Simple Interactive Models for Better Air Quality

An Analysis of Health and Carbon Benefits Using Integrated Air Pollution Modeling for Pune, India

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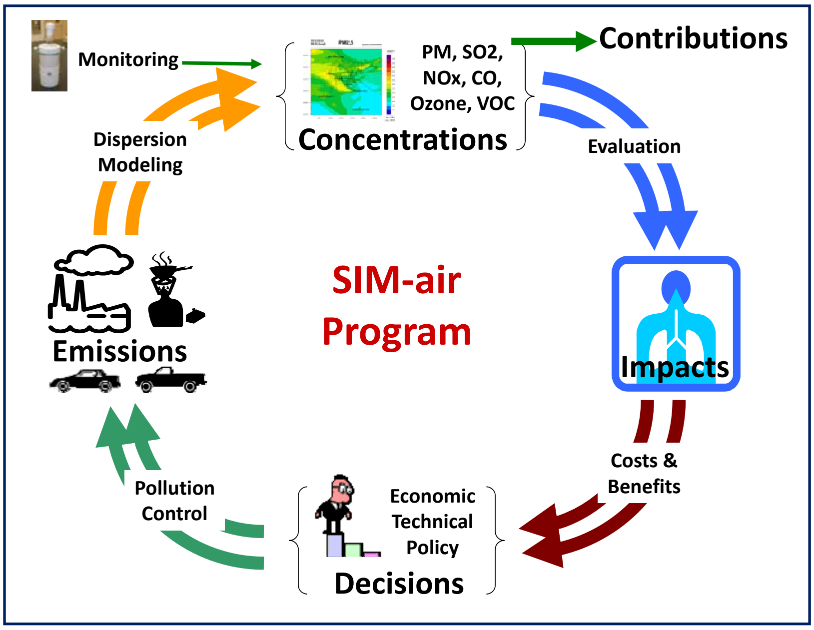
SIM-Series
No.37
2012

Pune city, located ~160 km east of the Greater Mumbai city (Maharashtra state), is located on the Deccan Plateau, at the confluence of Mula-Mutha rivers and at an elevation of ~560 meters above the mean sea level. The geographical administrative area of Pune city is ~450 square km and is known for several universities and educational institutions. It also has a well-established manufacturing, glass, sugar, and forging industries since the 1950-60s. Recently, the information technology (IT) and the auto industry have grown substantially. The Hinjawadi IT Park (officially called the Rajeev Gandhi IT Park) is a project started by Maharashtra Industrial Development Corporation (MIDC)[1]. Similar IT parks constructed under the SEZ schemes including the Magarpatta city to the east of the city with close to 5,000 households residing in the area. Automotive companies like Tata Motors, Mercedes Benz, Force Motors (Firodia-Group), Kinetic Motors, General Motors, Volkswagen, and Fiat have manufacturing facilities in and near Pune. Several automotive component manufacturers like Saint-Gobain Sekurit, TATA Autocomp Systems Limited, Robert Bosch GmbH, ZF Friedrichshafen AG, Visteon, and Continental Corporation also set up facilities in and around Pune.

Accelerating growth in the transport sector, a booming construction industry, and a growing industrial sector are responsible for the bad air quality in the city. While the estimates of health impacts are effective in raising overall concern about air quality, they do not specifically answer the question of where and how much pollution is coming from various sources. Further uncontrolled growth will lead to more pollution and require large recurring investments to control.

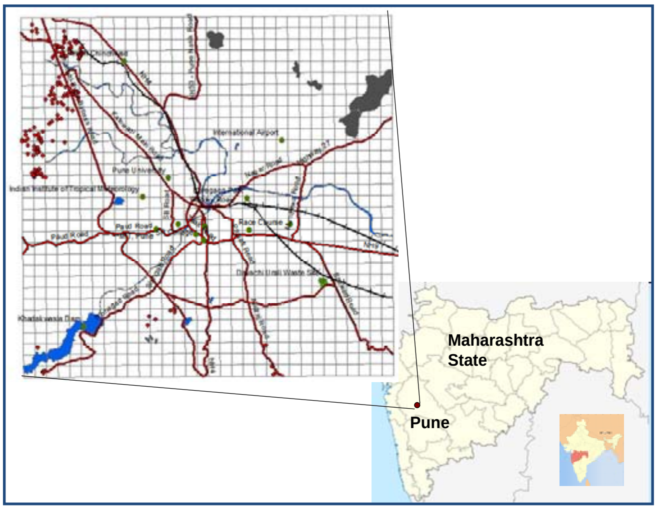


This study under ***the SIM-air program***[2] was initiated with support from the Climate Works Foundation (USA) and the Shakti Sustainable Energy Foundation (India) to better understand the sources of air pollution in the Pune city, to support an integrated dialogue between local pollution management and climate policy in a co-benefits framework. This study was carried for six cities – Pune in Maharashtra, Chennai in Tamilnadu, Indore in Madhya Pradesh, and Ahmedabad, Surat, and Rajkot in Gujarat states.

For the Pune city, a study domain of 32km x 32km was selected, which is large enough to cover the main district area, the nearest satellite city of Pimpri Chinwad, and cluster locations with sources that could influence the air quality in the main district areas. An executive summary of the city layout, geography, vehicle fleet, and air quality data, are presented in the following table.

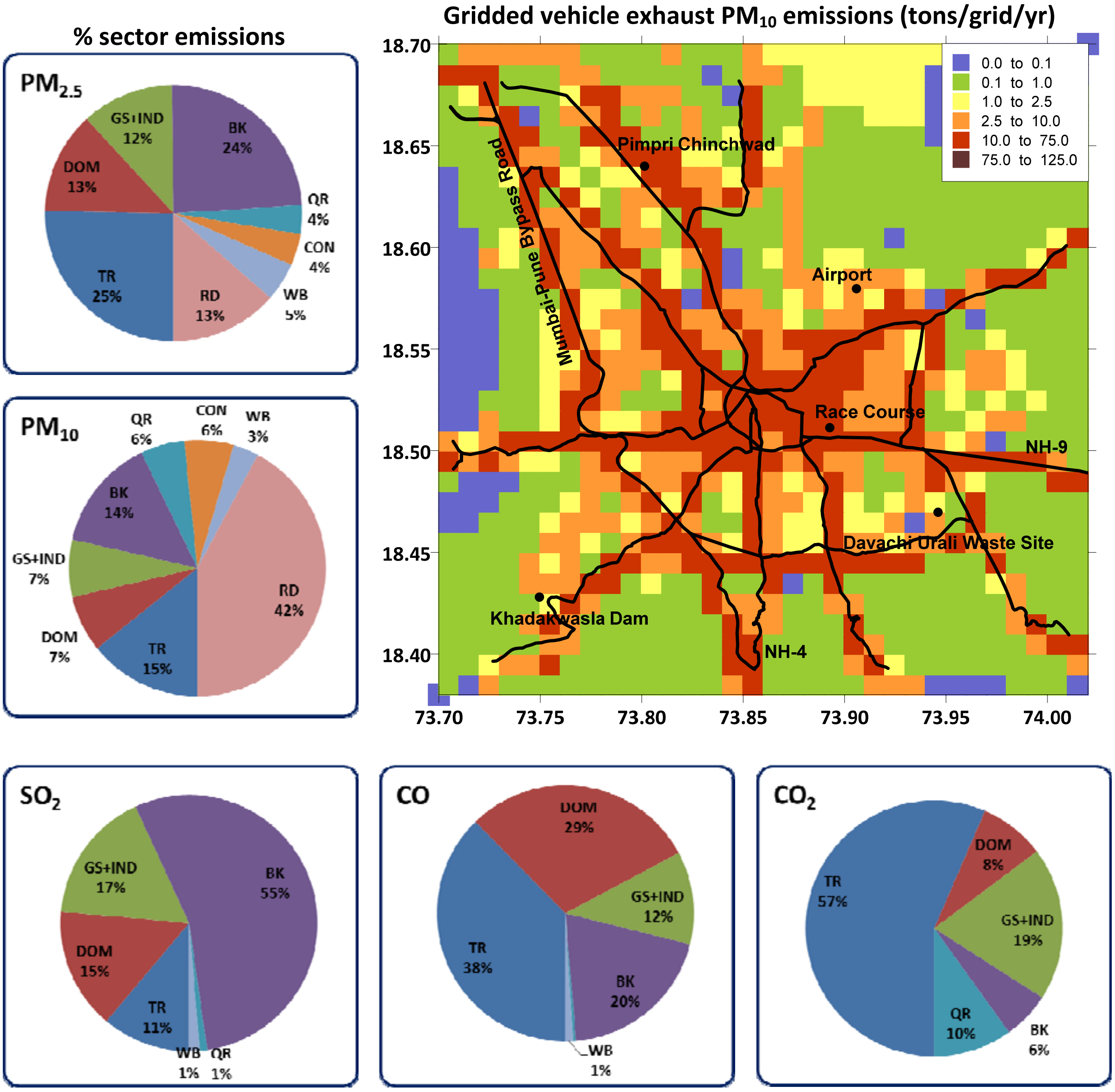
City at a Glance	Pune
Study domain size (km x km)	32 x 32
Longitude (degrees)	73°48'E
Latitude (degrees)	18°28'N
Land-Sea Breeze	NO
Elevation (meters)	560
domain Population (million)	6.5
City area (square km)	450
Power plants	NO
Installed capacity (MW)	-
Dominant fuel	NA
Industrial Estate	Medium
Brick Kilns – Bull Trench	NO
Brick Kilns (number)	400
Annual average PM$_{10}$ ($\mu g/m^3$)	60-160
Number of monitoring stations	5
PM$_{2.5}$ measurements	Limited
Vehicle Fleet (millions)	2.3 (2008)
(numbers rounded) Cars and Jeeps	323,400
2 Wheelers	1,708,100
3 wheelers	66,500
Buses + Stage Carriers	15,100
HDV + LDV + Others	151,730
% HDV of trucks	26%
% 2 Wheelers in total fleet	75%
% Cars in total fleet	14%

The main objectives of this study are (a) to establish a baseline emissions inventory for the criteria pollutants PM, SO_2, and NO_x, and the greenhouse gas (CO_2) from the known sources of air pollution (b) to analyze pollution due to these emissions and associated health impacts, based on dispersion modeling for the selected city domain (c) to analyze select interventions (from emissions and pollution perspective) for health benefits and GHG emission reductions and (d) to identify information gaps while building the emission inventories, which could further our understanding of air pollution sources in the city. While the definition of co-benefits framework varies, in this study, we used the local air pollution (particulate pollution) and related health impacts as the primary indicator, followed by GHG emission reductions.



An emissions inventory for the city of Pune was developed for all known sources ranging from the vehicle exhaust (passenger and freight), re-suspension dust on roads, domestic fuel combustion, industrial fuel combustion, in-situ diesel generators, and waster burning, for the base year of 2010. The city level emissions inventory if further segregated into 1km x 1km grids, presented in the above figure. Also represented in the figure are the main highways passing through the city, water dams and main streams (in blue), major brick kiln clusters (as red dots), and stone quarries (in black) to the east of the city.

Annual emissions for the base year 2010 are estimated at ~36,600 tons of PM_{10}, ~16,600 tons of $PM_{2.5}$, ~3,600 tons of SO_2, ~127,500 of NO_x, ~438,000 tons of CO, and ~13.4 million tons of CO_2. The percentage shares of contributing sectors are presented in the figure below, along with a representation of the gridded vehicle exhaust emissions.



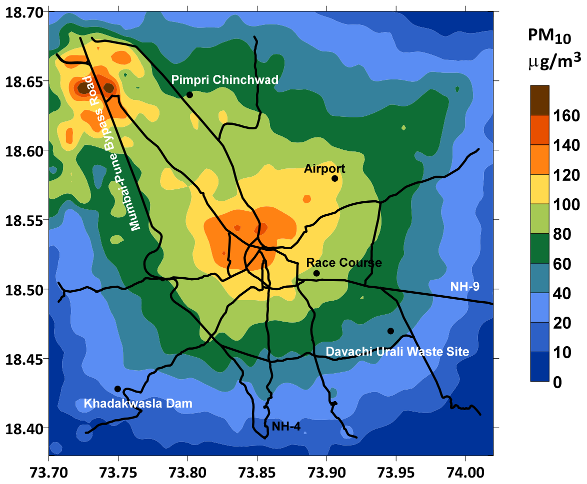
The PM_{10} emissions are dominated by re-suspension of dust on the roads, due to vehicular movement, followed by the vehicle exhaust, brick kilns, industries, domestic fuel burning, and waste burning. However, in case of the fine particulate matter, $PM_{2.5}$, the most harmful of the particulate fractions, vehicle exhaust, brick kilns, industries, and domestic fuel burning dominate the emissions followed by road dust. The road dust particles are traditionally large and mostly fall under the coarse (PM_{10}) fraction. The industrial estates are mostly located between the Pune city and the satellite city of Pimpri Chinchwad. The pie diagrams present the combined contribution of industries and the diesel generator sets (DGs), which are prevalent in the city due to regular power shortages. The DGs are a common sight at most of the hotels, hospitals, large institutions, apartment complexes, malls, markets, and the industries; which also contribute significantly to the SO_2, CO, and

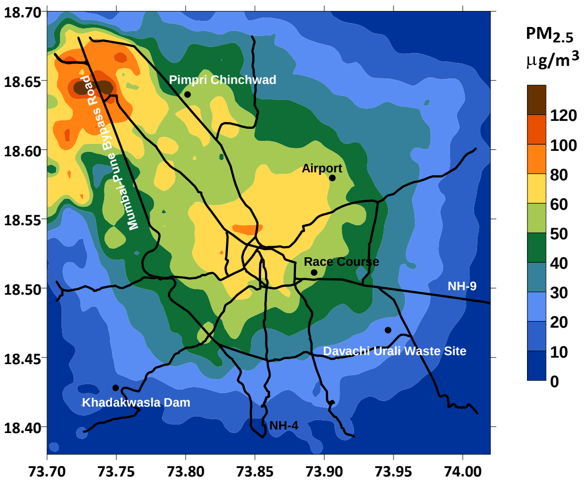
NO_x emissions. The domestic emissions are estimated for a varying mix of fuel use – LPG, coal, kerosene, and wood, based on the national census data at the district level. The brick kilns, located to the west of Pimpri Chinchwad, are all clamp style, one of the most inefficient methods in use for baking clay bricks, in which bricks are laid down with fuel burnt as a pile. These emissions are low-lying sources and consequently are as worse as vehicle exhaust and road dust emissions on the ground. The fuel used in these kilns is also a concern, as it varies from coal to a mix of biomass and fuel oil. For example, during the harvest seasons, due to their proximity to the agricultural land, most of the field residue is used for burning at the brick kilns.

For the Pune city, in 2006-07, an emissions inventory was developed by the Air Quality Management Cell, an independent organization associated with the zonal pollution control board of Pune. This work was carried out as part of the PREIS program[3] with technical support from the United States Environmental Protection Agency (USEPA). As part of this effort, significant training and field study activities were conducted, which forms a baseline reference for this study. Following the PREIS study, in 2006-07, Ministry of Environment and Forests (MoEF) and Central Pollution Control Board (CPCB) of India, carried out particulate pollution source apportionment study in six cities – Delhi, Kanpur, Chennai, Mumbai, Pune, and Bangalore[4]. As part of the study, an emissions inventory was also developed (and published in January, 2011). The emissions estimated under for Pune account for 32.3 tons PM_{10} per day, 41.4 tons per day of NO_x, and 7.1 tons per day of SO_2. Since, this is below estimates from this study, it is important to note the methodology employed in developing these inventories by CPCB. The inventory is for the base year of 2006-07 and represents only the sources in the main city district. This does not include the areas surrounding the main district where the industrial activity is generally larger than the in-district activities. The inventories were primarily surveyed and estimated for an area of 2km x 2km around the monitoring site selected for the source apportionment study and then extrapolated to the city district area. This could lead to some bias in the final inventory, as the modeled concentrations will not account for the long-range transport of emissions within the vicinity of the city districts. In case of Pune, the CPCB’s inventory does not account for the brick kiln emissions, with clusters ~20 km away from the city district boundaries.

The spatial gridding of the emissions to 1kmx1km grids was carried out in ArcGIS software. The vehicle exhaust and re-suspension of road dust emissions were gridded using spatial parameters like road and population density, interlinking with the source locations like the hotels, hospitals, large institutions, apartment complexes, malls, markets, and the industries, which act as the hotspots spread across the city. The same hot spot locations are also utilized for allocating the respective emissions to the cells. The road network is further split into highways, main roads, and arterial roads, to account for the distribution of majority of the truck emissions along highways and passenger vehicles along the main and arterial roads.

The dispersion modeling was carried using the ATMoS model (the Atmospheric Transport Modeling System), previous utilized for similar studies in Asia[5]. The modeled annual average PM_{10} and $PM_{2.5}$ concentrations are presented in the figure below.





The modeled concentrations in the central district area ranged from 80 to 140 µg/m^3 and the measured concentrations from the five monitoring stations (operated by the Maharashtra State Pollution Control Board) ranged from 60 to 160 µg/m^3. It is important to note that this is not a direct point to point comparison, rather comparison of results over a year and for an area. For the central district, industrial areas, and the brick kiln clusters, the annual average concentrations for PM_{10} are above the national ambient standard of 60 µg/m^3. Due to limited information on the $PM_{2.5}$ monitoring data, there are no comparisons available at this time. The $PM_{2.5}$ fractions (in emissions) are vetted with the emissions factors pertinent to the sectors and the dispersion modeling is conducted in a manner similar to PM_{10}, with different physical and chemical characteristics. As and when, more monitoring data is available from these cities, the $PM_{2.5}$ results will be re-visited for calibration and further analysis. In the above figure most of the city district areas exceed the annual average standard of 40 µg/m^3 for $PM_{2.5}$ concentrations.

Mortality & Morbidity in 2010	**Pune**
Domain size (km x km)	32 x 32
Study Domain Population (million)	6.5
PM_{10} emissions (tons/yr)	36,600
Estimated	
Premature Deaths	**3,600**
Adult Chronic Bronchitis	10,800
Child Acute Bronchitis	79,250
Respiratory Hospital Admission	5,000
Cardiac Hospital Admission	1,350
Emergency Room Visit	97,800
Asthma Attacks (million)	1.2
Restricted Activity Days (million)	10.4
Respiratory Symptom Days (million)	49.7

The dispersion modeling results for PM_{10} annual average concentrations, overlaid on the gridded population at the same resolution are utilized for calculating the health impacts presented in the table[6]. The dose-response functions for various endpoints (listed in the table) were well documented in the studies across the world[7]. It is important to note that total population listed in the table is for the entire modeling domain, which extends beyond the city limits.

Pune city in 2020

Mortality & Morbidity in 2020	Pune
Domain size (km x km)	32 x 32
Study Domain Population (million)	7.6
PM_{10} emissions (tons/yr)	38,000
Estimated **Premature Deaths**	**4,300**
Adult Chronic Bronchitis	12,900
Child Acute Bronchitis	94,500
Respiratory Hospital Admission	6,000
Cardiac Hospital Admission	1,600
Emergency Room Visit	116,650
Asthma Attacks (million)	1.4
Restricted Activity Days (million)	12.3
Respiratory Symptom Days (million)	59.1

The emissions, dispersion, and health impacts analysis was extended to the year 2020, with assumptions for economic growth. In case of the transport sector, the passenger vehicles were extrapolated at ~8%, motorcycles at ~10%, and the remaining private sector vehicles like short buses, commercial vehicles, etc., at ~1%. The industrial sector is estimated to grow at ~10%. It is also assumed that the emission standards will improve in the coming decade, including an improvement of on-road conditions for the vehicle movement, which will inherently reduce the deterioration rates and thus the emission loads. Hence, vehicle numbers are increasing at ~10%, the emissions are expected to taper off.

Six "what-if" interventions were modeled for 2020 to study the associated benefits in terms of health and CO_2 emissions (1) an increase in the non-motorized (NMT) shares (2) an increase in the public transport shares (3) alternative fuels for public transport and the 3-wheelers (4) a reduction in the silt loading on the roads (5) a technology improvement in the brick kilns and (6) a facility to bypass heavy duty trucks away from the city limits.

Co-benefits in 2020	Pune
Estimated PM_{10} emissions reduced under what-if's (tons/yr)	13,900
% compared to 2020 baseline	37%
Premature deaths saved	1,700
% compared to 2020 baseline	39%
Mortality cost savings (million USD)	71
Morbidity cost savings (million USD)	114
Estimated CO_2 emissions reduced under what-if's (million tons/yr)	3.0

A summary of the combined benefits for the city in terms of health and CO_2 emissions, up on implementation of these six interventions is presented in the table to the right. In conclusion, the results of this study are intuitive. Policies that promote public transportation and allow for NMT result in lower pollution levels and lower greenhouse gas emissions. Promoting alternative transport options is not only environmentally sustainable but it is also a socially progressive policy. The brick kiln sector, though outside the city administrative limits, has a significant role in the co-benefits. Because of the mix of fuels (including biomass), other pollutants like Black Carbon, have a vital role to play in the climate policy. The garbage burning and linked toxic emissions need a management solution. The dust re-suspension on the roads due to the vehicular movement is the low-hanging fruit for immediate improvements in city's air quality.

This study only captures the health and CO_2 emission benefits, and does not even begin to quantify the various externalities that would spin off, including a more cohesive urban community, better health and equity.

References

** Dr. Sarath Guttikunda and Ms. Puja Jawahar are from the UrbanEmissions.Info, New Delhi, India. The analysis and reviews presented in this paper are entirely those of the authors. If you have any questions, feedback, and/or suggestions to improve the material, and/or to join the mailing list for regular updates on the SIM-air family of tools and paper series, please contact - simair@urbanemissions.info

[1] The Economic Times, "Hinjewadi: The land of opportunity", December 7th, 2007
@ http://economictimes.indiatimes.com/articleshow/2604416.cms

[2] The SIM-air program is a family of open-source analytical tools to establish baseline emissions inventory, to conduct dispersion modeling, to assess the health impacts of air pollution, and to evaluate benefits of interventions to control pollution. The tools are designed in plug-n-play modules to estimate and supported by publicly available software (such as MS Excel) and Geographic Information Systems (GIS) data . Previous urban applications of these tools include Hyderabad and Delhi (India); Bangkok (Thailand); Lagos (Nigeria); Antananarivo (Madagascar); Shanghai and Shijiazhuang (China); Hanoi (Vietnam); Dhaka (Bangladesh); and Ulaanbaatar (Mongolia).

[3] Pune Regional Emissions Inventory Study (PREIS) @
http://www.unipune.ac.in/dept/science/environmental_science/es_webfiles/preis.htm

[4] The source apportionment study was conducted by Ministry of Environment and Forests and Central Pollution Control Board of India and details reports are available @ http://cpcb.nic.in/Source_Apportionment_Studies.php
This work was partly supported by Automotive Research Association of India. ARAI played an integral part in testing and establishing the emission factors for 62 vehicle categories in the Indian fleet.
Details are available @ https://www.araiindia.com.

[5] The Atmospheric Transport Modeling System (ATMoS) is a Lagrangian puff transport model, modified for use in urban and regional settings, with facilities to model multiple size fractions and multiple pollutants.
For details on the model and where to download, please visit @ http://www.urbanemissions.info

[6] The methodology employed for calculating the health impacts is presented in the SIM-air working paper No.06, "Estimating the Health Impacts of Outdoor Air Pollution", available @ http://www.urbanemissions.info, along with references and relevant databases of dose-response functions, incidence rates, and gridded population data

[7] The epidemiological studies to establish the dose response functions for various end points, like the premature mortality and morbidity effects were conducted in many countries across the world, with most coming from USA and Europe, and recently from Asia and Africa. These are reviewed and documented in "Outdoor Air Pollution and Health in the Developing Countries of Asia: A Comprehensive Review", November, 2010, Published by the Health Effects Institute (HEI), USA. Details on similar studies @ http://www.healtheffects.org