Report of the Steering Committee on Air Pollution and Health Related Issues

August 2015

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F. No. T.21022/41/2013-NCD

Government of India
Ministry of Health and Family Welfare

Nirman Bhawan, New Delhi
Dated 6th January, 2014

OFFICER ORDER

Subject: - Constitution of Steering Committee on Health related issues on Air Pollution.

With a view towards framing an action plan for mitigating the adverse health impacts of indoor and outdoor air pollution it has been decided to constitute a Steering Committee with the composition and terms of reference herein under**:**

Composition of the Committee

Sl. No.	Name & Designation	
1	Dr. K. Srinath Reddy, President, Public Health Foundation of India, New Delhi	**Co-Chairman**
2	Prof. Ambuj Sagar, Dean, Alumni Affairs & International Programs and Vipula and Mahesh Chaturvedi, Professor of Policy Studies Department of Humanities and Social Sciences, Indian Institute of Technology, New Delhi.	
3	Dr. Surindra K. Jindal, Ex-Professor in Pulmonary Medicine, PGIMER, Chandigarh.	**Members**
4	Dr. Dheeraj Gupta, Professor, Department of Pulmonary Medicine, WHO Collaborating Centre for Research and Capacity Building in chronic respiratory Diseases, PGIMER, Chandigarh	
5	Dr. Sundeep Salvi, Chest Research Foundation, Kalyaninagar, Pune-411014	
6	Prof(Dr.) Rohini Somanathan, Institute of Economic Growth, Delhi University, New Delhi	
7	Dr. Kalpana Balakrishnan, Department of Environment Health Engineering, Sri Ramachandra Medical College and Research Institute, Chennai - 600 116, India.	
8	Representative of Ministry of New and Renewable Energy to be nominated by Secretary, MNRE	
9	Representative of Central Pollution Control Board to be nominated by Secretary, Environment & Forests	
10	Representative of Ministry of Women & Child Development to be nominated by the Secretary, WCD.	
11	Representative of the Ministry of Road Transport & Highways to be nominated by the Secretary, RT&H.	
12	Chairman, New Delhi Municipal Council.	
13	Secretary, Department of Urban Development, Govt. of NCT of Delhi.	
14	Ms. Anumita Roy Chowdhury, Executive Director, Centre for science and Environment, Tughlakabad Institutional Area, New Delhi. India - 110062	
15	Dr. Mohd Shaukat, DDG (NCD), MOHFW, GOI	
16	Dr. D. Bachhani, DC (NCD), MOHFW, GOI	**Convener**

Dr. Kirk R. Smith, Professor of Global Environment Health, Director of the Global Health and Environment Programme, School of Public Health, University of California, Berkeley, California, who is currently visiting the IIT, Delhi has kindly consented to work with the Group as Special Advisor.

Terms of Reference

I. To examine and document the evidence available on indoor and outdoor air pollution and its impact on various health outcomes including Chronic Obstructive Pulmonary and other Respiratory Diseases.
II. To identify different institutional and individual sources responsible for causing indoor and outdoor air pollution using available evidence.
III. To suggest ways in which data can be gathered from various government sources which will facilitate studies of the causes and impact or air pollution.
IV. To commission such studies as are necessary on the causes and impact of indoor and outdoor air pollution.
V. To recommend action required to be taken in order to control/reduce the pollution caused by the sources identified.
VI. To recommend methods and framework to monitor indoor and outdoor air pollution and to achieve the targets adopted in this regard.
VII. Any other task relevant for the overall objectives.

The Steering Committee may wish to separate work related to indoor air pollution (AIP) from work related to outdoor air pollution (OAP) as it is likely that the issues arising will be somewhat different. The Steering Committee may accordingly wish to conduct its work in two sub groups recognizing that some members of the Steering Committee may need to be members of both Sub-Groups.

Tenure

The Steering Committee is constituted for a period of one year from the date of issue of this order. The Ministry of Health & Family Welfare, GOI reserves the right to extend the tenure of this Steering Committee as also to effect such other changes as may be necessary in public interest.

(Dr. C.V. Dharma Rao)
Director (NCD)

Distribution:

Co-Chairpersons, Adviser and all Members the Steering Committee.

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We would like to acknowledge our Special Advisors, Prof. Kirk R. Smith and Dr. Sarath Guttikunda, for their valuable guidance and contribution to this report.

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11	Prof. Rohini Somanathan	Delhi School of Economics
12	Dr. Sarath Guttikunda	Desert Research Institute/urbanemissions.info
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15	Dr. V. Rao Aiyagari	PHFI
16	Representative	Ministry of Road Transport and Highways
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The Public Health Foundation of India (PHFI), launched in 2006 by Prime Minister Manmohan Singh, is a response to redress the limited institutional capacity in India for strengthening training, research and policy development in the area of Public Health. PHFI recognizes the fact that meeting the shortfall of health professionals is imperative to a sustained and holistic response to the public health concerns in the country, which in turn requires health care to be addressed not only from the scientific perspective of what works, but also from the social perspective of, who needs it the most.

Executive Summary

1.1 Background

Air pollution has been recognized as the world's largest single environmental health risk. The Global Burden of Disease 2010 (GBD) ranked air pollution as a leading cause of death and disability in India. The GBD comparative risk assessment exercise showed that together exposures to $PM_{2.5}$ around households from use of solid cooking fuels (household air pollution – HAP) plus exposures in the ambient environment (ambient air pollution – AAP) was responsible for approximately 1.6 million premature deaths and 49 million Disability-Adjusted Life Years (DALYs) in India. Added together, HAP and AAP account for 9% of the national disease burden, and comprised the single largest risk factor of the over 60 risk factors examined in the study.

Globally, around 2.8 billion people continue to rely on solid fuels such as wood, dung and crop residues, and coal for cooking. As per the 2011 census, 780 million of them live in India. While the percentage of the population using solid fuels for cooking has decreased gradually over the years, the absolute numbers remain comparable. Indeed, more people cook with solid fuels today than the total Indian population in 1980. In simple traditional stoves, biomass combustion produces a range of toxic products resulting from incomplete combustion, including $PM_{2.5}$ that is roughly equal to burning about 400 cigarettes an hour during cooking. Given that this occurs at the times and places where people are breathing, a large percentage of the population (particularly women and children who tend to be in the kitchen most) are exposed to this source of pollution.

According to the World Health Organisation's (WHO) Ambient Air Pollution database, 13 of the top 20 cities in the world with the highest annual levels of $PM_{2.5}$ are now in India, with Delhi featuring at the top of the list. With relatively-weak policies to manage industrial, transport and other emissions, and increasing economic activity and industrialisation across the country, the situation is likely to get worse. In fact, ambient levels of $PM_{2.5}$ from transport sources alone are expected to double by 2030 if no action is taken.

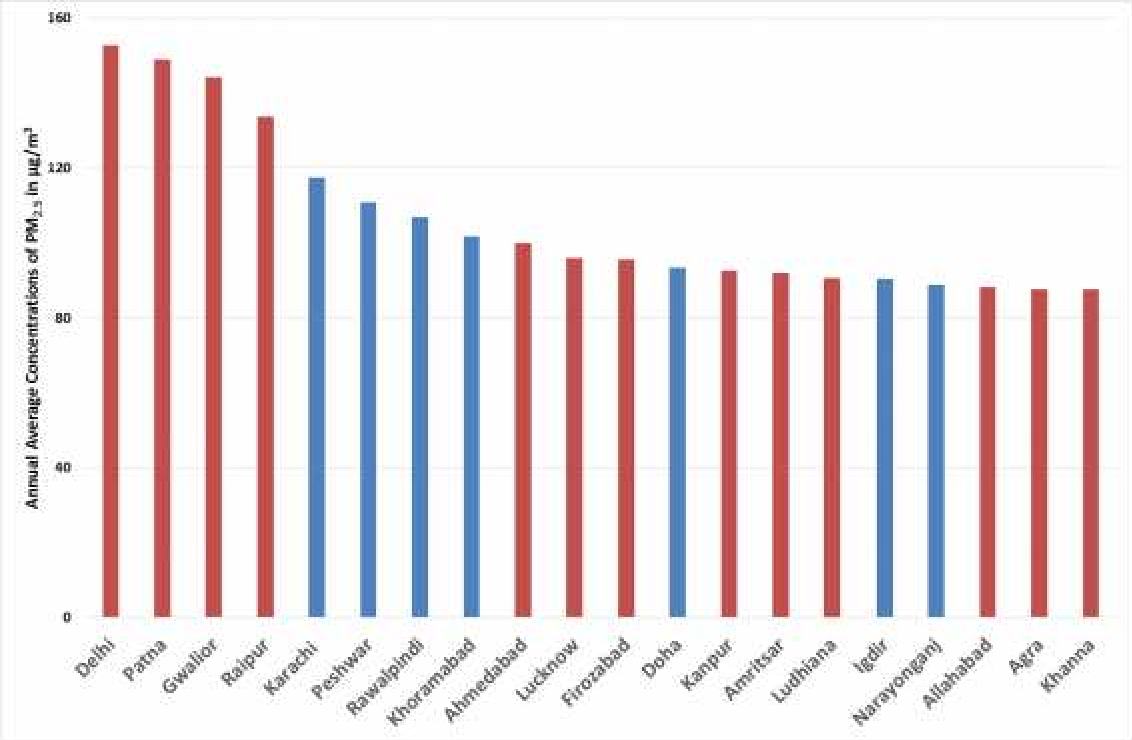


Figure 1: Top 20 cities with highest annual average $PM_{2.5}$ levels (WHO, 2014)

While exposure to air pollution is a risk factor common to both rural and urban populations, the routine monitoring of air quality as it stands, is nearly exclusively confined to large cities. This makes the task of understanding the nature and distribution of population exposures much harder. Moreover, studies have shown that emissions from cooking using biomass contributes to around one-quarter of ambient $PM_{2.5}$ air pollution in the country (Chafe et al., 2014). This serves to highlight that exposure to air pollution, be it ambient or household, is part of a continuum, and reinforces the need for an integrated approach towards mitigation and harm reduction. It was with this backdrop that the Ministry of Health and Family Welfare (MoHFW), Government of India, constituted an interagency steering committee on air pollution and health in January 2014 with the stated aims of:

1. Collating and critically appraising evidence available both at Indian and global levels linking air pollution exposure to adverse health effects, and
2. Providing recommendations for policy and programmatic responses across sectors which can both enable mitigation of exposure and adaptation for harm reduction.

This Committee broke new ground in its approach to understanding and managing health impacts of air pollution and is distinct from any such review carried out either in India or elsewhere in the world for the following reasons:

a) The explicit focus of the committee's mandate was health, the first time anywhere in the world that the issue of air pollution has been examined primarily from a health policy perspective. The committee also comprised experts from various domains and disciplines with the aim of addressing an issue of developmental importance from a health policy angle. Through this approach, the MoHFW highlighted that to protect the health of the general public, there is a need for an inter-sectoral approach engaging multiple agencies, and through multi-sectoral programmatic responses.

b) As the impact on health is the central theme of this report, the Committee has focused on integrated exposure of the population to all sources of air pollution – household and ambient – as the cornerstone of its approach, since health outcomes are determined by total exposure to air pollutants. This adds another layer to the conventional approach to air quality management, which focuses on mean ambient concentration standards that are health based, but which may be poor indicators of actual human exposures. An exposure-based approach can therefore aid in identifying (and prioritizing for policy action) those sources that significantly affect exposure.

Notably, the World Health Assembly 2015 also recently adopted a resolution to address the health impacts of air pollution, which highlights the key role national health authorities need to play in raising awareness about the potential to save lives and reduce health costs. The resolution has asked for strong cooperation between different sectors and integration of health concerns into all national, regional and local air pollution-related policies across both ambient and household sources of air pollution.

1.2 Air Pollution: Sources, Concentration, and Exposure

1.2.1. Household Air Pollution:

Household air pollution from solid cooking fuel use results primarily from incomplete combustion as conditions for efficient combustion of these fuels are difficult to achieve in the typical household stoves. Hundreds of different chemical substances are emitted during the burning of solid biomass in the form of gases and particles. In addition to small particles, carbon monoxide, and nitrogen oxides, which are regulated in India as outdoor pollutants, studies have shown that traditional chulhas produce hundreds of other toxic pollutants including formaldehyde, benzene, poly-aromatic hydrocarbons, and even dioxins.

Unlike ambient air quality, where national monitoring programmes provide at least some level of routine information, exposures to HAP have primarily been characterised by individual research studies, from as far back as the 1980s. Over the last three decades, the information on HAP exposures in India has become considerably more detailed with measurements of short-term and 24-hour household concentrations and exposures being available across a range of household configurations from multiple states. Indeed, the global exposure estimate for solid fuel users used in the 2010 Global Burden of Disease assessment (Lim et al 2012, Smith, et al 2014) was provided by an India exposure model.

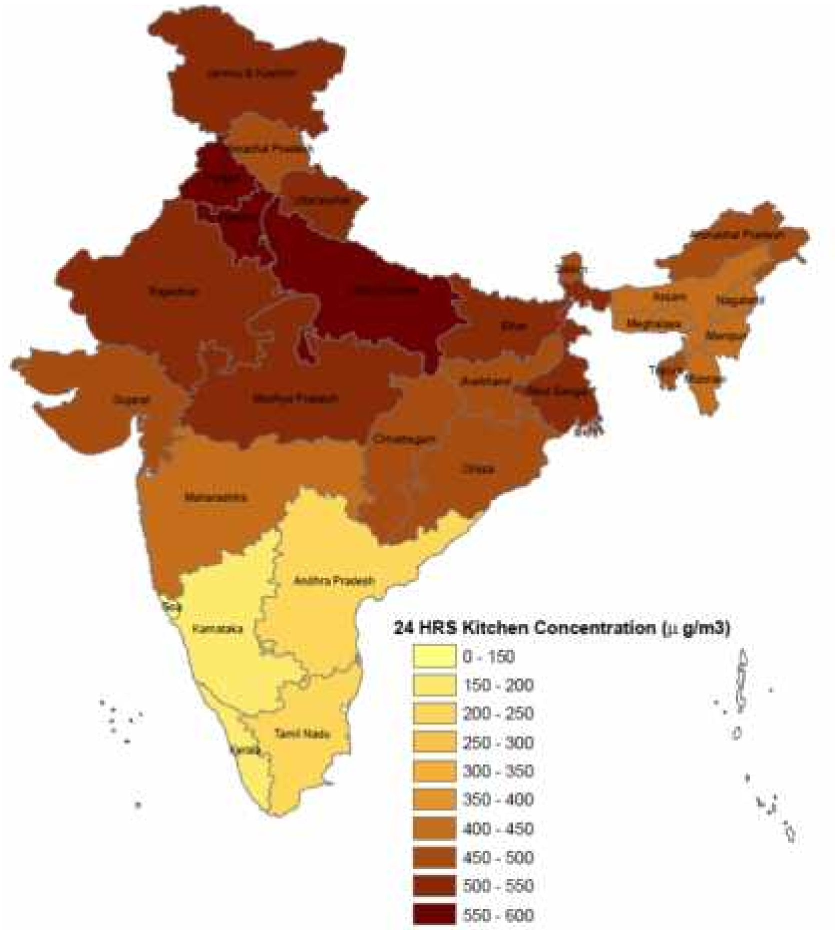


Figure 2: Distribution of 24-hr average kitchen area $PM_{2.5}$ concentrations in solid fuel using households across states (Source: Balakrishnan et al. 2013)

Although varying by state (Figure 2), national exposure models developed for solid fuel using household-level estimates average $PM_{2.5}$ exposures of 337 µg/m^3, 204 µg/m^3 and 285 µg/m^3 for women, men and children respectively, greatly in excess of the current WHO air quality guideline interim targets (WHO-AQG IT-1) of 35 µg/m^3, or the Indian standard of 40 µg/m^3.

Several recent studies (Chengappa et al. 2007, Dutta et al 2007, Balakrishnan et al 2014, Sambandam et al 2014), have also shown that many of the technologies used in the earlier or more recent models of 'improved' biomass cookstoves do not reduce emissions significantly enough to truly protect health. This is partly because as noted in chapter 4 of this report, the discernible health risks for most disease end points start at low levels of $PM_{2.5}$ concentration. Dropping exposures from 350 to 175 $\mu g/m^3$, for example, is not likely to produce much risk reduction, particularly compared to reaching the Indian standards of $40\mu g/m^3$or even lower.

1.2.3 Ambient Air Pollution:

The rapid growth in the industrial, power, and transportation sectors nationally, teamed with growing planned and unplanned urbanisation in India presents a cause for concern. Residents of urban settlements are exposed to increasingly higher levels of particulate matter (PM_{10} and $PM_{2.5}$), sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO) and ozone. While SO_2 levels have declined in recent years, levels of all other pollutants routinely exceed the National Ambient Air Quality Standards (NAAQS). In over half the cities monitored as part of the National Air quality Monitoring Programme (NAMP) levels of PM_{10} are critical, and over two-thirds exceed the mandated safe levels of 60 $\mu g/m^3$. The NO_2 levels have begun to increase in several cities. Available data from Delhi shows frequent violation of ozone standards as well. Although SO_2 levels have declined in cities overall, many cities still face unhealthy levels of several pollutants at once.

Broadly, though, assessment of source-wise contribution to air pollution is inadequate in India. Some studies have been carried out by different agencies in a few cities. The CPCB does operate air quality monitoring stations but they are very limited in number and mostly in large cities. Thus a national picture of the problem can only be derived through satellite modelling. As shown in figure 2 below, satellite modelling of $PM_{2.5}$ concentrations nationally showed a stark picture of ambient air pollution in rural areas. While most of southern India complied with the NAAQ standards, the Indo-Gangetic plain uniformly registered critical levels of $PM_{2.5}$ attributable to the presence of a large number of brick kilns, old and inefficient combustion technology, and the use of biomass and coal for household cooking and heating needs.

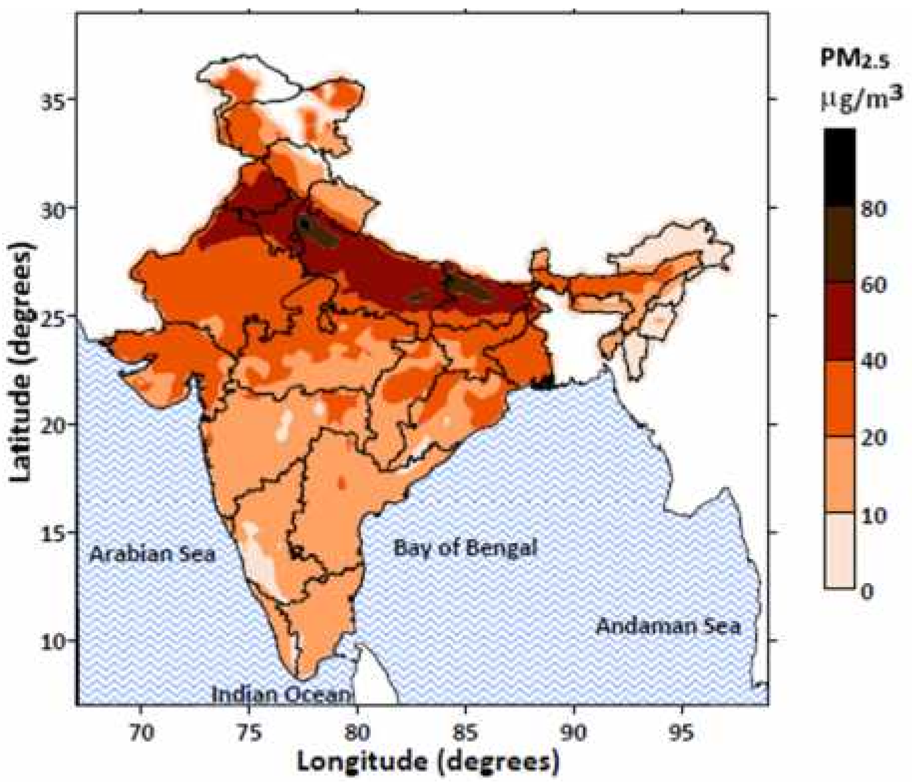


Figure 4: Ambient $PM_{2.5}$ concentrations derived from satellite observations (Van Donkelaar et al., 2012)

Studies have also shown a strong correlation between high levels of PM_{10} and SO_2, and proximity to coal fired power plants. With substantial growth in coal-based power predicted even in the most conservative of scenarios, and lax standards to address stack emissions, this is a problem that is only going to worsen with time.

Emerging work has also been focused on exposure apportionment in addition to identifying sources of emissions. These exposure apportionment calculations only refer to downwind exposure to sources, though, and do not yet account for near-field exposures, which many times can be much higher. Nevertheless, exposure apportionment estimates could be quite important in policy design and implementation to enable exposure mitigation from specific source, and to enhance traditional approaches to control by focusing efforts more directly on health-related exposures.

The revised ambient air quality standards of 2009 also included six carcinogenic air toxics and heavy metals. Data on their levels across the country is limited though, as cities haven't yet developed the capacity to continuously monitor air toxics.

Over the last three decades, a growing evidence base has been developed globally that has led to a detailed and increasingly comprehensive understanding of the HAP problem. The evidence base for

AAP health effects is much larger and includes thousands of studies worldwide. It is only recently, however, that it has been possible to combine the results of studies in order to examine the health impacts of each along the same spectrum. In addition, it is now realized that in many countries, including India, HAP contributes substantially to AAP. Thus, it is only prudent to also examine the exposure and response to air pollution in an integrated fashion.

1.3 Health Effects

In addition to a growing volume of studies in India that have examined the health effects of ambient and household air pollution over the last decades, there are now accepted techniques to derive estimates of health effects in India by reference to health effects studies done elsewhere. Similar techniques, which rely on exposure-response analyses, are widely utilized in policy across many environmental health risks, including those in water, toxic chemicals, workplace pollutants, etc. The health burden from ambient and household air pollution exposures is no longer thought to be limited to chronic and acute respiratory outcomes in men, women, and children as it is generally accepted that there are also impacts on ischemic heart disease, stroke, cataracts, and lung cancer. In addition, there is increasing evidence of adverse pregnancy outcomes, TB, asthma exacerbation, other cancers, and cognitive impairments. Just as with tobacco smoking, which produces the same set of impacts, air pollution needs now to be considered within public health programs concerning both non-communicable and communicable diseases.

The disease burden estimates for air pollution have been enormously strengthened through the development of what are now called “integrated exposure-response” (IER) relationships that uses the vast health literature of health effects from outdoor air pollution (mostly in developed countries), active smoking with the growing literature documenting effects from second-hand tobacco smoking (SHS) and household air pollution. These now show a gradual rise in risk for five major categories of disease (lung cancer, heart disease, stroke, chronic obstructive pulmonary disease, and child pneumonia) over nearly a factor of 1000 in exposure – with outdoor air pollution levels at the lower end, active smoking at the highest levels, and second-hand smoke and HAP being intermediate.

The consistency of effects across exposure spectrum through the IERs significantly enhances the confidence in the risk estimates. It also allows comparison of attributable disease burden estimates across combustion sources providing opportunities to evaluate intervention options on the basis of individual benefits as well as one or more co-benefits. In fact, it is the use of these IERs in the 2010

Global Burden of Disease assessment that resulted in the attribution of around 1.04 million premature deaths and 31.4 million DALYs to HAP resulting from solid cooking fuel use, and 627,000 deaths and 17.7 million DALYs to AAP in India.

The ubiquity of high levels of exposures across rural and urban populations, the range of health outcomes associated (including many with high underlying prevalence rates), and the populations at risk (includes all age groups, even babies and young children who do not smoke) together make the attributable disease burden significant.

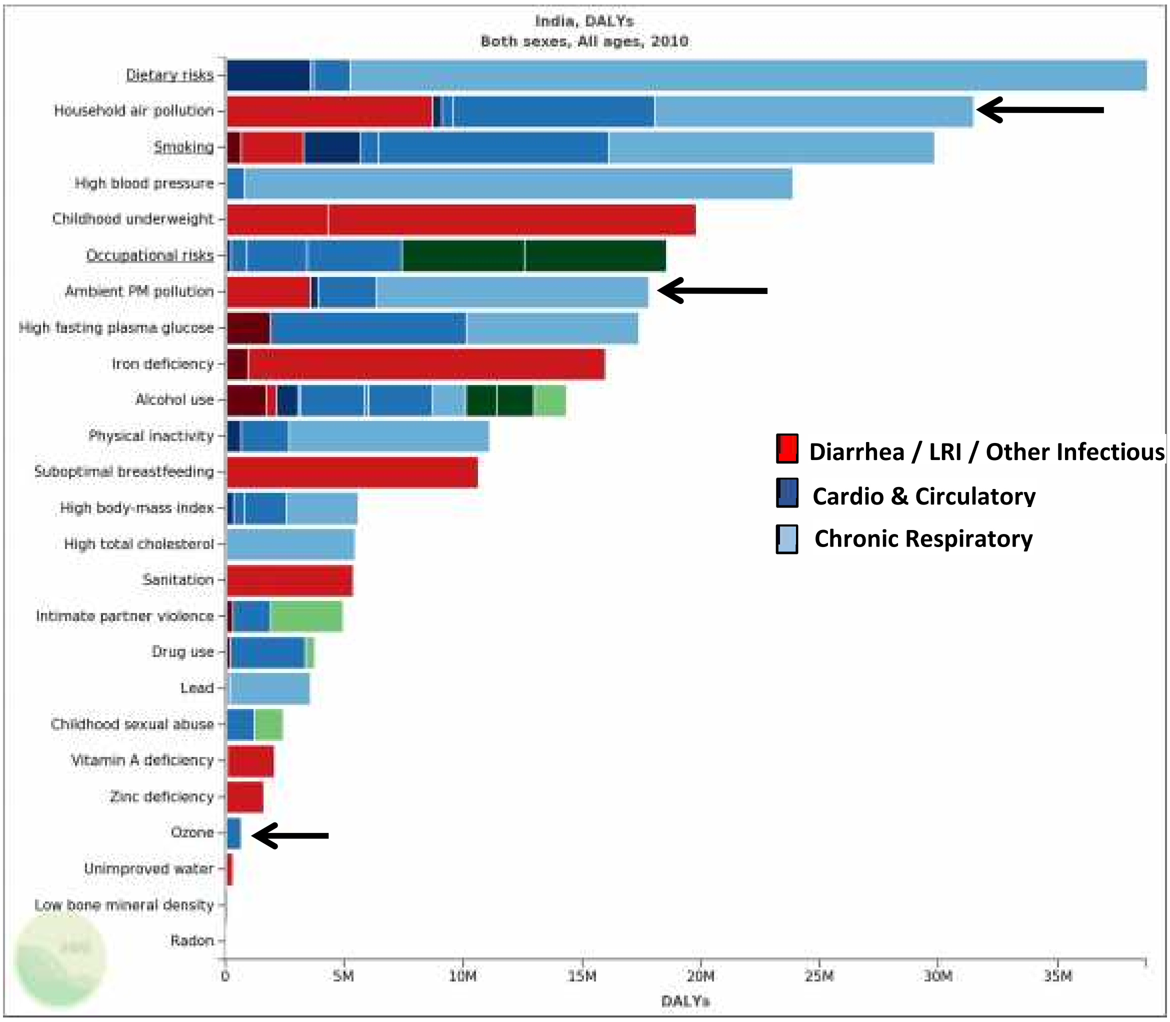


Figure 5: Ranking of risk factors based on DALY contribution in India (GBD, 2010)

1.4 Recommendations

Given the complex nature of the air pollution problem with a multiplicity of sources and impacts, it is clear that there is no "silver bullet" solution. Addressing this problem will require a multi-sectoral approach, driven by environment and health data, science, and evidence. The formulation, strengthening and implementation of policies and programs that are needed to tackle this major risk factor for our national burden of disease will require a concerted and coordinated effort across the government. While the MoHFW can implement some of the actions highlighted below, many others will require actions by other Ministries and agencies.

We believe that reduction of both emissions and exposures are important to protecting public health but a health policy driven prioritization of options has to be principally driven by exposure, since that ultimately determines health outcomes. Therefore, while we very much recommend reduction of emissions as much as possible to reduce overall population levels of exposure, the highest immediate priority has to be accorded to sources that lead to the greatest levels of exposure and adverse health impacts.

1.4.1 Source-wise actions to reduce exposure:

We recommend focusing on key air pollution sources that are implicated in long-term and episodic exposures. In each category, we list following sources in order of priority, based on exposure estimates, to reduce health impacts from air pollution.

1.4.1.1 Long-Term Exposures:

Household air pollution:

The WHO recommended emission rate targets for $PM_{2.5}$ (0.23 and 0.80 mg/min) and CO (0.16 and 0.59 g/min) in vented and unvented kitchens, respectively, require a shift to very clean sources of household energy. The two primary categories of options are 1) making clean sources available (i.e., electric cooking or gas (natural, bio or liquefied petroleum), or 2) making ubiquitously available sources (i.e., biomass) clean. In the case of the former, issues such as fiscal policies and distribution systems designed to make clean energy affordable and accessible to the poor will need particular attention. In the case of the latter, to reach health goals, current standards for biomass stoves in India need to consider the WHO emission rate targets, which will push advanced stoves even further than has happened to date. Furthermore, it should also be noted that HAP intervention strategies ideally require a community-level approach.

The need for such widespread uptake of clean cooking energy – and therefore a movement away from traditional energy sources and cooking practices – will require drawing on behavioural and social sciences, as has been the case in other health interventions such as improved sanitation, vaccine delivery, safer sex, and malaria control.

There also is a need to align programmes on clean fuels/cooking technologies across the concerned ministries and also leverage the National Biomass Cookstove Program of Government of India to improve access to clean cooking energy in a time bound manner.

Vehicular pollution:

There are a range of control measures to mitigate health impacts from vehicular pollution. We recommend an "avoid-shift-improve" framework as a way of prioritizing actions to manage health impacts from vehicles.

The "avoid" refers to avoiding vehicle use as much as possible, and, from a health point of view, particularly in areas with large or dense populations. A comprehensive perspective on avoiding vehicle use is based on integrated land-use planning which manages transport demand at the more fundamental level. In the short-term, targeted approaches can be put in place rather quickly. These can include financial disincentives such as higher taxes on fuels, congestion pricing, and/or increasing parking fees in heavily-populated areas. These can also be done through regulatory approaches such as making high-density areas vehicle free or limiting vehicle use more broadly.

"Shift" refers to shifting to modes of transport that reduce pollution and impact while still allowing free movement of goods and people. This can be achieved by making available mass transport such as buses and metro rail, or promoting avenues for non-motorized transport, such as bicycles, such that health impacts per passenger-km travelled are reduced.

"Improve" refers to improvement of technologies of vehicles so that they emit fewer pollutant per km travelled. This can be achieved through significantly tighter emission standards and fuel standards, which could lead to reduction of emissions per vehicle-km travelled and also prevent lock-in of polluting technologies in the new vehicle stock. This is complemented by tighter checks on on-road vehicles to ensure they do not emit grossly more than they are designed to emit. Health-based criteria could be prioritized to leapfrog emissions standards to Euro VI by 2020 and also cut toxic risk from diesel emissions.

It should be understood that there is no single panacea for reducing transport emissions and generally a range of measures are needed to mitigate these emissions. Therefore an integrated view to reducing health impacts from vehicle pollution is critical.

Trash burning:

Trash burning is a significant contributor to the overall pollution load in cities, and since the burning occurs primarily in highly populated areas such as residential neighbourhoods, it leads to high exposures through high intake fractions. Controlling trash burning will require strict enforcement of existing legislation banning the practice, teamed with improved infrastructure for collection and composting of vegetative waste and overall waste management.

Diesel generator sets:

Diesel generator sets, primarily located in residential areas or in commercial buildings, are a significant contributor to the pollution load in cities. As the electricity supply becomes more reliable, the use of diesel gensets should be discouraged. But as an interim measure, BEE-rated diesel generators that are more efficient and less polluting should be promoted as alternatives. Also the emissions standards for generator sets could be significantly tightened.

Road and construction dust:

Dust from local sources such as from areas of little or no green cover, construction sites, and re-suspension of road dust, is a major contributor to particulate matter (PM) levels in cities. Strategies to manage this form of pollution, and exposures to it, include formal adoption of dust control regulations and techniques including the implementation of street design guidelines for footpaths and cycle tracks with adequate vegetative barrier and paving without compromising recharge zone along the roads for ground water; putting in place guidelines for eliminating others local sources of dust (such as construction materials and waste); providing vegetative barriers – shrubs and trees wherever possible; limiting vehicular speed to reduce dust; implementing truck loading guidelines to control dust; use of appropriate covers for trucks and other hauling carriers; and gravel paving for all haul routes.

Pollution from construction dust can be addressed by enforcing good construction practices and making construction industry accountable for safe disposal and recycling of construction and demolition waste. The environment impact guidelines for construction industry, municipal solid waste guidelines, and the recent moves by the National Green Tribunal to enforce a moratorium on construction activities that have not adequately planned for disposal of waste material, can all help address this problem. However, these rules will have to be enforced with greater stringency at the state levels.

Brick kilns and other local industries:

These are significant contributors to the pollution load of cities as they are usually located just within or outside city limits, and the fuel sources they use (coal or agriculture residue) are highly polluting. A roadmap for tackling emissions from brick kilns would involve the phasing out of inefficient and highly polluting technology, and developing and implementing emissions standards that are in line with the technology standards, enforcing bans on inefficient kilns and promoting alternative building material and bricks.

Large sources (such as industries and power plants):

These sources will require two levels of action – Emissions standards to ensure quicker uptake of clean technologies to reduce overall emissions across the country and tight particulate standards for power plants and also introduce standards for nitrogen oxides, sulphur dioxides and mercury to reduce exposure to power plant emissions. Industry and power plants will also need a siting policy to ensure these are not located close to densely populated habitats. These sources will also require strong compliance monitoring.

1.4.1.2 Episodic Pollution

There also is a class of pollution sources that are episodic in nature ranging from biomass burning in households that might leads to high-pollution episodes two to three times a day, to vehicular pollution that occurs at peak travel times, to crop burning which is seasonal in nature. These episodes are important because of the high peak levels of pollution that might be reached for a short time. While the exact health impacts of such high exposures for short periods are not as well studied and understood as chronic exposure to air pollution, these impacts certainly are deleterious, particularly for vulnerable populations such as older persons, pregnant women, or those with respiratory conditions. Thus particular steps might be required to address these specific cases of episodic pollution.

In such cases, in addition to strategies that are directed at controlling these sources of episodic pollution, health advisories or public warning systems that intend to protect the general population (especially vulnerable groups) should be developed. Reporting of daily air-pollution related cardiovascular or respiratory hospital admissions by hospitals during particularly high episodic pollution events could also help in developing our understanding of the exposure-response relationship.

1.4.2 The Special Role of Ministry of Health and Family Welfare

With the establishment of this Steering Committee, the MoHFW has recognized that air pollution exposure (household and ambient) is responsible for a large proportion of the ill-health in India, rivalling or exceeding nearly every other risk factor that has been evaluated including poor nutrition, smoking, alcohol, high blood pressure, obesity, etc. In view of this, the Ministry should strengthen and direct its own considerable health systems more directly to adequately respond to the air pollution related health challenge. Steps that can be taken by the MoHFW include:

1.4.2.1. Better integration of air pollution and public health policies

The current legal framework is not adequately designed to address total exposure reduction through a strong compliance system to meet clean air targets. Incorporating explicit provisions in the statutory framework such as the Air Act (1986), and integrating policy drivers targeted at household air pollution management in MNRE mechanisms would work towards addressing this problem.

It is therefore recommended that the current legal framework for addressing air pollution and public health be reviewed to chart a roadmap for health-based decision-making process and an effective compliance system to reduce overall exposure to protect public health. The ongoing reforms of several environmental laws are an opportunity to address this issue, with the Ministry of Environment’s recent decision to include an objective health indicator in the Comprehensive Environmental Pollution Index for critically polluted areas being an important first step.

1.4.2.2. Integrate care pathways into existing national frameworks or programmes

The RSBY, the national flagship health insurance scheme, and several similar state-run schemes have contributed to lowering the burden of healthcare related impoverishment. This has been done primarily through coverage of in-patient services in public and private healthcare facilities. Data shows us however that a large proportion of health expenditure in the country is on OPD services, and on drugs. The vast majority of DALYs associated with air pollution exposure are attributable to NCDs, either respiratory or cardiovascular, which require sustained care over a long period of time.

The recent dialogue around a new National Health Assurance Mission (NHAM) has spoken, of among other things, increasing access to essential medicines, and integrating some mechanism for care of chronic conditions, both through expanding traditional allopathic care as well as wider adoption of indigenous medical practices such as AYUSH. To counter the large burden of disease attributable to air pollution exposure, it is vital that care pathways be developed and implemented through national programmes such as the NHAM, because as detailed elsewhere in this report, air pollution exposure disproportionately affects the poor and vulnerable.

1.4.2.3. Strengthen policy-making capabilities in the area of air pollution and health

In order to engage with the air pollution and health issue on an ongoing basis, the MoHFW needs to develop internal processes to use evidence from toxicological, epidemiological, and other scientific research for policy making, and to aid in the establishment of improved air pollution regulations. To facilitate this, the MoHFW can consider establishment of a standing expert group on air pollution and health that could provide inputs and advice to the MoHFW on a range of areas including monitoring and evaluation of various programmes, and assessment of ever-evolving state of science and its policy implications.

1.4.2.4. Air pollution data collection and health impacts research

There is an urgent need to develop a comprehensive air pollution monitoring network focusing on concentrations of key air pollutants from the health perspective. A focus on both the pollutants are important to calibrate technology choices for mitigation to prevent trade-offs between these pollutants. However, $PM_{2.5}$ monitoring can be prioritized for immediate roll out. This should not just be in urban areas but also in rural areas, i.e. focused on estimating population exposures. The MoHFW will need to take a key role in driving such data collection.

Working with the National Family Health Survey, the National Sample Survey Organization (NSSO), and others, the MoHFW should convene a group to enhance the current standardized household survey questions to better elucidate the health risks from household air pollution, and monitor changes. Risk assessments and economic analysis, both of health impacts of air pollution, as well as of mitigation strategies, could also be extremely helpful for policy-making.

1.4.2.5. Capacity building for public health practitioners and health care providers

Healthcare providers, who are key stakeholders, should be trained to become an effective medium for delivering harm-reduction strategies to their patients in their clinical practice. At the same time, there should also be additions to the curricula in medical and nursing schools in the country to include modules on air pollution and health to raise awareness in the health care community. Medical Associations can be powerful partners in this as well as in raising awareness and advocating for inter-sectoral cooperation. Medical professionals are independent and credible translators of scientific information to policymakers and to the public.

Given the ubiquity and magnitude of health impacts from air pollution in India, consideration should be given to developing national clinical criteria for evaluating patient risk from air pollution, which could then be disseminated to health workers to help them better identify air-pollution-related symptoms and also be more knowledgeable about the kind of protective measures to recommend.

1.4.2.6. Information-dissemination strategies to reduce air-pollution-related health impacts

The MoHFW could use its service infrastructure, such as ASHAs, public health clinics, and primary health centres to disseminate air-pollution related information including options for communities to reduce their exposures, particularly for the most vulnerable groups -- pregnant women and very young children.

Information on air pollutant concentrations should be made publicly available such that it could both assist with public understanding of pollution levels. Furthermore, integration of the Air Quality Index and other early-warning systems could be used as risk communication tools, with context-based health messaging.

Another possibility could be to an anti-pollution campaign, with a particular focus on HAP, to follow the successful anti-smoking campaign now prominent in Indian media. Possible examples include a national programme to establish "smokeless village" awards analogous to awards to villages for becoming "defecation free" (i.e., Nirmal Gram Puraskar) and the initiation of a media campaign to encourage families to provide clean cooking technologies to young brides, analogous to those in Gujarat to promote toilets as wedding gifts.

1.4.2.7. Strong and sustained linkages to other actors/programs

In order to address health impacts of air pollution from the range of sources that we have highlighted above, a multi-sectoral framework and accordingly a multi-ministry/agency structure should be in place. The MoHFW should be the coordinator for this structure. The MoHFW may also consider asking other relevant ministries (e.g. environment, power, new and renewable energy, rural/urban development) to undertake health impact assessment for major projects that might have an impact on public health.

In addition, we also suggest that it work with the health agencies at the state level to both sensitize them to the health impacts of air pollution and also give them guidance on best ways to address this problem.

Linking to the Swacch Bharat Abhiyan may be particularly salient, given the health (and other) impacts of air pollution and the relative lack of focus on air pollution in this initiative so far.

1.4.2.8. International Linkages and Agenda-Setting

International linkages, such as to WHO, should also serve both to stay abreast of the latest developments in this area, to build possible synergies with programs in other countries, and also to disseminate success stories from India. The organisation of a global meeting to highlight the work of this committee both in its approach and recommendations would help ensure that the MoHFW is not only taking the lead in addressing a major health problem within the country but also seen as a global leader in this area.

Increasing investments in health research that will provide evidence-based policies that can underpin risk-based assessments of air pollution impact on various health outcomes.

1.4.3 The Role of other Ministries and Agencies

Other Ministries/Agencies can also take a number of steps to help address the health impacts of air pollution as detailed in the table below.

1.	Ministry of Agriculture	• Policy in place to promote multiple uses of crop residues and prevent their on-farm burning
2.	Ministry of Finance	• Analysis of the economic and financial implications of the health and other impacts of air pollution
3.	Ministry of Labor and Employment	• Ensure regular health check- ups for early screening of NCD related risk factors among workers • Frame guidelines for health promoting workplaces, especially guidelines on indoor air quality and conduct workshops at different workplaces • Strengthen the capacity of ESI Hospitals to cater to the growing burden of respiratory diseases and NCDs • Exploring feasible options for RSBY to include OPD services for respiratory diseases, COPD, NCDs, etc. • Showcase and support companies which employ workplace policies that can reduce vehicular travel such as telecommuting, or placing the workplace in sites that are accessible through public transportation (ex. Metro) or non-motorised transport.
4.	Ministry of Human Resource Development	• Regular screening of school children for early detection diseases, which can be attributed to the existing air pollution • Inclusion of harmful health effects of environmental pollution (AAP and HAP) in the school curriculum, including current policies and mitigation practices that are designed to reduce air pollution • Improving indoor air quality of educational institutions nationwide • Improve walkability and access to educational institutions by non-motorised transport, thus minimizing the air pollution in the school surroundings • Sensitize students and teachers on using the Air Quality Index in planning outdoor school activities
5.	Ministry of Rural Development	• Include health promoting guidelines including clean air, as a part of the "Nirmal Gram Puraskar " / Model Villages evaluation criteria/ create alternate awards with specific criteria based on air pollution • Under integrated rural development, develop and implement micro level planning policies/schemes with Panchayati Raj Institutions to address the social determinants of health for reducing the hazards of air pollution (lack of education, unemployment, poverty, poor housing conditions, etc.)
6.	Ministry of Women and Child Development	• Advocate through Self Help Groups and Mahila Mandals for protection of women and children from significant exposure to smoke from biomass while inside the house. Awareness raising can be done to improve household ventilation to reduce smoke inhalation from lighting (ex. kerosene) or cooking fuels

7.	Ministry of Urban Development	• Formulate/revise urban transport policy which reduces vehicular pollution (Include Health Promoting city guidelines in the "100 Smart Cities") • Develop and implement policies to reduce indoor air pollution (like disincentivizing diesel gensets and promoting clean cooking fuels thus 'making available clean and making clean available') • Enforcement of ban on burning garbage or biomass (especially during winter months) • Help cities develop air pollution alerts & emergency plans based on the Air Quality Index or CPCB continuous air monitoring data
8.	Ministry of Environment, Forests and Climate Change	• Ensure that Central and State Pollution Control bodies are empowered to set industry-specific emission and effluent standards, monitor levels of pollutants and enforce penalties, thus preventing NCDs. • Strict implementation of Environment Impact Assessments (EIA) is a major tool to minimize the adverse impact of industrial activities on the environment • Effective implementation of 'National Green Tribunal' directives on trash burning/ waste disposal from different sources • Take strict measures for unregulated sectors (such as brick kilns, trash burning, stone crushing) which contributes to ambient air pollution
9.	Ministry of New & Renewable Energy	• Develop policies relating to truly clean chulhas (cookstoves) and to support further research and development. • Research and development of other non-conventional/renewable sources of energy and programmes relating thereto, including locally generated power to supply cooking appliances; • Support and strengthen Integrated Rural Energy Programme (IREP) with emphasis on indoor air pollution • Develop National Policy on clean Biofuels (biogas, ethanol, etc) and set up National Biofuels Development Board for strengthening the existing institutional mechanism and overall coordination. • Create a national consensus action plan for replacing biomass fuels with alternative clean fuels
10.	Ministry of Petroleum & Natural Gas	• Expand new initiatives to increase the availability of LPG and other cleaner fuels to the rural & tribal areas • Expand the piped natural gas network to reach out to a larger population • Better target LPG subsidies to poorer households
11.	Ministry of Power	• Promote the development of more efficient cooking devices • Evaluate the potential for electric cooking appliances to substitute for biomass and LPG

12.	Ministry of Information and Broadcasting	• Develop policies to ensure that media houses allocate free airtime for health promotion messages as a corporate social responsibility activity • Develop hard hitting, high impact and cost effective media plans, strategies and conduct activities for awareness generation on harmful effects of air pollution and options for their mitigation. • Ensure enforcement of relevant provisions in the Cable Television Networks Act to regulate advertisements of tobacco etc. • Involvement of Songs & Drama division; Department of Field Publicity to promote health promotion activity for air pollution and its impact on respiratory and NCD risk factors
13.	Ministry of Communications & Information Technology	• Use of mobile phones to encourage healthy choices and warn people about air pollution (both AAP and HAP, using Air Quality Index) • Establish Telemedicine linkages between different levels of health care
14.	Ministry of Law & Justice	• Support enforcement on bans of burning trash for heating or as a way of disposal
15.	Ministry of Road Transport and Highways	• Ensure effective implementation of New Motor Vehicles Act (once approved) • Ensure proper engine checks for vehicles to assess pollution levels
16.	Ministry of Parliamentary Affairs	• Create a Parliamentarians Forum on air pollution • Appointment of Members of Parliament on Committees established for air pollution attributable health effects
17.	Ministry of Panchayati Raj	• Create enabling conditions to facilitate community participation like self-help groups • Improve village level awareness of proper household ventilation and health hazards of exposure to biomass smoke
18.	NITI Ayog	• Evolve appropriate policy and strategies to strengthen the linkages between relevant sectors by looking into intersectoral issues and provide relevant mechanism for their convergence • Assess human and financial resources for addressing air pollution and take appropriate measures to strengthen ongoing programmes and conventions to address air pollution and health hazards • Advocate to include the agenda of air pollution in the agenda of relevant sectors • Appraise and extend recommendations for effective and equitable utilisation of health services considering the burden of air pollution and its impact on health

1. Introduction

Exposure to air pollution in whatever form, has long been globally recognized as an important risk factor for adverse health effects. However, this recognition has not yet translated into a coordinated multi-sectoral policy response that can reduce exposure and air pollution related burden of disease in India. Over 700 million people are still exposed to smoke from the use of biomass cookstoves nationwide, and India is home to 13 of the world's top 20 cities with the worst ambient air quality, as per the World Health Organization (WHO).

The Global Burden of Disease study conducted in 2010 ranked air pollution as the leading environmental risk factor worldwide, and as a leading cause of death and disability in India. The comparative risk assessment exercise showed that approximately 1.6 million premature deaths and 59 million Disability-Adjusted Life Years (DALYs) are attributable, in India, to $PM_{2.5}$ (fine particulate matter ≤ 2.5 μm in diameter), and other pollutants that are found in Household and Ambient Air Pollution (HAP & AAP). Taken together, HAP and AAP account for 9% of the national disease burden, and comprise the single largest risk factor of the over 60 risk factors examined in the study. GBD studies are evolving over time and the specific numerical estimates can be expected to change as well, but it is clear that particulate air pollution will remain one of the largest causes of ill-health in India until major efforts are made to reduce exposures in the population.

This is not surprising when we consider that the health impacts associated with exposure to air pollution are pervasive. Our review shows that exposure to air pollution, be it household or ambient, are linked to infectious diseases such as respiratory infections in infants, chronic respiratory illnesses and cancers in adults, and cardiovascular disorders such as ischemic heart disease and strokes. Further, studies conducted globally also show links to a multitude of other health outcomes at far lower exposure levels than are prevalent in India. Air pollution exposures also differentially affect particular groups due to factors such as age, sex, pre-existing conditions, socio-economic status, nutrition, and access to health care, thereby exacerbating existing vulnerabilities.

The global recognition of Non-Communicable Diseases (NCDs), as the leading cause of death and disability worldwide, was reinforced with the United Nations General Assembly's Political Declaration on NCDs in 2011, which adopted 9 global targets to reduce mortality and morbidity from NCDs by 25% by 2025. The subsequent adoption of an additional target on Household Air Pollution by countries in the WHO South East Asia Region in their Multi-Sectoral Action Plan on the Prevention and Control of NCDs, only served to highlight the fact that exposure to air pollution is a key risk factor across South Asia. The World Health Assembly 2015 has also adopted a resolution to address the health impacts of air pollution – the world's largest single environmental health risk. This resolution highlights the key role national health authorities need to play in raising awareness about the potential to save lives and reduce health costs. It has asked for strong cooperation between different sectors and integration of health concerns into all national, regional and local air pollution-related policies. (See Box: The resolution on air pollution passed in the World Health Agency, 2015).

This committee was constituted by the Ministry of Health and Family Welfare (MoHFW), Government of India, in January 2014 with the stated aims of:

1. Collating and critically appraising evidence available both at Indian and global levels linking air pollution exposure to adverse health effects, and
2. Providing recommendations for policy and programmatic responses across sectors which can both enable mitigation of exposure and adaptation for harm reduction.

This initiative is the first of its kind to be undertaken globally by a Ministry of Health, rather than one focused on the environment. This demonstrates that the primary motivation behind the setting up of the committee was to identify pathways to reduce the public health burden arising from air pollution exposure. The fact that the committee was tasked with tackling air pollution exposure as a whole, without exclusive focus on either ambient or household exposures, also signifies a growing understanding in India that exposure to air pollution, be it ambient or household, forms part of a continuum and cannot be examined in a compartmental manner. The active engagement of multiple non-health stakeholders in the committee is a recognition of the fact that while the focus on the issue may be provided by the MoHFW, the actions needed to protect the Indian public from these exposures need to flow through multi-sectoral programmatic responses.

Recent developments such as the introduction of a National Air Quality Index (under the framework of the Swachh Bharat Abhiyan) initially in 10 cities, and directives from the National Green Tribunal are welcome advances. Nevertheless, to actively reduce exposures and not just emissions, we believe that health should be at the centre of policy formulation across all sectors. We hope that this important first step taken by the MoHFW to highlight the health impacts of exposure to air pollution will go a long way towards focusing public and policy attention on a critical developmental issue of national importance. We believe that Swachh Bharat should extend to the promise of clean air to breathe, especially for the children of India in whom the future of India is vested. We also believe that this is possible, through resolute policy and programmatic responses which bind several sectors to concerted action. The recommendations of this committee offer such a blueprint for action.

Box 1: The Resolution on air pollution passed in the World Health Assembly 2015 -- on Health and the environment: addressing the health impact of air pollution

This resolution has urged Member States to develop air quality monitoring systems and health registries to improve surveillance for all illnesses related to air pollution; promote clean cooking, heating and lighting technologies and fuels; and strengthen international transfer of expertise, technologies and scientific data in the field of air pollution The key highlights on health outcomes of air pollution and relevant excerpts of this resolution are as follow:

- Air pollution is one of the main avoidable causes of disease and death globally.
- Even at relatively low levels air pollution poses risks to health, and because of the large number of people exposed it causes significant morbidity and mortality in all countries. However, although all populations are affected by air pollution, the distribution and burden of consequent ill-health are inequitable. The poor and disempowered, including slum dwellers and those living near busy roads or industrial sites, are often exposed to high levels of ambient air pollution. Women and children in households that have to use polluting fuels and technologies for basic cooking, heating and lighting bear the brunt of exposure to indoor air pollution.
- Pollutants with the strongest evidence for public health concern are fine particulate matter1 and gases (mainly carbon monoxide, ozone, nitrogen oxides, sulphur dioxide and volatile organic compounds). Fine particulate matter, which is widespread both indoors and outdoors, damages the health of more people than any other air pollutant, through the deposition of particles in smaller airways and alveoli in the lungs and their penetration into the bloodstream.
- Among the types of fine particulate matter, particular concern centres on elemental carbon and organic materials, transition metals and metal compounds; inorganic sulphates and nitrates; ammonia; sodium chloride; and mineral dust. Absorbed particles can damage inter alia lung function and the cardiovascular system, through oxidative stress, alteration of the electrical processes of the heart and systemic inflammation, leading to endothelial cell activation and dysfunction; altered blood pressure and heart rate, including heart rate variability; arrhythmia; and deregulated coagulation pathways; and ischaemia.

- Exposure to air pollution, especially fine particulate matter, is a leading risk factor for non-communicable diseases, in particular: ischaemia, myocardial infarction, stroke, chronic obstructive pulmonary disease and cancers. Of deaths due to outdoor air pollution 80% are attributed to heart disease and stroke and 20% to respiratory illnesses and cancers. For household pollution, acute respiratory diseases in children and chronic obstructive pulmonary disease are the most serious consequences, followed by heart disease and stroke. Indoor and outdoor air pollution together cause about one fifth of the global mortality from stroke and ischaemic heart disease, and more than one third of deaths from chronic obstructive pulmonary disease.
- Air pollution and in particular its fine particulate component have recently been classified as a cause of lung cancer by IARC, which had already classified diesel combustion and the burning of coal (two main causes of household and ambient air pollution) as the source of carcinogens. Around 30% of all lung cancer deaths can be attributed to the joint effects of household and ambient air pollution.
- Most sources of both ambient and household air pollution are directly influenced by the choice of energy technologies and fuels used, including the energy efficiencies of homes and transport systems. Therefore, the prevention of diseases related to air pollution depends on the implementation of specific sectoral policies that reduce air pollution at point of source (for instance, in energy and power generation, transport, urban planning, buildings, industry and agriculture).
- The use of cross-sectoral approaches to health, such as health in all policies, can help to identify the appropriate policy responses for tackling the main sources of air pollution in specific sectors, as well as related opportunities for more joint action.
- Integral to strategies to control the damaging effects of air pollution on health is the setting of clear health benchmarks, targets and reporting mechanisms for monitoring the effectiveness of air pollution control measures. The WHO's air quality guidelines for both ambient and indoor air quality provide benchmarks, which are considered by most countries when setting goals for clean air.

2. Framework for this Assessment: Health

Among the charges given to this Committee were

1. To recommend methods and framework to monitor indoor and outdoor air pollution and to achieve the targets adopted in this regard.
2. To recommend action required to be taken in order to control/reduce the pollution caused by the sources [both outdoors and indoors] identified.

This implies developing a way to set priorities for monitoring and control across pollution sources that affect human health, ranging from large industrial sources such as power plants to small ones such as household stoves, with many others in between. Not all sources are equal in their health impacts, however, and thus, from a health perspective, it is possible to design a framework that help set these priorities and allows for more effective outcomes by focusing first on the sources that have the biggest impact.

2.1 The Exposure Framework – Measure Where the People Are

The environmental health pathway in Box 1 shows the standard distinctions made in describing air pollution health impacts. Although the ultimate concern is human ill-health at the end of the environmental pathway, the easiest, and sometimes only, control points are at the other end, at sources and emissions (e.g., fuel quality and emissions controls). For optimal control strategies, one might prefer to utilize a risk measure such as health damage per unit emissions. Although health damage is the best indicator of risk, however, it usually is not useful as a monitoring indicator for control purposes because by the time the damage occurs, it is too late to apply control measures with much effect. In addition, nearly all health outcomes of interest are not specific to air pollution, such as heart disease, which is due to a range of risk factors. Sorting out what fraction is due to air pollution in any one situation is a matter for sophisticated research and not suitable for making regular decisions about controls.

Box 1: **Environmental health pathway:**

Figure 1-1: The environmental health pathway for air pollution

The environmental health pathway shown here illustrates conceptually the full pathway from sources of pollutants at one end of the pathway all the way to health effects at the other. The risk of ill-health can be measured at several points and interventions to reduce them can be initiated at several point. The source type – a dirty fuel for example – gives some idea of the potential risk, but does not allow for potential differences in combustion conditions and emissions control. Emissions, in turn, are often where controls are placed, but are difficult to measure for many millions of devices, such as stoves or vehicles.

Ambient concentrations are easier to measure, but do not always well represent true human exposures, which can be heavily influenced by nearby sources that do not affect general ambient concentrations. Dose, a measure of changes in the body due to pollutant exposures, can be an accurate measure of potential effect, but are not available for many important air pollutants. In general, exposures are considered the main measure for controlling and understanding pollutants for environmental health studies. Exposure lies midway along the pathway from source to effect and thus are reasonably responsive to controls of sources and emissions and are highly indicative of potential health effects. See also Box 3.

Traditionally, therefore, ambient concentration has been used as the indicator of risk -- it being directly affected by emissions but lying closer to health impacts along the environmental pathway. Thus, the risk measure for control is concentration resulting per unit emissions in a certain area. Limits are established, in turn, by linking concentration to health through studies that result in relative risk for specific disease per unit annual concentration (mostly carried out in specific populations through large epidemiological studies). It is accepted, however, that most populations will react similarly since it is not possible to duplicate such expensive and lengthy studies in every community around the world (WHO, 2006).

The remaining options for indicators in Box 1 are exposure and dose. Dose is the best indicator short of actual health damage and someday may well be used routinely as the best indicator for health impacts of all air pollution. Indeed, blood levels of carbon monoxide in workers and blood lead in children are today serving that purpose. Unfortunately, however, dose shares with ill-health itself the characteristic of providing information too late in many circumstances. Most important, however, appropriate dose measures are relatively poorly understood for many pollutants, including PM, and those that exist sometimes require expensive and invasive measurement methods. The developing field of "exposomics", however, may eventually make this possible by rapid processing of blood or other biological samples to look for subtle biomarkers of exposure for thousands of people at once (e.g., Shen et al., 2013).

Exposure, on the other hand, although lying further from the endpoint of concern than dose, does not share such formidable knowledge, monitoring, and cost constraints. It does, however, present more difficulties than simple ambient monitoring. Important benefits would be required, therefore, to justify switching to exposure-based indicators, such as, for example, annual exposure per unit annual emissions.

Traditionally, air pollution control measures have focused on limiting emissions such that ambient concentrations do not exceed specified levels or standards (WHO, 2006). For nearly all pollutants of interest, these levels have been established on the basis of health criteria referred to outdoor ambient pollutant concentrations. This procedure implicitly assumes that community ambient concentrations fairly represent the full exposure of the surrounding population. If this assumption was borne out, there would be little advantage to switching to exposure-based controls.

It has become clear, however, that such measurements are often rather poor indicators of absolute human exposures (NRC, 2012). For some pollutants, actual exposures are higher and for other pollutants, lower, depending on local circumstances. Indeed, in most societies less than 10% of the total person-hours are spent in areas where ambient levels represent actual exposure.

The remainder is spent indoors, along streets, or in other locations where local conditions predominate.

This is even truer in India, where there are often many relatively small local but strong sources of pollution near populations – biomass stoves, trash burning, three-wheelers, street vendors, small industries, etc. These sources contribute to human exposures in a greater proportion than they do to general ambient pollution.

Although total control of all environmental concentrations in every location, if this should be possible, would also eliminate all air pollution risk, it is not equally true that a particular level of partial reduction of sources with equal contribution to ambient level will reduce risk to the same degree. Exposure assessment research has demonstrated quite clearly that in many situations ambient concentration is not a good surrogate for total air pollution risk, because it fails to accurately indicate exposure or dose, the intermediary points of the chain of causation leading from emissions to the health endpoint of concern.

This is distinct from the success that outdoor epidemiologic studies have had in using *changes in ambient levels as a reasonable indicator of changes in risk*. Rarely, however, can such studies be used to derive *absolute health risk* in a particular location, which is a function of population exposure that is affected by much more than just outdoor levels, particularly in developing countries such as India. The result is that evaluating control strategies merely on the basis of how well they reduce ambient levels can be misleading, at least for health.

Because of these discrepancies, exposure assessment is an active branch of environmental research (USNRC, 1991, 2012) with its own journal, international scientific society, graduate degrees, databases, and WHO programs. Although somewhat harder to measure, exposure has been found to be a much better linkage between emissions and health than is ambient concentration, a finding of critical importance not only for control measures but also for epidemiology (USNRC, 2012). Indeed, many in the field believe exposure assessment to be the primary skill of environmental health sciences.

This realization has major economic and policy implications, as well. For example, the standard practice of ranking pollution sources on the basis of their contribution to ambient emissions for the purpose of establishing priorities for regulation and control may be creating distortions in their apparent relative importance from the health standpoint, although perhaps adequate for other purposes – visibility, for example.

In many cases, however, evaluation by exposure will not only re-order the ranking of major outdoor emission sources but will reveal an entirely different landscape of sources; those that may significantly affect exposure without appreciably affecting ambient concentration (Smith, 1988b). Local sources, such as those in households and neighborhoods, and along streets, can often be more important contributors of exposure to important pollutants than the large-scale industrial sources that traditionally have been the focus of air pollution control programs.

In India, household combustion of household solid fuels is probably the largest single source of exposure in the country, although only one of many contributors to ambient air pollution. Other near field sources, such as trash burning and vehicles, also contribute more to total exposure than to total ambient levels. Others, such as power plants with high stacks, in contrast, while being significant contributors to overall ambient levels contribute relatively less to exposure per unit emissions.

The simple point of total exposure assessment is that if you are worried about health effects from air pollution, you should "measure where the people are". Although perhaps obvious when stated, there is a long tradition of measuring in places where people hardly ever are, such as 24-hours per day on the tops of post offices or other public buildings, or conversely, along streets where average levels are higher than experienced by most people. TEA can reveal quite a different set of priorities for control, or at least a substantially different ordering, to allow us to use most effectively the necessarily limited resources to manage air pollution to minimize health impacts (although eventually we do want to control all sources).

Increasing sophistication has been achieved in monitoring total air pollution exposures. Starting initially with small-scale nonrandom studies with special populations, it is now becoming possible to determine the distribution of exposures to whole populations by use of a careful combination of probability-weighted sample selection, survey administration, and outdoor, indoor, and personal, and monitoring. Indeed, such a preliminary effort in India has estimated exposure to household air pollution by state (Balakrishnan et al., 2013; see Chapter 3).

Box 2: Basics of intake fraction:

Health impacts of airborne and other pollutants depend on the exposure of the population of concern, which depends not only on the amount and toxicity of emissions, but also their proximity to the population. Thus, if no one is downwind to breathe it, a pollutant released far from populations may not affect health significantly, while a pollutant released in the direct proximity of people, e.g. in homes, can have a major effect, even if released in relatively small amounts.

The metric used to compare such situations is called "intake fraction" (iF) which for airborne pollutants is simply the amount inhaled by the population divided by the amount released. (Bennett et al. 2002). This is usually expressed as ppm, i.e., the number of grams inhaled per million grams emitted. At the extreme, active cigarette smoking has an iF of 1,000,000, i.e. all of the smoke emitted is inhaled. For sources emitting into the ambient environment, the difference between intake fractions of major categories of pollution in India is more than an order or magnitude as shown in the illustrative figure below for several Indian cities.

Table 2-1. Illustrative intake fractions in Indian cities: See below

	Ambient intake fraction - ppm						Nearfield intake fraction - ppm					
	Hyderabad		Chennai		Vizag		Hyderabad		Chennai		Vizag	
PM2.5	Average	SD	Average	SD	Average	SD	Average	Ratio*	Average	Ratio*	Average	Ratio*
Vehicle.exhaust	129.6	64.4	89.4	11.6	28.7	6.8	?	?	?	?	?	?
Household	174.8	97.1	76.3	9.2	47.6	17.0	850	5	755	10	750	16
Waste.burning	139.8	74.3	109.9	14.6	26.9	7.7	?	?	?	?	?	?
Construction	174.7	92.7	85.9	10.4	37.8	10.9	?	?	?	?	?	?
Industries	65.1	16.8	36.9	12.0	24.0	9.7	?	?	?	?	?	?
Power Plants			8.1	9.6	7.4	7.0			?	?	?	?
Gen Sets	122.9	52.7	89.1	11.0	44.0	13.2	?	?	?	?	?	?
Dust	18.4	4.0	63.2	17.8	24.9	4.3	?	?	?	?	?	?
Brick kilns	6.8	1.9	11.6	8.4			?	?	?	?		

* Ratio to ambient intake fraction

The first column shows the ambient iFs. Weighting emissions by these factors for policy priorities would clearly give a much different priority to control decisions in many cases (Smith, 2002). This would mean, for illustration that a change in emissions from vehicles would be weighted per gram about 11 times than from power plants in Chennai. Or put another way, from a health standpoint, India should be willing to pay 11x more per gram in Chennai to reduce vehicle emissions that those from power plants in those cities since this would equalize their contribution to health protection per rupee spent.

The ambient iFs in the table, however, do not represent the full picture because they are based on estimates of the downwind intakes of the population from source emissions. The atmospheric modelling used cannot capture what happens right near sources, such is in the passenger compartments of vehicles or around the household for cookfuels, termed near-field. Nearly all sources have some near-field component, but the largest additions are from those directly in places where many people spend considerable time, perhaps in order of importance, households, vehicles, and residential trash burning.

The last columns of Table 2-1 shows preliminary estimates of the additional component of near-field iF for household cookfuels in the selected Indian cities based on data from several sources.

These show that there is a significant addition to total iF and consequent exposure in the Indian cities where these calculations have been done from household cookfuels from near-field iF. These are some 5-15x those of the ambient iFs by themselves since cooking is done right in the place and at the time people are nearby. This should be added to the ambient iFs in Figure 2-1 to obtain the total iF in order to understand the full health implications. Similar estimates are needed for other source categories, which, however, can be expected to be much smaller.

The estimates summarized here are preliminary and illustrative only. They are not meant to estimate national averages, but are likely not to be substantially different in other cities, although the ambient iFs are likely smaller in rural areas. Nearfield iFs for household cooking, in contrast, are likely similar in rural areas, emphasizing the importance of household air pollution in those areas. Nor does this example reflect the contribution to exposure from secondary particles created from such gaseous emissions as sulphur and nitrogen oxides. A full assessment would account for these as well.

One way to apply total exposure cost-effectively in control and regulation, is to determine the exposure effectiveness for each class of sources, which can be thought of as the fraction of emissions from each source category that actually make their way into the breathing zones of the population. This would allow different source categories to be compared on their relative risk. Different terms have been used since the 1980s for this concept, but early last decade a group of scientists agreed to use the common term, *intake fraction* (Bennett et al., 2002). This can be expressed as the dimensionless ratio of the amount breathed in divided by the amount emitted. It is related to exposure effectiveness by breathing rate. It can also be used for pollutants released in water, food, etc. See Box 2 for more discussion.

Thus, although relying on data on air pollution concentrations in different places where the Indian population spends time each day (microenvironments – see Box 3), this report assesses potential control measures as much as possible by analyzing how much they reduce total exposure to the population and not on the control of pollution levels in any one place – indoors or outdoors, for example. Thus, it does not focus explicitly on environmental quality, but rather human exposure which is a related but not equivalent metric. To inform its recommendation, therefore, the Committee relies where it can on the growing databases estimating the relative contributions of the major categories of pollution sources in India to exposure and uses the concept of intake fraction as the central way of weighting different categories of sources according to their relative importance for health and therefore deriving priorities for source control.

Intake fraction gives an estimate of how much health impact there is from each kilogram of pollutant released for different source categories, but of course some sources release much more pollution than others. If intake fraction is multiplied by the total emissions, however, the result can be termed “exposure apportionment”, i.e. how much total exposure is due to each source category, another important metric for policy (Smith 1988). See Box 4.

As noted in the recommendations for future research, however, there is a need to expand the measurements and modeling done in-country to better pin down exposure apportionment for different populations (i.e. who is most affected by which sources). Intake fraction modeling is one important approach but there are other methods as well, including those relying on variants of classic source-apportionment techniques. Secondary pollutants, such as ozone and secondary particles created downwind from emissions of gaseous precursors remain an issue, and a full assessment of exposure needs to consider these pathways as well. Thus traditional measures of ambient pollution still retain an important role. See Chapter 5 for more discussion.

Box 3: Basics of exposure assessment:

As shown in Box 1, exposure indicates how much people actually experience air pollution in their breathing zones. Thus, it depends not only on the concentration of the pollutant in each location where people spend time during the day (micro-environment) but also how long people spend in each place. The best way to measure exposure is to have people wear monitoring devices throughout their normal daily activities (personal monitoring). This is easier with some pollutants than others and unfortunately the technology for measuring personal exposures to small particles is not easy to use and not inexpensive. It also cannot be used with small children or infants. Nevertheless, done carefully, excellent results can be obtained.

Somewhat easier to use at large scale is a combination of micro-environmental monitoring (fixed monitors in representative places where many people spend time) and time-activity surveys or monitoring to understand who spends how long in each major location.

Using a combination of personal and micro-environmental monitoring for validation, it is also possible to use sophisticated statistical modelling techniques to accurately estimate exposures to populations using secondary data, such as household, socioeconomic, geographic and other information.

Box 4: Exposure apportionment:

An important additional metric for considering policy options is not only the marginal contribution to ill health of a source category, represented by intake fraction, but also the total contribution, since some sources are much more polluting than others. This can be represented in a general way by multiplying intake fraction by total emissions and comparing across source categories as shown in the figure using Indian data.

2.2 Innovations in this Report:

This assessment of the health impacts of air pollution is distinct from others done in India and elsewhere for two main reasons. Although conducted by a group with representatives from several agencies, it is among the first in any country organized by a Ministry of Health rather than organized by environmental protection agencies/ministries, which are normally charged with air pollution control in most countries. While health outcomes are often of concern whenever air pollution is examined, this assessment and its recommendations focuses centrally and directly on health because, as noted in Chapter 1, air pollution forms a major part of the national burden of disease in India. As with tobacco control, therefore, the Ministry of Health and Family Welfare in India, is focusing on actions that are needed to protect the Indian public from air pollution even though many of these actions must be taken entirely by or with the strong collaboration of other agencies and bodies (unlike health-protection programs such as immunization that are led by the MOHFW itself).

The second distinctive aspect of this report, which flows directly from its health focus, is that the Committee was charged with examining all sources of air public pollution exposure, not just those that contribute to either indoor or outdoor pollution. In the terminology of the field, the task taken on is to recommend ways to reduce total exposure of the population regardless of which sources and sectors are involved. Thus, household fuels that produce high indoor exposures are just as much under consideration as power plants, even though the relevant agencies involved and means of control are entirely different. As it is exposure that directly impacts health, such an approach is not only logical but also appropriate for a health-focused assessment, although nearly unique globally.

A corollary is that the assessment does not focus on either rural or urban populations, but rather on exposure of the entire Indian population.

As this report comes to air pollution from a health perspective, it focuses on small particle pollution, particularly from combustion sources. This is discussed more in Box 4, but stems from the much larger health and exposure evidence databases for this pollutant than most others. Of course, some particular populations may be exposed to high levels of other pollutants, particularly in occupational settings, but only combustion particles and their associated pollutants expose such a large fraction of the population at hazardous levels and consequently have such a major impact on the national burden of disease (see Chapter 4). Some of the same principles applied to particle exposures in this report, however, could be applied to control of other pollutants.

Box 5. Target pollutants

A number of distinct air pollutants are known to damage health, many of which have separate international and Indian guidelines and standards associated with them. As the health impacts of small particle are best characterized, as well as being largest, among all other air pollutants and because it serves better than any other pollutant for comparisons across most sources, this assessment focuses on airborne small particles. This is consistent with global approaches, since it is generally now believed that $PM_{2.5}$ (fine particles less than 2.5 micron in size) are the best indicator of health risk. India, however, like other countries has not yet completely supplemented its monitoring networks for PM_{10} (particles less than 10 micron) with $PM_{2.5}$ capability. As there is evidence that the "coarse" fraction (particles between 2.5 and 10 microns) also pose some risk, however, properly adjusted, PM_{10} measurements serve as a reasonable indicator of particle risk at present. See Chapter 3 for more discussion.

There are many other air pollutants that have been targets for outdoor air pollution control around the world including India, particularly the so-called criteria pollutants: NOx, SO_2, CO, lead, and ozone. Although of some direct concern and emitted as gases, NOx and SO_2 convert to particles downwind where they are included in measurements of particle levels. In addition, there is concern about a set of hazardous air pollutants including benzene, toluene, and xylene (BTX), generally in gaseous form and of most concern due to their carcinogenicity. Polyaromatic hydrocarbon (PAH) compounds are also sometimes controlled directly, often using indicators such as benzo(a)pyrene (BaP). Formaldehyde has been the focus of concern in indoor settings in some countries, due to its emissions from furnishings. Radioactive radon and thoron, which derive from natural substances in the ground, sometimes accumulate in housing and be of concern in certain geological regions, including parts of India. Of course, a major source of health-damaging exposure still occurs from second-hand tobacco smoke even as smoking is increasingly banned in public places.

This report focuses on small particles, however, because they seem to be by far the largest cause of ill-health today in India among all air pollutants. This is not to say that the others should be ignored, but in terms of burden of disease, they are less important today. In addition, many (e.g. PAH, CO, NOx, SO_2) of these other compounds are also found in combustion smoke mixtures, which are the major source of hazardous particle exposures. Thus improvements in fuel quality and combustion efficiency tend to reduce a range of health-damaging pollutants in addition to particles, but not necessarily in equal proportions. Others (e.g., formaldehyde, thoron) have completely different sources, however. Probably the next most important air pollutant in India is ozone, for which there is growing health effects evidence and the creation of which is complex. The current situation with regard to ozone is discussed briefly in Chapter 3.

The committee notes, however, that the same principles that apply to PM control from a health standpoint also apply to other pollutants, for example the importance of exposure. Thus, this report can be considered a model for future extension to other health-damaging air pollutants.

2.3 Final Comments

This first assessment by the Ministry of Health and Family Welfare is breaking new ground in many ways, but also has limitations. Although focusing on total exposure, it examines only public exposures, not those received in the workplace. Many occupations, however, experience high particle exposures, sometimes of particles with unusual characteristics. These are not addressed here. A second limitation is that the Committee has not considered any reweighting of exposures or control measures based on the implications of the non-linear exposure-response relationships that have emerged in recent years from the modelling of the results of multiple epidemiologic studies of particle air pollution in different settings. See Chapter 4. These results may imply less health benefit from similar changes in exposure starting at high levels rather than low, but a way to incorporate the implications consistently has not been developed as yet. The Committee recognizes that air pollution exposures differentially affect particular groups due to age, sex, pre-existing disease, access to health care, nutrition, and other factors. These factors were not formally assessed for the purpose of establishing control priorities, but comments are made where appropriate. See also recommendations in Chapter 5.

Finally, the report does not directly address the implications of control measures for meeting air pollution standards in India. This stems partly because, as in other countries, these standards themselves do not address exposure, but focuses on just one, albeit important, microenvironment – the outdoor urban environment. In this assessment, therefore, control measures that have little effect on urban ambient pollution but do promise important reductions in exposure and health impacts would be preferred to those that merely help reach outdoor standards in cities.

In the long run, India wishes to reduce concentrations to acceptable levels for all health-damaging pollutants in all places where people spend time. With current limitations of resources and knowledge, however, it will take us some time to reach that point. But the Committee believes that a focus on $PM_{2.5}$ and total population exposure would allow prioritization among control options and help us choose the most effective pathway of health reductions in moving toward that situation where exposure to health-damaging pollutants is eliminated (Smith, 1995). It can also lead potentially to innovative ways to find cost-effective health protection over time (Roumasset and Smith, 1990)

The Committee also recognizes that India has competing demands for investment to reduce other health risks as well other demands on public and private resources during development. As part of the final choices on control priorities, therefore, there is need to conduct comprehensive economic analyses of the costs and benefits of various approaches to air pollution control. The relative costs of control measures will reorder priorities. While such an exercise is important, it was beyond the scope and the timelines of this effort, but doing so is part of the recommendations in Chapter 5.

Similarly, the Committee recognizes that practical barriers may exist for some control measures due to technical or logistic reasons, which may reorder priorities until the barriers can be reduced.

Despite such provisos, we hope that this first and important step taken by the Ministry of Health and Family Welfare of focusing on the health impacts of air pollution will help deepen the public and policy attention on this critical issue and that this report will serve to further invigorate the important process of protecting the country's population from this major source of health impacts.

3. Ambient and Household Air Pollution and Exposures in India: Summary of Evidence

Household and ambient air pollution are among the leading risk factors contributing to the burden of disease in India, accounting for 6% and 3% of the national burden of disease, respectively (Lim SS et al 2012; IHME 2013). While this burden straddles rural and urban populations, routine air pollution monitoring, to the extent it has happened, has been almost exclusively confined to large cities, making it difficult to understand the nature and distribution of the full range of population exposures. Nearly 30% of ambient $PM_{2.5}$ concentrations in India are estimated to be attributable to household combustion of solid fuels (Chafe et al. 2014). This evidence is a clear pointer towards the fact that air pollution mitigation will require an integrated approach. In this section we provide a summary of the evidence on ambient and household air pollution and exposures in relation to major sources and emissions. The detailed exposure profiles serve as the basis for assessing the magnitude of health effects (described in Section 4) and the framing of recommendations (described in Sections 5) to holistically reduce health burdens attributable to air pollution in India.

3.1 Ambient Air Pollution

The conventional approach to addressing health impacts of air pollution has been driven by the need to set standard guidelines for ambient concentration of pollutants and develop regulatory policies and implementation plans to not to let the pollution concentration exceed that level. The ambient (outdoor) air quality has been taken as an indicator of population exposure. This is the standard regulatory practice across the world. This approach helps to assess the variation in trend over time and space to reflect the exposure situations and also the impact of pollution control efforts on long term trends.

Within this conventional framework the preferred approach to monitor the status of population health is to take the ambient monitoring information to do epidemiological studies that can assess the contribution of air pollution, the relationships between exposure and health, impact on people exposed to each concentration of air pollution in the community. Thus, ambient concentrations are used as the primary exposure metric in epidemiologic investigations of the health effects of urban air pollution. An underlying assumption of these studies is that measurements or modeled estimates of ambient concentrations serve as a proxy of population exposure to air pollution. While the validity of the assumption depends on a large number of factors that affect the intake fraction (as explained in Chapter 2), routine ambient air quality monitoring networks often account for such considerations while siting the monitors within a population. The population representativeness together with uniform standards of quality control often mandated within such networks has allowed the use of routine ambient air quality data as reliable exposure indicators. Epidemiological and toxicological studies cannot be widely applied because they are complex and require extensive time and resources. But these can be used to guide action across regions.

However, as the central focus of this report is health, it is important to emphasise that human exposure to air pollutants needs more explicit attention. Human exposure is influenced by a variety of situation that includes type of pollutant and its magnitude, duration and frequency of exposure; and toxicity of the specific pollutant. People are exposed during both indoors and outdoors activities. Therefore, sources and composition of indoor and outdoor pollutants and their relative contribution to total personal exposure need to be recognized. This can help to further refine the control strategies.

Exposure is the key in potential health impact. Personal exposure relates to integrated concentrations experienced by individuals in different situations and according to time spent. This is difficult to measure because individual behaviour is complex. On the other hand, population exposure is the exposure of everyone in the population. The ambient air quality can be considered to be an indicator of population exposure. Exposure monitoring will have to be made complimentary to ambient monitoring.

From the perspective of exposure high concentrations do not harm people if they are not present, and even low levels become relevant when many people are present all the time. In fact the WHO guidelines recognize the effects of some pollutants on population even at relatively low concentrations that are common in the environment. Also avoiding only occasional exceeding of air quality guidelines or threshold effect level of pollutants is not enough.

India needs to develop a more integrated approach to air quality management that will combine national level top down emissions control approaches across sectors and regions with more stringent action to reduce exposures in micro environments. This can help in selecting the most effective strategy for preventing risk and contributing to improving population health.

3.1 Ambient Air Quality

Air quality monitoring: 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, Forests and Climate Change, Government of India. The responsibility of routine air quality monitoring is shared by The Central Pollution Control Board at the national level, State Pollution Control Boards at the state level, and Pollution Control Committees in Union territories. The National Environmental Engineering Research Institute (NEERI) and autonomous research institutes also carry out monitoring on a limited scale. Delhi and Pune also have citywide monitoring networks outside the NAMP framework that is administered by the Ministry of Earth Sciences (SAFAR 2013). Numerous individual studies also report ambient air quality information on criteria air pollutants.

Air quality data is available from an ever expanding monitoring network in the country. Although there are 591 operating stations in 248 cities as of May 2015, however, there is time lag in data reporting. The latest available national level data is of year 2012 for 541 stations spread across 222 cities. These stations are a network established by the CPCB, in association with the states, called the National Air Quality Monitoring Programme (NAMP). Monitoring capacity for $PM_{2.5}$ is very limited in India. However, recently MOEF/CPCB have made a network of 11 cities to provide Air Quality Index and Bulletin based on Ozone, $PM_{2.5}$, PM_{10}, NO_2 among others, based on real-time data (status as on 22-06-2015). These cities have been connected with the official website for concurrent reporting of the air quality status and accompanying AQIs. Monitoring capacity for $PM_{2.5}$ is very limited in India. However, CPCB has put out more recent data for cities with more than million in population in their Environmental Information System (ENVIS) website.

The National Ambient Air Quality Standards were revised in 2009 and standards were revised for 12 pollutants including SO_2, NO_2, PM_{10}, $PM_{2.5}$, Ozone, Lead, Arsenic, Nickel, CO, NH_3, Benzene, and BaP (particulate phase). Of these, SO_2, NO_2 and PM_{10} are monitored regularly under the NAMP. Ozone is monitored in a few mega cities including Delhi. Other pollutants, such as $PM_{2.5}$, O_3, CO, and select air toxics such as BTX, BaP, As and Ni are being monitored on a limited scale as the capacities are being expanded. The rationale for selecting these pollutants is that they are ubiquitous in urban air and widely recognized as posing a potential risk to population health. These are also commonly regulated at a national or international level.

Air quality trends from NAMP data: The NAMP provides longitudinal data across multiple locations within the country. Results from analysis of routinely collected ambient air quality data available in the Environmental Data Bank maintained by CPCB (CPCB 2012)are summarized in Figures 1a to c in relation to the NAAQS and the WHO Air Quality Guidelines (WHO 2006)

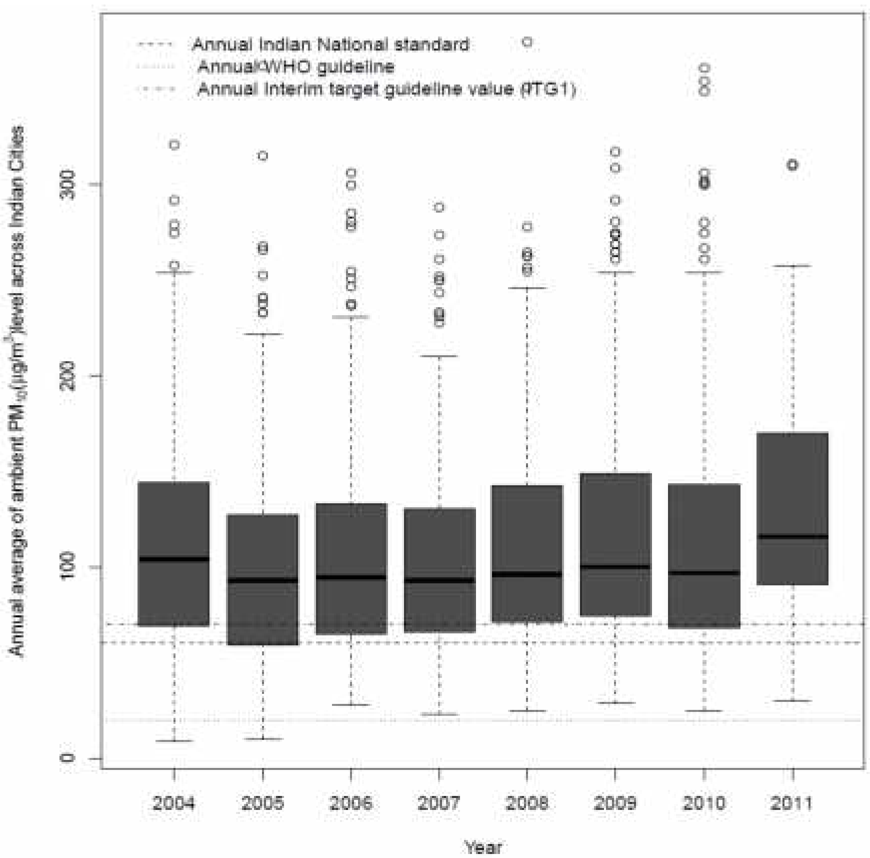


Figure 1a: Distribution of 24-hr ambient concentrations of PM_{10} across 456 stations covering 190 cities in 26 states and 5 Union Territories covered by the National Ambient Air Quality Monitoring Programme. Based on data from The Environmental Data Bank, Central Pollution Control Board (CPCB 2012).

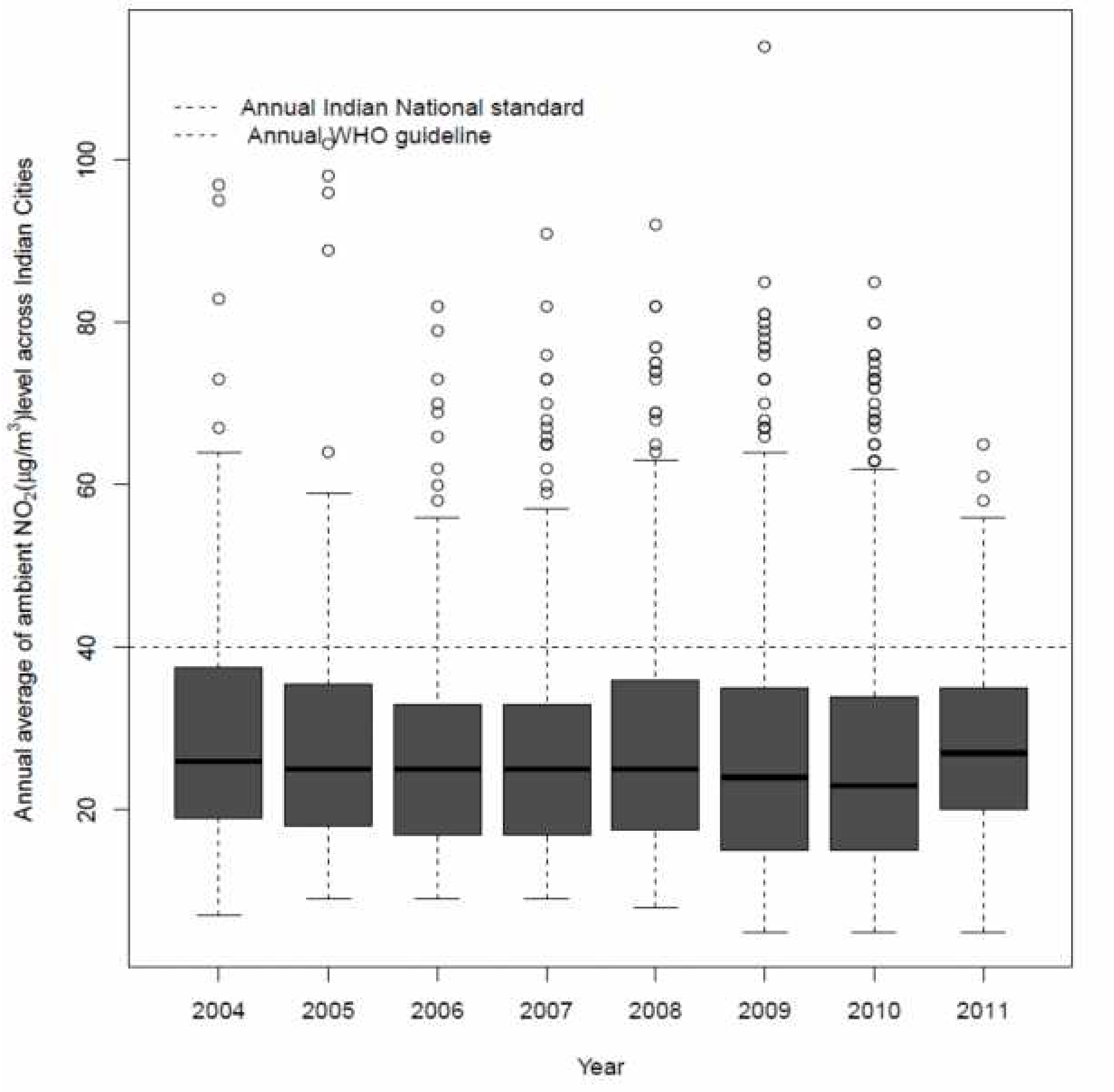


Figure 1b: Distribution of 24-hr ambient concentrations of NO_2 across 456 stations covering 190 cities in 26 states and 5 Union Territories covered by the National Ambient Air Quality Monitoring Programme. Based on data from The Environmental Data Bank, Central Pollution Control Board (CPCB 2012).

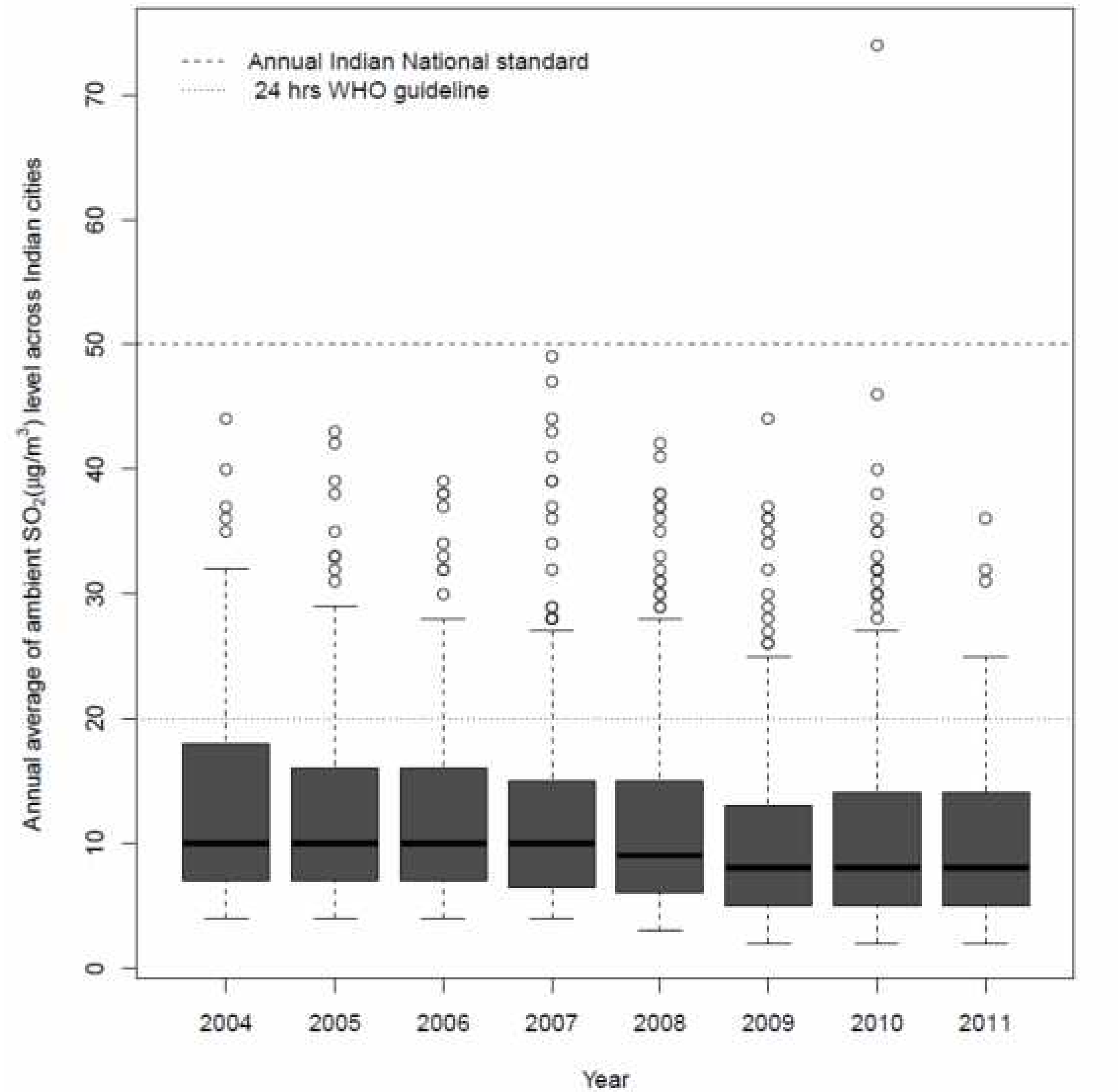


Figure 1c: Distribution of 24-hr ambient concentrations of PM_{10}, SO_2 and NO_2 across 456 stations covering 190 cities in 26 states and 5 Union Territories covered by the National Ambient Air Quality Monitoring Programme. Based on data from The Environmental Data Bank, Central Pollution Control Board (CPCB 2012).

While reporting air quality data under NAMP, the Central Pollution Control Board classifies cities based on the severity of air pollution. CPCB defines cities as 'critically' polluted if the levels of the criteria pollutants are more than 1.5 times the standards; levels up to 1.5 times the standards are labelled as high and up to 50% of the standards are moderate and less than 50% of the standards are labelled low. This gross classification indicates change in the air quality profile of the cities over time. For instance, the National Ambient Air Quality Status reports for the

Years 2009 and 2012 of CPCB shows that while number of cities monitored increased during this period, more cities have shown up in more polluted categories. In 2009 about 57 cities were classified as critical for PM_{10} that increased to 85 in 2012.These also include smaller and more obscure cities. Data on annual average PM_{10} concentrations indicate more than half of the 503 locations monitored across the country between 2004 to 2011 to be in excess of the NAAQS. This has continued to remain so in 2012. More cities have shown up in high and critical category for NO_x levels – increased from 9 to 12. Cities with moderate SO_2 levels have increased from 4 to 7 and one city showed up in high pollution bracket in 2012. But overall SO_2 levels have shown significant reduction over the years largely due to introduction of low sulphur fuels and relocation of polluting industries. The long term trends also show that some of the bigger cities like Delhi that have initiated air pollution control measures initially witnessed some air quality gains but have also experienced reversal of the gains. Limited information is currently available on ozone (See Box on ozone) or secondary particulates that can be of serious concern in many cities (as has been found in Delhi and Kanpur from studies conducted by CPCB and IIT Kanpur).

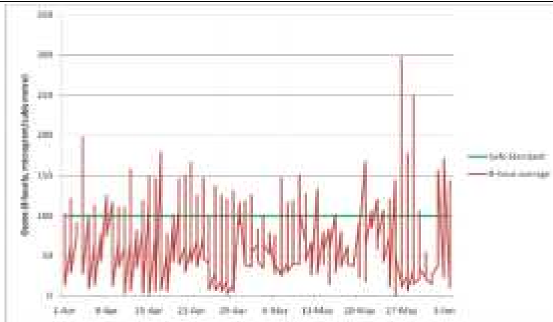
Box 1: Ozone

Ozone is included in the list of regulated pollutants in India. But its monitoring is extremely limited. Only a few state pollution control boards in mega cities of Delhi, Kolkata, Bengaluru, etc. have initiated ozone monitoring. But this is not reported under NAMP.

Delhi Pollution Control Committee is doing continuous monitoring of ozone in several locations in Delhi. This shows significant ozone build-up during summer months. Ground level ozone is not directly emitted by any source. This is formed when oxides of nitrogen and a range of volatile gases are exposed to each other in sunlight. In any year the period January to early June shows rapid build-up of ozone and more frequent violation of standards during summer months. Warmer temperatures and extreme events of heat waves compound the problem. On several occasion very high peak levels have been noted, close to 2.5 to three times the standards. Ozone (O3) is a secondary photochemical pollutant formed from the precursor's volatile organic compounds, NO_x and CO in the presence of sunlight.

Graph: Daily trends in Ozone levels in Delhi

(8 hourly standard – 100 micrograms per cum)



Source: Delhi Pollution Control Committee

Air quality standards: The newly revised Indian national standards (CPCB 2009b) for annual average PM_{10} of 60µg/m^3 is comparable to the Interim Target 1 (IT-1) guideline values for air quality recommended by the World Health Organization (WHO 2006), but much higher than the recommended WHO-guideline (WHO-AQG) value itself of 20 µg/m^3 indicating that significant residual health impacts may persist even if national standards are met (Table 1). The situation is similar for SO_2, with the annual NAAQS of 50 µg/m^3, being more than twice the 24-hr WHO-AQG levels of 20µg/m^3.With PM_{10}levels reported to be not only in excess of the national standards but critically high (defined as > 90µg/m^3 by CPCB, Govt. of India) across most locations, and the levels of SO_2 and NO_2 are in excess of the WHO-AQG levels at many locations, results from routine monitoring clearly indicate the high likelihood of substantial health impacts from criteria all pollutants across all urban locations.

Table 1: National standards for criteria air pollutants in relation to WHO Air Quality Guidelines

Pollutant	Averaging Time	Indian National Standard, 2009	WHO Guideline Values	WHO-ITG3	WHO-ITG2	WHO –ITG1
PM_{10}(µg/m^3)	Annual	60	20	30	50	70
	24-hour	100	50	75	100	150
$PM_{2.5}$(µg/m^3)	Annual	40	10	15	25	35
	24-hour	60	25	37.5	50	75
SO_2	Annual	50	-			
	24-hour	80	20	50	125	
	10 min	-	-			
NO_2(µg/m^3)	Annual	40	40			
	24-hour	80	-			
	1-hour	-	200			

India would need to reduce concentrations to acceptable levels for all health-damaging pollutants in all places where people spend time. A 2015 study has shown that major improvements in air quality would be required to substantially reduce mortality from $PM_{2.5}$ in India. (Apte 2015). If circa-2010 $PM_{2.5}$ levels were to remain constant, year-2030 projections suggest that per-capita mortality attributable to $PM_{2.5}$ would increase in India by 21%. This is mainly due to dramatic increase in the age >50 population. The comparatively young populations currently partially offset the burden of disease from $PM_{2.5}$ in India. To keep $PM_{2.5}$-attributable mortality rates (deaths per 100 000 people per year) constant, average $PM_{2.5}$ levels would need to decline by 20−30% over the next 15 years merely to offset increases in $PM_{2.5}$-attributable mortality from aging populations.

Air toxics: The revised ambient air quality standards of 2009 include six air toxics and heavy metals. Official data on these toxics is however sparse. In Delhi CPCB and Delhi Pollution Control Committee (DPCC) monitor ambient benzene levels that has increased quite notably in Delhi. Other cities including Bangalore, Chennai, Kanpur, Pune, and Kolkata have also reported high levels. Independent studies have reported data on other toxics like PAH. DPCC monitoring of benzene in Delhi shows that the daily average of benzene in several locations in Delhi can reach up to 35 $\mu g/m^3$ to close to 60 $\mu g/m^3$. Even in small trace amounts these can cause cancer, birth defects and damage immune system. The fact remains that several toxic pollutants are co-emitted along with particulate matter that contribute to health risk considerably. The goal of the air toxics monitoring program is to support reduction of public exposure to hazardous air pollutants or air toxics and characterize hazardous air pollutants concentrations in representative areas and trends over time to inform regulations.

Industrial Air Pollution: In 2010, the CPCB developed a methodology to identify industrial hotspots using risk assessment criteria defined in terms of Comprehensive Environmental Pollution Index (CEPI). (CPCB 2009a). The CEPI weights the toxicity of the agents, the volume of emissions, the scale of population exposed and the exposure pathways involved across media (including air water and soil). 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 VOCs, 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.

Nearly 43 industrial clusters across the country have been identified to be critically polluted (with a rating of more than 70) with primary contributions from chemical industries. 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. Although details of ambient concentrations of air toxics are not available in 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. Many 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 annual average concentration recorded across the NAMP monitors and the locations of the CEPI hotspots are illustrated in Figure 3. The CEPI ratings, where available, are listed by their ranking in Table 2 (furnished in Section 1.2).

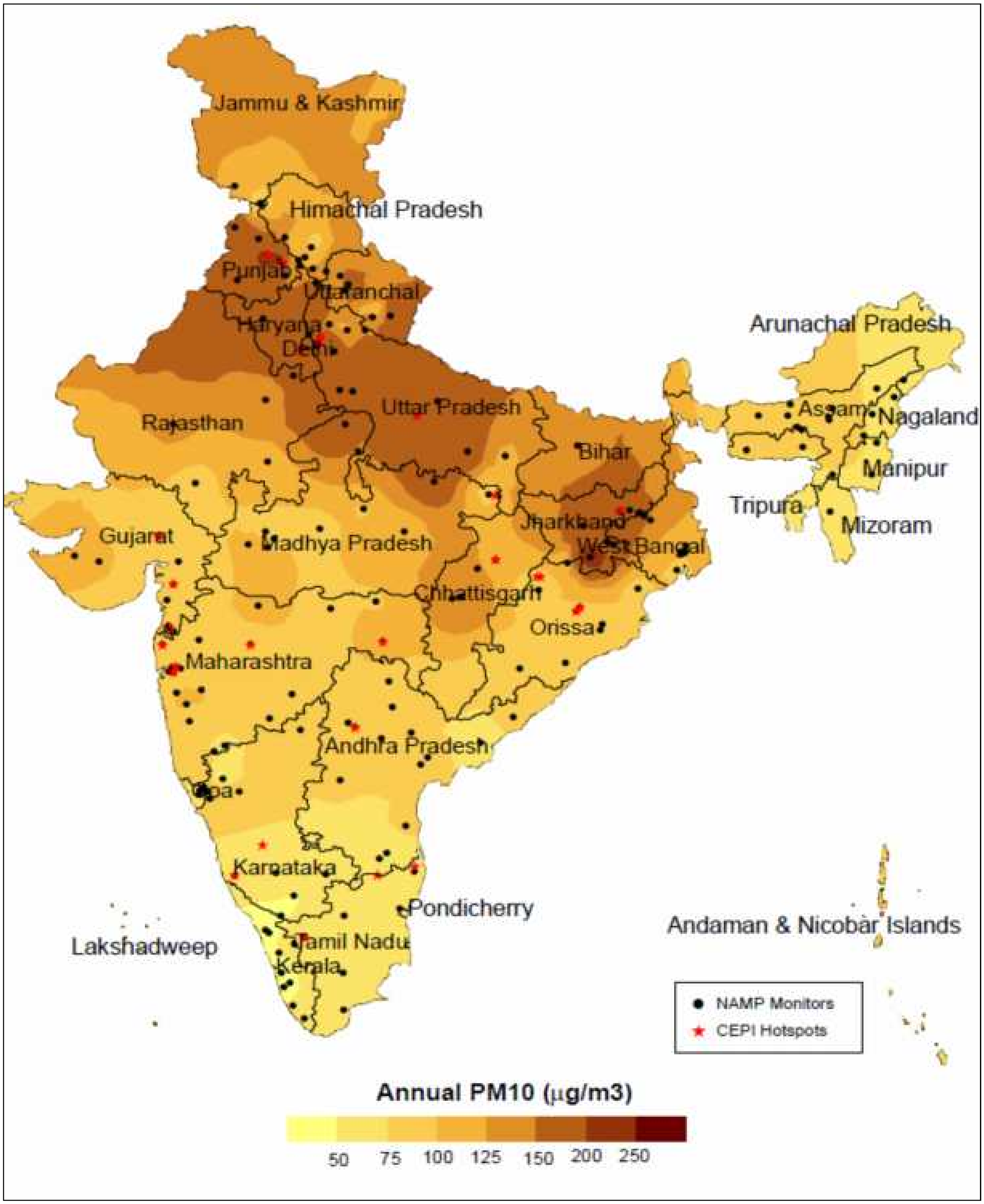


Figure 3: Inverse distance weighted averages of annual concentrations of PM_{10} recorded across NAMP monitors between 2004-2011in relation to monitor locations and CEPI hotspots (Based on data from The Environmental Data Bank, (CPCB 2012)and the CEPI Report, (CPCB 2009a) and reproduced with permission from (Balakrishnan et al. 2014))

Satellite Based Estimates for $PM_{2.5}$: To address the paucity of ambient $PM_{2.5}$ monitoring stations and almost complete absence of ambient air quality data in rural areas, several studies now report satellite data (Van Donkelaar et al. 2010) or have used hybrid models that use satellite data with emissions inventories to derive global ground-level ambient $PM_{2.5}$ concentrations (Brauer et al. 2012). These first-level estimates have provided the primary exposure metrics for burden of disease assessments for ambient air pollution. An extract of this data covering India is presented in **Figure 4**. Since the satellite extractions are available at 0.1° resolution (~10 km), there is some uncertainty associated with these derivatives and these retrieval methods are being improved, to complement on-ground measurements.

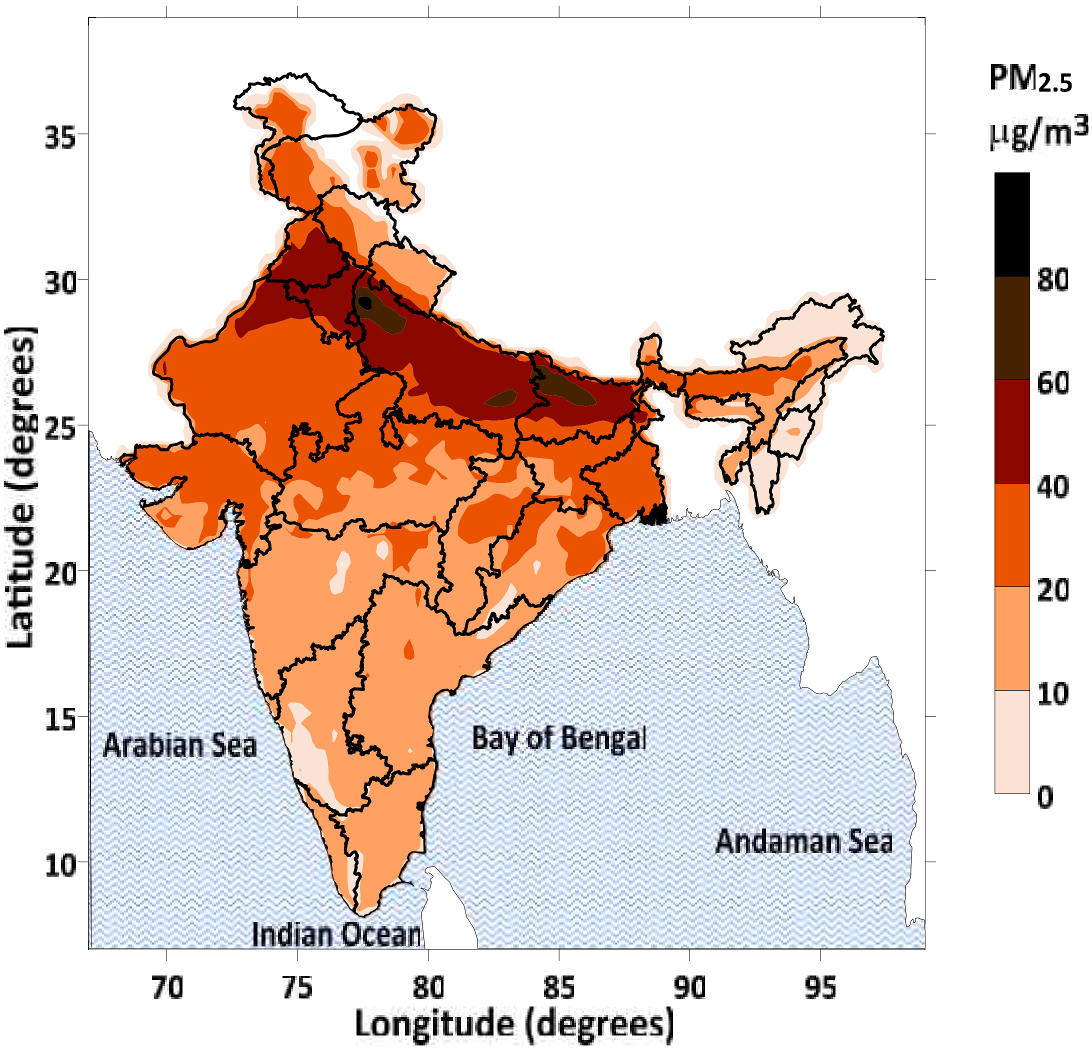


Figure 4: Ambient $PM_{2.5}$ concentrations derived from the satellite observations (Van Donkelaar et al. 2010)

More recently, refinements to these models have included bias correction in remote-sensing-based methodologies through inclusion of in-situ measurements from India and an analysis of spatio-temporal variability in relation to WHO-AQG levels (Dey et al. 2012).The study has shown $PM_{2.5}$ concentration in the populated rural areas of the Indo Gangetic Basin (IGB) to be larger than many urban centres in peninsular India (with mean annual $PM_{2.5}$ to be persistently greater than 50 $\mu g/m^3$ in the IGB and Mumbai metropolitan area) (Figure 5) and has identified five hotspots covering parts of eleven Indian states where $PM_{2.5}$ has increased by > 15$\mu g/m^3$ (in excess of WHO-ITG-3 levels) over the past decade (Figure 6). Similar increases in $PM_{2.5}$ concentrations have been reported in other studies (Brauer et al. 2012; Streets et al. 2009).

Besides $PM_{2.5}$ concentrations, satellite observations can also help estimate the concentrations of SO_2, NO_x, and CO, and help analyse the severity of on-ground anthropogenic and natural emission sources (Streets et al. 2013) as well as point to limitations arising from using city-level monitor data. For example, while SO_2levels in cities largely are in compliance with national standards, it may not represent a reduction in SO_2 emissions at the regional level. Interventions like low-sulphur diesel and relocation of heavy industries, including thermal power plants (TPPs) have resulted in city-level emission reductions. While only a handful of Indian cities have coal-fired TPPs within the city limits (for example Delhi, Chennai, Mumbai, and Ahmedabad), using the OMI satellite data, (Lu et al. 2013) reported that the annual average SO_2 concentrations in coal-fired power plant regions of India to have increased by more than 60% between 2005 and 2012. The coal-fired TPPs also contribute to ~50% of the total annual SO_2 emissions and ~15% of the total annual $PM_{2.5}$ emissions in India (GAINS 2010).

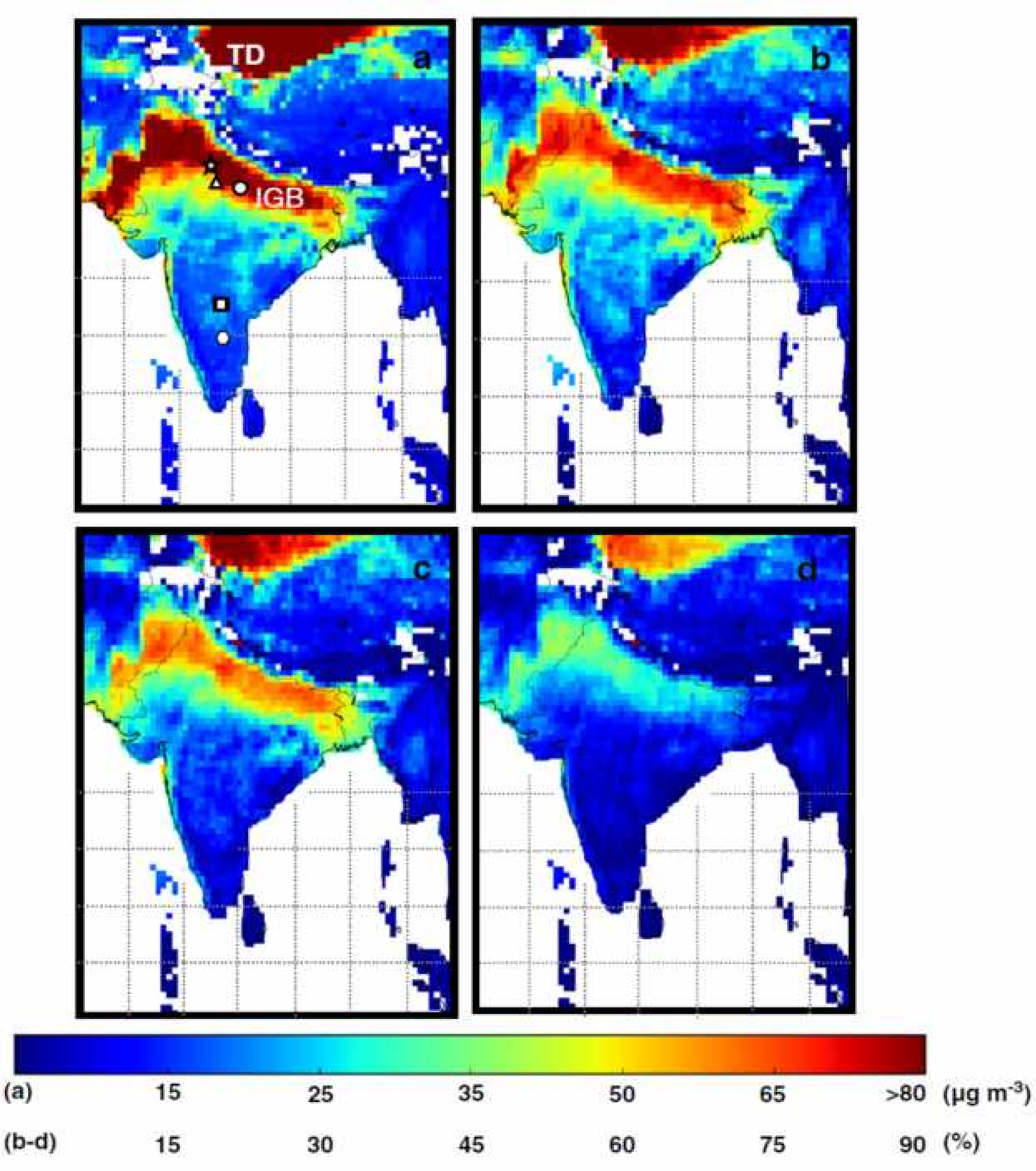


Figure 5: Spatial distributions of (a) mean annual $PM_{2.5}$ concentration (in μg/m^3) and percentage of days per year with mean daily $PM_{2.5}$ exceeding (b) 37.5 μg/m^3 (WHO IT-3), (c) 50 μg/m^3 (WHO IT-2) and (d) 75 μg/m3 (WHO IT-1) during Mar 2000–Feb 2010 over the Indian Subcontinent. Locations of Delhi, Kanpur, Agra, Hyderabad, Anantpur and Sunderban are shown by 'star', 'circle', 'triangle', 'square', 'hexagon' and 'diamond' respectively. (Dey et al. 2012)

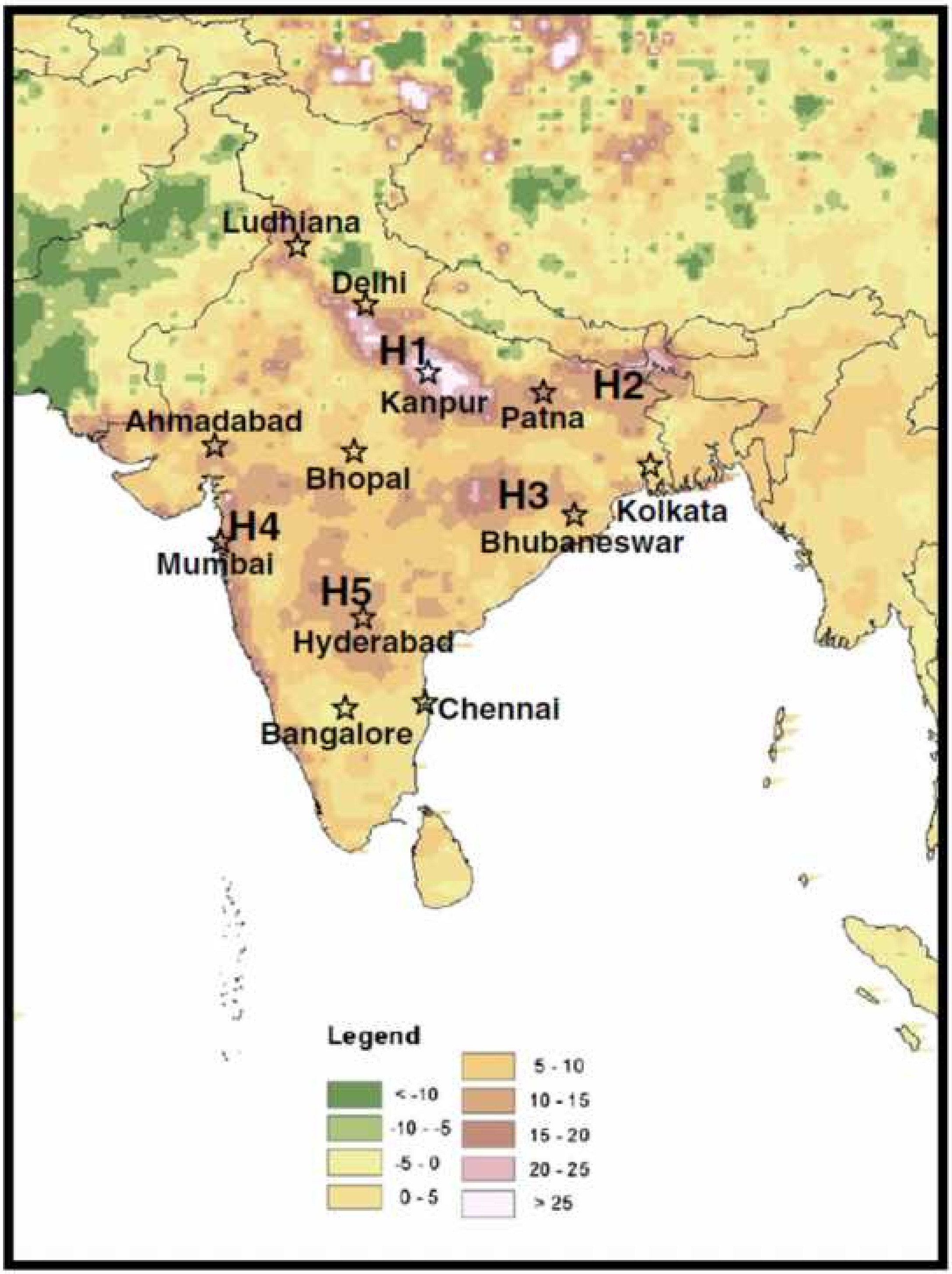


Figure 6: Spatial distribution of total changes in $PM_{2.5}$ concentration (in µg/m^3) during Mar 2000 - Feb 2010 over the Indian subcontinent. Increase of $PM_{2.5}$ by >15 µg/m^3 are characterized as hotspots. Five hotspots (marked as H1 to H5) are identified with locations of some of the large urban centers (shown by open stars) for reference. (Dey et al. 2012)

3.1.2 Sources and Emissions Related to Urban Ambient Air Pollution

While it is clear that it is not only urban areas but even many rural areas, especially in North India, that suffer from high levels of ambient air pollution, cities are both major sources of air pollution and major sufferers due to the high levels of exposures (due to high concentrations and large populations). Furthermore, a majority of the data and analysis on air pollution sources and emissions is from urban areas. Therefore we present a specific focus on these sources in order to provide guidance for air pollution control to mitigate health impacts.

"According to the 2011 census, 2774 rural settlements are now reclassified as urban settlements, pushing the total to 3894, primarily based on the definition of an urban settlement - population exceeds 5000, population density is above 400 per km^2, and more than 75% of the male workforce is employed outside of agriculture (Census-India, 2012). The population in urban areas is expected to grow from 30% to 50% by 2030 (MoUD, 2011). By 2030, the expected growth in industrial, transportation, household, and power generation sectors will consequently result in an increase in emissions and air pollution for almost all Indian cities and surrounding regions." (Guttikunda et al. 2014)

Ambient pollution sources in the urban and peri-urban/rural environment include various stationary, mobile and area sources of emission. These sources must be identified to enable effective management action to reduce exposure. Peri-urban and rural areas have large number of stationary sources including industrial units, power plants and brick kilns. These have local impacts as well as regional impacts. The Indo-Gangetic plain has the largest number of brick kilns, with old and inefficient combustion technology, using a mix of biomass and coal for combustion needs (Maithel et al. 2012). The states of Bihar, West Bengal, Jharkhand, Orissa, and Chhattisgarh harbor the largest coal mines in the country, and a cluster of power plants around the mines (Guttikunda & Jawahar 2014). Several large power plants also exist in the states of Punjab, Haryana, Delhi, and Uttar Pradesh, making the north and north-eastern belt the most polluted part of the country. The cities in the north are also landlocked, which are also affected by the prevalent meteorological conditions, unlike some of the Southern cities with the privilege of land-sea breezes (Guttikunda & Gurjar 2012).

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 the forty cities highlighted in Census-India (2012), the key urban characteristics are presented in Table 2. The 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. Another 30 cities have at least 30% of the households with a motorized two wheeler (2W) and 19 cities have at least 10% households with a four-wheeler (a car or a utility vehicle). Rate of motorization is high in Indian cities. Growing urban sprawl and inadequate public transport is increasing vehicles miles travelled. Change in fuel mix in transport sector shows high penetration of diesel that has serious toxicity concerns. Rapid increase in highway freight has become a significant source of urban air pollution.

While most cities are supplied with liquefied petroleum gas (LPG) for household use, there is still a significant portion of households using other fuels - such as kerosene, biomass, and coal. In fact, of the 40 cities in **Table 2**, 20 have at least 30% of households with a non-LPG cookstove.

Table 2: Cities at a glance

City	AR	Pop	A	B	C	D	E
Hyderabad	500	7,749,334	155	50%	14%	32%	No
Vijayawada	79	1,491,202	189	26%	4%	21%	No
Vishakhapatnam	159	1,730,320	109	36%	8%	21%	Yes
Guwahati	145	968,549	67	10%	3%	80%	No
Patna	86	2,046,652	238	32%	10%	29%	No
Korba	39	365,073	94	43%	8%	56%	No
Raipur	95	1,122,555	118	38%	9%	48%	No
Delhi	669	16,314,838	244	39%	21%	9%	No
Ahmedabad	275	6,352,254	231	51%	13%	24%	No
Rajkot	86	1,390,933	162	60%	10%	33%	No
Surat	155	4,585,367	296	44%	9%	28%	No
Vadodara	145	1,817,191	125	60%	14%	20%	No

Vapi	37	163,605	44	44%	11%	32%	No
Yamuna Nagar	41	383,318	93	42%	13%	24%	No
Dhanbad	45	1,195,298	266	31%	5%	72%	No
Jamshedpur	119	1,337,131	112	49%	12%	38%	No
Ranchi	106	1,126,741	106	43%	13%	36%	No
Bangalore	556	8,499,399	153	46%	18%	20%	No
Jammu	123	651,826	53	48%	25%	13%	No
Trivandrum	108	1,687,406	156	34%	17%	43%	Yes
Bhopal	178	1,883,381	106	48%	15%	30%	No
Gwalior	78	1,101,981	141	45%	8%	29%	No
Indore	102	2,167,447	212	50%	13%	17%	No
Jabalpur	104	1,267,564	122	46%	8%	34%	No
Ujjain	33	515,215	156	40%	6%	26%	No
Shillong	46	354,325	77	9%	16%	42%	No
Amritsar	90	1,183,705	132	50%	15%	21%	No
Chandigarh	115	1,025,682	89	47%	26%	27%	No
Ludhiana	167	1,613,878	97	50%	19%	19%	No
Chennai	426	8,917,749	210	47%	13%	17%	Yes
Agra	129	1,746,467	135	48%	12%	27%	No
Allahabad	71	1,216,719	171	54%	11%	26%	No
Firozabad	21	603,797	288	25%	4%	40%	No
Kanpur	150	2,920,067	195	11%	3%	42%	No
Lucknow	240	2,901,474	121	52%	15%	20%	No
Varanasi	102	1,435,113	141	40%	7%	29%	No
Asansol	49	1,243,008	254	27%	4%	61%	No
Durgapur	56	581,409	104	27%	4%	61%	No
Kolkata	727	14,112,536	194	12%	9%	34%	No

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)

For city administrators, regulating air pollution is the primary concern and accurate knowledge of the source contributions is vital to developing an effective air quality management program. The contribution of various sources to the ambient PM pollution is typically assessed via receptor modeling and this methodology has been applied in many Indian cities (CPCB 2010; Pant & Harrison 2012) . However, between 2000 and 2013, 70% of the known studies were conducted in five big cities - Delhi, Mumbai, Chennai, Kolkata, and Hyderabad and very limited number in other cities, which are also listed as exceeding the ambient standards and WHO guidelines.

Assessment of source contribution to pollution concentration in Indian cities: Several emissions inventory, and source apportionment studies have been carried out with different objectives, design, methods, pollutants and scale. In addition to these there are specific studies on chemical speciation of particulate matter and road dust. While some of these studies have included only primary emissions others have included both primary and secondary particulate. A large number of institutions including official monitoring agencies and research institutions in India and abroad have carried out these studies. Some of these institutions are Central Pollution Control Board, Indian Institute of Tropical Meteorology, Indian Institute of Technology, NEERI, Council for Scientific and Industrial Research and National Physical Laboratory, Bhaba Atomic Research Centre, Jawaharlal Nehru University, Urban Info among others. Evidences from these studies help to provide an insight into the pollution profile of several cities/locations. (See Table Summary findings of studies on emissions sources of $PM_{2.5}$ and PM_{10} in India). Most of these studies have been carried out in big cities of Delhi, Mumbai, Kolkata, Hyderabad, Bengaluru, Chennai etc. Some of the smaller cities include Kanpur, Nagpur, and Rourkela etc.

The only big official study is the multi-city study that was conducted by CPCB for six cities – Pune, Chennai, Delhi, Mumbai, Kanpur, and Bengaluru, at an approximate project cost of US$6 million (CPCB 2010). This study has considered PM_{10} and NOx.

The most commonly identified sources are vehicles, manufacturing and electricity generation industries, construction activities, road dust, waste burning, combustion of oil, coal, and biomass in the households, and marine/sea salt. Their relative contribution varies across cities.

Box: Case Study –Source Contributions in Delhi

Delhi, the city suffering from the highest levels of air pollution as result of both high concentration of sources and its geography, deserves special attention. This city has also witnessed air quality gains from pollution control measures as well as reversal of gains. No single sector is responsible for Delhi's air pollution. Rather, it is a combination of sources including industries, power plants, combustion of coal and biomass in households and otherwise, and transport (direct vehicle exhaust and indirect road dust) that contribute to air pollution (Garg et al. 2006; Gurjar et al. 2004; Reddy & Venkataraman 2002; Shah et al. 2000). While the meteorology plays a role to influence movement of pollution and concentrations that could vary over a season or during a day, a majority of the problem still lies with the sheer volume of emissions (both local and outside). Studies carried out in Delhi bring out some key dimension of the pollution trends:

Seasonal variation: The air quality is heightened by the meteorology in the region. The summary presented in Figure 8, shows that irrespective of the constant emissions over each month, the observed concentrations are invariably 40 to 80 percent higher in the winter months (November, December, and January) and 10 to 60 percent lower in the summer months (May, June, and July). The pattern is consistent over the years and the shift is primarily due to the variability in the mixing layer heights and wind speeds between the seasons (and years) (Guttikunda & Gurjar 2012). During the day, similar patterns are also evident, when the mixing height is routinely lower during the night time compared to the day, irrespective of the seasons.

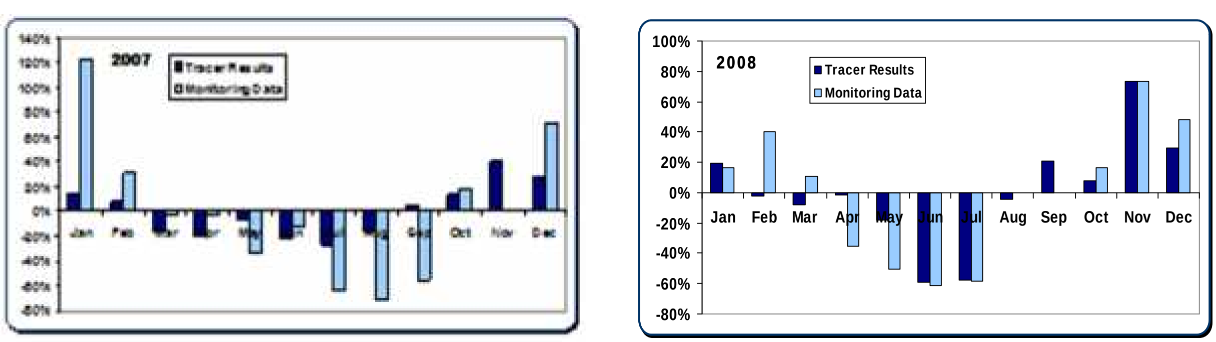


Figure 8: Percentage change in monitored monthly average $PM_{2.5}$ concentrations compared to the monitored annual average concentration and percentage change in estimated monthly average compared to annual average tracer concentration over Delhi, India

Seasonal changes in demand for fuel and natural pollution result in differing sources of air pollution in summer and winter. Figure 8 presents the results of source apportionment of the urban air pollution in Delhi, conducted by Georgia Tech University (USA) in 2005.

In the winter months, the mix of pollution sources changes dramatically. The use of biomass, primarily for heating contributes to as much as 30 percent of particulate pollution in winter. Most of this burning takes place at night, when the “mixing layer height” is low due to inversion in the winter months. In summer, biomass accounts for only 9 percent of particulate pollution. Another external factor is pollution due to agricultural clearing (Lindsey 2008). After the harvest of crops, clearing agricultural land is a common practice in surrounding (largely agricultural) states. The smoke reaches Delhi and contributes to the smog levels in the city (Johnston 2008).

One dimension of summer pollution in Delhi is high ozone level that increases public health risk substantially. Frequency of ozone levels exceeding the standards, and levels rising to 2.5 times the standards has become common during summer months. Its precursors NOx and VOCs will require strong control to protect public health.

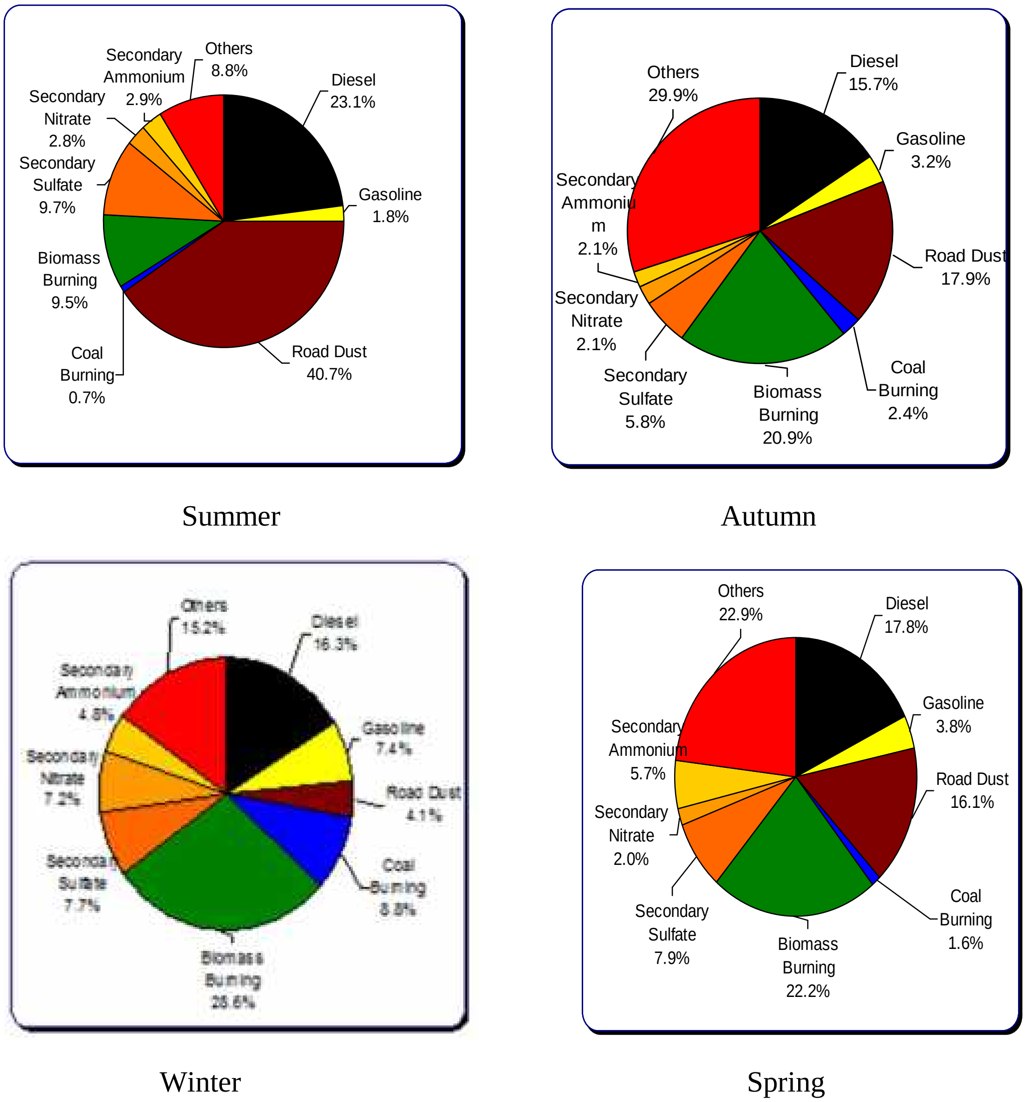
In summer dust storms from the desert, south-west of Delhi also contribute to the increased fugitive dust in the city. This is exacerbated by the low moisture content in the air, which causes a higher re-suspension of road dust (40 percent of particulate pollution in summer, compared to 4 percent in winter).

Sources of pollution: Transportation, power plants, biomass burning and ambient dust, are major contributors to particulate pollution in Delhi. All the estimates available from different studies in Delhi for particulate pollution show transport contributes to $PM_{2.5}$ in the range of 16 to 45 per cent; industry about 13 per cent; brick kilns 11 per cent and diesel generator sets about 16 per cent. When evidences from studies on contribution of sources to gaseous pollutants are considered the share of combustion sources dominate. For instance, the IITM study for the National Capital Region of Delhi shows transport sector contribute 60% of CO, 63% of NOx, and 91% of VOC, Industry and power plant contribute 34% of NOx together, and 65% and 18% of SO2 respectively.

With a growing city, the corresponding transportation needs are fueling a rise in private vehicles (2 and 4 wheelers) and taxis and auto-rickshaws (Aggarwal 2008). As a result, operating traffic speeds have reduced for all vehicles, thus increasing idling time and pollution (Down To Earth 2008). The efforts to address this by building flyovers that connect and bypass major junctions in the city have not yielded results as expected. At the same time lax emissions standards and increased use of diesel have aggravated pollution impacts of vehicle fleet. Solution addresses only the supply side of the equation does not influence demand management. In fact, as it becomes easier to take a private vehicle, the number of vehicles have increased (about 1400 new registrations per day in 2014) thus negating many of the planned improvements. In addition, the increase in the on-street parking and encroachments has exacerbated the situation. Most of the air polluting industry have been shifted out of Delhi. Rajghat Power plant has been shut down and Indraprastha has been made gas based. Badarpur which is coal based is operating at half its payload. There are ~1000 brick kilns on the boundaries of the city that use coal and fuel oil. (MoEF 1997).

Challenge of the road dust: With regard to road dust it may be noted that chemical analysis of road dust in Delhi have shown high amount of toxic chemicals and metals. The University of Birmingham has carried out PM_{10} road dust analysis in Mathura Road, in New Delhi in the summer of 2013 (Pant 2014). They found several elements, including copper, zinc, cadmium and lead in high concentrations (i.e. micrograms of element per gram of dust) of toxic chemicals and metals including copper, Barium, Zinc, and Lead. These are found in much higher concentrations than that is expected in soil. These elements are associated with severe health effects. Emissions on roads and along the roads eventually settle on soil particles.

Figure 9: $PM_{2.5}$ Source apportionment results for Delhi



3.1.3 Assessing contributions to ambient exposure

Measuring ambient concentrations of pollutants (as described in section 1.1) and recognition of major sources/source strengths (as described in section 1.2) are important inputs for assessing population-level health risks from ambient air pollution. These need to be supported by data on exposures, as they are central in the environmental pathways for health effects (as described in Chapter 2). Although collecting exposure data routinely on large populations is not a very feasible proposition, exposure assessment studies can provide valuable information to begin developing estimates of intake fraction and assessing exposure attributions. This in turn can pave the way for control strategies that are more “exposure-” rather than “emission-”centric. The evidence base from such exposure assessment studies in India is small but certainly feasible, as described below.

In the urban setting for instance, vehicular emissions contribute to significant human exposure. There have been a number of studies in Indian cities focusing on exposures from specific sources such as vehicular pollution and include research on specific exposed groups such as the traffic police, road side commuters etc. that have estimated exposures using a combination of micro-environmental concentration measurements and time- activity recalls (Malhotra et al. 2000; Sumeet Saksena et al. 2003; Sree Devi et al. 2009; Devi et al. 2013). GIS based methods have estimated nearly 55% of the population (~7.8 million people) in Delhi, to be residing within 500 meters from roads and at risk from near source traffic pollution (Jerrett et al. 2010). Measurements of commuter exposures in Delhi (Apte et al. 2011) have also shown in vehicle $PM_{2.5}$ concentrations to be at least 1.5 times higher than corresponding ambient concentrations and exposure concentrations of 190 $\mu g/m^3$ (peak concentrations exceeded 300 $\mu g/m^3$) .

More recently, modeling approaches have been developed to estimate intra-urban intake fraction values for distributed ground-level primary pollutant emissions for all worldwide cities with a year 2000 population of 100,000 or more, incorporating global data sets of demographic and meteorological parameters as model inputs. Population-weighted mean for India was estimated to be around 52 ppm (with New Delhi and Kolkata exceeding 100ppm). In comparison, US cities reported an average of 21ppm and Chinese cities reported an average of 44ppm (with much higher levels of city populations when compared to India).

The Appendix presents illustrative (and preliminary) examples of exposure apportionment analysis for some selected cities. This kind of exposure apportionment analysis shows, for example, that emissions from low-lying sources and in highly populated areas (such as from vehicles, households and open waste burning) can lead to disproportionately higher exposures (in comparison to fraction of emissions). Exposure mapping in cities can help to plan source and location specific action plan to mitigate exposure impacts.

Existing air monitoring systems do not fully address the population exposure to toxic air pollutants. It is important to estimate the level and distribution of exposure in the population; identify the population groups with high exposure; and the risks of potential health effects. Monitoring design should be refined to allow use of data for assessing the effects on population health. The pollutants, measurement of time scales and locations are relevant to assessing human exposure and the expected health effects. This should address the differences in air quality within a city based on activity and time spent.

3.2 Household Air Pollution

"Nearly 74% of India's population continues to rely on solid fuels (such as biomass, dung and coal) for their everyday household energy needs." (Pyne et al. 2014) Household air pollution (HAP) from solid cookfuel use results primarily from incomplete combustion as conditions for efficient combustion of these fuels are difficult to achieve in traditional stoves that are predominant in households. Hundreds of different chemical substances are emitted during the burning of solid fuels in the form of gases and particles. In addition to small particles, carbon monoxide, and nitrogen oxides, which are regulated in India as outdoor pollutants, studies have shown that traditional chulhas produce hundreds of other toxic pollutants including formaldehyde, benzene, poly-aromatic hydrocarbons, and even dioxins (Smith 1987; Cooper 1980; Naeher et al. 2007). Further, the amount and characteristics of pollutants produced during the burning of solid cookfuels depend on several factors including composition of, and moisture levels in, the biomass fuel, combustion conditions (temperature and air flow), mode of burning, and even shape of the combustion chamber (Smith 1987; Smith et al. 2000).

Unlike ambient air pollution, where the national monitoring programmes provides routine information on ambient concentrations across multiple cities, information on HAP exposures has largely come from individual research studies. Over the last three decades, well over 200 studies have characterized HAP exposures in solid fuel using households of developing countries (dominated by studies from India). Methods used to estimate exposures have ranged from questionnaire-based assessments to long-term field based measurements of household area concentrations and personal exposures for women, men and children. A compilation of studies reporting results from quantitative measurements of HAP across global regions is available in the WHO Global Household Air Pollution Database (Balakrishnan et al. 2014).

*Household level measurements c*onducted as far back as the 1980s (Aggarwal et al. 1982; Smith et al. 1983), studies from India showed kitchen concentrations and in a few instances, personal exposures for women for Total Suspended Particulate Matter (TSP), Carbon monoxide and Benzo-a-pyrene to be in significant excess of relevant air quality standards in village households of Gujarat. While measurements of HAP have not been included in global epidemiological investigations until recently, these exposure assessments provided some of the first evidence for consequent health burdens.

Over the last three decades, the information on HAP exposures in India has become considerably more detailed with measurements of short- term and 24-hour household concentrations and exposures being available across a range of household configurations from multiple states.

Table 1 provides a brief summary of measurement results from these studies. The distribution of exposures is now well recognized to be heterogeneous and complex with multiple determinants (such as fuel/stove type, kitchen area ventilation, and quantity of fuel, age, gender and time spent near the cooking area) influencing spatial and temporal patterns of exposures within and between households. However, regardless of the variability in results across studies, the measurements have provided unequivocal evidence of extreme exposures in all solid cook-fuel using communities, often many fold higher than recommended pollutant specific WHO-AQGs .

Also, while most of solid-fuel use related exposures occur in the rural indoors, the use and accompanying high exposures is not uncommon among the urban poor who may be receiving double burdens from polluted outdoor and indoor air. Limited data are currently available, however, to assess the scale and levels of such exposures.

Table1: Summary of results from exposure assessment studies for HAP in India

	Author /Study Area	Fuel	Stove type	Sampling duration	Levels of pollutants reported Kitchen(K),Living(L),Outdoor(O),Ambient(A),Personal(P)
1	Aggarwal et al (1982), Ahmedabad, Gujarat (Urban)	Wood/dung /charcoal	Traditional	Half-an-hour during cooking	(K)TSP: 7203–26147 (µg/m3) (K)PAH (BaP): 1270–8248 (ng/m3)
2	Smith et al (1983) Anand, Gujarat (Rural) (Boria, Meghva, Denapura, Rampura villages)	Wood	Traditional	Meal duration	(K)TSP: 6400(µg/m3) BaP: 4100 (ng/ m3)
			Improved Chulha	Meal duration	(K)TSP: 4600(g/m3) BaP: 2400 (ng/ m3)
				Meal duration	(A)TSP: 1500(g/m3) BaP: 500 (ng/ m3)
3	Ramakrishna et al(1988) Kerala, Karnataka, Haryana(Rural)	Wood	Traditional	Meal duration	(K)TSP: 3200–3300(µg/m3) CO: 7–19 (mg/ m3)
			Improved Chulha	Meal duration	(K)TSP: 1700–2900(µg/m3) CO: 5.7–8.9 (mg/ m3)
4	Menon et al (1998) MadhyaPradesh,	Wood	Traditional	Meal duration	(P)TSP: 2000–5000(µg/m3) ;

Table1: Summary of results from exposure assessment studies for HAP in India					
	Author /Study Area	Fuel	Stove type	Sampling duration	Levels of pollutants reported Kitchen(K),Living(L),Outdoor(O),Ambient(A),Personal(P)
	Pondicherry (Rural) (Islamnagar, Padaria, Ariyur, Perambia, Adampur villages)				(P)CO: 30.9–74.4 (ppm); (P)BaP: 138-164(ng/m3)
5	Norboo et al (1991) Jammu &Kashmir (Rural) (Chuchot Sharma village)	Wood	Traditional	Meal duration	(K)CO: 12–29.8 (mg/ m3)
6	Saksena et al (1992) Pauri District, Uttar Pradesh(Rural)	Wood	Traditional	Meal duration	(K)TSP: 5600(µg/m3) CO: 21 (mg/ m3)

3.3 Population-level Estimates

More recently, progress in burden of disease assessment methodologies has necessitated development of population-level exposure estimates to link HAP exposure with relevant health outcomes using Integrated-Exposure-Response Curves (IERs) (Burnett et al. 2014). The global exposure estimate for solid fuel users used in the 2010 Global Burden of Disease assessment (Lim SS et al 2012; Smith et al. 2014) was provided by an India exposure model (Balakrishnan et al. 2013) developed on the basis of HAP measurements (of $PM_{2.5}$) in rural households drawn from four Indian states and data on multiple cooking-related household variables available in the National Family Health Survey (Figure 10). The model provided state and national estimates for household concentrations of $PM_{2.5}$ in both solid and clean fuel using rural households (Table 2) and allowed estimates of exposures for men, women and children based on the relationship between household concentrations and resulting personal exposures reported in a global database of studies (Balakrishnan et al. 2014). These estimates for India were, in fact, applied to all countries to derive the global burden of disease.

National exposure models developed for solid fuel using household-level estimates average $PM_{2.5}$ (particulate matter less than 2.5 µm in aerodynamic diameter) exposures to concentrations of 337 µg/m3, 204 µg/m3 and 285 µg/m3 for women, men and children respectively (Balakrishnan et al. 2013) , greatly in excess of the current WHO air quality guideline interim targets (WHO-AQG IT-1) of 35 µg/m3, (WHO 2006) or the Indian standard of 40 µg/m3 (CPCB 2009b).

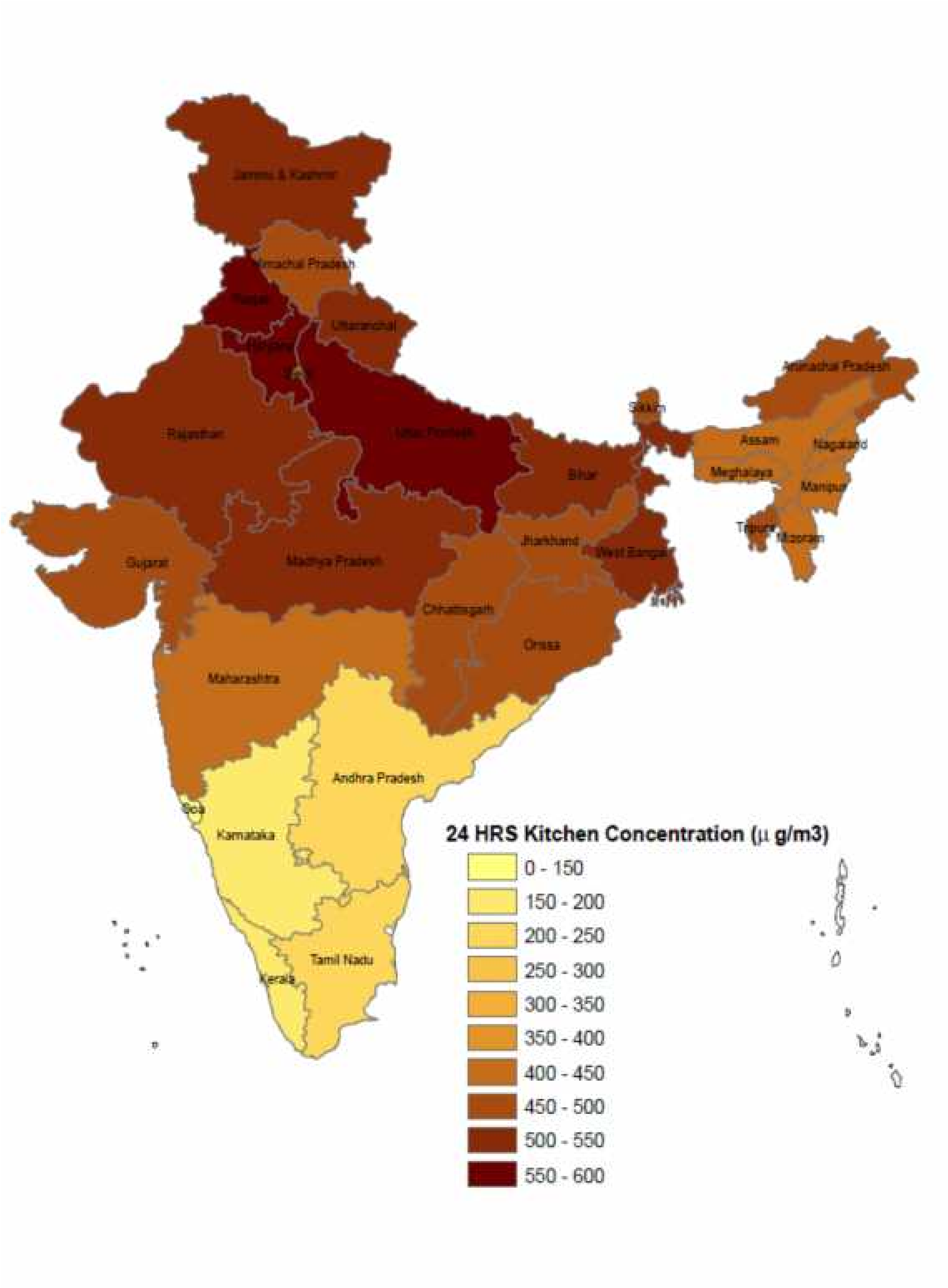


Figure 10: Distribution of 24-hr average kitchen area $PM_{2.5}$ concentrations in solid fuel using households across states. Source: (Balakrishnan et al. 2013)

Table 3: 24-hr PM2.5 kitchen area concentrations in rural and urban solid fuel using households across states (Balakrishnan et al. 2013)

State[1]	Population	%SF Use	24 hr $PM_{2.5}$ kitchen area concentrations (μg/m^3) in solid cookfuel using households (95% CI)			Weight in overall estimate for all solid- fuel-users	
			Rural solid-fuel- users	Urban solid- fuel- users	All solid-fuel-users	Rural	Urban
ANDHRA PRADESH (25)	7621007	41.93	214 (154–296)	187 (135–259)	207 (150–287)	0.76	0.24
ARUNACHAL PRADESH (11)	1097968	65.79	472 (331–673)	409 (286–585)	463 (325–660)	0.85	0.15
ASSAM (17)	26655528	67.45	454 (328–629)	415 (298–578)	448 (323–622)	0.85	0.15
BIHAR (9)	82998509	79.04	514 (350–754)	505 (344–742)	512 (349–751)	0.75	0.25
CHHATTISGARH (21)	20833803	81.35	478 (345–663)	469 (339–649)	476 (344–660)	0.81	0.19
DELHI (6)	13850507	13.38	587 (396–875)	411 (292–579)	442 (310–631)	0.18	0.82
GOA (27)	50671017	35.99	191 (140–262)	119 (86–163)	173 (126–238)	0.75	0.25
GUJARAT (23)	1347668	53.66	491 (361–667)	423 (311–576)	480 (354–653)	0.85	0.15
HARYANA (5)	6077900	71.8	557 (383–814)	513 (353–749)	553 (380–807)	0.90	0.10
HIMACHAL PRADESH (2)	21144564	53.73	482 (356–653)	413 (305–559)	480 (355–650)	0.97	0.03
JAMMUAND KASHMIR (1)	26945829	57.01	508 (367–706)	427 (308–593)	501 (361–696)	0.91	0.09
JHARKHAND (19)	10143700	85.05	495 (342–716)	503 (347–730)	497 (344–720)	0.74	0.26
KARNATAKA (26)	52850562	65.75	199 (145–274)	181 (132–250)	196 (143–270)	0.84	0.16
KERALA (28)	31841374	71.71	183 (135–249)	158 (117–216)	176 (130–240)	0.73	0.27
MADHYA PRADESH (22)	2318822	57.16	512 (370–711)	502 (362–698)	510 (368–709)	0.82	0.18
MAHARASHTRA (24)	96878627	34.18	461 (340–627)	385 (283–524)	438 (323–596)	0.70	0.30
MANIPUR (13)	2293896	60.14	447 (319–628)	376 (268–528)	426 (304–599)	0.71	0.29
MEGHALAYA (16)	60348023	63.21	444 (320–618)	384 (274–541)	431 (310–600)	0.77	0.23
MIZORAM (14)	888573	35.36	463 (318–673)	331 (228–482)	446 (307–649)	0.88	0.12
NAGALAND (12)	1990036	64.66	430 (308–601)	399 (286–558)	421 (302–589)	0.72	0.28
ORISSA (20)	36804660	83.1	467 (325–671)	453 (315–653)	464 (323–668)	0.81	0.19
PUNJAB (3)	24358999	56.3	582 (390–870)	529 (355–791)	575 (386–861)	0.88	0.12
RAJASTHAN (7)	56507188	73.55	532 (384–740)	514 (368–717)	530 (381–737)	0.86	0.14
SIKKIM (10)	540851	41.58	469 (345–641)	374 (272–515)	468 (344–639)	0.99	0.01
TAMIL NADU (29)	62405679	50.85	210 (152–290)	182 (132–251)	205 (148–282)	0.80	0.20
TRIPURA (15)	3199203	77.12	472 (348–643)	429 (315–585)	467 (344–635)	0.87	0.13
UTTAR PRADESH (8)	8489349	59.87	601 (411–882)	578 (397–846)	596 (408–874)	0.79	0.21
UTTARANCHAL (4)	166197921	70.98	512 (370–711)	422 (303–589)	503 (363–699)	0.90	0.10
WEST BENGAL (18)	80176197	58.32	505 (360–710)	490 (349–690)	501 (357–705)	0.74	0.26
India	**1026066960**	**58.66**	**455 (321–646)**	**430 (303–613)**	**450 (318–640)**	**0.80**	**0.20**

HAP Exposures in relation to 'improved' cookstove stove deployment

As described in Annexure 2 - Table 1, several recent studies (Chengappa et al. 2007; Dutta et al. 2007; Balakrishnan et al. 2014; Sambandam et al. 2014) have shown that many of the technologies used in the earlier models of 'improved' or the more recent models of "advanced combustion" biomass cook-stoves do not reduce emissions, and therefore exposures, sufficiently to truly protect health. This is partly because households rarely shift 100% to the new stove because it does not represent a fundamental change from the old one (Bhojvaid et al. 2014; Lewis & Pattanayak 2012). In addition, those that perform better rely on electric blowers to stabilize the combustion and increase air flow, which increase cost, require access to a source of power, and can only be manufactured in central facilities using high-quality materials under good quality control. Some do well in the lab, but in the field tend to have worse performance because households use a wide variety of fuels over the year of different sizes and moisture contents and do not always tend the stoves as intended by designers. Even well-performing chimney stoves do not serve the purpose (as they merely displace the smoke outdoors) particularly in a village setting with many households using biomass fuel located near each other. Although limited rural outdoor monitoring has been performed, available data indicate ambient levels in densely populated solid fuel using communities to be well in excess of WHO-AQG levels (Balakrishnan et al. 2004; Smith et al. 1983). Indeed, in such communities, it may be difficult to achieve WHO-AQG levels within households if only a few households switch. Complete changeover of a community to clean fuels, such as LPG, however, should result in major reductions in exposure, but has not been yet studied in detail (Balakrishnan et al. 2013; Sambandam et al. 2014).

HAP Contribution to Ambient Air Pollution

It has long been recognized that household combustion of solid fuels not only produces harmful pollution indoors, but—with pollutants exiting through windows, chimneys, or gaps in walls and roofs—it also contributes to AAP (Smith & Liu 1994). This is particularly concerning for villages with high densities of solid fuel using households and where ambient $PM_{2.5}$ concentrations are often, but not always, lower than in most cities but nevertheless high enough to be of concern (Brauer et al. 2012). However, until recently there were no reliable estimates of the contribution from HAP related emissions to AAP. Drawing on two existing global models the Fast Scenario Screening Tool for Global Air Quality and Instantaneous Radioactive Forcing (TM5-FASST) hosted by European Union Joint Research Center, the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model of the International Institute for Applied Systems Analysis. A recent study (Chafe et al. 2014) has calculated the proportion of ambient $PM_{2.5}$ attributable to household combustion of solid fuels for some 170 countries; subsequently, this estimate was applied to derive the AAP-attributable disease burden due to HAP. In 2010, the fraction of outdoor combustion-derived $PM_{2.5}$ pollution attributable to household cooking with solid fuels was estimated to be around 26% in India. This clearly is a substantial contribution and particularly important from a health perspective, since the contribution of the HAP to AAP is also taking place (by definition) where the people are and therefore probably contributing disproportionately to exposures from AAP.

3.4 Summary of Evidence

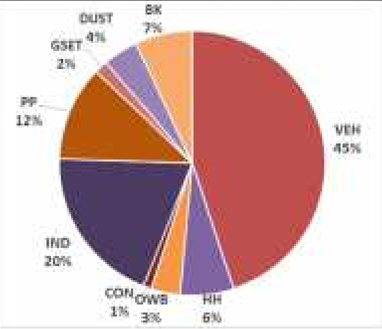
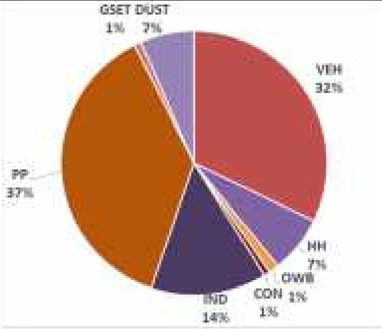
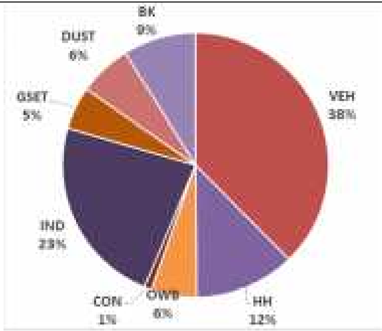
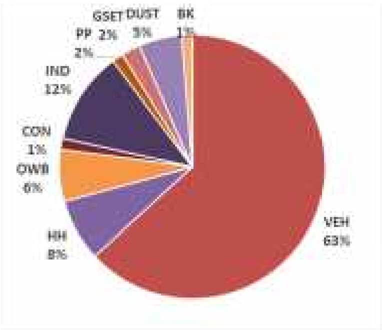
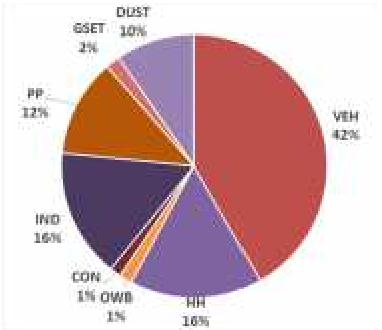
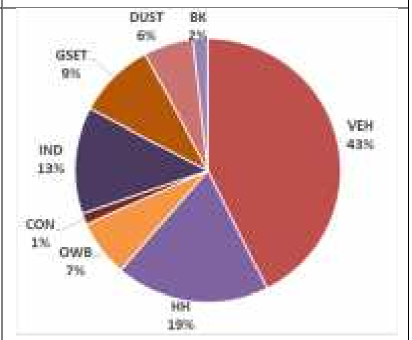
The data on AAP and HAP exposures in India summarized in this section provides a robust evidence base for

1. Continued wide-spread prevalence of health-damaging exposures from urban emissions and solid fuel use for urban and rural populations respectively, across all states
2. Limited impact from the current scale and/or nature of interventions to produce health relevant exposure reductions and
3. The need to address substantial contributions from solid cooking fuel emissions, in addition to other traditionally considered major sources, to ambient concentrations and consequently to population exposures.

Section 4 describes the nature and magnitude of health impacts attributed to ambient and household air pollution exposures. The ubiquity of exposures together with the range of exposure overlaps across urban –rural boundaries argues for examining air pollution exposures holistically, with careful considerations of relative source strengths and intake fractions, while designing interventions. Sections 5 and 6 build on the exposure evidence presented here and the health evidence presented in section 4 to propose pragmatic and necessary next steps to reduce the exposure and consequent health burdens.

Appendix: Illustrative intake fraction and exposure apportionment analysis

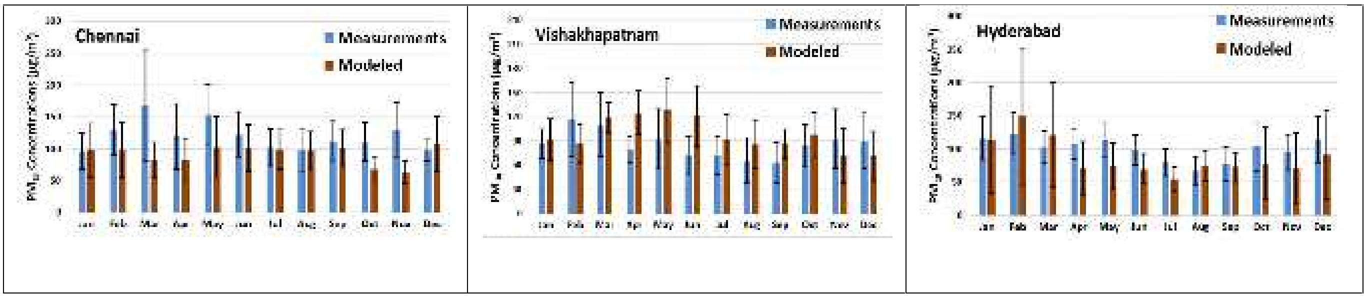
A prerequisite to an urban air quality management plan is some idea of the pollution sources and their relative risks to human health in a city. While the receptor modeling studies have highlighted the shares of various sectors to the ambient PM pollution and the health assessments (GBD and similar urban studies) have emphasized the influence of ambient PM pollution on human health, there is an inherent gap in understanding the relative health risk of various sectors in the cities. In this context, intake fractions (IFs) could help. By definition, IFs summarize the emission-to-intake relationship for a specific source as the fraction of emissions that are inhaled by an exposed population (Bennett et al. 2002; Humbert et al. 2011; Apte et al. 2012; Tainio et al. 2014). For three cities – Chennai, Hyderabad, and Vishakhapatnam, we present the IFs for eight major urban sectors – vehicle exhaust, domestic cooking and heating, diesel generator sets, large power plants, road and construction dust, brick kilns, and open waste burning.

	Chennai	Vizag	Hyderabad
$PM_{2.5}$ emission apportionm			
$PM_{2.5}$ exposure apportionm			

VEH = vehicle exhaust; DOM = domestic cooking and heating (contribution to outdoor and not indoor); OWB = open waste burning; CON = construction dust; IND = industrial combustion; GSET = diesel generator sets; DUST = road resuspension dust; BK = brick kiln combustion; PP = Power Plants

The urban emissions inventory is maintained on a GIS platform and spatially segregated at a finer resolution of 0.01° in longitudes and latitudes (equivalent of 1km) and for further use in atmospheric modeling. Spatial proxies such as grid based population density, road density (defined as number of km per grid), and grid level commercial activity like industries, brick kilns, hotels, hospitals, apartment complexes, and markets were used to distribute emissions. This exercise allows us to identify and study the hot spots across the city, via spatial apportionment of the emission loads. The grid-level concentrations were calculated using the Atmospheric Transport Modeling System (ATMoS) dispersion model, with the wind conditions (direction and speed), mixing heights, and precipitation fields from the National Center for Environmental Prediction (NCEP 2014) and the WRF 3.5.1 meteorological model. This 3-dimensional data is available at 1 hour interval for the model year 2012.

The ATMoS model results for ambient PM_{10} concentrations were compared with the monitoring data available from the National Ambient Monitoring Program (NAMP) – operated, maintained, and disseminated by the Central Pollution Control Board (New Delhi, India). The variation in the modeled data is spatial in nature, i.e., it represents the standard deviation in the monthly average concentrations over an area covering the urban parts of the city's. This was done to capture the representative urban average of concentrations, given the variations in the spatial representation of the emissions and load of emissions.



The comparison of the PM pollution ranges also ascertains the emissions inventory estimation, spatial disaggregation to one km^2 grids, and dispersion model architecture, which captures primary and secondary PM contributions.

4. Health Effects of Ambient and Household Air Pollution Exposures in India

4.1 Health Effects of Ambient Air Pollution

Over the last two decades**,** numerous toxicological, controlled human exposure, and epidemiological studies have examined the health effects associated with short- and long-term exposure to ambient air pollution (particularly in relation to PM, SO_2, NO_2 and ozone exposures) and have served as the basis for pollutant specific air quality guidelines (AQGs) provided by the WHO (WHO 2006) The spectrum of adverse health effects associated with air pollution exposure (Box 1) ranges from increase in prevalence acute and chronic respiratory symptoms, changes in pulmonary function and adverse reproductive outcomes (including low birth weight and pre-term delivery) to increased mortality from cardiovascular or respiratory diseases or lung cancer(WHO 2006, 2014). The International Agency for Research on Cancer has classified outdoor air pollution, particulate matter from outdoor air pollution and indoor emissions from household combustion of coal as a known human carcinogenic (IARC Group 1) and emissions from the combustion of biomass fuels as a probable human carcinogen (Group 2A) (IARC 2010; Loomis et al. 2013).

While the rapidly developing countries of Asia including India, bear bulk of the burden of ambient air pollution exposures, the representation of studies from high-exposure settings in the ambient air pollution epidemiological literature globally has been modest (HEI 2010). A comprehensive review of literature of Asian studies in 13 countries conducted by the Health Effects Institute, USA in 2010, identified some 43 studies (published between 1987 and 2007) reporting health effects in relation to ambient air pollution in India (HEI 2010). The studies (mostly concentrated in the cities of Delhi and Mumbai) report results primarily from cross-sectional assessments of respiratory morbidity. Roughly half of the studies estimated the effects of exposure to both PM and gaseous pollutants while half estimated these effects of exposure on the basis of residential proximity to air pollution sources and haze. Most studies reported significant associations between ambient air pollution and prevalence of acute and chronic respiratory symptoms. Three studies performing time-series analyses reported significant increases in acute respiratory illness (Bladen et al 1989), all-cause mortality (Cropper et al 1997) and emergency visit for cardio-respiratory conditions (Pandey et al 2005). A detailed description of individual studies may be found in the HEI webpages (Link).

Box 1 Health effects of ambient air pollution considered during the development of the WHO Air Quality Guidelines (WHO 2006)

Effects attributed to short-term exposure

- Daily mortality
- Respiratory and cardiovascular hospital admissions
- Respiratory and cardiovascular emergency department visits
- Respiratory and cardiovascular primary care visits
- Use of respiratory and cardiovascular medications
- Days of restricted activity
- Work absenteeism
- School absenteeism
- Acute symptoms (wheezing, coughing, phlegm production, respiratory infections)
- Physiological changes (e.g. lung function)

Effects attributed to long-term exposure

- Mortality due to cardiovascular and respiratory disease
- Chronic respiratory disease incidence & prevalence (asthma, COPD, chronic pathological changes)
- Chronic changes in physiologic functions
- Lung cancer
- Chronic cardiovascular disease
- Intrauterine growth restriction (low birth weight at term, intrauterine growth retardation, small for gestational age)

Health effects of household air pollution considered during the development of the WHO Indoor Air Quality Guidelines for Household Fuel Combustion (WHO 2014)

- Child acute lower respiratory infections (ALRI)
- Adverse pregnancy outcomes (low birth weight, stillbirth, pre-term birth)
- Stunting
- All-cause child mortality (under 5-years)
- Chronic obstructive pulmonary disease (COPD)
- Lung cancer
- Cardiovascular disease (CVD)

- Cataract
- Adult acute lower respiratory infections (ALRI)
- Child cognitive development
- Asthma
- Cancer of the upper aero-digestive tract
- Cancer of the uterine cervix
- Tuberculosis

Several other recent studies report an extensive range of respiratory effects and disease biomarkers associated with ambient air pollution in rural, peri-urban and urban communities. Major agricultural regions in Punjab and Haryana are home to thousands that are potentially exposed to life threatening smoke from agricultural burning. A study conducted in a rural community in Patiala, Punjab state showed that significant decreases in mean values of pulmonary function tests before and after straw burning were seen among young residents (ages 21-25) and caused more unrecoverable decrease in pulmonary function tests of child participants (ages 10-13) (Awasthi et al. 2010). A large scale study on 5,671 children in Delhi (Siddique et al. 2011) documented reduced lung function among healthy school-aged children (ages 9–17) when compared to a control group of children in West Bengal and Uttranchal. After controlling for confounders, ambient PM_{10} was associated with restrictive (OR=1.35, 95% CI 1.07–1.58), obstructive (OR=1.45, 95% CI 1.16–1.82), and combined type of lung function deficits (OR=1.74, 95% CI 1.37–2.71) in children. A community based study in a critical polluted area in Punjab documented detrimental effects of ambient air pollution among residents (ages 15 to 55). Residents from two towns (MandiGobindgarh or “steel town” and Morinda, a relatively less polluted town) were surveyed and tested for pulmonary lung function. Participants living in MandiGobindargh had an increased risk of developing chronic respiratory symptoms of 1.5 (95% CI: 1.2-1.8) (Kumar et al. 2014).

Several recent studies also document cyto-pathological changes in response to exposure to ambient air pollution, adding 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. In rural communities using biomass, smoke 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 in rural populations 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 haemorrhage in the lungs (Roy et al. 2001). 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). 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.

More recently, results from a coordinated set of time-series studies examining the association of natural all-cause mortality with PM_{10} exposures in the cities of Chennai, Delhi and Ludhiana have been published (Balakrishnan et al. 2011a; Kumar et al. 2010; Rajarathnam et al. 2011). The concentration–response functions developed through these studies suggest a generally similar risk of mortality associated with PM exposure (ranging from 0.15% to 0.4% increase in risk per 10-µg/m3 increase in PM_{10} concentrations) when compared with the multicity studies conducted in China, South Korea, Japan, Europe, and North America (Table 1). The association of mortality with exposure to NO2 observed in Delhi was also similar to values reported from other studies in Asia (Wong et al. 2008). The associations were fairly consistent in spite of the fact that concentrations of criteria air pollutants were substantially higher than those observed in the United States and Europe (HEI 2010; Wong et al. 2008) and there are notable differences in demographics, source mixtures, public health status, and other factors.

	Pollutant	% Excess Risk of Mortality (95% CI)	Lag	Reference
Single Cities				
Chennai	PM_{10}	0.4(0.2, 0.7)	1 day	Balakrishnan et al 2011
Delhi	PM_{10}	0.15(0.07, 0.23)	0-1 day	Rajarathnam et al 2011
Delhi	SPM	0.23(0.1)[b]	2 days	Cropper et al 1997
Ludhiana	Visibility[c]	0.7(0.1, 1.2)	1 day	Kumar et al. 2010
Bangkok	PM_{10}	1.25(0.82, 1.69)	0-1 day	Wong et al 2010b
Hong Kong	PM_{10}	0.53(0.26, 0.81)	0-1 day	Wong et al 2010b
Shanghai	PM_{10}	0.26(0.14, 0.37)	0-1 day	Wong et al 2010b
Wuhan	PM_{10}	0.43(0.24, 0.62)	0-1 day	Wong et al 2010b
Multi Cities				
4 Asian cities	PM_{10}	0.55(0.26, 0.85)	0-1 day	Wong et al 2010b
7 South Korean cities	SPM	0.17(0.08, 0.26)	0-1 day	Lee et al 2000
13 Japanese cities	SPM	0.49(0.38, 0.60)	0 day	Omori et al 2003
Meta-analysis of 82 Asian studies	Various	0.27(0.12, 0.42)	Various	HEI ISOC 2010
12 Canadian cities	PM_{10}	0.86(0.32, 1.40)	1 day	Katsouyanni et al 2009
32 European cities	PM_{10}	0.33(0.22, 0.44)	1 day	Katsouyanni et al 2009
89 U.S. cities	PM_{10}	0.29(0.18, 0.40)	1 day	Katsouyanni et al 2009

Table 1: Comparison of excess risks of all natural cause mortality associated with PM 10 exposures from time-series analysis in Indian cities with other selected single/multi-city studies in Asia, North America and Europe (Adapted from (HEI 2010))

A few studies now also provide estimates of premature mortality attributable to ambient air pollution in individual cities (Table 2). Considerable uncertainties however surround these estimates, calculated on the basis of unit risks derived from single city (Cropper et al. 1997; Guttikunda and Jawahar 2012; Kandlikar and Ramachandran 2000; Shah and Nagpal 1997) or meta-analysis ((Neema and Goyal 2010) of time-series studies that address only short-term exposures.

Table 2: Estimated premature mortality due to outdoor air pollution in India

Table 2: Estimated premature mortality due to outdoor air pollution in India				
City/Region	Study year	Pollutant	Premature mortality	Reference
All India	1990	PM_{10}	438,000	IHME (2013
Delhi	1990	Total PM	5070	Cropper et al. (1997)
Mumbai	1991	PM_{10}	2800	Shah and Nagpal (1997)
Delhi	1993	PM_{10}	3800-6200	Kandlikar and Ramachandran (2000)
Mumbai	1993	PM_{10}	5000-8000	Kandlikar and Ramachandran (2000)
Delhi	2001	PM_{10}	5000	Nema and Goyal (2010)
Kolkata	2001	PM_{10}	4300	Nema and Goyal (2010)
Mumbai	2001	PM_{10}	2000	Nema and Goyal (2010)
Chennai	2001	PM_{10}	1300	Nema and Goyal (2010)
Ahmedabad	2001	PM_{10}	4300	Nema and Goyal (2010)
Kanpur	2001	PM_{10}	3200	Nema and Goyal (2010)
Surat	2001	PM_{10}	1900	Nema and Goyal (2010)
Pune	2001	PM_{10}	1400	Nema and Goyal (2010)
Bhopal	2001	PM_{10}	1800	Nema and Goyal (2010)
Pune	2010	PM_{10}	3600	Guttikunda and Jawahar (2012)
Chennai	2010	PM_{10}	3950	Guttikunda and Jawahar (2012)
Indore	2010	PM_{10}	1800	Guttikunda and Jawahar (2012)
Ahmedabad	2010	PM_{10}	4950	Guttikunda and Jawahar (2012)
Surat	2010	PM_{10}	1250	Guttikunda and Jawahar (2012)
Rajkot	2010	PM_{10}	300	Guttikunda and Jawahar (2012)
All India	2010	$PM_{2.5}$ + ozone	695,000	IHME (2013)
Delhi	2010	$PM_{2.5}$	7350 to 16,200	Guttikunda and Goel (2013)
Delhi	2030	$PM_{2.5}$	22,000	Dholakia et al. (2013)

The non-availability of cohort studies to address long-term exposures and chronic health effects in India – such as the MESA (Adar et al. 2013; Cohen et al. 2009), Nurses Health ((Puett et al. 2009; Puett et al. 2014), ACS ((Pope II 2002) studies in the US and the SAPALDIA study in Europe(Zemp et al. 1999) and more recently the ESCAPE (Adam et al. 2015; Pedersen et al. 2013) studies in Europe, currently is a major gap in the available evidence base to reliably estimate the effects of long-term exposure on annual average rates of mortality from chronic cardiovascular or respiratory diseases and impacts on life expectancy, the metrics that may be the most meaningful and relevant to policy(see Box 2).

Box 2: Select examples of recent cohort studies addressing long –term exposures to air pollution and chronic health effects

The Multi-Ethnic Study of Atherosclerosis and Air Pollution (MESA Air) was initiated a decade ago to understand the relation between individual level long-term pollution exposure and progression of atherosclerosis and incidence of cardiovascular disease (CVD). Initial findings from this prospective study shows associations with increased progression of the intima-medial thickness (IMT) of the common carotid artery (Adar et al. 2013)Adar et al. 2013; Cohen et al. 2009)

The prospective cohort study among female US based nurses (Nurses Health study) shows association between traffic related pollution and $PM_{2.5}$ and PM_{10} exposures to increased risk of lung cancer among non-smokers and long-term former smokers, and increase in risk of all-cause mortality and incident fatal coronary heart disease (Puett et al. 2014, 2009).

The European Study of Cohorts for Air Pollution Effects (ESCAPE) (Raaschou-Nielsen et al. 2013), a meta-analyses of 17 European cohorts reported significant associations between air pollution and lung cancer incidence. The meta-analyses showed statistically significant associations between risk for lung cancer and PM_{10} (hazard ratio [HR] 1·22 [95% CI 1·03—1·45] per 10 μg/m3). For $PM_{2.5}$ the HR was 1·18 (0·96—1·46) per 5 μg/m3. The same increments of PM10 and PM2·5 were associated with HRs for adenocarcinomas of the lung of 1·51 (1·10—2·08) and 1·55 (1·05—2·29). New evidence from the ESCAPE study add to evidence of associations between natural cause mortality with long-term exposure to $PM_{2.5}$, increased risk of coronary events, and restricted foetal growth (Beelen et al. 2015; Adam et al., 2015; Cesaroni et al. 2014; Pedersen et al., 2013).

From a policy perspective, on the other hand, enough is known from studies in India to indicate that it is reasonable to apply the substantial evidence on AAP health effects in other countries to the Indian situation, with appropriate caveats. This is particularly so because AAP levels are so high that the uncertainties do not make important difference in the estimated size of the effects. Recent developments in global burden of disease (GBD) methodologies however afford a promising approach to address health effects of air pollution in the absence of locally-available evidence in high-exposure settings globally ((Burnett et al. 2014).

We therefore provide a detailed description of the results from the GBD 2010 assessment ((Lim et al. 2012) that provide disease-burden estimates attributable to both ambient and household air pollution in India in Section 3. Section 2 describes studies concerning health effects of household air pollution to serve as prelude to the subsequent discussion of GBD methodologies and results.

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4.2 Health Effects of HAP Exposures

The first publications in the international health literature noting the impacts of HAP were probably those of the noted Indian cardiologist, Dr. Padmavati, in the late 1950s in which she observed that the only plausible explanation for the *corpulmonale* (a serious heart condition secondary to chronic lung disease) seen in young, rural, non-smoking women was heavy air pollution from cook fires (Padmavati and Pathak, 1959). Starting in the 1980s, numerous epidemiological studies conducted in developing countries (including India) have examined health effects associated with HAP exposures especially among women and children. A description of many of the India studies may be found in a recent review (Balakrishnan et al. 2011b).

It is important to note that unlike ambient air pollution and health effects studies that have for the most part relied on quantitative estimates of ambient concentrations as exposure metrics, most epidemiological studies on household air pollution and health effects have used qualitative indicators such as use of solid vs clean fuels type of fuel used, involvement in cooking or proximity to stove as exposure metrics.

The first systematic consolidation of this evidence was performed for the 2000 Global Burden of Disease (GBD) assessment led by WHO. Strong evidence of excess risks for solid-fuel users was established for three categories of health outcomes (Smith et al. 2004), namely acute lower respiratory infections in children under 5, chronic obstructive lung disease in women and lung cancer (for coal users) with moderate or weak evidence for a range of other outcomes including lung cancer for biomass users, cataracts, asthma and TB. Since then, a range of systematic reviews (Dherani et al. 2008; Kurmi et al. 2010; Po et al. 2011; Pope et al. 2010; Sapkota et al. 2008; Stern-Nezer 2010) have strengthened the evidence for association for these and new categories of health effects including birth weight, pre-term births and other cancers. Many studies conducted in India are included in the systematic reviews and inform the meta-analytical estimates and are described in Section 3 as part of the GBD 2010 results.

Development and application of continuous exposure–response functions to estimate excess health risks associated with HAP has been facilitated by the recent studies that have used long-term individual exposure measures on children (Smith et al. 2011) for acute lower respiratory infections and exposure modeling to provide population level estimates (Balakrishnan et al. 2013b) for other outcomes ((Burnett et al. 2014; Smith et al. 2014a).

4.3 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 as a sum of the contribution 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.

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). Therefore, 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, namely, household air pollution (HAP), ambient air pollution (AAP), active tobacco smoking (ATS) and second hand tobacco smoke (SHS). Based on these estimates, 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; Smith et al. 2014b). The IERs (Figure 1) 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 . Table 3 provides a listing of primary and secondary health outcomes that were considered in the GBD 2010 assessment.

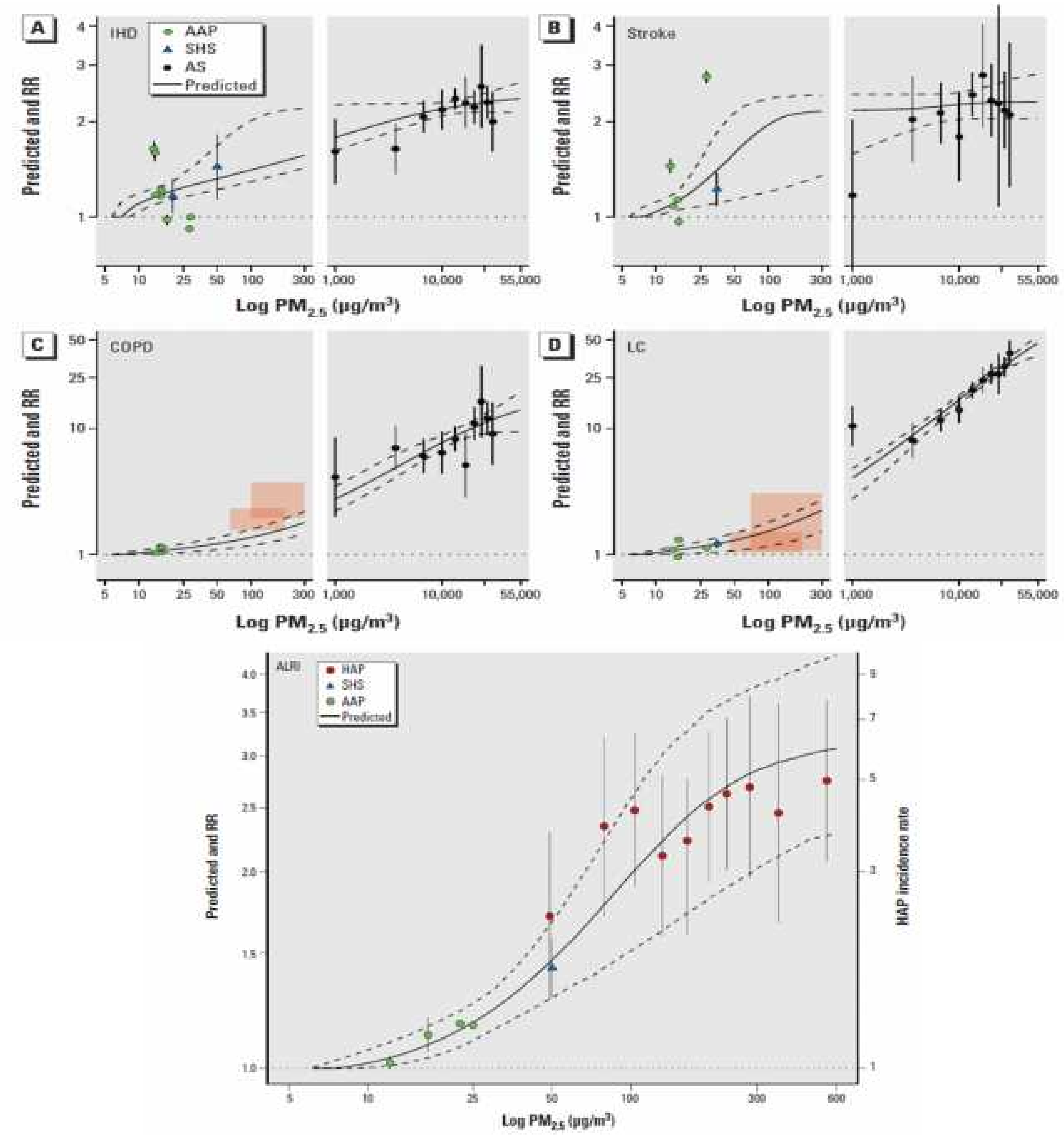


Figure 1: Predicted values of IER model (solid line) and 95% CIs (dashed line) and type-specific RRs (points) and 95% CIs (error bars) for IHD (*A*), stroke (*B*), COPD (*C*), and LC (*D*) mortality. Shaded boxes for COPD and LC mortality represent uncertainty (height) and exposure contrast (width) of RR HAP estimates for males (smaller boxes) and females (larger boxes) separately. Lower panel shows the predicted values of IER model (solid line) and 95% CIs (dashed line) and type-specific RRs (points) and 95% CIs (error bars) for ALRI in infants (Burnett et al. 2014)

Table 3: Listing of primary and secondary health outcomes included for ambient and household air pollution related attributable burdens in the GBD 2010 assessment

Outcome	Method for risk estimation	References
Outcomes common to ambient and household air pollution (included using IERs)		
Child ALRI Ischemic Heart Disease Stroke Lung Cancer (Adults) COPD (Adults)	Based on quantified primary outcome and exposures using Integrated Exposure-Response (IER) functions for ALRI (from studies concerning HAP, AAP and SHS), Lung Cancer (from studies concerning HAP, AAP, SHS and ATS) and Ischemic Heart Disease/Stroke (from studies concerning AAP, SHS and ATS).	(Balakrishnan et al. 2013a; Brauer et al. 2012; Burnett et al. 2014; Smith et al. 2014a)
Ambient air pollution outcomes (included using meta-analytical estimates)		
Asthma	Based on systematic reviews /meta-analyses of studies conducted primarily in countries of North America and Europe	(Anderson et al. 2013)
Low Birth Weight	Based on systematic reviews /meta-analyses of studies conducted primarily in countries of North America and Europe	(Sapkota and A. Chelikowsky 2010)
Household Air Pollution outcomes (included using meta-analytical estimates)		
Cataract (Adults)	Based on quantified primary outcome and qualitative (binary) exposure indicators (such as solid vs. clean fuels) in systematic reviews /meta-analyses of studies conducted in developing countries with supporting epidemiologic studies from other particle exposures(including ambient air pollution(AAP), secondhand smoke (SHS) and active tobacco smoking (ATS)).	(Smith et al. 2014a)
Adult ALRI TB Stillbirth Cancer of the upper aero-digestive tract Cancer of the uterine cervix	Based on quantified outcome and qualitative exposure indicators from studies across multiple developing countries to allow meta-analyses and supporting epidemiological studies from other particle exposure settings (as described above) but with inadequate adjustment for confounding and inconsistencies in effect estimates.	
Asthma Pre-term Births	Based on non-quantified outcomes and exposures with limited consistency but supported by epidemiological studies from other particle exposure settings	

Since GBD 2010 relied largely on estimates from cohort studies for the IERs used in AAP related burden estimates, the unavailability of such studies in India precluded their inclusion.

Several studies conducted in India were however included in the meta-analyses for each of the primary health outcomes considered for HAP related burden assessments , as these satisfied stringent criteria for eliminating sources of biases and adjustments for confounding (Table 4a). We also summarize results from a range of studies that contributed to secondary outcomes currently not included in burden estimates(Table 4b), as these represent evidence for growing number of additional health outcomes likely to be impacted by HAP exposures and will likely be included in future burden of disease assessments.

Table 4a: Listing of major health studies in India included in systematic reviews and meta-analysis for HAP related burden assessments in GBD 2010

Health Outcome	India studies	Reported range of ORs in India studies	Meta-analysis estimate from systematic reviews of global studies
COPD	Behera et al (1991)	3.04 (2.15-4.31)	(Kurmi et al. 2010) 2.80 (1.85–4.0) (Po et al. 2011) 2.4(1.47-3.93) Hu et al 2.44(1.9-3.33) (Smith et al. 2014c) 1.93(1.61-2.92)
	Qureshi et al (1994)	2.10 (1.50 to 2.94)	
	Dutt et al (1996)	2.8(0.61-12.85)	
	Malik et al(1985)	2.95(1.6-5.44)	
	Pandey et al(1984)	4.05(3.23-	
	Jindal et al(2006)	1(0.79-1.27)	
ALRI	Pandey et al (1989)	2.45(1.43-4.19)	Dherani et al(2008) Smith et al(2014) 1.78 (1.45–2.18)
	Mishra et al (2004)	2.2(1.16-4.18)	
	Kumar et al (2004)	3.67(1.42-10.57)	
	Mishra et al (2005)	1.58 (1.28–1.95)	
Lung Cancer (Biomass)	Gupta et al (2000)	1.52 (0.33–6.98)	Smith et al (2014) 1.18(1.03-1.35)
	Sapkota et al(2008)	3.76 (1.64–8.63)	
	Behera et al (2005)	3.59(1.08-11.67)	
Cataracts	Mohan et al (1989)	1.61 (1.02–2.50)	Smith et al (2014)

	Badrinath(1996)	4.91(2.82-8.55)	2.46(1.74-3.5)
	Sreenivas(1999)	1.82(1.13-2.93)	
	Saha(2005)	2.4(0.9-6.38)	
	Zodpey et al (1999)	2.37 (1.44–4.13)	
Lung Cancer(Coal)	Behera et al(2005)	3.59 (1.07 to 11.97) women	Hosgood et al (2011) 2.15(1.61-2.89) Bruce et al 2015 1.21(1.05 to 1.39) for men; 1.95 (95% CI 1.16 to 3.27) for women
	Gupta et al(2001)	2.62 (0.47 to 14.5) women 2.78 (0.97 to 7.98) men	
	Sapkota et al(2008)	0.75 (0.45 to 1.24)	
Ischemic Heart Disease	No direct HAP studies available anywhere in the world. GBD 2010 estimates based on interpolation in IERs and supported by HAP studies on blood pressure and S-T segment depression		Burnett et al (2014) McCracken et al (2007,2011) Baumgartner (2011)
Stroke			

Table 4b: Listing of major health studies related to solid fuel combustion in India (for disease categories not currently included HAP attributable burden estimations)

Health Outcome	India studies	Reported ORs	Meta-analysis estimate
Low birth weight	Mavalankar et al (1991)	1.23 (1.01–1.5)	Pope et al (2010) 1.38 (1.25–1.52)
	Tielsch et al(2009)	1.7(0.92–3.10)	
Still birth	Mavalankar et al (1991)	1.5 (1.04–2.17)	Not available
	Mishra et al (2005)	1.44 (1.05–1.98)	
	Tielsch et al (2009)	1.34 (0.76–2.36)	
	Epstein et al (2013)		
Blindness	Mishra et al(1999)	1.32 (1.16–1.50)	Not available
Tuberculosis	Gupta et al (1997)	2.54 (1.07–6.04)	Sumpter et al (2013) 1.3(1.04-1.62)
	Mishra et al (1999)	2.58 (1.98–3.37)	
	Shetty et al (2006)	0.90 (0.46–1.76)	
	Kolappan et al (2009)	1.7 (1–2.9)	
	Lakshmi et al (2012)	3.14(1.15–8.56)	
	Behera et al (2009)	0.60 (0.22–1.63)	

National Health Impacts

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 µg/m^3, 337 µg/m^3 and 204 µg/m^3 for children, women and men respectively(Balakrishnan et al. 2013b; Smith et al. 2014a). 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 µg/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).

With the availability of quantitative exposure estimates and IERs, GBD 2010 used the same TMRED (counterfactual) of approximately ~7 µg/m^3 annual mean $PM_{2.5}$ across both the risk factors to estimate the total risk range for burden calculations. This counterfactual represents approximate levels in the cleanest cities and is roughly equivalent to what can be achieved by vented cooking with gas fuels.

In 2010, approximately 1.04 million premature deaths and 31.4 million DALYs were attributable to household air pollution (HAP) resulting from solid cooking fuels in India 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.

Figure 2 provides a ranking of the leading risk factors responsible for the national burden of disease burden of disease, underscoring the importance of addressing disease burdens attributable to air pollution in India. Indeed, the burden from ambient and household air pollution together exceeded the burden from any other risk factors among the 60+ risk factors examined in the GBD 2010 exercise**.**

A comparison of the estimates of the burden of disease attributable to major sources of combustion particles in India are summarized in Table 5 and Figure 3. These estimates underscore the inter-related contributions from HAP and AAP exposures to the burden of disease in India and provides a basis for comparison to important public health concerns (smoking and passive smoking) that have traditionally received a good deal of attention for reducing the burden from the same diseases of concern.

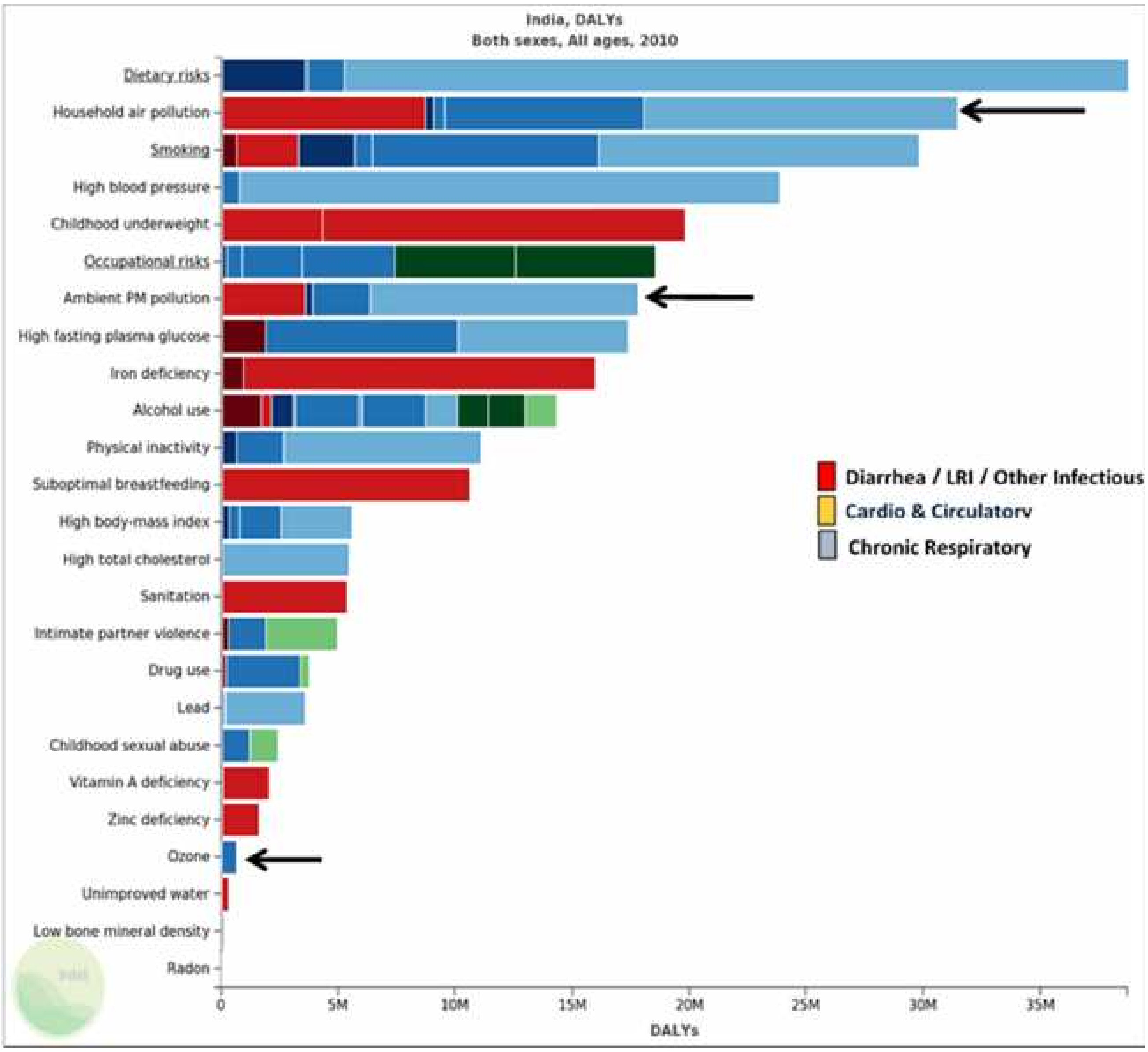


Figure 2: Ranking of leading risk factors contributing to the national burden of disease in India (Source: IHME 2013)

Deaths	PM HAP Deaths	PM AAP Deaths	PM ETS Deaths	PM ATS Deaths	PM Total Deaths
Lower Respiratory Infections <5	100383	40732	30048	0	171163
COPD	362429	108792	0	282860	754080
Cancers of the Trachea, Bronchus and Lung	14506	12729	757	46356	74347
IHD	343664	305266	21910	317011	987851
Stroke (Cerebrovascular Disease)	201276	159954	9270	137234	507734
Total	1022258	627473	61985	783461	**2495175**
DALYs	**PM HAP DALYs**	**PM AAP DALYs**	**PM ETS DALYs**	**PM ATS DALYs**	**PM Total DALYs**
Lower Respiratory Infections < 5	8638607	3503152	2586490	0	14728249
COPD	8560004	108792	0	8635069	17303866
Cancers of the Trachea, Bronchus and Lung	367265	12729	17034	1226224	1623251
IHD	8930148	305266	573688	8503157	18312259
Stroke (Cerebrovascular Disease)	4485358	159954	203001	3171893	8020206
Total	30981382	4089893	3380213	21536343	**59987831**

Table 5: Results from GBD 2010 for disease burden attributable to particulate matter in India (based on data from (IHME 2013) and reproduced with permission from (Ghosh et al. 2014) PM-Particulate Matter; DALYs-Disability adjusted Life Years; HAP-Household Air Pollution; AAP-Ambient Air Pollution; ETS-Environmental Tobacco Smoke; ATS-Active Tobacco Smoking.

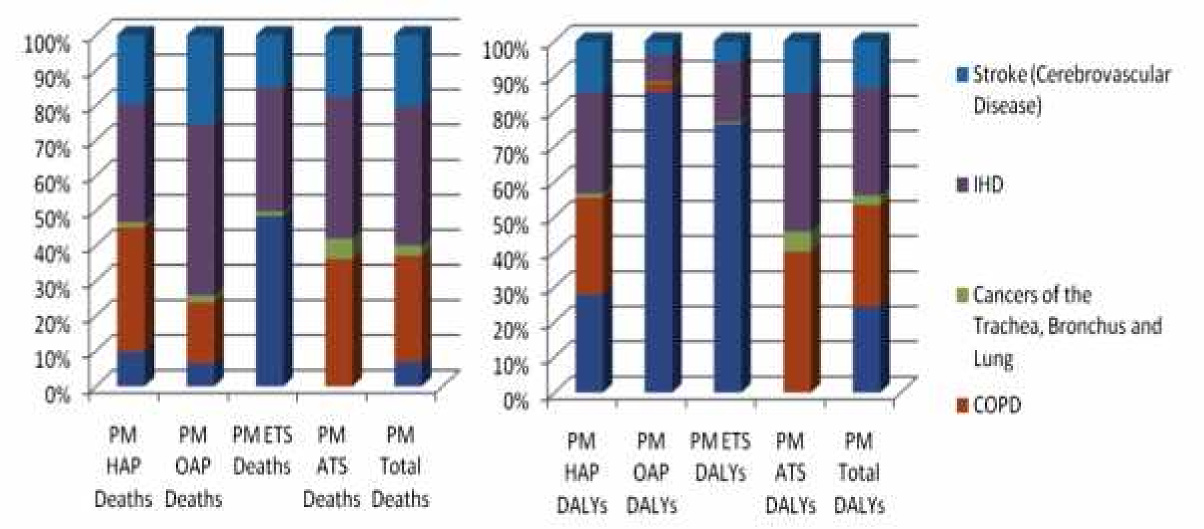


Figure 3: Percent of the disease burden attributable to exposures from combustion particulate matter exposures in India(based on data from (IHME 2013) and reproduced with permission from(Ghosh et al. 2014) PM-Particulate Matter; DALYs-Disability adjusted Life Years; HAP-Household Air Pollution; AAP-Ambient Air Pollution; ETS-Environmental Tobacco Smoke; ATS-Active Tobacco Smoking. PM-Particulate Matter; DALYs-Disability adjusted Life Years; HAP-Household Air Pollution; AAP-Ambient Air Pollution; ETS-Environmental Tobacco Smoke; ATS-Active Tobacco Smoking.

4.4. Summary of Evidence on Health Effects of Ambient and Household Air Pollution

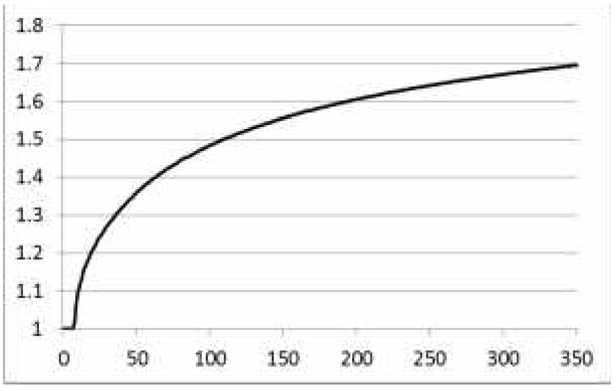
Several features of the evidence on the air pollution attributable disease burden in India have significant implications for policy options. We summarize some of the key features below:

1. There is a now long history and a substantive volume of studies in India that have examined the health effects of ambient and household air pollution. While there are some critical gaps in the literature (such as the paucity of exposure-response or cohort studies), the comprehensive evidence on the prevalence of health damaging levels of exposure (Chapter 3) and the comparability of available study results to the global pool of evidence (this chapter) argue for imminent action on both ambient and household air pollution.
2. The health burden from ambient and household air pollution exposures is no longer thought to be limited to chronic and acute respiratory outcomes in men, women and children. With increasing evidence of health impacts from ischemic heart disease, stroke, lung cancer and ALRI among adult men and women and a range of plausible outcomes including adverse pregnancy outcomes, TB, Asthma and other cancers, air pollution needs to be considered within public health programs concerning non-communicable and communicable diseases.
3. The disease burden estimates for air pollution have been enormously strengthened through the development of what are now called “integrated exposure-response” (IER) relationships that uses the vast health literature of health effects from outdoor air pollution (in developed countries),

active smoking with the growing literature documenting effects from secondhand tobacco smoking (SHS) and household air pollution. These now show a gradual rise in risk for five major categories of disease (lung cancer, heart disease, stroke, chronic obstructive pulmonary disease, and child pneumonia) over nearly a factor of 1000 in exposure – with outdoor air pollution levels at the lower end, active smoking at the highest levels, and SHS and HAP being intermediate. The consistency of effects across exposure spectrum through the IERs significantly enhances the confidence in the risk estimates. It also allows comparison of attributable disease burden estimates across combustion sources providing opportunities to evaluate intervention options on the basis of individual benefits as well as one or more co-benefits.

4. Although the risk levels are lower than for active smoking , the ubiquity of high levels of exposures across rural and urban populations, the range of health outcomes impacted (includes many with high underlying prevalence rates) and populations at risk (includes all age groups, even babies and young children who do not smoke) together make the attributable disease burden large. The disease burden estimates thus provide the most justifiable grounds for adding impetus for intervention efforts.
5. The current IERs need to be strengthened by evidence on acute and chronic health effects at the high levels of exposures commonly encountered in India. The shape of the IERs however, provides important insights for scoping the nature and scale of interventions for ambient and household air pollution. The most discernible risk reductions for most disease end points appear at the annual mean WHO-IT-1 values of 35μg/m^3 for $PM_{2.5}$ concentrations. This can be seen for example with heart disease in the figure 4 below. Dropping exposures from 350 to 175 ug/m^3, is not likely to produce much risk reduction compared to reaching 35 ug/m^3 or even lower.

Excess risk of IHD



PM $_{2.5}$ concentrations

Figure 4: Risk of ischemic heart disease from exposure to air pollution. Relative risk on the y-axis – annual average $PM_{2.5}$ exposure on the x-axis in ug/m3. Based on integrated exposure-response analysis and exposure models in India. (Source: GBD 2010 study).

With an increasing burden attributable to non-communicable diseases (from AAP and HAP), this indicates that air pollution exposure reductions would need to be substantial and sustained over long periods to significantly reduce this burden.[1] It is well known that a smoker who cuts back from many cigarettes smoked per day to just a few gains relatively little reduction of heart disease and other major risks. People need to stop smoking entirely to obtain the health protection. We now realize that this is so for ambient and household air pollution as well. Interventions would need to be benchmarked against levels that are adequately "clean" to produce the desired health benefits and not just "improved" when compared to "dirty" baseline. Since both the urban and rural populations are impacted, albeit to a different degree by ambient vs. household air pollution exposures, the current evidence argues for an emphasis on exposure reductions from both categories of sources.

6. The current non-availability of cohort studies addressing long-term exposures and chronic health effects in India is a major gap in the available evidence base to reliably estimate the effects on annual average rates of mortality from chronic cardiovascular or respiratory diseases and impacts on life expectancy, the metrics that may be the most meaningful and relevant to policy. The global evidence points to rising negative impacts of short and long-term air pollution exposures. We can draw insight from these studies in designing longitudinal studies or health surveillance systems. Subsequent efforts in data collection and investment in epidemiological and exposure assessment studies must be made to address this gap. Research employing newer methods in pollution modeling such as dispersion, land use regression or integrated remote sensing and on-the-ground (in-situ pollution monitor) observations with readily accessible morbidity or mortality outcomes data can generate health impact assessments for Indian cities and rural areas (Cesaroni et al. 2014; Yao et al. 2013; Henderson et al. 2011; Henderson et al. 2007).

7. Finally, given the ubiquity of sources, the interrelated contributions from ambient and household air pollution sources to population exposures, and the likely commonality of health effects associated with particulate matter pollution, strategic epidemiological studies that perform integrated analyses across HAP and AAP exposure settings could be very helpful in informing policy actions in India. The Indian Council of Medical Research has initiated such a process

[1] A recent study suggests that if circa-2010 $PM_{2.5}$ levels were to remain constant, by the year 2030, per-capita mortality attributable to $PM_{2.5}$ would increase in India by 21%. This is mainly due to dramatic increase in the age >50 population. In other words, our comparatively young populations currently partially offset the burden of disease from $PM_{2.5}$ in India. To keep $PM_{2.5}$-attributable mortality rates (deaths per 100 000 people per year) constant, average $PM_{2.5}$ levels would need to decline by 20−30% over the next 15 years merely to offset increases in $PM_{2.5}$-attributable mortality from aging populations (Apte et al. 2015).

through the establishment of integrated rural-urban cohorts to examine health effects of air pollution in pregnant mothers, young children and adults (Balakrishnan et al 2011). These efforts would need to be augmented to examine the broad range long-term adverse health effects impacted jointly by exposures to AAP and HAP.

Indeed such new evidence would allow the design of strategies that bring HAP and AAP jointly under the domain of air quality regulation and chronic disease management in India and elsewhere in the world where such exposures coexist. Success with such efforts in India can pave the way for similar efforts across global regions.

5. Recommendations for Mitigating Air Pollution and Health Impacts

The earlier chapters have shown that there is a range of sources that contribute to air pollution in India and that these have significant health impacts. In this chapter, we offer recommendations and steps that can help better understand the health impacts of air pollution as well as prevent and mitigate such impacts. Given the complex nature of the problem with a multiplicity of sources of air pollution and multiplicity of impacts, it is clear that there is no "silver bullet" solution. Addressing this problem will require a multi-sectoral approach, driven by environmental and health data, science, and evidence. The strengthening and implementation of policies and programs that are needed to tackle this major risk factor for our national burden of disease will require a concerted and coordinated effort across the government. While the MoHFW can implement many of the actions highlighted below, many others will require actions by other Ministries and agencies.

In line with the discussion in Chapter 2, we believe that reduction of both emissions and exposures are important to protecting public health but a health-policy-driven prioritization among options has to be driven by exposure, since that ultimately is what determines health outcomes. Therefore, while we recommend reduction of emissions as much as possible ultimately to reduce overall population levels of exposure, the highest immediate priority has to be accorded to sources that lead to the greatest levels of exposure and adverse health impacts.

5.1 Source-wise Actions to Reduce Exposure

We recommend focusing on key air pollution sources that are implicated in long-term and episodic exposures. In each category, we list following sources in order of priority, based on exposure estimates, to reduce health impacts from air pollution.

5.1.1 Long-Term Exposures

i. Household air pollution: The greatest health impacts from air pollution in India comes from the use of biomass and coal for household cooking energy.. Emissions from these fuels (in devices that lead to poor combustion) lead to high exposures due to their high intake fractions, i.e. they are released in households just at the times people are present. It is now understood that the combination of these high exposures and the nature of the pollutant mix leads to significant health impacts that have were not understood two decades ago. Importantly, this is not just a rural problem but also an urban problem both because solid fuels are used by poor urban populations and because HAP contributes to ambient air pollution. Consequently a focus on this will reap significant health benefits, given that HAP is the second-largest contributor to the burden of disease in India and that much of the pollution is due to very specific sources.

The WHO recommended emission rate targets for $PM_{2.5}$ (0.23 and 0.80 mg/min) and CO (0.16 and 0.59 g/min) for stoves in vented and unvented kitchens, respectively, require a move to very clean sources of household energy. The two primary categories of options are 1) making clean sources (i.e., electric cooking or gas (natural, bio or liquefied petroleum) available or 2) making ubiquitously available sources (i.e., biomass) clean. In the case of the former, issues such as fiscal policies and distribution systems designed to make clean energy affordable and accessible to the poor will need particular attention. In the case of the latter, to reach health goals, current standards for biomass stoves in India need to consider the WHO emission rate targets, which will push advanced stoves even further than has happened to date.

Furthermore, it should also be noted that HAP intervention strategies ideally require a community-level approach. If only a few houses in a locality switch to clean cooking while the others continue to use polluting sources, the movement of the air pollution out of households and into the local ambient environment will result in substantial nullification of any gains in health. The need for such widespread uptake of clean cooking energy – and therefore a movement away from traditional energy sources and cooking practices- will require drawing on behavioural and social sciences to create a change in the social context of cooking fuels, as has been the case in other areas of health protection such as improved sanitation, vaccine delivery, safer sex, and malaria control.

There also is a need to align programmes on clean fuels/cooking technologies across the concerned ministries and also leverage the National Biomass Cookstove Program of Government of India to improve access to clean cooking energy in a time bound manner.

ii. Vehicular pollution: Vehicles are one of the major contributors of ambient air pollution and exposure in urban areas. Since this pollution is emitted in areas where there are many people (both others traveling on or near roads as well as those residing or working nearby), the exposure levels (and intake fractions) are quite significant, which makes the control of such pollution very salient.

There are a range of control measures to mitigate health impacts from vehicular pollution. Borrowing terminology from the transport area, we recommend an “avoid-shift-improve” framework as a way of prioritizing actions to manage health impacts from vehicles.

The “avoid” here refers to avoiding vehicle use as much as possible, and, from a health point of view, particularly in areas with large or dense populations. A comprehensive perspective on avoiding vehicle use is based on integrated land-use planning which manages transport demand at the more fundamental level. For example, urban design can be made more compact to reduce travel distances and improve access. While such integrated land-use planning can be very effective at managing transport demand, it is a long-term process. In the short-term, targeted approaches can be put in place rather quickly. These can include financial disincentives such as higher taxes on fuels, congestion pricing, or increasing parking fees in heavily-populated areas or through regulatory approaches such as making high-density areas vehicle free or limiting vehicle use more broadly (for example, by allowing odd- and even-numbered license plates to be on the road only on alternate days), whereas the targeted financial and regulatory approaches mentioned above can be put in place in a shorter time frame.

“Shift” refers to shifting to modes of transport that reduce pollution and impact while still allowing the movement of goods and people. This can be achieved by making available mass transport such as buses and metro rail or promoting avenues for non-motorized transport, such as bicycles, such that health impacts per passenger-km travelled are reduced.

“Improve” refers to improvement of technologies of vehicles so that they emit fewer pollutant per km travelled. This can be achieved through significantly tighter emission standards and fuel standards, which could lead to reduction of emissions per vehicle-km travelled and also prevent lock-in of polluting technologies in the new vehicle stock. [For instance, only at the level of at Euro VI emissions standards the particulate emissions both in terms of mass and numbers from diesel vehicles can be effectively controlled along with the controls on nitrogen oxides.] This is complemented by tighter checks on on-road vehicles to ensure they do not emit grossly more than they are designed to emit. These programmes will have to be improved for effectiveness to control health-related pollutants such as particulate matter, which are a particular concern with diesel vehicles. Many studies have shown that only a small fraction of high-polluting vehicles may be responsible for a substantial fraction of the pollution load. Increasing congestion on roads as vehicle densities increase can offset some of the gains from improved technology and fuel quality, thereby showing another inter-linkage betwene these various strategies. For health purposes, “improve” can also be take the form of alternate routes, such as city bypass roads, that divert traffic away from populated areas and therefore is an improvement on the metric of impact (but only if there are zoning restrictions to prevent housing or commercial developments abutting these alternate routes, otherwise all that will be achieved is shifting of exposure).

It should be understood that there is no single panacea for reducing transport emissions and generally a range of measures are needed to mitigate these emissions. Importantly, a comprehensive view is required to achieve desired health benefits – for example, promoting cycling and pedestrian travel without reducing pollution from other vehicles on road may expose these travelers to pollution because of their proximity to polluting vehicles. Therefore an integrated view to reducing health impacts from vehicle pollution is critical.

iii. Trash burning: Trash burning also is a significant contributor to the overall pollution load in cities. When this burning occurs in highly populated areas such as residential neighbourhoods, it leads to high exposures due to large intake fractions. In addition, trash often contains plastics and other materials that release additional toxic species when burned.

Controlling trash burning will require strict controls on this activity while also providing suitable infrastructure for trash disposal and composting of organic waste. This also will have the benefit of reducing other public health issues relating with inadequate and/or improper disposal of garbage. In cities like Delhi there is already a legal ban on open burning but its enforcement has remained a challenge. While burning of vegetative waste can be contained through municipal agencies by improving the infrastructure for collection, composting and distribution of compost material and by penalising for non-compliance, night-time trash burning by the poor for heating (in colder areas) can be reduced with enhanced access to affordable electricity.

iv. Diesel generator sets: Diesel generator sets can also be a significant contributor to the air pollution load in cities. And, as with trash burning, these generator sets – often powering residential or commercial buildings – are located in areas with significant populations, again leading to high exposures.

The emission from these generator sets can be reduced by mandating stringent emission controls (certainly more than for mobile diesel vehicles, but that also should be possible since these run at a constant load). As the electricity supply becomes more reliable, the use of diesel generator sets should be discouraged.

v. Road and construction dust: This also is a significant contributor to the pollution – specifically particulate matter load – in cities. A major part of this dust comes from local sources – from open areas that have limited or no green cover, construction sites, and re-suspension of dust from the road.

Strategies to manage this form of pollution, and exposures to it, include formal adoption of dust control regulations and techniques.

For road dust, this could include the implementation of street design guidelines for footpaths and cycle tracks with adequate vegetative barrier and paving without compromising recharge zone along the roads for ground water; putting in place guidelines for eliminating others local sources of dust (such as construction materials and waste); providing vegetative barriers – shrubs and trees wherever possible; limiting vehicular speed to reduce dust; implementing truck loading guidelines to control dust; use of appropriate covers for trucks and other hauling carriers; gravel paving for all haul routes. One could also consider phasing in mechanical/ vacuum based street sweeping wherever feasible and needed or the sprinkling of recycled water to reduce dust circulation (but not by compromising other uses of water).

Construction dust can be addressed by enforcing good construction practices and making construction industry accountable for safe disposal and recycling of construction and demolition waste. The environment impact guidelines for construction industry, the municipal solid waste guidelines, and the recent moves by the National Green Tribunal to enforce a moratorium on construction activities that have not adequately planned for disposal of waste material, all can help address this problem. But these rules will have to be made more explicit at the state levels.

vi. Brick kilns and other local industries: These turn out to be surprisingly-significant contributors to many cities since these are often located within or just outside city limits and the pollution from their dirty furnaces (often burning coal or agricultural waste) can travel into populated areas.

Emissions from such sources that are individually small but together may be significant contributors are notoriously difficult to manage. The main option would be to regulate the pollution from such sources while also providing sources of clean energy options for them.

The roadmap for brick kilns needs to mandate (and enable) improvement in technology, ban on inefficient kilns, and enforcement of stringent emission standards to contain pollution. The other option is to look beyond the mud-clay brick and find building materials which are environmentally suitable and less polluting. Part of the challenge – and opportunity – is to explore the possibility of sourcing building material from industrial and mining waste and fly ash. This will enable recycling and reuse and also improve material efficiency. India has a growing “waste” of construction and demolition material that is currently adding to pollution. This material can be gainfully used in the making of building material. This requires changes in the specifications for use of recycled materials in concrete making.

vii. Large sources (such as industries and power plants): These sources will require two levels of action: Emissions standards to ensure quicker uptake of clean technologies to reduce overall emissions across the country and tight particulate standards for power plants and also introduce standards for nitrogen oxides, sulphur dioxides and mercury to reduce exposure to power plant emissions. Industry and power plants will also need a siting policy to ensure these are not located close to densely populated habitats to reduce exposure and intake fraction. These sources will also require strong compliance monitoring.

For some areas, such as coastal ports, shipping may be a major polluter and steps to manage pollution from these sources – for example, mandating strict limits on the use of their engines and quality of fuels in proximity to the port – may be taken.

vii. Other assorted sources (such as street vendors): There also are other cases where each polluter may be small but again, their location in areas with significant footfall, such as in the case of street vendors, is likely important because of high exposure and intake fraction, not least for the vendor due to the many hours of use. There are few data on this but this may be worthy of consideration. Again, the solution here would be to supply clean forms of energy for cooking and heating.

5.1.2 Episodic Pollution

There also is a class of pollution sources that are episodic in nature, which may be important because of the high peak levels of pollution that might be reached for a short time. While the exact health impacts of such high exposures for short periods are not as well studied and understood as chronic exposure to air pollution, these impacts certainly are deleterious, particularly for vulnerable populations such as older persons, pregnant women, or those with some respiratory conditions. Thus particular steps might be required to address these specific cases of episodal pollution:

1. Use of biomass in households, where the early stages of combustion, even with cleaner biomass stoves, may create short but high pollution events that occur two to three times a day.

2. Vehicular pollution, where specific peak times (office hours or times of truck entry into cities) may lead to spikes in pollution on a daily basis. In North India, this may be exacerbated in

winter months that lead to an inversion at night, thereby reducing the volume of air in which the pollution is trapped, thereby leading to very high concentrations.

3. The use of biomass for heating in cities that have colder winter months, often along streets in residential neighbourhoods. This practice contributes to daily peaks but only during specific seasons and in the northern part of the country.

4. Crop waste burning, again may be a seasonal pollution issue in areas that abut agricultural lands.

5. In some parts of North India, summer time dust storms (again episodes that occur seasonally) may lead to very high particulate levels.

In such cases, in addition to strategies that are directed at controlling these sources of episodic pollution, with a particular focus on $PM_{2.5}$ and ozone (such as improving clean-energy access to shift people away from biomass and travel restrictions), health-based public warning systems that intend to protect the general population but especially vulnerable groups should be developed. These, of course, will require the development of better forecasting techniques (e.g., building upon the Air Quality Index), as they are most useful if the warning can be given the day before. But once available, such information could be disseminated through media channels (and maybe even take a lesson from the playbook of dissemination strategies that have been very successfully deployed in the anti-tobacco campaigns).

5.2 The Special Role of the MOHFW

With the establishment of this Steering Committee, the MoHFW has recognized that air pollution exposure (indoor and outdoor) is responsible for a major portion of the ill-health in India, rivalling or exceeding nearly every other risk factor that has been evaluated including poor nutrition, smoking, alcohol, high blood pressure, high BMI, etc. Thus, the Ministry may wish to consider strengthening and directing its own considerable health systems more directly to adequately respond to the air pollution and health challenge (as is the case in many other parts of the world (see Annexure 1).

We discuss in some detail some of these and other steps that could be taken by the MOHFW:

5.2.1 Better integration of air pollution and public health policies

The Draft National Health Policy released earlier this year states under its section on preventive and promotive health that “Action would be taken on reducing indoor and outdoor air pollution and measured through decreases in respiratory disease especially in children, and other pollution related illnesses". Indeed, the draft policy mandates the Ministry of Health and Family Welfare to develop concerted inter-sectoral policy initiatives and actions to take forward the international call for "Health in All", embedded in the framework of Health for All.

This is an explicit recognition that policy initiatives and effective implementation of the linked programmes in the health sector would succeed only to the extent they are complimented by appropriate policy and programmes in other environment related sectors. This inter-sectoral approach will have to be leveraged to maximise health benefits. For health-based criteria to become the basis of air quality regulations, policy reforms and enabling legal framework are needed for integrated action across sectors.

The current legal framework is not adequately designed to address total exposure reduction through a strong compliance system to meet clean air targets. Currently, air quality governance is located within the statutory framework defined by the Air Act (Prevention and Control of Pollution Act (1981). This Act, if also conjoined with the Environment Protection Act 1986 confers strong statutory powers for source-wise pollution control. But it requires an additional mechanism to ensure clean air targets are met in the airshed to reduce health risks. The Air Act has not made explicit provision for public health protection. As a result, currently, policy making related to emissions standards for pollution control from different sources do not require review of health information, health impact assessment or health cost benefit analysis to guide policy action.

The 12th Five-Year Plan for the first time stated that cities should meet air quality norms by the end of the plan period. This can be broadened to all air sheds to address both urban and rural pollution in an integrated manner with a clear framework for compliance. The current air quality laws are not adequately applied to reduce exposures in both urban and rural areas.

Health information is a critical part of the decision making process. Every major regulation requires Regulatory Impact Analysis. A key part of that is essentially explaining the reason for the regulation, why it is necessary, which usually means the health needs and what will be the benefits to public health if the regulation is adopted (see Annexure 2).

Health impact assessment of regulations and health-cost benefits are not an administrative requirement in India though independent studies have estimated health costs and benefits to build the case for effective decisions. For instance, the 2013 estimates of the World Bank for India shows that while health and environmental costs of particulate pollution is as much as 3 per cent of the GDP, the cost of its mitigation would be much less than 1 per cent of the GDP. Such assessments can go a long way in driving public policies to mitigate air pollution, as we have seen in other countries.

Mitigation of household pollution does not have a cohesive legal framework. Currently, it is addressed through programmes and projects of different ministries -- Ministry of Renewable Energy for improving emissions from cooking devices; and Ministry of Petroleum and Natural Gas and Ministry of Power for improving access to cleaner fuels. But clean fuel programmes do not have clear policy drivers targeted at household pollution management. Thus, access to clean and affordable energy for all will require stronger policy mandate and more explicit linkage with the control of household air pollution. The Ministry can promote the development of an appropriate legal framework within the GoI to address this problem in an integrated manner with health at the centre.

It is therefore recommended that the current legal framework for addressing air pollution and public health be reviewed to chart a roadmap for health-based decision-making process and an effective compliance system to reduce overall exposure to protect public health. The ongoing reforms of several environmental laws are an opportunity to address this issue, with the Ministry of Environment's recent decision to include an objective health indicator in the CEP Index for critically polluted areas being an important first step.

5.2.2 Strengthen policy-making capabilities in the area of air pollution and health

In order to engage with the air pollution and health issue on an ongoing basis, MOHFW needs to develop internal processes to use evidence from toxicological, epidemiological, and other scientific research for policy making, and to improve air pollution regulations. To facilitate this, the MOHFW can consider establishment of a standing expert group on air pollution and health that could provide inputs and advice to MOHFW on a range of areas including monitoring and evaluation of various programs in this area; assessment of ever-evolving state of science and its policy implications.

5.2.3 Air pollution data collection and health impacts research

There is an urgent need to develop a comprehensive air-pollution-monitoring network – focusing on concentrations of $PM_{2.5}$ and ozone that are key air pollutants from the health perspective. A focus on both the pollutants are important to calibrate technology choices for mitigation to prevent trade-offs between these pollutants. However, $PM_{2.5}$ monitoring can be prioritized for immediate roll out. This should not just be in urban areas but also in rural areas. Siting should be based on population distribution – i.e., measure where the people are, not where the pollution is. It should also be useful to integrate data from various sources (e.g., ground-level fixed sensors, mobile sensors, sentinel sites, remote and satellite sensing).

Since responsibility for collection of this data comes under the Ministry of Environment, Forests & Climate Change (MOEF&CC), MOHFW could coordinate with them on this as well as source apportionment studies. At the same time, it should also launch a complementary program of exposure assessment and exposure apportionment. In fact, monitoring exposure requires special attention. One possibility would be to start with monitoring at current demographic and health surveillance sites (so there also is available information on health outcomes) but there needs to be a strategy for deployment in order to understand population-level exposure to air pollution. As noted earlier, it is also possible to carry out surveillance in existing health institutions to record emergency admissions or cases of respiratory or acute coronary events. MoHFW may also choose a few sentinel urban hospitals to report daily counts of admissions and/or mortality due to air pollution related conditions – asthma, IHD, stroke, ALRI, etc.

The Ministry might also consider how to work with the National Sample Survey Organization (NSSO) and other survey agencies to develop standardized questions to understand household-level energy usage that is such a major contributor to air-pollution-related health impacts.

Exposure assessment and health impact assessment (through epidemiological studies as well as other approaches, for example, using biomarkers) is critical to better understand health impacts in the local context to assist in policy-making. Risk assessments and economic analysis, both of health impacts of air pollution, as well as of mitigation strategies, could also be extremely helpful for policy-making.

In fact, accounting for the health cost of air pollution is particularly important. Systematic and robust valuations of acute and chronic illnesses linked to air pollution should be integrated with decision making on resource allocation for air pollution mitigation. A few studies have emerged in India assessing the cost associated with health impacts but they have not had any significant influence on policy decisions, even though they show high economic costs of pollution. For instance, a World Bank study (2013) stated that out of the estimated Rs 3.75 trillion cost of environmental degradation in India, outdoor air pollution accounts for Rs 1.1 trillion annually. About 30% PM10 reduction would cause health gains worth US $67 billion. Such analyses can help ensure that the air quality measures are health- and welfare-based and addresses equity. Such analysis can provide an evidence base for policy making, given that the country has competing demands for investment to reduce other health risks as well other demands on public and private resources during development.

Overall, it is important to use evidence-based biological concepts (culled from global and national research) and other risk-analytic approaches to inform health policies and promote intersectoral policies and regulations (e.g., those focused on energy use or transport) with the view to reduce or prevent harmful effects of environmental insults to the public.

5.2.4 Capacity building for public health practitioners and health care providers

Healthcare providers, who are key stakeholders, should be trained to become an effective medium for delivering harm-reduction strategies to their patients in their clinical practice. There are several types of capacity building activities that could be considered: formal degrees offered by public health institutions, short-term programs conducted on specific topics or workshops and conferences to build specific skill. Tools, resources and guidance materials for public health practitioners should also be made available.

At the same time, there should also additions to the curricula in medical and nursing schools in the country to include modules on air pollution and health to raise awareness in the health care community. Medical Associations can be powerful partners in this as well as raising awareness and advocating for intersectoral cooperation. Medical professionals are independent and credible translators of scientific information to policymakers and to the public.

Given the ubiquity and magnitude of health impacts from air pollution in India, consideration should be given to developing national clinical criteria for evaluating patient risk from air pollution. MOHFW could disseminate these clinical criteria to health workers to help them better identify air-pollution-related symptoms and also be more knowledgeable about the kind of protective measures to recommend both for the normal population and for those already affected by chronic diseases such as COPD and asthma. This is particularly important for ensuring an appropriate response to the higher incidence of asthma and acute coronary events during high periods of exposure (episodic pollution) which may occur seasonally (e.g., winter, or dust storms).

5.2.5 Information-dissemination strategies to reduce air-pollution-related health impacts

MOHFW could use its service infrastructure, such as ASHA workers and public health clinics, to disseminate air-pollution related information including options for communities to reduce their exposures, particularly for the most vulnerable groups -- pregnant women and very young children.. Health workers and primary health centres can also help inform or deliver information on intersectoral public programmes or subsidies that can ease the burden of environmental exposures. Such examples include subsidy schemes for LPG, promoting biogas schemes, sustainable farming technologies to discourage straw burning, etc.

Information on air pollutant concentrations should be made publicly available such that it could both assist with public understanding of pollution levels. For example, data showing the correlation between air pollution episodes and relevant hospital admissions could be routinely reported to the media to show how such admissions rise during air pollution episodes. Furthermore, integration of AQI and other early-warning systems (that could be developed with the Indian Institute of Tropical Meteorology and/or the Indian Meteorological Department) could form the basis of risk communication tools, with context-based health messaging. As an example, certain vulnerable groups (elderly, those with respiratory or cardiovascular problems) receive targeted messages to remain indoors during red zone days. Messages can be broadcasted as text messages or through siren warning systems in high density areas. The Ministry can work with city government to implement action plans to direct public transport, education, healthcare systems to responses during high pollution days.

Another possibility could be to an anti-pollution campaign, with a particular focus on HAP, to follow the successful anti-smoking campaign now prominent in Indian media. Presumably the same advertising agencies might even be tapped. In this vein, perhaps even initiate a national programme to establish "smokeless village" awards analogous to awards to villages for becoming "defecation free" (i.e., Nirmal Gram Puraskar). Another possibility perhaps could be the initiation of a media campaign to encourage families to provide clean cooking technologies to young brides, analogous to those in Gujarat to promote toilets as wedding gifts.

5.2.6 Strong and Standing Linkages to other Actors/programs

In order to address health impacts of air pollution from the range of sources that we have highlighted above, a multi-sectorial framework and accordingly a multi-ministry/agency structure should be in place. The MOHFW should be the coordinator for this structure. The MOHFW may also consider asking other relevant ministries (e.g. power, new and renewable energy, urban development) to undertake health impact assessment for major projects that might have an impact on public health.

In addition, we also suggest that it work with the health agencies at the state level to both sensitize them to the health impacts of air pollution and also give them guidance on best ways to address this problem. The Ministry of Environment/Central Pollution Control Board's efforts to integrate health impact assessment in the Critically Polluted Areas could serve as a useful example of Inter-Ministerial coordination.

Linking to the Swacch Bharat Abhiyaan may be particularly salient, given the health (and other) impacts of air pollution and the relative lack of focus on air pollution in this initiative so far.

5.2.7 International Linkages and Agenda-Setting

International linkages, such as to WHO, should also serve both to stay abreast of the latest developments in this area, to build possible synergies with programs in other countries, and also to disseminate success stories from India.

Medical associations serve as effective policy and media advocates to highlight burgeoning problems. Collective action at this level may tip the public discourse enough to force re-evaluation of intersectoral programmes.

As a specific suggestion, we believe that given the pioneering nature of this effort – both the integrative nature of the exercise and the analysis and prioritization of policy responses on the basis of exposure (as noted in Chapter 2) – MOHFW should consider a major international meeting (potentially in partnership with WHO) to highlight the work of this committee in terms of both its approach and recommendations and provide guidance to other developing countries on this issue. That will help ensure that MOHFW is not only taking the lead in addressing a major health problem within the country but also seen as a leader globally in this area.

5.3 Role of other Ministries/Agencies

We also highlight below measures that can be taken by other Ministries/Agencies to help address the health impacts of air pollution.

1.	Ministry of Agriculture	• Policy in place to promote multiple uses of crop residues and prevent their on-farm burning
2.	Ministry of Finance	• Analysis of the economic and financial implications of the health and other impacts of air pollution
3.	Ministry of Labor and Employment	• Ensure regular health check- ups for early screening of NCD related risk factors among workers • Frame guidelines for health promoting workplaces, especially guidelines on indoor air quality and conduct workshops at different workplaces • Strengthen the capacity of ESI Hospitals to cater to the growing burden of respiratory diseases and NCDs • Exploring feasible options for RSBY to include OPD services for respiratory diseases, COPD, NCDs, etc. • Showcase and support companies which employ workplace policies that can reduce vehicular travel such as telecommuting, or placing the workplace in sites that are accessible through public transportation (ex. Metro) or non-motorised transport.
4.	Ministry of Human Resource Development	• Regular screening of school children for early detection diseases, which can be attributed to the existing air pollution • Inclusion of harmful health effects of environmental pollution (AAP and HAP) in the school curriculum, including current policies and mitigation practices that are designed to reduce air pollution • Improving indoor air quality of educational institutions nationwide • Improve walkability and access to educational institutions by non-motorised transport, thus minimizing the air pollution in the school surroundings • Sensitize students and teachers on using the Air Quality Index in planning outdoor school activities
5.	Ministry of Rural Development	• Include health promoting guidelines including clean air, as a part of the "Nirmal Gram Puraskar " / Model Villages evaluation criteria/ create alternate awards with specific criteria based on air pollution • Under integrated rural development, develop and implement micro level planning policies/schemes with Panchayati Raj Institutions to address the social determinants of health for reducing the hazards of air pollution (lack of education, unemployment, poverty, poor housing conditions, etc.)
6.	Ministry of Women and Child Development	• Advocate through Self Help Groups and Mahila Mandals for protection of women and children from significant exposure to smoke from biomass while inside the house. Awareness raising can be done to improve household ventilation to reduce smoke inhalation from lighting (ex. kerosene) or cooking fuels

7.	Ministry of Urban Development	• Formulate/revise urban transport policy which reduces vehicular pollution (Include Health Promoting city guidelines in the "100 Smart Cities") • Develop and implement policies to reduce indoor air pollution (like disincentivizing diesel gensets and promoting clean cooking fuels thus 'making available clean and making clean available') • Enforcement of ban on burning garbage or biomass (especially during winter months) • Help cities develop air pollution alerts and emergency plans based on the Air Quality Index or CPCB continuous air monitoring data
8.	Ministry of Environment, Forests and Climate Change	• Ensure that Central and State Pollution Control bodies are empowered to set industry-specific emission and effluent standards, monitor levels of pollutants and enforce penalties, thus preventing NCDs. • Strict implementation of Environment Impact Assessments (EIA) is a major tool to minimize the adverse impact of industrial activities on the environment • Effective implementation of 'National Green Tribunal' directives on trash burning/ waste disposal from different sources • Take strict measures for unregulated sectors (such as brick kilns, trash burning, stone crushing) which contributes to ambient air pollution
9.	Ministry of New & Renewable Energy	• Develop policies relating to truly clean chulhas (cookstoves) and to support further research and development. • Research and development of other non-conventional/renewable sources of energy and programmes relating thereto, including locally generated power to supply cooking appliances; • Support and strengthen Integrated Rural Energy Programme (IREP) with emphasis on indoor air pollution • Develop National Policy on clean Biofuels (biogas, ethanol, etc) and set up National Biofuels Development Board for strengthening the existing institutional mechanism and overall coordination. • Create a national consensus action plan for replacing biomass fuels with alternative clean fuels
10.	Ministry of Petroleum & Natural Gas	• Expand new initiatives to increase the availability of LPG and other cleaner fuels to the rural & tribal areas • Expand the piped natural gas network to reach out to a larger population • Better target LPG subsidies to poorer households
11.	Ministry of Power	• Promote the development of more efficient cooking devices • Evaluate the potential for electric cooking appliances to substitute for biomass and LPG

12.	Ministry of Information and Broadcasting	• Develop policies to ensure that media houses allocate free airtime for health promotion messages as a corporate social responsibility activity • Develop hard hitting, high impact and cost effective media plans, strategies and conduct activities for awareness generation on harmful effects of air pollution and options for their mitigation. • Ensure enforcement of relevant provisions in the Cable Television Networks Act to regulate advertisements of tobacco etc. • Involvement of Songs & Drama division; Department of Field Publicity to promote health promotion activity for air pollution and its impact on respiratory and NCD risk factors
13.	Ministry of Communications & Information Technology	• Use of mobile phones to encourage healthy choices and warn people about air pollution (both AAP and HAP, using Air Quality Index) • Establish Telemedicine linkages between different levels of health care
14.	Ministry of Law & Justice	• Support enforcement on bans of burning trash for heating or as a way of disposal
15.	Ministry of Road Transport and Highways	• Ensure effective implementation of New Motor Vehicles Act (once approved) • Ensure proper engine checks for vehicles to assess pollution levels
16.	Ministry of Parliamentary Affairs	• Create a Parliamentarians Forum on air pollution • Appointment of Members of Parliament on Committees established for air pollution attributable health effects
17.	Ministry of Panchayati Raj	• Create enabling conditions to facilitate community participation like self-help groups • Improve village level awareness of proper household ventilation and health hazards of exposure to biomass smoke
18.	NITI Ayog	• Evolve appropriate policy and strategies to strengthen the linkages between relevant sectors by looking into intersectoral issues and provide relevant mechanism for their convergence • Assess human and financial resources for addressing air pollution and take appropriate measures to strengthen ongoing programmes and conventions to address air pollution and health hazards • Advocate to include the agenda of air pollution in the agenda of relevant sectors • Appraise and extend recommendations for effective and equitable utilisation of health services considering the burden of air pollution and its impact on health

Annexure 1

Highlights of global practices in health sector involvement in air pollution matters

There are examples from different parts of the world of direct involvement of health sector in air quality management:

Brazil: Brazil's VIGIAR or Environmental Health Surveillance specific to air quality aims to reduce health impact of air pollution. VIGIAR activities include determination of acute and chronic health effects of air pollution, evaluating social and economic impacts of those affected, defining AQ and health indicators and guiding policies to protect health risk. These activities are led by the Ministry of Health and are within broader programs established by the whole government. It was under a series of national health surveillance programs that included infectious disease, NCDs and environmental health.

New Zealand: New Zealand developed Environmental Health Indicators in 2008 that included adherence to national AQ standards and monitoring of respiratory diseases.

Vancouver: Vancouver Island Health Authority included Air Quality among its core public health functions. Strategies include testing of air quality; assessing health impacts of key ambient air pollution at neighborhood level; identification of local hotspots; collaboration with other sectors to reduce concentration of ambient air pollution and development of community air quality management plans.

Canadian and US systems provide daily forecasts and warnings. New York City also has community air survey reports published almost annually by NYC Health and its partners. The National Collaborating Center for Environmental Health (NCCEH) in Canada has produced the Air Quality Assessment Tools: A Guide for Public Health practitioners. This describes specific tools exist to address different components of air quality, including sources, emissions, and topographical and meteorological conditions.

Philippines: In the Philippines reports from the environment department may quote the department of Health on statistics routinely collected mortality and morbidity data, but weak. In a few instances, health departments, whether as a lone entity or within local governments, produce their own plans and strategies to monitor the effects of air pollution on health. Tools, resources and guidance materials for public health practitioners are available. The University of the Philippines College of Public Health offers a Master of Science degree specializing on Environmental Health. Most professionals came from public health, biology or nursing background. The Philippines is planning to develop a respiratory health program which may include guidance to practitioners and the public as such.

Source: WHO, Urban Health Initiative: Health System Engagement with Air Quality/ Air Pollution Policy, 9 May 2015, Mimeo

Annexure 2:

1. **Summary results of assessment of contribution of pollution sources to $PM_{2.5}$ and PM_{10} in Indian cities**

SIX-CITY STUDY OF CPCB	$PM_{2.5}$	PM_{10}
Air quality monitoring, emission inventory and source apportionment study for Indian cities, National Summary Report (CPCB 2011)		**Bangalore (54.30 t/day)** Domestic Combustion 3% Paved & Unpaved Road Dust 20% Vehicle Exhaust 41% Construction 14% Industries 14% DG Sets 7% Others 0% **Kanpur (9.4 t/day)** Domestic Combustion 19% Paved & Unpaved Road Dust 14% Vehicle Exhaust 20% Construction 0% Industries 33% DG Sets 1% Others 13% **Pune (32.3 t/day)** Domestic Combustion 7% Paved & Unpaved Road Dust 61% Vehicle Exhaust 18% Construction 4% Industries 1% Others 8% **Chennai (11.02 t/day)** Domestic Combustion 0% Paved & Unpaved Road Dust 73% Vehicle Exhaust 14% Construction 9% Industries 2% Others 2% **Mumbai (73.5 t/day)** Domestic Combustion 2% Paved & Unpaved Road Dust 30% Vehicle Exhaust 6% Construction 9% Industries 23% Others 31% **Delhi (147.2 t/day)** Domestic Combustion 8% Paved & Unpaved Road Dust 53% Vehicle Exhaust 7% Construction 8% Industries 22% DG Sets 0% Others 2%

OTHER STUDIES IN DELHI	$PM_{2.5}$	PM_{10}
Emissions inventory of anthropogenic $PM_{2.5}$ and PM_{10} in Delhi during Commonwealth Games 2010, Indian Institute of Tropical Meteorology, Pune (Sahu 2011)	Relative contribution of $PM_{2.5}$ emissions from different sectors in Delhi-NCR Regions Power: 4% Residential: 27% Transport: 45% Industry: 24%	Relative contribution of PM_{10} emissions from different sectors in Delhi-NCR Regions Power: 11% Residential: 34% Transport: 29% Industry: 26%
Multi-Pollutant Emissions Inventory for the National Capital Region of Delhi Urbanemissions.info, SIM-air Working Paper (Guttikunda & Calori 2012)	Transport 26% Domestic 11% Diesel gensets 5% Brick kilns 13% Industries 13% Construction 4% Waste burning 6% Road dust 9% Power plant 15%	Transport 18% Domestic 7% Diesel gensets 3% Brick kilns 9% Industries 9% Construction 6% Waste burning 4% Road dust 31% Power plant 13%
Characterization of ambient $PM_{2.5}$ at a pollution hotspot in New Delhi, India and inference of sources University of Birmingham; Central Road Research Institute; Desert Research Institute (Pant, Shukla, et al. 2015)	Receptor modelling $PM_{2.5}$, Mathura Road, Delhi Wood smoke- 23.3% (winter) Traffic- 18.7% (summer)/ 16.2% (w) Dust- 14.3% (s)/ 3.9% (w) Sulphate-20.5%(s)/10.6% (w) Nitrate- 8.4% (s)/ 12.4% (w) Chloride- 4.8% (s)/ 12.3% (w) Other organic matter- 33.3% (s)/ 21.4% (w)	

Variation of OC, EC, WSIC and trace metals of PM_{10} in Delhi, India CSIR-National Physical Laboratory (Sharma, T. Mandal, et al. 2014)		Variation of organic carbon (OC), elemental carbon (EC), water soluble inorganic ionic components (WSIC) and major and trace elements of particulate matter (PM_{10}) were studied over Delhi Analysis quantifies the contribution of soil dust (20.7%), vehicle emissions (17.0%), secondary aerosols (21.7%), fossil fuel combustion (17.4%) and biomass burning (14.3%) to PM_{10} mass concentration at the observational site of Delhi.
Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Delhi. National Environmental Engineering Research Institute, Nagpur, India (2010) (Part of six city study of CPCB) (Gargava et al. 2014)		Power Plant 18% Industrial boilers 1.2% Residential 8.3% Paved road dust 55% Vehicles 6.9%
Health impacts of particulate pollution in a megacity—Delhi, India Transport Research and Injury Prevention Program, Indian Institute of Technology, New Division of Atmospheric Sciences, Desert Research Institute (2013) (Guttikunda & Goel 2013)	Delhi: For six residential and industrial zones Sector contributions to ambient $PM_{2.5}$ Vehicular exhaust: 16–34%, Diffused sources: 20–27% Industries: 14–21% Diesel generator sets: 3–16% Brick kilns: 4–17%	
Source apportionment of PM_{10} by using positive matrix factorization at an urban site of Delhi, India (20144) CSIR-National Physical		PM_{10} CSIR- NPL Campus Soil: 20.7% Vehicles: 17.0% Secondary-inorganic 21.7% Fossil

Laboratory, Road, New Delhi (Sharma, T. K. Mandal, et al. 2014)		fuel-coal/heavy oil 17.4% Industry 4.5% Sea salt 4.4%
Airborne inhalable metals in residential areas of Delhi, India: distribution, source apportionment and health risks Jawaharlal Nehru University, Delhi (2012) (Khillare & Sarkar 2012)		PM_{10} in Residential sites Crustal 49-65% Vehicular 27-35 Industrial 4-21%
Speciation of ambient fine organic carbon particles and source apportionment of $PM_{2.5}$ in Indian cities Georgia Institute of Technology, Atlanta, Georgia, USA (2007) (Chowdhury et al. 2007)	Diesel- 22% (summer)/ 10 (winter) Gasoline- 2% (s)/ 9 (w) Road Dust- 42 % (s)/ 11 (w) Coal- 2% (s)/ 14% (w) Biomass- 7% (s)/ 20% (w) Sulphate- 10% (s)/ 8% (w) Nitrate- 3% (s)/ 7% (w) Ammonium-3% (s)/ 5 % (w) Other Mass- 11% (s)/ 17 % (w)	
The PM_{10} fraction of road dust in the UK and India: Characterization, source profiles and oxidative potential University of Birmingham, Central Road Research Institute University of Toronto University of Massachusetts, Science of The Total Environment Volumes 530–531, 15 October		The PM_{10} fraction of road dust samples was collected at two sites in Birmingham, UK (major highway and road tunnel) and one site in New Delhi, India.

2015, Pages 445–452 (Pant, Baker, et al. 2015)		
Spatial and Temporal Variation of Heavy Metals in Atmospheric Aerosol of Delhi JNU (2004) (Khillare et al. 2004)		SPM Residential/industrial/commercial sites in Delhi Vehicular and industrial emissions (60) Crustal (22)
Chemical characterization of atmospheric particulate matter in Delhi, India, Part II: Source apportionment studies using PMF 3.0 Indian Institute of Tropical Meteorology Pt. Ravishankar Shukla University C.N.R. Institute of Atmospheric Pollution, Italy Journal: Sustain. Environ. Res., 23(5), 295-306 (2013) 295	Road-traffic source (determined by temporal correlation among Pb, Cu, Zn, Ni and V with strong correlation between Pb and Zn) with more than 60% contribution to receptor site.	
STUDIES IN MUMBAI	**$PM_{2.5}$**	**PM_{10}**
Source apportionment of suspended particulate matter at two traffic junctions in Mumbai, India Bhabha Atomic Research Centre Indian Institute of Technology, Mumbai *Atmospheric Environment* *Volume 35, Issue 25, September 2001, Pages 4245–4251* (Kumar et al. 2001)		SPM observed at Sakinaka traffic junction: Road dust contributed to 41%, vehicular emissions to 15%, marine aerosols to 15%, metal industries to 6% coal combustion to 6% 16% possible sources not known Gandhinagar traffic junction: Road dust: 33%,

		Vehicular emissions 18%, Marine aerosols 15%, Metal industries 8% Coal combustion 11% Possible sources not known: 16% Lead in the SPM in intersections: Vehicular emissions: 62%, Road dust: 17% Metal industries: 11% Coal combustion: 7% Marine aerosols: 3%
Source Apportionment of Coarse and Fine Particulate Matter at Navi Mumbai, India Bhabha Atomic Research Centre, India Clarkson University, Potsdam, US Kothai et al., Aerosol and Air Quality Research, Vol. 8, No. 4, pp. 423-436, 2008 (Kothai et al. 2008)	Contribution to the average fine particulate mass concentration Soil 3% two-stroke emission with fugitive dust, 18% Industrial emission 23% Motor vehicles 29% Sea Salt 9%	Source apportionment studies showed maximum contribution of the coarse fraction was from Sea Salt: 35% Crustal: 25% Industrial: 14% Vehicular: 10% Fugitive emissions: 7%.
STUDIES IN CHENNAI	**$PM_{2.5}$**	**PM_{10}**
Source characterization of PM_{10} and $PM_{2.5}$ mass using a chemical mass balance model at urban roadside Indian Institute of Technology Madras	Particulate matter (PM_{10} and $PM_{2.5}$) concentrations monitored at a busy roadside in Chennai City, India. The emission inventory at the study area identified the likely PM emission	

Science of The Total Environment Volume 433, 1 September 2012, Pages 8–19 (Srimuruganandam & Shiva Nagendra 2012)	sources. --diesel exhausts (43–52% in PM_{10} and 44–65% in $PM_{2.5}$) --gasoline exhausts (6–16% in PM_{10} and 3–8% in $PM_{2.5}$) are found to be the major source contributors --paved road dusts (PM_{10} = $PM_{2.5}$ = 0.–2.3%), --brake lining dusts (0.1% in PM_{10} and 0.2% in $PM_{2.5}$), --brake pad wear dusts (0.1% in PM_{10} and 0.01% in $PM_{2.5}$), --marine aerosols (PM_{10} = $PM_{2.5}$ = 0.1%) --cooking (~ 0.8% in PM_{10} and ~ 1.5% in $PM_{2.5}$).	
Application of positive matrix factorization in characterization of PM_{10} and $PM_{2.5}$ emission sources at urban roadside Department of Civil Engineering, Indian Institute of Technology Madras		The 24-h average coarse (PM_{10}) and fine ($PM_{2.5}$) fraction of airborne particulate matter (PM) samples were collected for winter, summer and monsoon seasons during November 2008–April 2009 at an busy roadside in Chennai city, India. ---marine aerosol (40.4% in PM_{10} and 21.5% in $PM_{2.5}$) ---secondary PM (22.9% in PM_{10} and 42.1% in $PM_{2.5}$) ---motor vehicles (16% in PM_{10} and 6% in $PM_{2.5}$), ---biomass burning (0.7% in PM_{10} and 14% in $PM_{2.5}$), ---tire and brake wear (4.1% in PM_{10} and 5.4% in $PM_{2.5}$),

		---soil (3.4% in PM_{10} and 4.3% in $PM_{2.5}$) ---other sources (12.7% in PM_{10} and 6.8% in $PM_{2.5}$).
STUDIES IN HYDERABAD	**$PM_{2.5}$**	**PM_{10}**
Source apportionment of particulate matter in the ambient air of Hyderabad city, India Jawaharlal Nehru Technological University Universiti Sains Malaysia, Penang, Malaysia Noorul Islam University Islamic Azad University, Iran Atmospheric Research Volume 101, Issue 3, August 2011, Pages 752–764 (Gummeneni et al. 2011)	PM_{10} and $PM_{2.5}$ assessment conducted in Punjagutta site, a critical traffic corridor Results indicate for PM_{10} ---resuspended dust (40%), ---vehicular pollution (22%), ---combustion (12%), ---industrial (9%) ---refuse burning (7%) in PM_{10}; For $PM_{2.5}$ ---vehicular pollution (31%) dominated ---resuspended dust (26%), ---combustion (9%), ---industrial (7%) ---refuse burning (6%).	
Receptor model-based source apportionment of particulate pollution in Hyderabad, India DRI, APPCB Environmental Monitoring and Assessment	Three stations for PM_{10} and $PM_{2.5}$ size fractions for three seasons PM_{10} pollution is dominated by the direct vehicular exhaust and road dust (more than 60 %). $PM_{2.5}$ has mixed sources of	

July 2013, Volume 185, Issue 7, pp 5585-5593 (Guttikunda et al. 2013)	vehicle exhaust, industrial coal combustion, garbage burning, and secondary PM	
STUDIES IN KOLKATA	**$PM_{2.5}$**	**PM_{10}**
Chemical mass balance source apportionment of PM_{10} and TSP in residential and industrial sites of an urban region of Kolkata, India Environmental Engineering Division, Department of Civil Indian Institute of Technology, Kharagpur NEERI, Mumbai Journal of Hazardous Materials Volume 142, Issues 1–2, 2 April 2007, Pages 279–287 (Gupta et al. 2007)		Source apportionment revealed that the most dominant source throughout the study period at residential site was coal combustion (42%), while vehicular emission (47%) dominates at industrial site to PM_{10}. Paved road, field burning and wood combustion contributed 21%, 7% and 1% at residential site, while coal combustion, metal industry and soil dust contributed 34%, 1% and 1% at industrial site, respectively, to PM_{10}.
Source apportionment of PM_{10} at residential and industrial sites of an urban region of Kolkata, India Indian Institute of Technology, Kharagpur Atmospheric Research Volume 84, Issue 1, March 2007, Pages 30–41 (Karar & Gupta 2007)		PM_{10} and its chemical species mass concentrations were measured once in a week at residential (Kasba) and industrial (Cossipore) sites of an urban region of Kolkata solid waste dumping contributed 36%, vehicular emissions 26%, coal combustion 13%, cooking 8%, and soil dust 4% at the residential site. 37% to vehicular emissions, 29% to coal combustion, 18% to electroplating industry, 8% to tyre wear

		1% to secondary aerosol at the industrial site. Due to the limitation in source marker species analyzed, 13% at Kasba and 7% at Cossipore could not be apportioned to any possible sources by this technique.
STUDIES IN KANPUR	**$PM_{2.5}$**	**PM_{10}**
Chemical Characterization and Source Apportionment of Submicron (PM_1) Aerosol in Kanpur Region, India IIT Kanpur Aerosol and Air Quality Research, 10: 433–445, 2010 ISN: 1680-8584 print / 2071-1409 (Chakraborty & Gupta 2010)	PM_1 (particles having aerodynamic diameter < 1.0 µm) concentrations were measured at a sampling site inside the Indian Institute of Technology (IIT) Kanpur Average PM_1 concentration was found to be highest (199 µg/m3) during winter and lowest (31 µg/m3) during monsoon season. Anions including Nitrate and sulfate among others contributed up to 35% of the total PM_1 mass. Secondary sources and vehicular emissions were the two main sources contributing to PM_1 mass with minor contributions from paved road dust and coal combustion sources.	
STUDIES IN BHILAI DURG	**PM_{10}**	**$PM_{2.5}$**
Source apportionment of personal exposure of fine particulates among school communities in India Pt. Ravishankar Shukla	Indoors and road-traffic dusts have played dominating role in school located near to National Highways.	

University, Raipur Environmental Monitoring and Assessment July 2008, Volume 142, Issue 1-3, pp 227-241 (Gadkari & Pervez 2008)	Major dominating source is ambient-outdoors in case of school located near to steel plant downwind.	

STUDIES IN ROURKELA	$PM_{2.5}$	PM_{10}
TSP aerosol source apportionment in the urban region of the Indian steel city, Rourkela Department of Civil Engineering, National Institute of Technology Particuology Volume 20, June 2015, Pages 124–133 (Kavuri et al. 2015)	Particles related to steel production, road dust, and soil were dominant in all seasons. A fertilizer plant was found to contribute particles in summer and monsoon. Wood combustion, diesel exhaust, and liquefied petroleum gas contributed significantly in spring and winter. While diesel exhaust, industrial manufacturing, solid waste burning, cement kilns, and construction were found to contribute to TSP at various times throughout the year.	
STUDIES IN NAGPUR	**$PM_{2.5}$**	**PM_{10}**
Source Apportionment of $PM_{2.5}$ Using a CMB Model for a Centrally Located Indian City NEERI ARAI	Vehicular emissions were major contributing sources at residential 57%, 62% and 65%%; Followed by secondary inorganic aerosol 16%, 12%, 16%; at R, C and I sites, respectively.	

Aerosol and Air Quality Research, 14: 1089–1099, 2014 (Pipalatkar et al. 2014)	Biomass burning 15%, 11%, 9% at R, C and I sites, respectively. Re-suspended dust 6, 10, 7% at R, C and I sites, respectively.	

2. Table on HAP exposure studies***

Annexure 3

Global practices: Effective legal frameworks for health-driven air pollution control

Several countries have adopted legal framework for effective compliance with the goals of clean air and reduced health risks.

USA: The Clean Air Act in the USA is the key piece of legislation which requires EPA to set national ambient air quality standards in order to protect public health. EPA has to demonstrate attainment of these standards —with an adequate margin of safety. This is done through the states, who have to submit a State Implementation Plan (SIP) showing how they will meet, and by when, the standards for which they exceed the AAQS. The states must identify the major emission sources and then lay out a specific plan on how and when they will show attainment for a specific pollutant. The Act also requires the major sources of air pollution to meet stricter emissions control in non-attainment areas.

EPA has to approve the SIPs. When the EPA approves the plan the rules specified therein are federally enforceable. If the State does not submit an adequate plan, they can be subject to sanctions—withholding federal funds for example—or have the EPA produce a FIP Federal Implementation Plan.

Every major regulation has a cost-benefit analysis but this is not required by the law but rather is an administrative requirement. Every 5 years EPA reviews all the health information for the criteria air pollutants and based on the review considers whether the existing air quality standard for that pollutant is adequate to protect public health with an adequate margin of safety. If it is not adequate EPA is required to revise the standard. That standard then drives the entire process – states must take actions to comply with it as quickly as reasonably possible and faces penalties if they don't do so. Where EPA has direct responsibility such as for automobile emission standards or power plant standards, the protection of health is the primary driver but other factors such as the state of technology and cost of implementation are also considered. For instance, the estimated benefits of Tier 2 emissions standards for light-duty, heavy-duty and non-road vehicles rules are expected to be USD 175 billion, which more than justifies the investments of USD 11 billion that are expected to be required in order for attainment of these emission standards.

EPA and California Air Resources Board (CARB) also have a separate Toxic Air Contaminant (TAC) program. Legislation is required to address this issue and there is a lengthy list of toxics including benzene and diesel particulates that have gone through a detailed risk assessment/risk management process. The risk assessment is overseen by the California Office of Environmental Health Hazard Assessment (OEHHA), which provides scientific advice to the California EPA (drawing on the work of a Scientific Advisory Board composed of national health experts). The OEHHA process informs CARB if a program to manage risks from specific pollutants is necessary. For example, it took nearly 10 years to complete the risk assessment for diesel particulate.

Moreover, for air toxics the EPA sets 'maximum achievable control technology (MACT) standards' that are based on emissions levels of air toxics already achieved by the better-controlled and lower-emitting sources in an industry.

There also is a strong and ongoing engagement with scientific institutions and universities to keep abreast of the state of knowledge on relevant areas of air pollution and health. For example, many of the health studies are contracted by CARB to the University of California system. The CARB also is guided by a Research Screening Committee consisting of outside experts.

Europe: The European Commission has set health-based target for air quality. The Thematic Strategy on Air Pollution aims by 2020 to cut the annual number of premature deaths from air pollution related disease by almost 40 per cent from the 2000 level. While covering all major pollutants it pays special attention to fine particulates and ground level ozone. It would also set a cap on concentration on most polluted areas. Emissions ceiling will be brought into line with the objectives. Europe also sets standards for each toxic air pollutant individually, based on its particular health risks.

China: China has also drafted Clean Air Act that makes public health its stated objective. It states that its objective is "to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population". It provides for environmental health effect research and preparation of environmental health assessments for each of the hazardous air pollutants.

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