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Nature of air pollution, emission sources, and management in the Indian cities

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HIGHLIGHTS

- Air quality monitoring in Indian cities.
- Sources of air pollution in Indian cities.
- Health impacts of outdoor air pollution in India.
- Review of air quality management options at the national and urban scale.

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ABSTRACT

The global burden of disease study estimated 695,000 premature deaths in 2010 due to continued exposure to outdoor particulate matter and ozone pollution for India. By 2030, the expected growth in many of the sectors (industries, residential, transportation, power generation, and construction) will result in an increase in pollution related health impacts for most cities. The available information on urban air pollution, their sources, and the potential of various interventions to control pollution, should help us propose a cleaner path to 2030. In this paper, we present an overview of the emission sources and control options for better air quality in Indian cities, with a particular focus on interventions like urban public transportation facilities; travel demand management; emission regulations for power plants; clean technology for brick kilns; management of road dust; and waste management to control open waste burning. Also included is a broader discussion on key institutional measures, like public awareness and scientific studies, necessary for building an effective air quality management plan in Indian cities.

1. Introduction

Air quality is a cause for concern in India, particularly in cities and air pollutants including particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and ozone (O_3) often exceed the National Ambient Air Quality Standards (NAAQS). According to the World Health Organization (WHO), 37 cities from India feature in the top 100 world cities with the worst PM_{10} pollution, and the cities of Delhi, Raipur, Gwalior, and Lucknow are listed in the top 10 (WHO, 2014). A similar assessment by WHO, in 2011, listed 27 cities in the top 100. More than 100 cities under the national ambient monitoring program exceed the WHO guideline for PM_{10}.

In India, the national ambient standard for CO is better than the WHO guideline. The NO_2, SO_2, and O_3 standards are at par with the guidelines. However, the standards for PM_{10} (Aerodynamic diameter <10 μm) and $PM_{2.5}$ (aerodynamic diameter <2.5 μm) are lagging (comparative details in Supplementary Material).

As cities are increasing in size and population, there is a steady demand for motorized vehicles in both personal and public transport sectors. This puts substantial pressure on the city's infrastructure and environment, particularly since most Indian cites have mixed land use. For 40 cities highlighted in Census-India (2012), the key urban characteristics are presented in Table 1. The

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Table 1
Cities at a glance.

City	AR	Pop	A	B	C	D	E	F	PM_{10} (μg/m^3)	SO_2 (μg/m^3)	NO_2 (μg/m^3)
Hyderabad	500	7,749,334	155	50%	14%	32%	70.82 (40)	No	81.2 ± 34.0	5.0 ± 2.4	22 ± 7.0
Vijayawada	79	1,491,202	189	26%	4%	21%		No	79. ± 14.9	4.6 ± 0.5	13.5 ± 3.1
Vishakhapatnam	159	1,730,320	109	36%	8%	21%		Yes	91.2 ± 34.8	11.9 ± 12.7	29.1 ± 13.8
Guwahati	145	968,549	67	10%	3%	80%		No	132.6 ± 89.9	8.1 ± 3.3	16.6 ± 5.3
Patna	86	2,046,652	238	32%	10%	29%		No	138.8 ± 84.4	5.3 ± 2.8	32.9 ± 18.8
Korba	39	365,073	94	43%	8%	56%		No	116.9 ± 17.	13.3 ± 0.7	21.3 ± 0.8
Raipur	95	1,122,555	118	38%	9%	48%	65.85 (63)	No	272.2 ± 43.3	17.8 ± 3.7	45.9 ± 2.7
Delhi	669	16,314,838	244	39%	21%	9%		No	260.1 ± 117.1	6.5 ± 4.2	51.1 ± 17.2
Ahmedabad	275	6,352,254	231	51%	13%	24%	75.28 (22)	No	94.3 ± 21.8	15.9 ± 3.5	20.9 ± 4.0
Rajkot	86	1,390,933	162	60%	10%	33%	66.76 (59)	No	105.6 ± 27.	11.3 ± 2.1	15.4 ± 2.6
Surat	155	4,585,367	296	44%	9%	28%	57.9 (79)	No	89.1 ± 13.1	18.6 ± 3.9	26.3 ± 3.2
Vadodhara	145	1,817,191	125	60%	14%	20%	66.91 (57)	No	86. ± 34.6	16.2 ± 5.8	30.2 ± 13.1
Vapi	37	163,605	44	44%	11%	32%	88.09 (2)	No	78.3 ± 8.1	16.4 ± 1.9	23.9 ± 1.7
Yamuna Nagar	41	383,318	93	42%	13%	24%		No	281.5 ± 132.3	12.7 ± 2.7	27.1 ± 3.3
Dhanbad	45	1,195,298	266	31%	5%	72%	78.63 (13)	No	164. ± 95.5	16.6 ± 3.5	41. ± 8.9
Jamshedpur	119	1,337,131	112	49%	12%	38%	66.06 (61)	No	171.7 ± 13.4	36.4 ± 2.2	49.3 ± 3.9
Ranchi	106	1,126,741	106	43%	13%	36%		No	178.9 ± 67.9	18.1 ± 2.2	31.6 ± 3.0
Bangalore	556	8,499,399	153	46%	18%	20%		No	109.4 ± 92.6	15. ± 3.1	37.5 ± 6.0
Jammu	123	651,826	53	48%	25%	13%		No	118.2 ± 37.4	8.2 ± 4.4	12.7 ± 3.4
Trivandrum	108	1,687,406	156	34%	17%	43%		Yes	62.9 ± 17.8	9.7 ± 5.2	26.1 ± 5.2
Bhopal	178	1,883,381	106	48%	15%	30%		No	118.5 ± 73.2	7.1 ± 2.4	17.5 ± 5.9
Gwalior	78	1,101,981	141	45%	8%	29%	54.63 (83)	No	227.7 ± 84.6	8.6 ± 1.9	16.8 ± 4.1
Indore	102	2,167,447	212	50%	13%	17%	71.68 (38)	No	160.6 ± 73.4	9.4 ± 4.3	16.4 ± 6.5
Jabalpur	104	1,267,564	122	46%	8%	34%		No	135.7 ± 13.0		24.3 ± 2.1
Ujjain	33	515,215	156	40%	6%	26%		No	78.4 ± 42.0	10.9 ± 3.4	11.9 ± 3.1
Shillong	46	354,325	77	9%	16%	42%		No	78.8 ± 31.0	19.4 ± 19.0	12.5 ± 5.4
Amritsar	90	1,183,705	132	50%	15%	21%		No	188.7 ± 24.2	14.8 ± 2.2	35.1 ± 3.1
Chandigarh	115	1,025,682	89	47%	26%	27%		No	79.9 ± 32.6	5.8 ± 0.5	15.4 ± 7.8
Ludhiana	167	1,613,878	97	50%	19%	19%	81.66 (10)	No	251.2 ± 21.9	8.4 ± 2.3	36.2 ± 7.0
Chennai	426	8,917,749	210	47%	13%	17%		Yes	121.5 ± 45.5	12.1 ± 3.5	20.8 ± 7.0
Agra	129	1,746,467	135	48%	12%	27%	76.48 (19)	No	184.1 ± 95.9	6.6 ± 3.5	20.8 ± 12.1
Allahabad	71	1,216,719	171	54%	11%	26%		No	165.3 ± 70.7	3.6 ± 1.0	23.7 ± 15.9
Firozabad	21	603,797	288	25%	4%	40%	60.51 (75)	No	195.6 ± 78.2	21.6 ± 4.8	32.1 ± 4.9
Kanpur	150	2,920,067	195	11%	3%	42%	78.09 (15)	No	211.5 ± 25.3	7.5 ± 1.2	31.3 ± 4.9
Lucknow	240	2,901,474	121	52%	15%	20%		No	200.4 ± 28.4	8.4 ± 1.0	36.1 ± 2.6
Varanasi	102	1,435,113	141	40%	7%	29%	73.79 (29)	No	125.3 ± 8.4	17.2 ± 0.7	19.6 ± 0.7
Asansol	49	1,243,008	254	27%	4%	61%	70.2 (42)	No	162.7 ± 98.7	9.4 ± 3.1	61.8 ± 18.5
Durgapur	56	581,409	104	27%	4%	61%	68.26 (52)	No	172.5 ± 107.1	9.8 ± 3.2	63.9 ± 18.6
Kolkota	727	14,112,536	194	12%	9%	34%		No	160.8 ± 109.3	17.3 ± 15.4	59.7 ± 27.8

Notes: AR = build-up area (in km^2) is estimated from Google Earth maps; A = population density (per hectare); B = % households with a motorized two wheelers; C = % households with a four wheeler; D = % households with a non-gas cookstove; E = CEPI rating (rank); F = is the city coastal.

urban population varies from 1.5 million to 17 million. The data shows that regardless of population size, 30 cities are densely populated with 100 persons per hectare or more, 30 cities have at least 30% of the households with a motorized two wheeler (MTW), and 19 cities have at least 10% households with a four-wheeler (a car or a utility vehicle). While most cities are supplied with liquefied petroleum gas (LPG) for domestic use, there is still a significant portion of households using other fuels – such as kerosene, biomass, and coal. Of the 40 cities in Table 1, 20 have at least 30% of households with a non-LPG cookstove.

In 2010, the Central Pollution Control Board (CPCB) developed the Comprehensive Environmental Pollution Index (CEPI), a methodology to assess air, water, and soil pollution at the industrial clusters in the country (CPCB, 2009). While industries typically rely on the grid electricity for operations and maintenance; frequent power cuts often necessitate the use of in-situ electricity generation (using coal, diesel, and heavy fuel oil), which adds to the industrial air pollution load. The study identified 43 clusters with a rating of more than 70, on a scale of 0–100, and listed them as critically polluted for further action. Most of these clusters are in and around major cities – most notably Korba (Chhattisgarh), Vapi (Gujarat), Faridabad and Ghaziabad (outside of Delhi), Ludhiana (Punjab), Kanpur and Agra (Uttar Pradesh), Vellore and Coimbatore (Tamil Nadu), Kochi (Kerala), Vishakhapatnam (Andhra Pradesh), Howrah (West Bengal), and Bhiwadi (Rajasthan). The CEPI ratings, where available, are listed by their ranking in Table 1.

The global burden of disease (GBD) assessments, listed outdoor air pollution among the top 10 health risks in India. The study estimated 695,000 premature deaths and loss of 18.2 million healthy life years due to outdoor $PM_{2.5}$ and ozone pollution (IHME, 2013). Among the health risk factors studied, outdoor air pollution was ranked 5th in mortality and 7th in overall health burden in India. Household (indoor) air pollution from burning of solid fuels was responsible for an additional one million premature deaths. A substantial increase was observed in the cases of ischemic heart disease (which can lead to heart attacks), cerebrovascular disease (which can lead to strokes), chronic obstructive pulmonary diseases, lower respiratory infections, and cancers (in trachea, lungs, and bronchitis). Several other studies have estimated premature mortality rates due to outdoor PM pollution for several Indian cities, using similar methodologies and are summarized in Table 2.

While the field of air pollution and atmospheric science is gaining ground in India and there has been a surge in the published research, much of the knowledge is widely scattered. While reviews in the past have provided scientific recommendations (Pant and Harrison, 2012; Krishna, 2012), there has been no concerted effort towards addressing the various aspects of the air pollution (source to impacts), and providing a global summary as well as gaps in current knowledge. Existing local (and international) knowledge can be leveraged in designing effective interventions in India, where pollutant sources are often complex. In this paper, we aim to present an overview of the emission sources and control options for