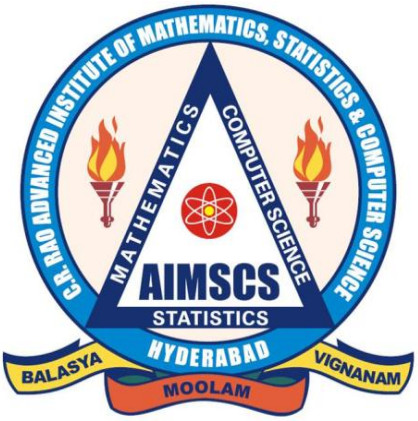
CRRAO Advanced Institute of Mathematics, Statistics and Computer Science (AIMSCS)

Research Report



Author (s): **Saumyadipta Pyne, Santu Ghosh, Kalpana Balakrishnan, Krishnendu Mukhopadhyay, Sankar Sambandam, Naveen Puttaswamy, Moumita Chakraborty, Parthasarathi Ghosh, Manas Ranjan Ray, Dona Sinha**

Title of the Report: **Exposures to air toxics from ambient and household air pollution in India: On addressing attributable cancer disease burdens**

Research Report No.: **RR2014-03**

Date: **February 3, 2014**

**Prof. C R Rao Road, University of Hyderabad Campus,
Gachibowli, Hyderabad-500046, INDIA.
www.crraoaimscs.org**

Exposures to air toxics from ambient and household air pollution in India:

On addressing attributable cancer disease burdens

Santu Ghosh[1], Kalpana Balakrishnan*[1], Krishnendu Mukhopadhyay[1], Sankar Sambandam[1], Naveen Puttaswamy[1], Moumita Chakraborty[1], Parthasarathi Ghosh[2], Manas Ranjan Ray[3], Dona Sinha[3], Saumyadipta Pyne*[2]

[1]ICMR Center for Advanced Research on Environmental Health (Air Pollution), Department of Environmental Health Engineering, Sri Ramachandra University, Chennai, India; [2]CR Rao Advanced Institute of Mathematics, Statistics and Computer Science, Hyderabad, India; [3]Chittaranjan National Cancer Institute, Kolkata, India.

*Corresponding Authors

Abstract

According to WHO Global Burden of Disease measurements, air pollution ranks among the leading risk factors contributing to the burden of disease in South Asia. Significant costs in terms of premature mortality and years of life lost due to time lived in states of less than full health are attributable to exposures to both ambient and household air pollution. We show the measures and intensities of both forms of pollution in India, and the disease burden profiles, including cancers, associated with them. Then we summarize the IARC assessments on carcinogenicity of ambient and household air pollution, and conclude with a list of specific priorities for action.

Introduction

Air pollution ranks among the leading risk factors contributing to the burden of disease in South Asia. The World Health Organization (WHO) global burden of disease (GBD) measures burden of disease using the disability-adjusted-life-year (DALY), which combines years of life lost due to premature

mortality and years of life lost due to time lived in states of less than full health. In the Comparative Risk Assessment (CRA), conducted as part of the Global Burden of Disease (GBD-CRA) 2010 Project (Lim et al. 2012) in India, approximately 1.04 million premature deaths and 31.4 million DALYs were attributable to household air pollution (HAP) resulting from solid cook-fuels while 627,000 premature deaths and 17.8 million DALYs were attributable to ambient air pollution (AAP), in the form of fine particles (measured as $PM_{2.5}$) annually. Household and ambient air pollution account for 6% and 3% of the total national burden of disease (IHME 2013), respectively, and together exceed the burden from any of the other risk factors examined in the GBD-CRA in 2010. The total attributable disease burden estimates for AAP and HAP in India in 2010 are also considerably higher than the previous estimates for these risk factors in GBD-2000 (WHO 2004). The large and steadily increasing burden that now straddles both rural and urban settings in India and thus warrants a closer examination of the nature of the exposure and associated disease profiles. While several previous reviews have focused on exposures to criteria air pollutants and cardio-respiratory health effects, exposures to air toxics and the implications for cancer disease burdens in particular remain poorly described. In this review, we consolidate information from recent publications to better understand the available evidence on the carcinogenicity of air pollution and identify priorities for research and policy in India. We also identify specific opportunities for statistical modeling to close some key data gaps in this area.

Ambient air pollution exposures

Ambient air quality information in India is collected primarily by the National Air quality Monitoring Programme (NAMP) administered by the Central Pollution Control Board (CPCB), Ministry of Environment and Forests, Government of India (GoI). Particulate matter (PM) in the air includes particles of less than 10 micrometers in diameter (measured as PM_{10}) which are small enough to enter the human lungs, with the potential of causing serious health problems. Even smaller “fine” particles ($PM_{2.5}$) of less than 2.5 micrometers in diameter can be due to combustion such as in motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes. Criteria air pollutants monitored under the NAMP include PM_{10}, SO_2 and NO_2. However, $PM_{2.5}$ and select air toxics such B(a)P, As and Ni have only recently been included in the revised National Ambient Air Quality Standards (NAAQS) (CPCB 2009a) and are slowly being added to the routine monitoring

being performed under the NAMP. Analysis of routinely collected ambient air quality data that are available in the Environmental Data Bank maintained by CPCB (CPCB 2012) indicates annual average PM_{10} concentrations to exceed the NAAQS at more than half of the 503 locations monitored across the country between 2004 to 2011 (Figure 1).

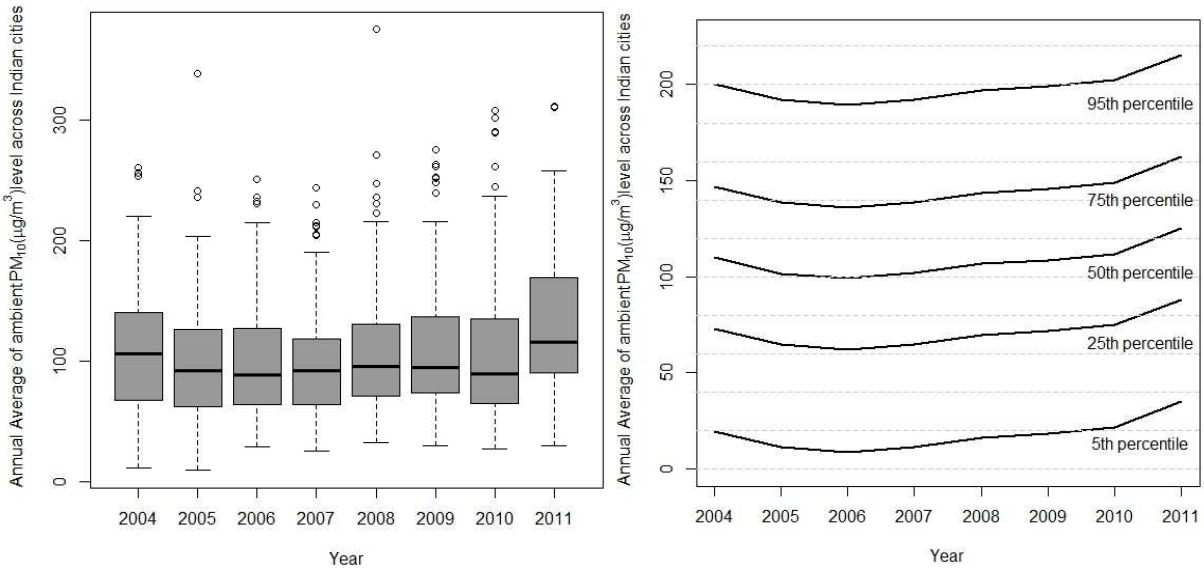


Figure 1: Distribution of 24-hr ambient concentrations of PM_{10} across Indian cities covered by the National Ambient Air Quality Monitoring Programme (Based on data from The Environmental Data Bank, Central Pollution Control Board (CPCB 2012a)).

The newly revised Indian national standards (CPCB 2009a) for annual average PM_{10} of 60µg/m^3 are comparable to the Interim Target 1 (IT-1) guideline values for air quality as recommended by WHO (WHO 2006), which are still much higher than the recommended WHO-guideline (WHO-AQG) value of 20 µg/m^3 indicating that residual health impacts may persist even if the national standards were met. Given that the levels not only exceed the national standards but are also critically high (defined as > 90 µg/m^3 by CPCB, GoI) across most locations, these results from routine monitoring clearly provide unequivocal evidence for substantial health impacts from PM and its constituents in Indian urban locations.

While limited data are available on PM composition within the NAMP data, the reported mass concentrations are likely indicators for exposures to complex mixtures that include air toxics, as suggested by the available information on major sources (Figure 2).

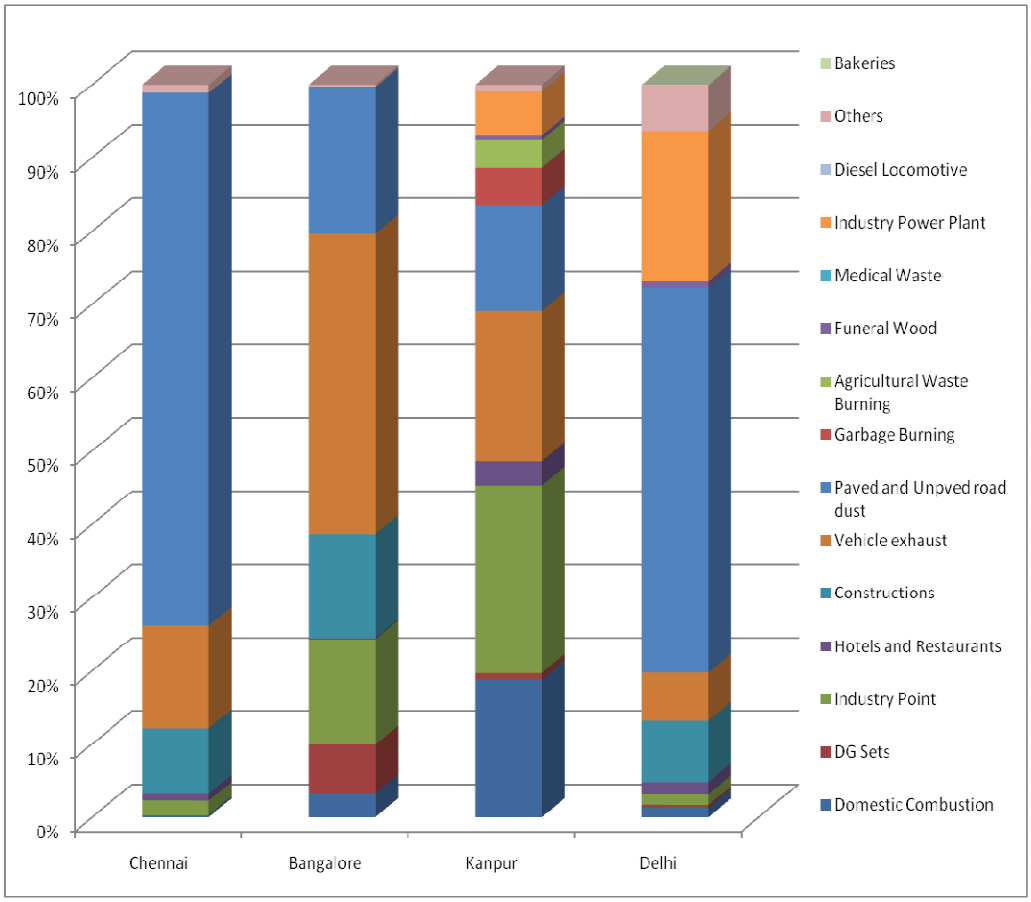


Figure 2: Exposure to complex mixtures in some Indian cities: sample results from the National Source Apportionment Study conducted by CPCB; Adapted from (CPCB 2011).

Vehicle exhaust, road and soil dust, secondary particulates, construction activities, oil burning (e.g. diesel or heavy oil), biomass burning, coal combustion, kerosene combustion and industries have been identified as dominant sources for criteria air pollutants in a representative set of major cities in a national source apportionment exercise concluded recently (CPCB 2011). High Elemental Carbon (EC) to Organic Carbon (OC) ratio (EC/OC) obtained from samples across cities also indicates significant contributions from

vehicular emissions. Further, within the transport sector, the maximum contributions were estimated to come from heavy duty diesel vehicles (40 – 59% of PM_{10} and 43 – 75% of NO_2). Diesel exhaust was labelled as a confirmed human carcinogen (Group I) in a recent assessment by The International Agency for Research on Cancer (IARC 2012). Given the nature of sources that especially involve diesel combustion, the levels of PM in urban locations are of special concern for health endpoints related to carcinogenicity.

Yet another indication of the extent of air toxics exposures is available through a recent initiative undertaken by the CPCB to identify industrial hotspots have been identified by the CPCB using risk assessment criteria defined in terms of the Comprehensive Environmental Pollution Index (CEPI). The CEPI weights the toxicity of the agents, the volume of emissions, the scale of population exposed and the exposure pathways involved. Of special relevance to carcinogenicity is the fact that unlike criteria air pollutant data provided by the NAMP, the CEPI includes weighted contributions from a range of compounds that includes probable carcinogens (USEPA Class 2 and 3 or substances with some systemic toxicity, such as VOC's, PAHs, PCBs), as well as known carcinogens or chemicals with significant systemic or organ system toxicity (such as vinyl chloride, benzene, lead, radionuclide, hexavalent chromium, cadmium, and organophosphates). A CEPI score of 70 is deemed to indicate significant toxic impacts. Thus, 43 industrial clusters across the country have been identified to be critically polluted with primary contributions from chemical industries. Although the details of ambient concentrations of air toxics may not available in the publications reporting CEPI scores, the description of the procedure used to compute the CEPI score suggests significant emissions and exposures to compounds known to be associated with carcinogenic endpoints at these sites. The annual average concentration recorded across the NAMP monitors and the locations of the CEPI hotspots are illustrated in Figure 3.

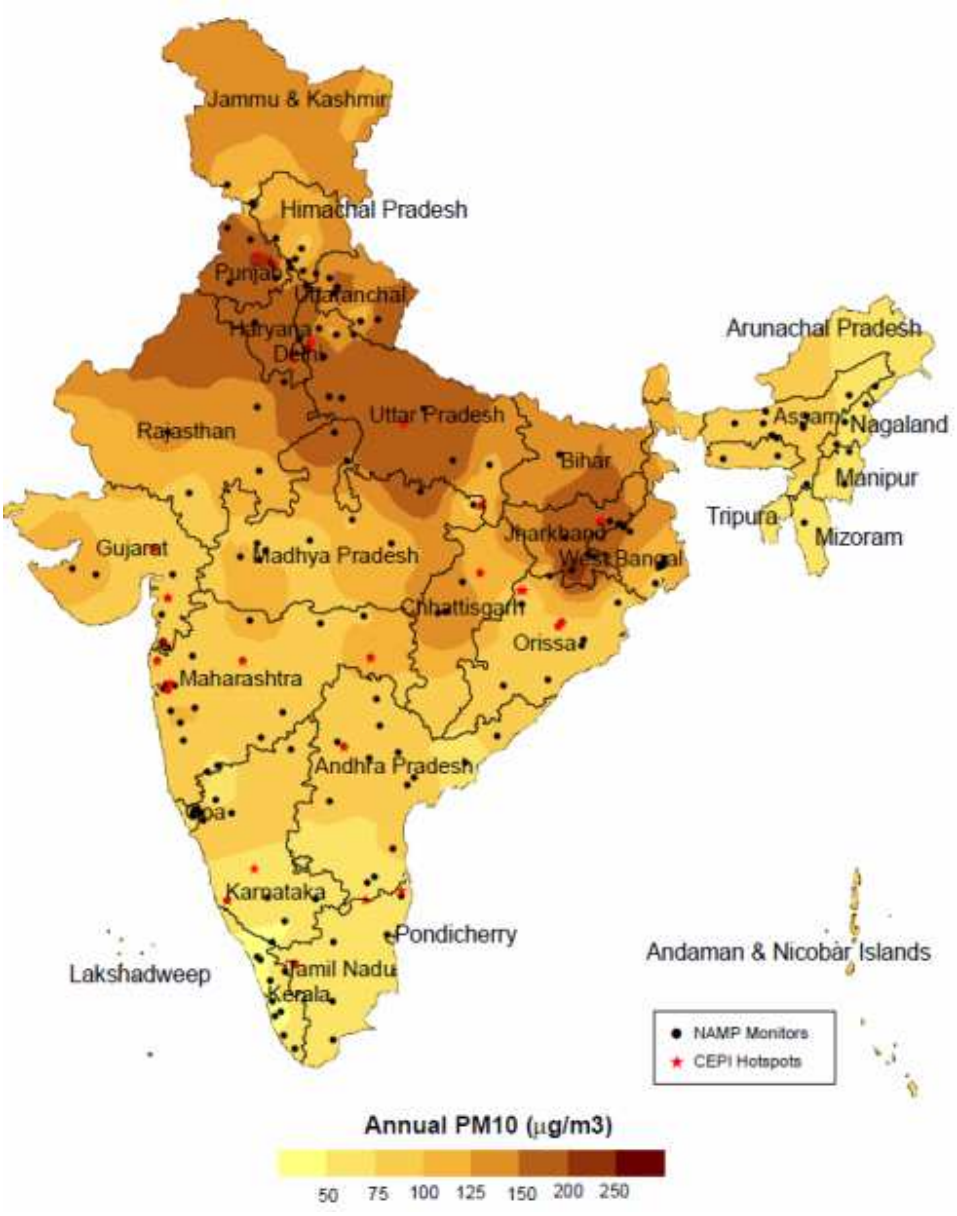


Figure 3: Inverse distance weighted averages of annual concentrations (as shown by color intensities on the map) of annual PM_{10} recorded across NAMP monitors between 2004-2011 in relation to monitor locations and CEPI hotspots (based on data from The Environmental Data Bank (CPCB 2012) and the CEPI Report (CPCB 2009b)).

A limited number of ambient air pollution related research studies also report quantitative exposure information pertaining to air toxics. Table 1 provides a description of the range of concentrations / exposures reported in select studies.

Reference	Study Area City (State)	Period of monitoring	Pollutant	Averaging Period; Units	Range	Mean (SD)
(Rajput and Lakhani 2010)	Agra (Uttar Pradesh)	2005- 2006	Total PAHs bound to PM 10	24-30 hrs ; ng/m^3	15-392	119
(NEERI 2006)	Delhi (Delhi)	1991-2005	Total PAHs bound to Total Suspended Particulate Matter (TSPM)	24hrs ; ng/m^3		850
	Chennai (Tamil Nadu)					679
	Kanpur (Uttar Pradesh)					660
	Mumbai (Maharashtra)					581
	Kolkata(West Bengal)					969
(Sharma H et al. 2008)	Delhi (industrial)	2003	Total PAHs bound to TSPM	24hrs ; ng/m^3		2098
	Delhi(traffic)					1511
	Delhi(residential)					1108
(Sharma et al. 2003)	Delhi	2001-2001	Total PAHs bound to TSPM	24hrs ; ng/m^3	35-116	
(Gupta et al. 2006); (Vaishali et al. 1997)	Nagpur	2005-2006	Total PAHs bound to TSPM	24hrs ; ng/m^3		106
(Kulkarni and Venkataraman 2000)	Mumbai	1996	Total PAHs bound to TSPM	72hrs ; ng/m^3	24.5-38.8	
(Raiyani et al. 1993)	Ahmedabad	1993	Total PAHs bound to TSPM	24hrs ; ng/m^3	90-195	
(Herlekar et al. 2012)	Mumbai(industrial)	2007-2008	Total PAHs bound to PM 10	24hrs ; ng/m^3		247.70 ± 163.19
	Mumbai (residential)					47.84 ± 14.07
(CPCB 2011)	Bangalore	2007	Formaldehyde	24hrs	8-12	11
	Chennai				0.02-0.18	0.06
	Delhi				0.2-1.7	0.9
	Kanpur				0.06-0.25	0.14
	Mumbai				0.1-24.6	2.3
	Pune				1.3-3.8	2.5
	Bangalore	2007	Benzene	24hrs	7-237	119

	Chennai				4-17	10
	Delhi				2-11	5
	Kanpur				5-68	27
	Mumbai				-	
	Pune				28-96	57
	Bangalore	2007	1,3, Butadiene	24hrs	0.5-3.7	2.18
	Chennai				0.5-1.8	1.1
	Delhi				0.2-1.6	0.78
	Kanpur				-	-
	Mumbai				-	-
	Pune				0.4-2.5	1.2
(Chattopadhyay et al. 2007)	Kolkata	2004-2005	Benzene	4 hrs, µg/m3	15.2-40.7	
(Majumdar et al. 2011)	Kolkata	2005	BTEX	4 hrs, µg/m3	Benzene (ind-out): 18.7-58.1, 17.3-47.2	BTEX: 42, 69.3, 22.8,52.1, 21.6
(Masih et al. 2012)	Agra, Uttar Pradesh	2006-2007	Total PAHs	24 hrs, ng/m3	2.29-113.56	
(Singh et al. 2013)	Coastal refinery zone, India	2009	BTEX	8 hrs µg/m3,	3.69 - 56.67	

Table 1: Reported range concentrations of air toxics in studies conducted across Indian cities.

Household air pollution exposures

Use of solid fuels (such as biomass and coal) for household energy needs including cooking and heating has been well recognized as a major contributor to air pollution exposures in populations of developing countries (WHO 2006). An estimated 2.8 billion people globally (Smith et al. 2013) and nearly 74% of India's population continue to rely on such solid fuels (Census 2011). The incomplete combustion of these solid fuels in inefficient cook stoves results in much of the fuel energy to be emitted as potentially toxic pollutants, including particles of varying sizes, CO, NO_2, volatile and semi-volatile organic compounds such as formaldehyde and benzo(a)pyrene (BaP), methylene chloride, and dioxins (Naeher et al. 2007). Well over 200 studies that have measured air pollution levels in developing country

households, across all WHO regions (Saksena et al. 2003), including numerous studies in India, have provided unequivocal evidence of extreme exposures in households using solid cook-fuels, often many fold higher than recommended WHO Air Quality Guidelines (AQGs) (WHO 2006). These studies have also shown the distribution of exposures to be heterogeneous and complex with multiple determinants (such as fuel/stove type, kitchen area ventilation, fuel quantity, age, gender and time-activity profiles influencing spatial and temporal patterns within and between households/ individuals across world regions. In communities that heavily rely on solid cook-fuels, household emission of pollutants can also be a significant contributor to ambient air pollution. As a result, these communities often suffer from elevated indoor and outdoor air pollution. Table 2 provides a summary of select studies in India that reported results from measurements of household air pollution. These measurements have been largely focused on PM or CO measurements with limited information available on concentrations of air toxics. However, biomass smoke has been shown to contain 17 pollutants designated as priority pollutants by the USEPA because of their toxicity in animal studies, up to 14 carcinogenic compounds, 6 cilia-toxic and mucous coagulating agents, and 4 co-carcinogenic or cancer promoting agents (Naeher et al. 2007). Carcinogenic PAHs, methylated PAHs, and nitrogen-containing heterocyclic aromatic compounds have also been reported in the particles emitted from bituminous (smoky) coal combustion (Mumford et al. 1987). The PM exposure profiles reported in solid fuel settings thus indicate exposures to a range of air toxics with significant implications for carcinogenicity related health impacts.

Reference, Location	Fuel	Stove type	Sampling duration	Levels of pollutants reported
(Aggarwal et al. 1982) ; Gujarat (Urban)	Wood/ Dung/ Charcoal	Traditional	Half-an-hour during cooking	TSP: 7203-26147 (μg/m^3); PAH (BaP): 1270-8248 (ng/m^3)
(Smith et al. 1983) Gujarat(Rural)	Wood	Traditional	Meal duration	TSP: 6400(μg/m^3) ; BaP: 4100 (ng/m^3)
		Improved	Meal duration	TSP: 4600 (g/m^3); BaP: 2400 (ng/m^3)
(Ramakrishna 1988) Kerala, Karnataka, Haryana (Rural)	Wood	Traditional	Meal duration	TSP: 3200-3300 (g/m^3) CO: 7-19 (mg/m^3)
		Improved	Meal duration	TSP: 1700-2900 (g/m^3) CO: 5.7-8.9 (mg/m3)
(Menon 1988) Andhra Pradesh(Rural)	Wood	Traditional	Not specified	TSP: 2000-5000 (g/m^3) CO: 30.9-74.4 (mg/m^3)
(Norboo et al. 1991) Jammu & Kashmir State(Rural)	Wood	Traditional	Meal duration	CO: 12-29.8 (mg/m^3)
(Saksena et al. 1992) Uttar Pradesh(Rural)	Wood	Traditional	Meal duration	TSP: 5600 (μg/m^3) ; CO: 21 (mg/m^3)
(Raiyani et al. 1993) Gujarat (Urban)	Wood/ Dung/ Charcoal	Traditional	Meal duration	TSP: 1190-3470 (μg/m^3) BaP: 38-410 (ng/m^3)
(Smith et al. 1994) Maharashtra((Urban)	Crop Residues/ Wood	Traditional	Meal duration	PM_{10}: 900-1100 (μg/m^3)
(TERI 1995) Uttar Pradesh (Rural)	Wood	Traditional	Meal duration	PM_5: 850-1460 (μg/m^3)
(Mandal et al. 1996) Delhi (Urban)	Wood	Traditional	4 hours	TSP: 646 (μg/m^3)
(Balakrishnan et al. 2002) Tamil Nadu (Rural)	Wood/ Crop residues/ Wood Chips	Traditional	1-2 hours during cooking / 24 hours	PM_4: 1307-1535 (μg/m^3) PM_4: 847-1327 (μg/m^3)
(Saksena et al. 2003) New Delhi (Urban)	Wood	Traditional	Meal duration	PM_5: 1204 (μg/m^3) CO: 13.7 (mg/m^3)
(Balakrishnan et al. 2004) Andhra Pradesh (Rural)	Wood/ Dung/ Crop residues	Traditional	22-24 hours	PM_4 (Wood): 431-467 (μg/m^3) PM_4(Dung): 297-666 (μg/m^3) PM_4 (Crop Residues): 215-357 (μg/m^3)
(Bhargava et al. 2004) Uttar Pradesh (Rural)	Wood/ Dung	Traditional	1-hour during cooking	BaP: 0.5-1.86 (%)

(Sinha et al. 2006) Gujarat (Rural)	Wood/ Dung	Not Specified	45 min to 1-hour during cooking	Benzene: 45-114.3 ($\mu g/m^3$) Toluene: 2-8.5 ($\mu g/m^3$)
(Smith et al. 2007) Maharashtra Madhya Pradesh (Rural/ Peri-urban)	Wood	Traditional	48 hours	$PM_{2.5}$: 520-1250 ($\mu g/m^3$) CO: 9.02-12.4 (mg/m^3)
	Wood	Improved	48 hours	$PM_{2.5}$: 330-940 ($\mu g/m^3$) CO: 6.17-7.6 (mg/m^3)
(Massey et al. 2009) Uttar Pradesh (Peri-Urban)	Wood	Traditional	24 hours	$PM_{2.5}$: 173-178($\mu g/m^3$) PM_{1}: 133-153 ($\mu g/m^3$) $PM_{0.5}$: 73-96 ($\mu g/m^3$) $PM_{0.25}$: 6-8 ($\mu g/m^3$)
(Balakrishnan et al. 2013) Tamil Nadu, Madhya Pradesh, Uttaranchal,West Bengal (Rural)	Wood, Dung	Traditional	22-24 hours	$PM_{2.5}$: 157-741 ($\mu g/m^3$)

Table 2: Reported range of household air pollution concentrations in studies conducted across solid fuel using households of rural/urban districts in India

Previous global burden of disease (GBD) (WHO 2004) estimates for household air pollution (HAP) from solid cook-fuel use were based on simple indicators of exposure such as type of cook-fuel used, as few epidemiological studies could perform quantitative measurements. Recent progress in GBD methodologies that use integrated–exposure–response (IER) curves (described later), for combustion particles required the development of models to estimate quantitative HAP exposures experienced by large populations. Given the heterogeneity in exposures and the resource intensiveness of such measurements, it is necessary to develop and validate models that can predict average HAP exposures in relation to household level variables for which data could be available either from national surveys or easily collected using questionnaires. GBD 2010 used results from one of first such modeling exercises that estimated state and national average household concentrations of $PM_{2.5}$ from solid cookfuel use for India, on the basis of quantitative air pollution measurements and information on household level variables from multiple states (Balakrishnan et al. 2013). The state and national average $PM_{2.5}$ concentrations related to solid fuel use estimated using such models are shown in Figure 4.

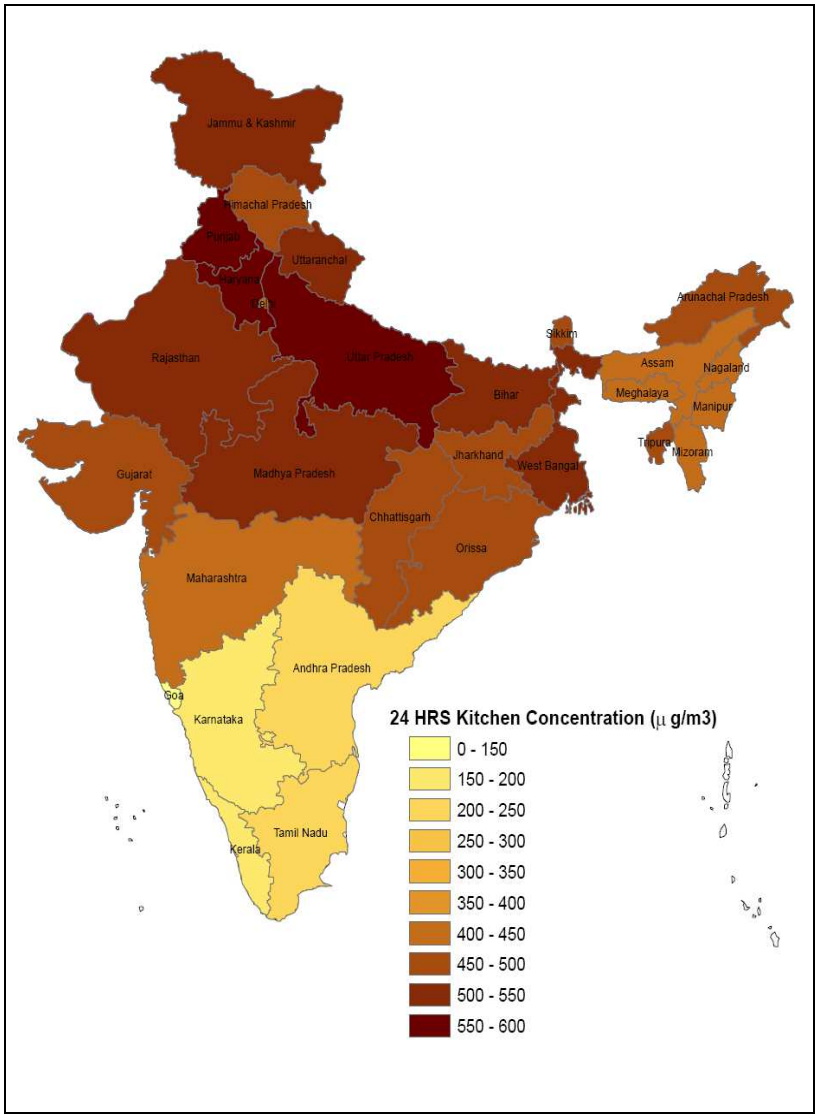


Figure 4: State level household concentrations of $PM_{2.5}$ from solid fuel use, as shown by color intensities on the map (Adapted from Balakrishnan et al 2013).

Disease burden profiles in relation to ambient and household air pollution

The basic approach used in burden of disease assessments and the comparative risk assessment has been to calculate the proportion of deaths or disease burden due to specific risk factors (e.g. hypertension caused by increased salt intake) while holding other independent factors unchanged, and determine the total burden from that contributed by each risk factor. In the Comparative Risk Assessment (CRA) done as part of the Global Burden of Disease Project (GBD-2010), the global and regional burdens were estimated for more than 60 other risk factors (Lim et al. 2012). As described in Lim et al. this involved (1) selection of risk–outcome pairs to be included in the analysis based on criteria about causal associations; (2) estimation of distributions of exposure to each risk factor in the population; (3) estimation of etiological effect sizes, often relative risk per unit of exposure for each risk–outcome pair; (4) choice of an alternative (counterfactual) exposure distribution to which the current exposure distribution is compared, also termed the theoretical-minimum-risk exposure distribution (TMRED) and (5) computation of burden attributable to each risk factor, including uncertainty from all sources.

Since for many disease endpoints, exposure –response information has been available mostly in relation to ambient $PM_{2.5}$ exposures and/or smoking studies in developed countries (with only a few studies populating the evidence base for household air pollution), the CRA-GBD 2010 project relied on the use of Integrated Exposure-Response functions (IERs) to generate consistent risk estimates across the four major categories of combustion particle exposures. This included, household air pollution (HAP), ambient air pollution (AAP), active tobacco smoking (ATS) and second hand smoke (SHS) and IERs were generated for disease endpoints concerning ischaemic heart disease (IHD), stroke, lung cancer, and child acute lower respiratory infections (ALRI) (Burnett et al. 2014(forthcoming); Smith et al. 2014

(forthcoming)). The IERS were based on an exponential decay model with a power of concentration (that did not constrain the relationship to be linear) and allowed the evidence from epidemiological studies concerning any of the categories of combustion particles to be pooled using the daily dose of $PM_{2.5}$ as the primary exposure metric, thereby straddling across some 3orders of magnitude in exposure levels. It also allowed the HAP risk estimates to be made for diseases known to be caused by ATS, SHS, and AAP, but for which there are no or minimal HAP studies by interpolating between ATS results at higher exposures and SHS/AAP results at lower exposures . The IER for lung cancer used in GBD-CRA 2010 is expected to available soon (Burnett et al. 2014(forthcoming));(Smith et al. 2014 (forthcoming)). Figure 5, as reproduced from an earlier publication (Pope et al. 2011), which provided the basis for the GBD-CRA 2010 IERs, illustrates the form of IERs across combustion particle sources for lung cancer. The HAP exposure model used in GBD 2010 (based on measurements and modeling results from India), estimated daily average $PM_{2.5}$ exposures of 285 $\mu g/m^3$, 337 $\mu g/m^3$ and 204 $\mu g/m^3$ for children, women and men respectively (Balakrishnan et al. 2013), (Smith et al. 2014 (forthcoming)). The global model used for AAP exposures (that for the first time included ambient air quality of rural areas) estimated a 2010 population-weighted annual mean $PM_{2.5}$ of 27.2 $\mu g/m^3$ in India, up 6% from 1990, with a distribution that includes much higher levels in urban and some rural areas (Brauer et al. 2012).

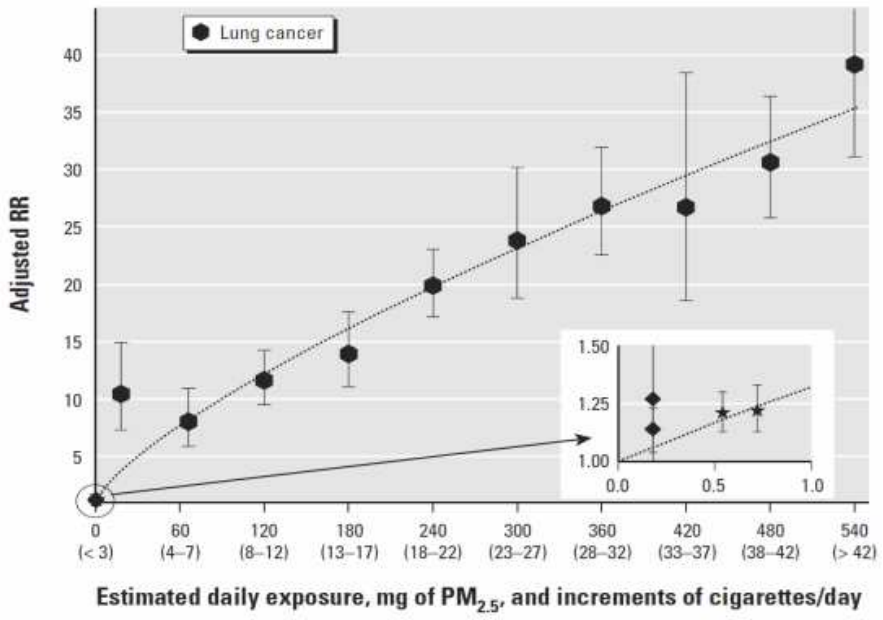


Figure 5: An Integrated Exposure-Response (IER) Curve (reproduced with permission from Environmental Health Perspectives – figure from Pope et al. 2011). It shows that exposure-response functions for lung cancer with adjusted RRs (with 95% confidence intervals) of lung cancer mortality plotted over estimated daily exposure of $PM_{2.5}$ (milligrams) and increments of cigarette smoking relative to never smokers). Diamonds represent risk estimates for PM2.5 from air pollution; stars represent comparable pooled RR estimates associated with second hand smoke (SHS). The dotted lines represent the nonlinear power function fit through the origin and the estimates (including active smoking, SHS, ambient $PM_{2.5}$). The fitted function, RR = 1 + $0.3195(dose)^{0.7433}$, represents a monotonic, nearly linear exposure–response relationship with fairly constant marginal increases in RR with increasing exposure. Estimated doses from different increments of active smoking are dramatically larger than estimated doses from ambient air pollution or SHS; therefore, associations at lower exposure levels (due to ambient air pollution and SHS) are shown as inset with a magnified scale.

With the availability of quantitative exposure estimates and IERs, the HAP and AAP working groups were able to use the same TMRED (counterfactual) of approximately ~7 $\mu g/m^3$ annual mean $PM_{2.5}$ across both the risk factors to estimate the total risk range for burden calculations. This counterfactual chosen by the AAP CRA working group in GBD 2010 represents approximate levels in the cleanest cities and is roughly equivalent to what can be achieved by vented cooking with gas fuels. Estimates of burden of disease in terms of deaths and DALYs in India attributable to major sources of combustion particles and major categories of disease end points are summarized in Table 3 and Figure 6. These estimates underscore the inter-related contribution from HAP and AAP exposures to the burden of disease in India.

Deaths	PM HAP Deaths	PM AAP Deaths	PM ETS Deaths	PM ATS Deaths	PM Total Deaths
Lower Respiratory Infections <5	100382.858	40731.847	30048.084	0	171162.79
COPD	362428.25	108792.2	0	282859.7265	754080.179
Cancers of the Trachea, Bronchus and Lung	14505.75	12728.53	756.96496	46355.87592	74347.1237
IHD	343664.248	305266.01	21909.584	317011.352	987851.192
Stroke (Cerebrovascular Disease)	201275.994	159954.43	9270.0864	137233.632	507734.144
Total	1022257.10	627473.02	61984.719	783460.5864	**2495175**
DALYs	PM HAP DALYs	PM OAP DALYs	PM ETS DALYs	PM ATS DALYs	PM Total DALYs
Lower Respiratory Infections <5	8638606.9	3503152.1	2586489.5	0	14728248.5
COPD	8560004.15	108792.2	0	8635069.2	17303865.6
Cancers of the Trachea, Bronchus and Lung	367264.872	12728.53	17033.778	1226224.287	1623251.47
IHD	8930148.22	305266.01	573688.02	8503156.68	18312258.9
Stroke (Cerebrovascular Disease)	4485358.08	159954.43	203001.12	3171892.5	8020206.13
Total	30981382.22	4089893.3	3380212.4	21536342.67	**59987831**

Table 3: Results from GBD 2010 for disease burden attributable to particulate matter in India (based on data from (IHME 2013)). PM-Particulate Matter; DALYs-Disability adjusted Life Years; HAP-Household Air Pollution; AAP-Ambient Air Pollution; ETS-Environmental Tobacco Smoke; ATS-Active Tobacco Smoking.

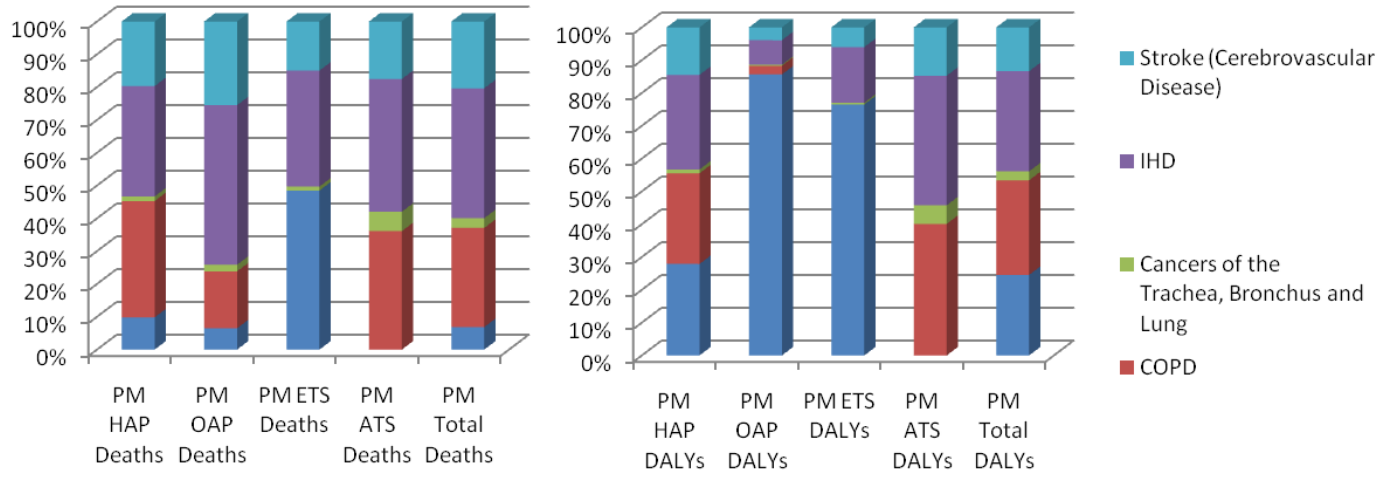


Figure 6: Percent contributions to burden of disease (Deaths and DALYs) from major categories of particulate matter in India (Based on data from (IHME 2013)).

Summaries of IARC assessments on carcinogenicity of ambient and household air pollution

In October 2006, the Expert Working Group for International Agency for Research on Cancer (IARC) Monograph Vol. 95 (IARC 2010) evaluated the carcinogenicity of the household use of solid fuels and high-temperature frying. The report was updated with information on "coal only" in 2012 (IARC 2012). IARC has classified indoor air pollution (IAP) from coal combustion as a known human carcinogen (Group 1) and from the combustion of biomass fuel as a probable human carcinogen (Group 2A) (IARC 2010). Cancers that have been associated with IAP include cancers of the lung, upper aero-digestive tract, and cervix, among which lung cancers have been the most well studied and well characterized (IARC 2010). IARC based its determination that household exposure to coal combustion by-products causes lung cancer in humans principally on strong epidemiological studies that were able to adequately address tobacco use and other relevant factors as confounders. The concentration of polycyclic aromatic hydrocarbons (PAHs) in emissions from indoor coal combustion were found to be associated with lung cancer, and both the cytochrome P450 and aldo-keto-reductase pathways, as well as polymorphisms in DNA repair and phase II pathways, have been shown to modify the association (IARC 2010). Signaling pathways implicated in tumor growth and metastasis such as those involving expression of the toll-like receptor (TLR) and receptors for advanced glycation end-products (RAGE) were found to be influenced by air pollution (Shoenfelt et al. 2009) (Reynolds et al. 2011).

In experiments with animals, inhalation of emissions from coal, burned under conditions similar to those in epidemiological studies, increased the incidence of various types of malignant lung tumours, squamous-cell carcinomas and adenocarcinomas in male and female Kunming mice and Wistar rats. Based on consistent evidence of carcinogenicity in human and experimental animal studies and strong

evidence of mutagenicity, IAP from combustion of coal was classified as confirmed carcinogen (Group1). However, there were significantly fewer studies of lung cancer in association with the combustion of biomass, and the studies that are available did not evaluate associations according to the specific type of fuel used, thus making comparisons difficult. Although, exposure to 1,3-butadiene, benzene, formaldehyde, PAHs, and acetaldehyde as measured from air samples was highly correlated with exposure to indoor wood burning for heating homes (these agents themselves being individually known to be mutagenic) and changes in expression and phosphorylation of P53 in lung cancer patients who were exposed to wood smoke were noted, because of limited evidence from human and experimental animal studies, IAP from biomass combustion was labeled as a possible carcinogen (Group 2A).

In 2013, The IARC Working Group (Monograph Volume 109) unanimously classified outdoor air pollution and particulate matter from outdoor air pollution as carcinogenic to humans (IARC Group 1), based on sufficient evidence of carcinogenicity in humans and experimental animals and strong mechanistic evidence. An increased risk of lung cancer was consistently observed in cohort and case-control studies including millions of people and many thousands of lung cancer cases from Europe, North America, and Asia with many studies adjusting for confounding by smoking. Evidence regarding the carcinogenicity of outdoor air pollution in experimental animals came from prior work concerning diesel engine exhaust and of emissions from the combustion of coal and wood (IARC 2010, 2012). All of these agents that can be present in outdoor air were shown previously to cause benign and malignant lung tumors in mice or rats. Several studies in which animals were exposed to traffic related air pollution or were injected subcutaneously with organic solvent extracted material from particles collected from outdoor air pollution, showed increased incidence of injection-site tumors, including fibrosarcomas, and

pulmonary adenoma or adenocarcinoma. In particular, association between traffic pollution and leukemias has been studied at length. Recently, weak associations were found to exist between early exposure to traffic pollution and several childhood cancers (Heck et al. 2014). Finally, exposure to polluted outdoor air in occupational settings or urban and industrial areas was also associated with changes in the expression of genes involved in DNA damage and repair, inflammation, immune and oxidative stress response, as well as altered telomere length and epigenetic effects such as DNA methylation. Thus, based on strong evidence of carcinogenicity from human and experimental animal studies and mutagenicity, ambient air pollution was classified as a confirmed human carcinogen (Loomis et al. 2013).

Several recent studies documenting cyto-pathological changes in response to exposure to ambient and household air pollution are now becoming available to add to the evidence base for carcinogenicity of air pollution in India. Traffic policemen and street hawkers of the city occupationally exposed to vehicular emission reported elevated levels of neutrophils and eosinophils in the sputum samples (Lahiri et al. 2006). These findings suggest persistent inflammation in response to air pollution-induced oxidative stress. Cooking with biomass has also been reported to alter sputum cytology (increasing counts of neutrophils, lymphocytes, eosinophils and alveolar macrophages (AM)) increase airway inflammation (higher sputum levels of IL-6, -8 and TNF-α) and oxidative stress (enhanced ROS generation and depletion of SOD activity) that might result in further amplification of the tissue damaging cascade in women chronically exposed to biomass smoke (Banerjee et al. 2012; Dutta et al. 2013). Prevalence of mucus plugs, goblet cell hyperplasia, and nuclear anomaly of columnar epithelial cells was found to be higher in urban subjects exposed to high levels of urban air pollution in Kolkata as compared to controls drawn from relatively cleaner peri-urban zones (Ray and Lahiri 2010). However,

as compared to these controls, Papanicolau-stained sputum samples of biomass users showed 3-times higher prevalence of metaplasia and 7-times higher prevalence of dysplasia in airway epithelial cells (AEC) (Roychoudhury et al. 2012). Siderophages (iron-containing macrophages in sputum indicative of either past intrathoracic bleeding or extravasations of red blood cells into the alveoli due to a sluggish blood flow) were abundant in sputum of the residents of Delhi and Kolkata implying microscopic hemorrhage in the lungs (Roy et al. 2001). Elastin is a fibrous protein present in the elastic tissues of lung. Elevated levels of elastase (a proteolytic enzyme found in the lysosomes of neutrophils and alveolar macrophages capable of destroying elastin and causing alveolar degradation) were reported in urban populations of Delhi and Kolkata with some of the highest levels recorded in automobile service station workers, traffic policemen and roadside hawkers (Basu et al. 2001). Cumulative exposure to biomass smoke has also been shown to increase oxidative stress-mediated activation of Akt signal transduction potentially increasing the risk of lung cancer (Roychoudhury et al. 2012). Currently, the biological evidence of activated carcinogenic mechanisms associated with air pollution is substantial and growing, and is corroborated by studies conducted in the Indian context.

Priorities for action

As may be seen from the preceding account describing the magnitude and extent of air pollution exposures across rural and urban environments in India, the recent evidence on the burden of disease attributable to air pollution exposures and the comprehensive evidence of carcinogenicity (provided by the IARC assessments), it is clear that there is an imminent need to identify certain priorities for action. We describe below some key areas for such prioritization efforts.

a. Generating nationally representative and systematic data on exposure profiles for air toxics across urban and rural populations

The data on criteria air pollutants in the country are quite robust as nationally representative datasets become more widely available. However, information on air toxics is still too sparse and is not collected across a representative range of settings to allow estimation of exposures to air toxics. Without a critical mass of such data, to conduct precise modeling exercises is difficult. Further, given that the air toxics are an important part of both vehicular and solid fuel emissions and multiple agents in these emissions, and since the mixtures themselves have been evaluated to be carcinogenic, detailed information on the composition and concentration of air toxics is critical for assessment of risks in exposed populations. Wider availability of sampling and analysis infra-structure and broader validation of field protocols across typical rural/urban settings is critical for generation of such data. A network of accredited laboratories would need to be engaged routinely to allow the generation of such information in the near-term with adequate sampling and design strategies for country-wide coverage.

b. Augmenting efforts to estimate emission/exposure profiles for diesel exhausts

Automobile ownership is on the rise along with overall socio-economic development that is taking place in India. With the recent evaluation by IARC on the carcinogenicity of diesel exhaust, the expanding fleet of diesel vehicles and the complex engine-fuel mixes in operation, there is an imminent need for profiling population exposures specifically to diesel exhaust. Detailed source apportionment and/or emissions inventory exercises would also allow refinements in the existing modeling methods that rely on chemical transport (such as the WRF-Chem) used now to generate long-range exposure profiles for air toxics.

c. Creating geo-coded datasets from available cancer registries

An increasing base of information is becoming available through the cancer case registries maintained by individual tertiary care facilities in addition to records available through National Cancer Institutes and The National Cancer Registry (maintained by the Indian Council of Medical Research). While city or district level estimates of incidence are available across many locations, detailed geo-coding of residences reporting cancer cases has not been attempted. Such spatial mapping combined with temporal surveillance data would be much more powerful for analysis of exposures in terms of source contributions. A modest level of seed grants to schools could enable institutions maintaining such registries to efficiently generate such data through student efforts. Once routine geo-coding is enabled, integration with air quality datasets can be relatively easily accomplished on GIS platforms. Specific training and capacity building efforts on GIS for college level graduates would allow the mapping to be undertaken routinely and also motivate them to conduct research on such problems.

d. Initiating the conduct of a co-ordinated set of observational and/or experimental studies for air pollution and cancer across rural and urban populations in India

The available base of epidemiological studies on air pollution and cancer in India is rather small with most studies plagued by inadequate adjustment for confounding or exposure misclassification. The lack of routinely accessible cancer registry information has been a major impediment to be able to design observational studies that can use routinely collected data. A co-ordinated set of studies that straddle across rural and urban exposure situations would be enormously helpful in identifying exposure and impact hotspots. Wherever feasible, air pollution exposures can be added as an additional variable in on-going long term studies concerning cancer surveillance, prevalence or management.

Adding to the evidence base from epidemiological studies concerning air toxics and cancer in India can be valuable in closing the gap between risk estimates from ambient and household air pollution exposures. As may be seen in Figure 5, there is considerable uncertainty for lung cancer risk estimates in the range < 0.5 mg/m^3 of daily dose of $PM_{2.5}$ (i.e. 500 µg/m^3), the range of relevance for ambient and household air pollution in India. There is limited evidence from epidemiological studies on cancers for many other organ systems and thus substantial information from a range of exposure settings are needed to establish accurate modeling of the exposure-response relationships on firmer grounds.

Further, given the complexity of conducting epidemiological studies on cancer, evidence for mutagenicity can be efficiently collected by standardizing in-vitro protocols for testing concentrated air pollutant mixtures from urban or rural hotspots. This would allow recognition of signatures for carcinogenicity as populations face risk from complex mixtures of unknown composition from new sources of emissions in their specific communities. Focusing on biomarker studies concerning exposure, early detection of biological effects and susceptibility would afford an improved understanding of the range of health impacts. With infra-structure for genome-wide omic studies becoming more widely available in the country, the creation of a network of necessary bio-repositories and systematic analysis may allow a detailed understanding of disease (cancer) susceptibility, and thus afford opportunities for targeted intervention. Unprecedented rates of industrialization and development, in conjunction with rapid urbanization, migration and changing lifestyles, may need appropriate designs for spatio-temporal, longitudinal or prospective investigation of potential health outcomes of different forms of air pollution exposures, for instance, *in utero* and in early childhood. Further insights can be derived from multi-sectoral data resources such as the national census – e.g., occupation, socio-economic disparities, etc., which may either affect or be affected by the health outcomes of air pollution. Finally, studies in the

emerging field of epigenetic epidemiology could shed light on both harmful as well as protective mechanisms in exposed populations brought about by possible gene-environment and gene-diet interactions due to exposures that are specific to different geographic and socio-economic contexts present in India, which may lead to further research on remedial strategies.

e. Including air toxics exposure and cancer surveillance as part of future air pollution intervention programs

Numerous efforts are underway to design and implement air quality interventions in the urban and rural settings. Newer emissions control norms for vehicles and industries, more stringent auto-fuel policies, zoning restrictions, construction of green landscapes, and new electricity-run metro-railways are expected to change exposure profiles across cities as well as over time. Similarly a major effort to provide cleaner cook-stoves and or cleaner fuels is being proposed under initiatives by the Ministry of New and Renewable Energy to reduce health, environment and quality of life impacts associated with solid fuel use among rural populations. Maintaining national-scale databases that capture changes associated with such environmental experiments would afford a unique opportunity to test shifts in disease profiles in response to exposure reductions. Such observations would strengthen both the scientific evidence as well as add more evidence for policy based actions. Creation of templates and the infra-structure for routine surveillance would however be key to take advantage of such opportunities.

f. Harnessing Big Data in Environmental Studies

While large datasets on air pollution are being generated continuously, sophisticated statistical methodology such as Bayesian hierarchical models are required for combining evidence across multiple locations while quantifying sources of heterogeneity and identifying effect modification. In addition,

new methodologies and collaborations may be developed for Big Data research for integration and mining of high-volume multi-sectoral datasets including pollution monitoring and related streams, public health and hospital event records, satellite and remote sensor data, geo-referenced dynamic data on traffic and other emissions, crowdsourced data (e.g., using mobile phones, apps) and the increasingly resourceful social networks, etc., for timely discovery of emerging patterns of health and disease.

Conclusion

Air pollution continues to be a major public health concern in India with a wider and greater burden from a range of non-communicable diseases including cancer, affecting all age groups in our communities. While focusing on criteria air pollutants and acute respiratory end points in major metropolitan cities may provide some insights on the extent of the health impacts of air pollution, this may be just reflect the proverbial tip of the iceberg. There is a tremendous need for better understanding of the landscape of exposure and attributable disease distributions both in India and elsewhere. Our review has provided a detailed justification for the need for such an understanding on air toxics and carcinogenicity of air pollution. It is hoped that the provided information serves to add impetus to on-going and new efforts for prevention directed at reducing the massive public health burden from air pollution in rural and urban India.

Acknowledgments

SP is supported by Ramalingaswami Fellowship of DBT and grants from MoS&PI and DST CMS. PG is supported by DST CMS grant.

References

1. Aggarwal AL, Raiyani CV, Patel PD, Shah PG, Chatterjee SK. 1982. Assessment of exposure to benzo(a)pyrene in air for various population groups in ahmedabad. Atmos Environ 16:867-870.
2. Balakrishnan K, Sankar S, Parikh J, Padmavathi R, Srividya K, Venugopal V, et al. 2002. Daily average exposures to respirable particulate matter from combustion of biomass fuels in rural households of southern india. Environ Health Perspect 110:1069-1075.
3. Balakrishnan K, Sambandam S, Ramaswamy P, Mehta S, Smith KR. 2004. Exposure assessment for respirable particulates associated with household fuel use in rural districts of andhra pradesh, india. Journal of Exposure Science and Environmental Epidemiology 14:S14-S25.
4. Balakrishnan K, Ghosh S, Ganguli B, Sambandam S, Bruce N, Barnes DF, et al. 2013. State and national household concentrations of pm2.5 from solid cookfuel use: Results from measurements and modeling in india for estimation of the global burden of disease. Environ Health 12:77.
5. Banerjee A, Mondal N, Das D, Ray M. 2012. Neutrophilic inflammatory response and oxidative stress in premenopausal women chronically exposed to indoor air pollution from biomass burning. Inflammation 35:671-683.
6. Basu C, Ray M, Lahiri T. 2001. Traffic-related air pollution in calcutta associated with increased respiratory symptoms and impaired alveolar macrophage activity. J Environ Poll 8:187-195.
7. Bhargava A, Khanna RN, Bhargava SK, Kumar S. 2004. Exposure risk to carcinogenic pahs in indoor-air during biomass combustion whilst cooking in rural india. Atmos Environ 38:4761-4767.
8. Brauer M, Amann M, Burnett RT, Cohen A, Dentener F, Ezzati M, et al. 2012. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environ Sci Technol 46:652-660.
9. Burnett R, Pope III C, Ezzati M, Olives C, Lim S, et al. 2014(forthcoming). An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ Health Perspect.
10. Chattopadhyay BP, Mukherjee A, Mukherjee K, Roy Chowdhury AL. 2007. Exposure to vehicular pollution and assessment of respiratory function in urban inhabitants. Lung 185:263.
11. CPCB. 2009a. National ambient air quality standards. New Delhi.
12. CPCB. 2009b. Comprehensive environmental assessment of industrial clusters. (Ecological Impact Assessment Series). New Delhi:Central Pollution Control Board.
13. CPCB. 2011. Air quality monitoring, emission inventory and source apportionment study for indian cities. New Delhi , India.
14. CPCB. 2012. National ambient air quality staus and trends in india 2010 New Delhi, India.
15. Dutta A, Roychoudhury S, Chowdhury S, Ray M. 2013. Changes in sputum cytology, airway inflammation and oxidative stress due to chronic inhalation of biomass smoke during cooking in premenopausal rural indian women. Int J Hyg Environ Health 216:301-308.
16. Gupta D, Nag S, Mukhopadhyay UK. 2006. Characterisation of pm 10, pm2.5 and benzene soluble organic fraction of particulate matter in an urban area of kolkata, india Environ Monit Assess 115:205-222.
17. Heck, J.E., et al. Childhood Cancer and Traffic-Related Air Pollution Exposure in Pregnancy and Early Life. Environ Health Perspect, 2014, DOI:10.1289/ehp.1306761
18. Herlekar M, Elizabeth JA, Kumar R, Gupta I. 2012. Chemical speciation and source assignment of particulate (pm10) phase molecular markers in mumbai. Aerosol and Air Quality Research 12:1247-1260.

19. IARC. 2010. Household use of solid fuels and high-temperature frying. Lyon, France:International Agency for Research on Cancer, World Health Organisation.
20. IARC. 2012. Diesel and gasoline engine exhausts and some nitroarenes. Lyon, France:International Agency for Research On Cancer, World Health Organisation.
21. IHME. 2013. The global burden of disease: Generating evidence, guiding policy-south asia regional edition.Institute for Health Metrics and Evaluation.
22. Kulkarni P, Venkataraman C. 2000. Atmospheric polycyclic aromatic hydrocarbons in mumbai, india. Atmos Environ 34 2785-2790.
23. Lahiri T, Ray M, Lahiri P. 2006. Health effects of air pollution in delhi. New Delhi:Central Pollution Control Board.
24. Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the global burden of disease study 2010. Lancet 380:2224-2260.
25. Loomis D, Grosse Y, Lauby-Secretan B, Ghissassi FE, Bouvard V, Benbrahim-Tallaa L, et al. 2013. The carcinogenicity of outdoor air pollution. The Lancet Oncology 14:1262-1263.
26. Majumdar D, Mukherjeea A, Sen S. 2011. Btex in ambient air of a metropolitan city. Journal of Environmental Protection 2:11-20.
27. Mandal AK, Kishore J, Rangesamy S. Pah concentration in indian kitchen and its relation to breast carcinoma. In: Proceedings of the Proceedings of the 7th International Conference on Indoor Air Quality and Climate, Nagoya, Japan, 2, 1996, Vol. 2, 349-351.
28. Masih J, Singhvi R, Kumar K, Jain VK, Taneja A. 2012. Seasonal variation and sources of polycyclic aromatic hydrocarbons (pahs) in indoor and outdoor air in a semi arid tract of northern india. Aerosol and Air Quality Research 12:515-525.
29. Massey D, Masih J, Kulshrestha A, Habil M, Taneja A. 2009. Indoor/outdoor relationship of fine particles less than 2.5 mm (pm2.5) in residential homes locations in central indian region. Build Environ 44:2037-2045.
30. Menon P. 1988. Indoor spatial monitoring of combustion generated pollutants by indian cookstoves. Honolulu,USA:University of Hawaii, Honolulu.
31. Mumford JL, He XZ, Chapman RS, Cao SR, Harris DB, Li XM, et al. 1987. Lung cancer and indoor air pollution in xuan wei, china. Science 235:217-220.
32. Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ, et al. 2007. Woodsmoke health effects: A review. Inhal Toxicol 19:67-106.
33. NEERI. 2006. Ambient air quality status for ten cities of india(1991-2005). Nagpur:National Environmental Engineering Research Institute.
34. Norboo T, Yahya M, Bruce NG, Heady JA, Ball KP. 1991. Domestic pollution and respiratory illness in a himalayan village. Int J Epidemiol 20:749-757.
35. Pope CA, 3rd, Burnett RT, Turner MC, Cohen A, Krewski D, Jerrett M, et al. 2011. Lung cancer and cardiovascular disease mortality associated with ambient air pollution and cigarette smoke: Shape of the exposure-response relationships. Environ Health Perspect 119:1616-1621.
36. Raiyani CV, Jani JP, Desai NM, Shaha JA, Kashyap SK. 1993. Levels of polycyclic aromatic hydrocarbons in ambient environment of ahmedabad. Indian Journal of Environmental Protection 13:206-216.
37. Rajput A, Lakhani N. 2010. Measurements of polycyclic aromatic hydrocarbons in an urban atmosphere of agra,india. Atmosfera 23:165-183.
38. Ramakrishna J. 1988. Patterns of domestic air pollution in rural india. Honolulu,USA:University of Hawaii, Honolulu.

39. Ray M, Lahiri T. 2010. Air pollution: Health and environmental impacts.CRC Press,Taylor and Francis Group, 165-201.
40. Reynolds, P. R., Wasley, K. M. and C. H. Allison. Diesel Particulate Matter Induces Receptor for Advanced Glycation End-Products (RAGE) Expression in Pulmonary Epithelial Cells, and RAGE Signaling Influences NF-κB–Mediated Inflammation. Environ Health Perspect. 2011, 119(3): 332–336.
41. Roy S, Roy M, Basu C, Lahiri P, Lahiri T. 2001. Abundance of siderophages in sputum. Indicator of an adverse lung reaction to air pollution. Acta Cytol 45:958-964.
42. Roychoudhury S, Mondal N, Mukherjee S, Dutta A, Siddique S, Ray M. 2012. Activation of protein kinase b (pkb/akt) and risk of lung cancer among rural women in india who cook with biomass fuel. Toxicol Appl Pharmacol 259:45-53.
43. Saksena S, Prasad R, Pal RC, Joshi V. 1992. Pattern of daily exposure to tsp and CO in the garhwal himalaya. Atmos Environ 26A 2125-2134.
44. Saksena S, Singh PB, Prasad RK, Prasad R, Malhotra P, Joshi V, et al. 2003. Exposure of infants to outdoor and indoor air pollution in low-income urban areas - a case study of delhi. J Expo Anal Environ Epidemiol 13:219-230.
45. Saksena S, Thompson L, Smith KR. 2003. The indoor air pollution and exposure database: Household pollution levels in developing countries. Part 7/1/2003:University of California, Berkeley; The World Health Organisation.
46. Sharma H, Jain V, Khan Z. 2008. Atmospheric polycyclic aromatic hydrocarbons in urban air of delhi during 2003. Environ MonitAssess 147:43-55.
47. Sharma N, Sawant A, Uma R, Cocker D. 2003. Preliminary chemical characterization of particle-phase organic compounds in new delhi, india. 37:4317-4323.
48. Shoenfelt J, et al. Involvement of TLR2 and TLR4 in inflammatory immune responses induced by fine and coarse ambient air particulate matter. J Leukoc Biol. 2009, 86(2):303-12.
49. Singh RK, Ramteke DS, Juneja HD, Pandya GH. 2013. Ambient air quality monitoring in terms of volatile organic compounds (vocs) occupational health exposure at petroleum refinery. International Journal of Environmental Protection 3:22-32.
50. Sinha SN, Kulkarni PK, Shah SH, Desai NM, Patel GM, Mansuri MM, et al. 2006. Environmental monitoring of benzene and toluene produced in indoor air due to combustion of solid biomass fuels. Sci Total Environ 357:280-287.
51. Smith KR, Aggarwal AL, Dave RM. 1983. Air pollution and rural biomass fuels in developing countries: A pilot village study in india and implications for research and policy. Atmos Environ 17:2343-2362.
52. Smith KR, Apte MG, Ma Y, Wongsekiarttirat W, Kulkarni A. 1994. Air pollution and the energy ladder in asian cities. Energy 19:587-600.
53. Smith KR, Dutta K, Chengappa C, Gusain P, Masera O, Berrueta V. 2007. Monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance: Conclusions from household energy and health project. Energy for sustainable development 11:5-18.
54. Smith KR, Frumkin H, Balakrishnan K, Butler CD, Chafe ZA, Fairlie I, et al. 2013. Energy and human health. Annu Rev Public Health 34:159-188.
55. Smith KR, Bruce N, Balakrishnan K, Adair-Rohani H, Balmes J, Chafe Z, et al. . 2014 (forthcoming). Millions dead: How do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. Ann Rev of Public Health 35.
56. TERI. 1995. Biomass fuels, indoor air pollution and health: A multi-disciplinary, multi-centre study. New Delhi:The Energy Research Institute.
57. Vaishali R, Phadke KM, Thakre R, Hasan M. 1997. Pahs in respirable particulate matter in nagpur city. Journal of the Indian Association for Environmental Management 24:11-16.

58. WHO. 2004. Comparative quantification of health risks: Global and regional burden of disease due to selected major risk factors Geneva.
59. WHO. 2006. Who air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide; global update 2005; summary of risk assessment Geneva.