ahmedabad, Surat, and Rajkot, to establish an information base of multi-pollutant emissions, dispersion modeling for ambient particulate concentrations, an analysis of interventions, and a review of information gaps, especially those necessary to support an effective urban air quality management plan.

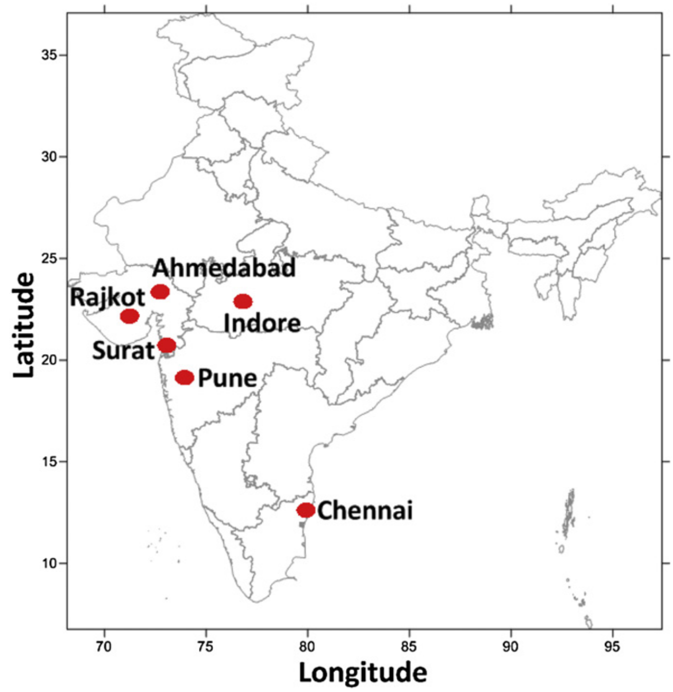

Fig. 1. Geographical layout of the six Indian cities in the study.

2. City background

We have defined the study domains for the six cities such that they are large enough to cover the main district area, the nearest satellite cities, and locations with sources that could influence the air quality in the populated district areas. Table 1 presents a summary of the city domains, sizes, population, monitoring stations, range of ambient PM_{10} levels, vehicle fleet, power plants, and brick kilns in the vicinity of the city district. PM_{10} refers to the particulate matter (PM) with an aerodynamic diameter less than 10 micron meter. We present the geographical location of the cities in Fig. 1 and the city maps with features such as, main roads, highways, points of interest, brick kiln clusters, industrial estates, power plants (for three cities – Chennai, Ahmedabad, and Surat) and an approximate main district boundary are presented in Supplementary Figures S1–6. The large patches in the city maps of Chennai and Surat indicate the Bay of Bengal and the Arabian Sea respectively; and the smaller in-land patches in Pune, Chennai, Indore, and Rajkot indicate lakes and dams.

Table 1
Summary of the geographical layout, monitoring data and emission sources for year 2010 for the six Indian cities.

	Pune	Chennai	Indore	Ahmedabad	Surat	Rajkot
Study domain size (km × km)	32 × 32	44 × 44	32 × 32	44 × 44	44 × 44	24 × 24
Longitude (degrees)	73°48′E	80°16′E	75°32′E	72°35′E	72°50′E	70°47′E
Latitude (degrees)	18°28′N	13°52′N	22°25′N	23°02′N	21°10′N	22°18′N
Land–Sea breeze	NO	YES	NO	NO	YES	NO
Elevation (m)	560	7	550	53	13	134
Domain population (million)	6.5	8.5	3.3	7.8	5.0	1.4
City area (square km)	450	1200	134	700	105	310
Number of monitoring stations	5	6	3	6	3	2
Annual average PM_{10} (μg m^{-3})	60–160	60–120	60–170	80–100	75–100	80–120
$PM_{2.5}$ measurements	Limited	Limited	NO	Limited	NO	NO
Vehicle fleet (millions)	2.3 (2008)	3.8 (2010)	1.2 (2010)	1.4 (2010)	1.3 (2007)	1.1 (2010)
Cars and Jeeps	323,400	565,350	127,300	213,500	132,750	126,700
2 Wheelers	1,708,100	2,986,600	907,000	1,038,000	1,063,000	878,000
3 Wheelers	66,500	55,400	14,000	65,500	65,400	8860
Buses + Stage carriers	15,100	15,600	35,200	5400	1900	79
HDV + LDV + Others	151,730	123,920	93,200	75,860	69,840	46,900
Power plants	NO	YES (2)	NO	YES (2)	YES	NO
Power plants (main fuel)	–	Coal	–	Coal	Gas	–
Brick kilns (number)	400	600	120	320	200	–
Brick kilns (type)	Clamp	Bull trench	Clamp	Clamp	Clamp	–