Air Pollution and Health in India:

A review of the current evidence and opportunities for the future

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DALYs – Disability Adjusted Life-Years

GBD – Global Burden of Disease

PM – Particulate Matter

GDP – Gross Domestic Product

LPG – Liquefied Petroleum Gas

HAP – Household Air Pollution

VOC – Volatile Organic Compounds

PAH – Polyaromatic Hydrocarbons

CO – Carbon monoxide

SO_x – oxides of Sulphur

NOx – oxides of Nitrogen

EC – Elemental Carbon

OC – Organic Carbon

TSP – Total Suspended Particles

RSPM – Respirable Suspended Particulate Matter

ETS - Environmental Tobacco Smoke

IGP – Indo-Gangetic plain

AAP – Ambient Air Pollution

WHO – World Health Organisation

NAAQS – National Ambient Air Quality Standards

NAMP - National Air Quality Monitoring Programme

CPCB - Central Pollution Control Board

CAAQMS - Continuous Ambient Air Quality Monitoring Stations

ACRB – Agriculture Crop Residue Burning

USEPA – United States Environmental Protection Agency

ALRI - Acute Lower Respiratory Infections

HEI – Health Effects Institute

IHME – Institute for Health Metrics and Evaluation

IIT – Indian Institute of Technology

PAPA – Public Health and Air Pollution in Asia

TB – Tuberculosis

COPD - Chronic Obstructive Pulmonary Disease

CVD – Cardiovascular disease

SDG – Sustainable Development Goals

NRHM – National Rural Health Mission

NHM – National Health Mission

HMIS - Health Management Information System

CHC – Community Health Centres

NIMHANS - National Institute of Mental Health and Neuro-Sciences

NFHS - National Family Health Survey

DLHS - District Level Household Survey

AHS – Annual Health Survey

NMHS – National Mental Health Survey

HIV – Human Immunodeficiency Virus

RCH – Reproductive and Child Health

MCCD - Medical Certification of Cause of Death

IDSP - Integrated Disease Surveillance Programme

ICMR – Indian Council for Medical Research

PBCRs - Population Based Cancer Registries

HBCRs - Hospital Based Cancer Registries

EHR - Electronic Health Records

IHIP - Integrated Health Information Platform

MCH – Maternal and Child Health

ICD – International Statistical Classification of Diseases and Related Health Problems

UT – Union Territory

LMIC - low and middle-income country

LC – Low Cost

DPCC – Delhi Pollution Control Committee

EPIC - Energy Policy Institute at University of Chicago

CEEW - Council on Energy, Environment and Water

MPCB - Maharashtra Pollution Control Board

SAFAR - System of Air Quality and Weather Forecasting and Research

MSW – Municipal Solid Waste

CLAIM - Clean Air India Movement

AQI - National Air Quality Index

PIL - Public Interest Litigation

CEPI - Comprehensive Environmental Pollution Index

ASHA – Accredited Social Health Activist

NSSO – National Statistical Survey Organisation

1. Introduction

Air pollution is a major and growing risk factor for ill health in India, contributing significantly to the country's burden of disease. As per the Global Burden of Disease comparative risk assessment for 2015, air pollution exposure contributes to approximately 1.8 million premature deaths and 49 million disability adjusted life-years (DALYs) lost, ranking it among the top risk factors for ill health in India. Home to 10 of the top 20 cities with the highest annual average levels of $PM_{2.5}$ as per the WHO Urban Ambient Air Quality Database (2016)[1], and with several studies showing a worsening trend over time[2,3], it is safe to say that rapid urbanization and industrial development have adversely affected urban air quality due to vehicular and industrial emissions. Simultaneously, over two-thirds of rural Indians caught in the 'chulha trap' use biomass fuels such as wood, dung or coal to satisfy their cooking and heating needs, resulting in smoke-filled homes and extremely high levels of exposure especially to women and children.

Rural and urban India are both affected by poor air quality. There is, however, heterogeneity in sources and pollutant profiles. For instance, use of cooking fuels varies between urban and rural households, vehicular density is vastly different in cities and villages, and differing climatology and geography across India affects regional and seasonal levels of ambient air pollution.

Air pollution has been termed a democratizing force[4] but it is far from that, as it propagates existing environmental injustices. Studies have shown that children and the elderly are particularly vulnerable to air pollution exposure. Air pollution exposure has shown to slow lung development in children[5], affect cognitive development[6], and has resulted in high levels of mortality from respiratory infections[7]. The elderly are more likely to develop chronic respiratory and cardiac illnesses as a result of long-term exposure, and are more susceptible to heart attacks and strokes during episodic high pollution events. Vulnerable also are those of a lower socio-economic status, with studies showing they are more susceptible to insults from air pollution exposure for a variety of reasons including occupation, housing, cooking fuel use, the common link being poverty[8].

While environment, health and development are frequently pitted in adversarial roles in the discourse on economic growth, published evidence argues that they are very much in consonance. A study published by the World Bank[9] in 2016 revealed that air pollution cost India approximately 8% of its GDP or $560 billion in 2013, as a result of lost productivity due to premature mortality and morbidity. This study, while a great first step, failed to capture the healthcare costs of treating air pollution-induced illnesses, which if factored in, could produce a far larger number.

To address the multi-dimensional, multi-sectoral problem of air pollution requires a cogent and considered approach that takes into account the best available epidemiological evidence, benefit-cost analyses of various interventions, and a strong communications platform to ensure broad awareness of the health impacts of air pollution and the advantages of mitigation. The review carried out for this report however, shows us that there is a dearth of work carried out in all of the areas mentioned above.

While the epidemiological evidence for the health impacts of air pollution in India is strong, strengthening it in several aspects as outlined in this report would aid in more informed policymaking. There are challenges however that preclude high quality research on the health effects of air pollution from being conducted in India, and many of these have to do with the quality and the availability of air quality and health outcome data. At the moment, the health evidence base on air pollution is primarily based on cross-sectional or time-series studies which have been conducted in large cities through primary research. Challenges remain in conducting such studies with secondary data due to (a) the availability of quality health outcome data from the public and private sector, thwarted by the poor uptake of any standardized electronic health records framework, and (b) the sparse coverage and questionable quality of air quality data collected by government agencies. This lack of data also ensures that there remain challenges in conducting long-term studies on the health impacts of air pollution (particularly ambient), since the historical records of air quality data in most cities (particularly $PM_{2.5}$) go back only a few years, with many missing data points.

While the research evidence base needs to be strengthened further, there have been some significant developments in the policy space, recognizing that the evidence necessary to develop policy is already there. The Union Ministry of Health & Family Welfare in 2014 constituted a Steering Committee of experts on air pollution, with the report of this committee released in late 2015/early 2016. The Committee's Report on Air Pollution and Health Related Issues[10] outlined targeted actions to improve health outcomes associated with air pollution by moving beyond air quality management. Following this, there have been some concrete policy actions including improving rural LPG access through the Pradhan Mantri Ujjwala Yojana. The establishment of a Standing Committee on Air Pollution, proposed to be chaired by the Health & Environment Secretaries, is under consideration at the ministerial level. However, most action on air pollution is often driven by the judiciary, with the National Green Tribunal and the Supreme Court taking the lead. The directives from the Judiciary have led to the fast-tracking of newer fuel and emissions standards for vehicles, and a focus on reducing air pollution during episodic events such as Diwali. Such decision-making, however, is often characterized by a lack of in-depth understanding of the health impacts and a focus on short-term solutions without a larger vision to improve air quality.

The purpose of this analytical white paper is to identify effects of health concerns for air pollution on government and public actions in India, identify barriers and opportunities; and propose recommendations on how to use heath concerns to build support for air pollution control and prevention. Given the status of the evidence and the challenges outlined, the authors still believe that much can be done to (a) document the health impacts of air pollution; (b) engage diverse stakeholder groups to call for multi-sectoral action; (c) raise awareness especially amongst vulnerable populations; and (d) carry out impact evaluations. This diversity of sources and drivers ensures that a Pan-India policy to achieve the National Ambient Air Quality Standards (NAAQS) has till date been unarticulated. What can drive this, however, is the localization of evidence, broadening awareness of the health impacts, and ensuring that accountability is at the heart of policymaking.

1.1 Methodology

A structured review of available literature on air pollution and health in India was conducted. This involved searching for articles and reports on online databases such as PubMed as well as resources from ministry websites. To supplement findings from the literature reviewed, a stakeholder consultation was undertaken, and some secondary data analysis was conducted. A questionnaire survey was developed and disseminated among stakeholders with expertise in the areas of air pollution and associated health impacts, including environmental health researchers, physicians, and ministry officials. These expert stakeholders were identified through purposive sampling and were contacted via email. Some were followed up with in-person at the National Consultation on Environmental Health, hosted by the Centre for Environmental Health (to which the authors are affiliated), held on June 5th 2017 at New Delhi. Inputs from group discussions held at the consultation are also factored into this report. Further details of experts consulted and the questionnaire tool are attached in Annexures. The report was reviewed by two internal and two external reviewers before submission.

2. Air Pollution Exposure & Trends

Air quality, whether ambient or household, differs across India, with varied sources, pollutants, climatology, geography, and cultures. Over time, however, trends indicate deterioration in both urban and rural India, whether it is due to rapid urbanization and consequent rising vehicular and industrial emissions or the ‘chulha trap’ resulting in poor indoor air quality.

2.1 Household air pollution

Individuals spend close to three-fourths of their day (around 18 hours) in indoor environments, which include residences and workplaces[11]**.** Indoor activities such as cooking, heating, cleaning, incense burning, tobacco smoking, refrigeration, and air conditioning are significant contributors of air pollutants emissions[11–15]. The infiltration of ambient air into indoor environments through ventilation intakes, doors and windows also result in household air pollution (HAP)[16]. Fine and ultrafine particulates, biological aerosols, volatile organic compounds (VOCs), poly aromatic hydrocarbons (PAHs), carbon monoxide (CO), oxides of sulphur and nitrogen (SO_x and NO_x) are typically found indoors in households where biomass is used for cooking or heating[17–19]. In the following sections, exposures associated with indoor pollution, their spatial heterogeneity and urban-rural differences in the Indian subcontinent will be outlined.

2.1.1 Activity based exposures

Cooking and heating: Biomass combustion, involved in cooking and heating practices, is the principal source of HAP in India[19]. Close to 60% of Indian households use biomass (in the form of firewood, charcoal, manure, and crop residues) as their main energy source for cooking, while around 30% use LPG[20]. More than 250 teragrams (Tg) of biomass is estimated to be used annually for cooking activities in India, resulting in significant emissions of pollutants such as PM, elemental and organic carbon (EC and OC), CO, NO_2, VOCs, and PAHs[21–23].

In India, women spend close to 1.7-2.4 hours/day for cooking, while men spend around 0.08-0.1 hours/day in the vicinity of a kitchen[13]. Total suspended particles (TSP) exposures during cooking are reported to be as high as 7000 $\mu g/m^3$, while respirable suspended particulate matter (RSPM) exposures are reported to be in the range of 500-2,000 $\mu g/m^3$[13,24]. Results from a large cohort study (N~3000) in Nepal indicate 24 hour average indoor $PM_{2.5}$ levels as high as 1400 $\mu g/m^3$ in households with biomass usage for heating and cooking activities[25]. Studies have found sizeable differences in diurnal averaged PM levels between households using cleaner cooking fuels like LPG (75 $\mu g/m^3$) and dirty fuels like biomass (≈360 $\mu g/m^3$)[13] in indoor living areas. Table 1 shows typical indoor pollutant levels reported in India under usage of various domestic fuels.

Reference	Location	Fuel Type	Sampling Area	Sampling Duration	Concentration (μg/m^3)		
Smith et al. (1983)	Gujarat	Wood	Kitchen	Cooking period (45 min)	TSP		6400
Menon (1988)	Madhya Pradesh, Pondicherry	Wood	Kitchen	Cooking period (2 hours)	TSP		2000 – 5000
Parikh et al. (2001)	Tamil Nadu	Biomass and LPG	Kitchen, Living room	Meal duration (2 hours)	PM_{10}		
						Kitchen	Living room
					Biomass	2000	1800
					LPG	80	70
Balakrishnan et al.(2013)	Madhya Pradesh, Tamil Nadu, Uttaranchal, West Bengal	Biomass, Dung cake, and LPG	Kitchen, Living room	24 h	$PM_{2.5}$		
						Kitchen	Living room
					Biomass	590	157
					Dung cake	741	190
					LPG	179	95

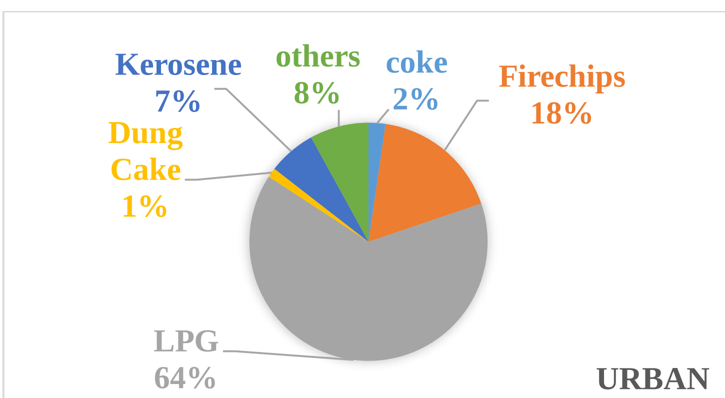
Table 1. Cooking time indoor TSP, PM_{10}, $PM_{2.5}$ levels with the usage of biomass, dung cakes, and LPG as domestic fuels

Incense and tobacco burning: Incense burning emits significant quantities of fine particulate matter ($PM_{2.5}$), CO, NOx, PAHs, and VOCs[26–28]. The duration of burning typically ranges between 5-45 minutes in indoor environments. Particulate emissions from incense burning (~50 mg/g) are found ~5 times higher than due to cigarette smoking (10 mg/g) [11,29,30]. Goel et al. (2017)[11] observed PM_{10} levels elevate to ~2500 µg/m^3 inside sanctums of Kanpur temples during incense burning. About 75-90% of PM_{10} mass is found to be contributed by particles less than 2.5 µm which indicate significant emissions of fine and ultrafine particulate matter from incense burning.

Environmental tobacco smoke (ETS) also contributes significantly to HAP in India[31]. Tobacco smoke contains over 4000 chemicals, including at least 70 carcinogens, released whenever a tobacco product is smoked. Tobacco smoking can increase indoor $PM_{2.5}$ levels by 400-500%[32]. A study carried out in indoor environments of pubs and restaurants of Mumbai reported a drastic increase in $PM_{2.5}$ levels from 240.8 µg/m^3 to 669.95 µg/m^3 post introduction of indoor smoking[32].

2.1.2 Rural-urban heterogeneity

HAP sources differ between rural and urban locations[31]. More than 89% of the rural Indian population relies on biomass for cooking purposes whereas urban India mostly uses LPG (65%)[20]. Indoor emissions from the domestic sector are therefore more significant in rural rather than urban India. In contrast, the infiltrated ambient pollution fraction into indoor environments are higher in cities than villages. This is due to higher on-road vehicular density, which contributes larger quantities of air pollution emissions[31]. The diurnal averaged RSPM levels were reported to be as high as ~350 µg/m^3 in typical Indian rural households where biomass is used as a domestic fuel. Rural households using LPG for domestic activities are observed to have lower HAP levels (~75 µg/m^3) than urban houses using LPG (~135 µg/m^3), indicating a larger contribution of ambient sources to indoor exposures in Indian urban areas[13,33]. Figure 1 shows the distribution of various domestic fuels in urban and rural India.



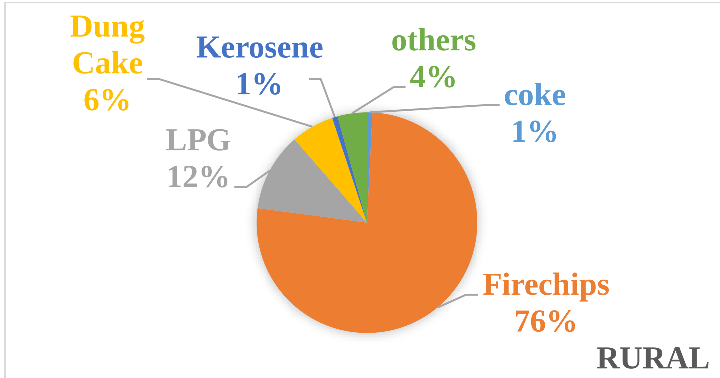


Figure 1. Proportions of usage of various domestic fuels in rural and urban India

(Source: Census of India 2011[20])

2.1.3 Spatial Heterogeneity

Diverse climatology, geography, population, culture and fuel usage[21,34,35] generate varying indoor air quality across India, as shown in modelled average indoor $PM_{2.5}$ concentrations based on quantitative air pollution measurements in 4 Indian states. Higher indoor $PM_{2.5}$ concentrations (in the kitchen area) are observed in north Indian states in the Indo-Gangetic Plain (IGP) i.e. Uttar Pradesh (UP), Delhi, Punjab, and Haryana (557-601 $\mu g/m^3$), while lower concentrations are observed in southern states such as Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh (183-214 $\mu g/m^3$). Higher concentrations in northern states in the IGP are attributed to extensive usage of dung cakes for cooking activities and biomass for heating activities due to cold winters[22]. Figure 2 shows the model estimated spatial variation of kitchen $PM_{2.5}$ concentrations across India.

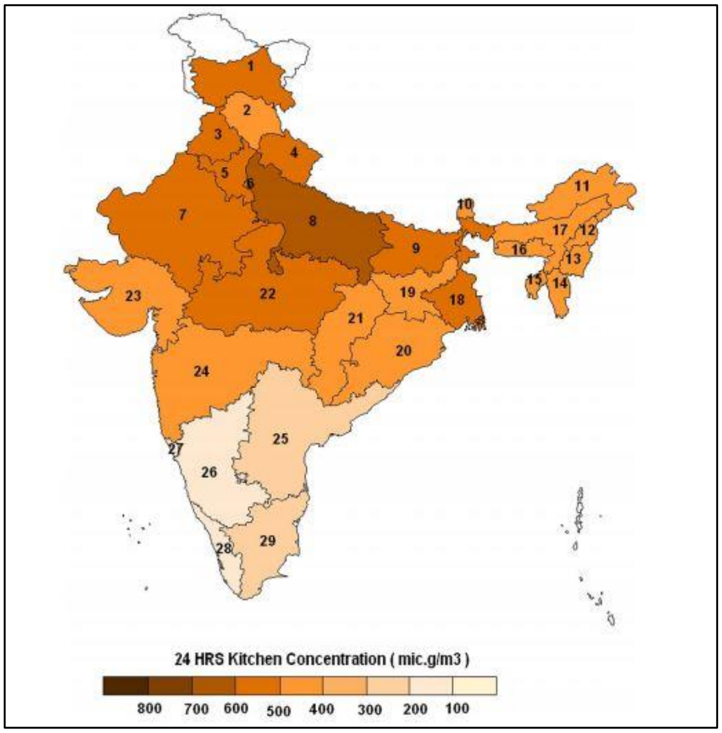


Figure 2. 24 hr averaged $PM_{2.5}$ kitchen concentrations in India

(Source: Balakrishnan et al., 2014)

2.1.4 Impact of socio-economic status

Exposure to air pollution is dependent on socio-economic and socio-cultural differences[31]. A majority of urban slums in India are located close to factories and highways. Therefore, people residing in slums are more prone to higher exposures from industrial and vehicular emissions[36,37]. Densely populated localities with absent exhaust vents, coupled with the use of low quality domestic fuels (such as biomass, dung etc.), and the presence of unpaved roads further deteriorates indoor air in slums[31,36]. A study carried out by Kulshreshtha et al. (2008)[38] identified differences of 110-175 µg/m^3 in indoor PM concentrations between low and high income houses. Another study carried out in Mumbai also reported higher indoor pollutant concentrations in low income houses than affluent ones[39].

2.2 Ambient air pollution

Among major health risk factors in India, ambient air pollution (AAP) is ranked 5th in mortality and 7th in overall health burden. According to the World Health Organisation (WHO), 10 of the 20 most polluted cities in the world are in India, including Delhi, Patna, Gwalior, Raipur etc.[1] PM levels often exceed the National Ambient Air Quality Standards (NAAQS) in more than three-fourths of Indian cities[2]. The primary PM sources in India are emissions from industries, power plants, vehicles, construction activities, biomass combustion for domestic activities, and waste burning[31,40–43]. These sources are widely varied across the country.

2.2.1 Monitoring by government agencies

Ambient air quality monitoring in India is largely focused in urban areas, with a limited coverage in its rural locations[3,44]. The National Air quality Monitoring Programme (NAMP) is a nation-wide campaign launched by India's Central Pollution Control Board (CPCB) to monitor primary pollutants (SO_2, NO_2, PM_{10} and $PM_{2.5}$) levels in urban and semi-urban areas[45]. Under NAMP, CPCB operates more than 629 monitoring stations in 264 Indian cities and towns[46] and provides pollutants data from the late 1980s. Further, CPCB also operates ~60 continuous ambient air quality monitoring stations (CAAQMS) in 35 major cities of 14 Indian states (Figure 3). Apart from the primary air pollutants listed above, pollutants such as Benzene, Ozone, and PAHs are also monitored real time in CAAQMS stations[47]. CPCB started commissioning CAAQMS stations from 2008 onwards, and by 2015, it completed setting up stations in all its target cities. In addition, several state-level pollution regulatory authorities also monitor primary pollutants levels in various urban and industrial locations within their respective states.

Figure 3. Indian states with online monitoring stations (circular indicators are provided over the states) (***Source: CPCB, 2017***)

2.2.2 PM levels: current scenario and regional variations

$PM_{2.5}$ levels are in excess of the WHO annual standard of 10 μg/m^3 in over 70% of the Indian subcontinent. The present Indian annual standard for $PM_{2.5}$ (40 μg/m^3) set by CPCB is in between WHO's Interim targets 2 and 3. Recent studies have shown, through a combination of ground monitoring and satellite data, that the annual averaged $PM_{2.5}$ levels in the Indian subcontinent are in the range of ~10-100 μg/m^3 [3,31]. Higher concentrations are observed over north Indian cities, while lower concentrations were observed over south Indian rural locations[31,48]. Among metro cities, New Delhi, Kolkata, Mumbai, and Hyderabad have the highest $PM_{2.5}$ levels (annual average concentrations: 40-81 μg/m^3) and exceed the prescribed permissible standards (40 μg/m^3); Chennai has the lowest $PM_{2.5}$ levels (~25 μg/m^3)[a]. Diurnal averaged $PM_{2.5}$ levels over Delhi and Kolkata are recorded as high as 300 μg/m^3, higher than the CPCB permissible standard of 60 μg/m^3 [49,50]. Further, diurnal averaged $PM_{2.5}$ levels in Tier 2 north and central Indian cities such as Agra, Kanpur, Raipur and rural locations of the IGP are on par with levels over major Indian cities such as Delhi and Kolkata[31,51].

As discussed, India exhibits a wide spatial heterogeneity in air pollution. Major Indian metro cities and regions in the IGP have been identified as critically polluted areas[31]. The concentrations over these locations are found to be at least 2-4 fold higher than levels over southern India (Figure 4). Colder winters, which necessitate the extensive use of biomass and coal for cooking and heating activities, and the presence of a large number of brick kilns (~65% of total 100,000 kilns across India) with inferior technology result in higher pollutant concentrations over the IGP[52]. In addition, shallow mixing heights and low wind speeds causes low atmospheric dilution rates over the IGP region than the rest of India. This results in poor dispersion of pollutants which further enhances pollutants levels[53].

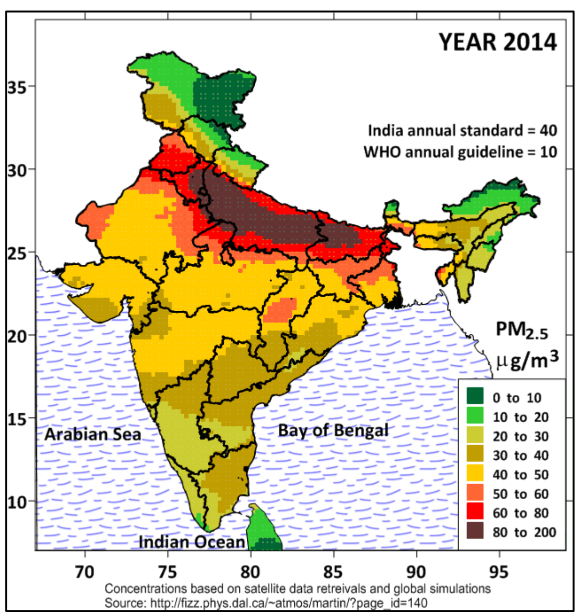


Figure 4. $PM_{2.5}$ variations over India[b]

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[a] Based on data analysis of $PM_{2.5}$ concentrations measured at US consulates; data available at: https://in.usembassy.gov/air-quality-data-information/

[b] (*Source:* http://fizz.phys.dal.ca/~atmos/martin/?page_id=140; http://www.urbanemissions.info)

2.2.3 Trends over time

Analyses of long-term $PM_{2.5}$ trends over the Indian subcontinent indicate an alarming rate of increase in levels. $PM_{2.5}$ concentrations have increased more than ~15 µg/m^3 over the last decade (2001-2010) in eleven Indian states which includes Telangana, Maharashtra, Gujarat, Madhya Pradesh, Orrisa, and all the states in the IGP. In the IGP region, the increase observed is higher than 25 µg/m^3 due to significant rise in population and fossil fuel usage[3]. Figure 5 shows the magnitude of increase of $PM_{2.5}$ concentrations over the subcontinent, recorded between 2001 and 2010. On similar lines, Jain et al. (2017)[54] also identified an increase of ~45% in ambient $PM_{2.5}$ levels over the 15 years (2001-2015) in Varanasi, in the IGP (~3% per annum). A total increase of ~50 µg/m^3 in ambient $PM_{2.5}$ concentrations occurred during this period. Further, PM_{10} levels over four major Indian cities (Delhi, Mumbai, Kolkata, and Chennai) also reflected an increasing trend over the last decade. Around 10-50% increase has been observed in ambient PM_{10} levels between 2001-2011[2].

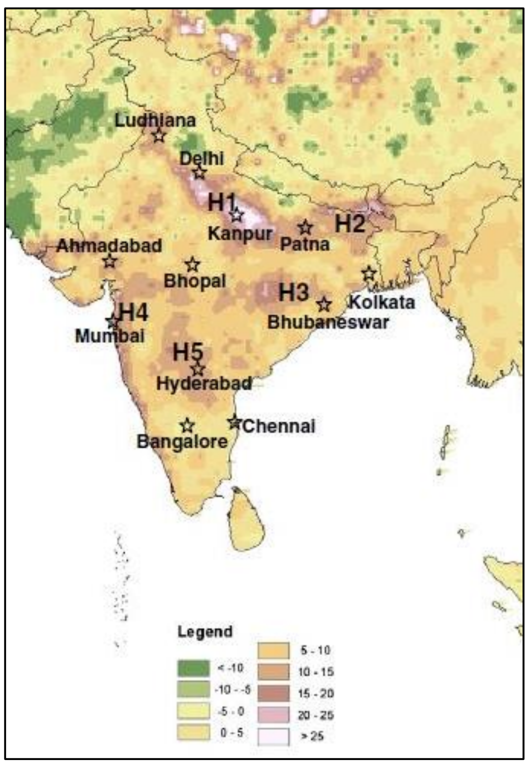

Figure 5. Increase in $PM_{2.5}$ concentrations between 2001-2010 (*Source*: Dey et al., 2012)

2.2.4 Rural-urban heterogeneity

In India, wide differences exist in air pollution sources between urban and rural locations[52]. Vehicular emissions and construction activities are predominant sources of air pollution in urban India. Studies on kerbside $PM_{2.5}$ measurements in major Indian cities reported diurnal averaged concentrations as high as

100-550 μg/m^3 [31,55] due to a significant impact from vehicular traffic. On the other hand, biomass combustion, fugitive emissions from unpaved roads, agriculture crop residue burning (ACRB), and brick kilns result larger pollutant emissions in rural India[21,31,56–61]. During ACRB periods, diurnal averaged ambient $PM_{2.5}$ levels in rural India were reported to elevate up to ~125 μg/m^3, which is more than twice the CPCB prescribed limits (60 μg/m^3) [62].

Meteorology plays a significant role in seasonality in air pollution trends across India[63]. However, in rural India, in addition to meteorology, activities such as ACRB are also responsible for pollution episodes post monsoon and winter seasons[52,56,64]. For e.g., Agarwal et al. (2012)[62] observed differences as high as 75 μg/m^3 in ambient $PM_{2.5}$ levels between ACRB and non-ACRB periods in rural Indian locations over IGP.

2.2.5 Projections going forward

Rapid urbanization in the Indian subcontinent is seeing a resulting rise in migration to cities[65]. Consequently, India's population will be largely urban by 2050 and is expected to grow to 50% from its present share of 31.5%[66]. Urbanization promotes increased energy and fuel consumption, primarily in the transport and industrial sectors, resulting in higher air pollution levels[67]. It is estimated that $PM_{2.5}$ emissions in India will increase by ~25% by 2030, whereas sulphur dioxide (SO_2) and nitrogen oxides (NOx) emissions will increase by 3-5 times. Emissions of VOCs, which are major carcinogens, are estimated to shoot up to 30% [68]. Annual averaged PM_{10} levels in all major Indian cities are expected to reach 150 μg/m^3 by 2050 [69].

3. Health Impacts

Exposure to air pollution, both household and ambient, is associated with a broad range of acute and chronic health effects from minor physiologic disturbances, to death from respiratory and cardiovascular diseases[70]. Short-term exposure to ambient particulate and gaseous pollutants has been linked to higher rates of hospital admissions for cardiovascular and respiratory illnesses, exacerbation of pre-existing respiratory illnesses, and death through ischemic heart disease or stroke[10]. Longer-term exposure to $PM_{2.5}$ has been associated with ALRI in children, developmental disorders, cardiovascular mortality, decreased lung function, COPD, diabetes, and lung cancers[71,72]. More recent work has also established links between exposure to $PM_{2.5}$ and low birthweight and preterm birth[73,74].

Nationally, while pilot studies since the early 1980’s showed household exposure to air pollution to be harmful to health, air pollution was not considered a serious risk factor for ill health until the work conducted in the last 10-15 years to quantify the burden associated with air pollution exposure nationally. This culminated with the Global Burden of Disease comparative risk assessment carried out in 2010[75] which showed that exposure to smoke from the burning of solid fuels for cooking/heating, and exposure to ambient particulate and gaseous pollution were the single largest environmental risk factor for ill health. Subsequent updates published for the years 2013 and 2015 show us that the contribution of air pollution as a risk factor only continues to grow over time, with the current burden globally estimated to be 7 million deaths annually[76]. The burden is disproportionate in low- and middle- Income Countries[76], which continue to industrialize at a rapid rate[77], while also continuing the use of biomass fuels for cooking and heating[78].

3.1 Health impacts of exposure to air pollution in India

Ambient Air Pollution:

Even though the bulk of the burden of ambient air pollution exposure is borne by developing countries in Asia, the representation of studies conducted in these settings has not been significant. A review of the literature by Health Effects Institute in 2010 of air pollution studies conducted in 13 countries in Asia, identified around 43 studies (published between 1980 and 2008) on the health impacts of ambient air pollution. Most of the research, conducted in the megacities of Delhi and Mumbai[79], reported association between ambient air pollution and the prevalence of acute and chronic respiratory symptoms. Those which performed time-series analyses reported three very significant associations , between air pollution and health impacts - significant increases in acute respiratory illness[80], all-cause mortality[81] and emergency visits for cardio-respiratory conditions[82].

Research studies published since 2010 have reported higher rates of mortality as a result of short-term exposure to PM and other pollutants. Some of them have estimated premature mortality as a result of exposure to ambient air pollution in individual cities[83–85]. Other studies have also used similar methods in other cities and in other time periods[86]. The research shows similar levels of increase in daily mortality associated with ambient particulate matter as was the case in other countries such as China, South Korea, Japan, etc. Table 2 below shows the estimated premature mortality due to outdoor air pollution as estimated for the future years from studies measuring health effects of short-term exposure to air pollution in individual cities 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)

All India	2010	$PM_{2.5}$	486,100	Chowdhury & Dey (2016)
6 Cities	2013	PM_{10}	6,849/million popn.	Maji et al. (2016)

Table 2: Estimated premature mortality due to ambient air pollution in India
(Source: Adapted from Ministry of Health & Family Welfare Steering Committee Report on Air Pollution & Health Related Issues 2015*[10]*)

The Indo-Gangetic plains account for a large percentage of the estimated mortalities. In a recent study conducted by IIT Bombay[87], the DALYs as a result of air pollution doubled from 0.34 to 0.75 million in Delhi in the years 1995 to 2015 while for Mumbai this figure increased from 0.34 to 0.51 million DALY in the same period. The same study estimated air pollution as the cause of around 80665 premature adult deaths in Delhi and Mumbai in 2015.

Household Air Pollution:

In the late 1950s, the Indian Cardiologist Dr. Padmavati associated household air pollution with heart disease in a study which observed young, rural, non-smoking women suffering from corpulmonale – a serious heart condition – which could only be explained by their exposure to heavy air pollution from cookstove smoke[88]. It was, however, much later that the first systematic consolidation of evidence on the health risks of household air pollution exposure was performed for the 2000 Global Burden of Disease (GBD) assessment. A range of studies have since been carried out in India on the health impacts of HAP, ranging from pilot studies by Smith et al (1983)[24], to more recent large scale clinical trials examining the links between air pollution and low birth weight in children[89]. Over the years, a strong body of evidence has been established linking HAP with three broad categories of health outcomes in India - acute lower respiratory infections in children under five years of age[90], chronic obstructive pulmonary disease in women, and lung cancer (especially in users of coal)[91]. There is also a moderate or weak evidence for a broad range of other outcomes such as pre-term births, low birth weight, cataracts, asthma and Tuberculosis[92–94].

According to the Census 2011, about 64% of Indian households use solid fuels (which goes to as high as 85% in rural areas) for cooking and heating purposes[20]. Census figures also show that while the percentage of users reliant on biomass for cooking and heating has reduced between 2000-2010, the absolute number remains around 700 million, with urban areas showing an uptick in the use of biomass. Given the pervasive use of biomass for cooking and heating, the GBD 2015 estimated 977,094 deaths in 2015 associated with HAP exposures, with a significant number in women and children. An estimated 400000 deaths in India happen as a result of acute lower respiratory infection (ALRI) in children below five years of age, with a third of the risk attributable to HAP exposures[95]. Table 3 below outlines the best available evidence on HAP exposures and various health outcomes in India that were factored into the GBD exercise, and in the Ministry of Health Steering Committee Report.

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)	
	Walia et al (2016)		
	Sarkar (2017)		
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)	
	Krishnan et al (2015)		
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)	
	Mukherjee et al (2014)		
	Assad et al (2016)		
Cataracts	Mohan et al (1989)	1.61 (1.02–2.50)	Smith et al (2014) 2.46(1.74-3.5)
	Badrinath(1996)	4.91(2.82-8.55)	
	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)	
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)	
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 3: Major health studies in India for HAP related burden assessments

(Source: Adapted from Ministry of Health & Family Welfare Steering Committee Report on Air Pollution & Health Related Issues 2015[10])

3.2 Evidence for Policy

Much of the evidence base for the development of integrated exposure-response relationships for HAP in the Global Burden of Disease (GBD) is based on work which has been done in India. There have been a number of studies, from the early 1980s, that have managed to capture household exposure and health impacts. The knowledge base for global household air pollution and linking it to biomass combustion has, therefore, been developed on the basis of studies which have been conducted in India (and Nepal) in the mid-1980s where a wide range of impacts have been studied. In this, while the strength of evidence for COPD and ALRI in children is strong, the evidence for other outcomes such as TB, cataract and asthma need strengthening with more long-term studies[83].

While a fair number of cross-sectional and time-series studies have been carried out to assess the impact of ambient air pollution and mortality, the evidence base remains weak on several counts. There is a relative paucity in the number of studies assessing the impact of $PM_{2.5}$ exposures on health outcomes including mortality, with most studies projecting forward. This can be attributed to the lack of available data on $PM_{2.5}$ (as covered in section 4). There is also a lack of strong evidence to establish the exposure-response relationship between $PM_{2.5}$ and mortality due to cardiovascular diseases and cancers, as well as between long-term exposure and development of cardio-metabolic and cardio-pulmonary diseases. This lack of Indian studies at high levels of exposure on these counts was also echoed by expert respondents, who cited the need to replicate long-term studies carried out elsewhere such as the Nurse's Health[96,97], MESA Air[98] and ESCAPE[99] studies.

That said, there is a wealth of evidence both nationally and globally to make the case for action on air pollution exposure reduction at this point in time. This, coupled with the evidence from studies in other countries can be used to make strong arguments especially from a policy perspective. In the absence of local data, the size of the effects can be estimated, especially since the ambient air pollution levels are very high in developing countries in that the uncertainties would not make a significant difference[10]. There is also a growing understanding that scientific evidence generation is an ongoing process, and that policy can be designed at a particular point in time based on local and global evidence available at that time.

3.3 Strengthening the Evidence Base

Epidemiological evidence on the health impacts of air pollution plays a pivotal role in the setting of regulatory standards for pollution at levels considered sufficiently safe for human health. It also plays a key role in defining national health priorities and in allocation of funds to national and state health programmes. But our review and consultations with various key stakeholders informs us that the lack of a strong local evidence base, especially for ambient air pollution, forces policymakers to rely on global evidence, much of which has been generated at far lower exposure levels. In the section below, we identify some areas that could be strengthened, based on the review and stakeholder consultation.

I. Need for studies on the effects of long-term exposures to air pollution

Though time series and cross-sectional studies provided some of the most consistent evidence of serious acute health effects of air pollution in North America, Europe and to some extent in Asia, chronic health effects estimates can only be generated through long-term observation of large population-based cohort or panel studies. Several long-term studies have been conducted in North America and Europe, the results of which provide a great wealth of evidence on long-term health effects but at relatively lower spectrum of exposures (below 50µg/m^3 of $PM_{2.5}$). Thus, the integrated exposure-response relationships used in the GBD comparative risk assessment may have underestimated the health burden for regions with higher spectrum of exposure such as India or China[7]. While several studies are underway in China to catalogue the long-term effects of AAP exposure, there are only a handful ongoing in India. The levels of exposure may be similar across both countries, but the composition of $PM_{2.5}$ is different due to the various emissions sources involved, necessitating investment in long-term studies in India. The assessments of health impacts of air pollution and the benefit-cost analysis of air pollution control measures rely mostly on estimates of how exposure affects the incidence of chronic cardiovascular and respiratory illness or death, providing another basis for the conduct of long-term exposure-response studies.

II. Studies of comparable design and conducted across various sites to build a broader evidence base

While there is a need for cohort studies to establish the long term effects of exposure to air pollution on health, low cost time series studies to estimate short term or episodic impact of air pollution on health outcomes, primarily on daily morbidity and mortality. Studies which are of comparable design, analysed consistently and conducted across the region will not only be able to provide more accurate distribution of effect estimates over entire exposure gradient prevalent within the region but also account for sociodemographic confounding uniformly. Hence, coordinated multicentre studies across the region are most efficient way to bolster the evidence base for health effects of air pollution[100].

III. The role of socio-economic disparities in exposure to air pollution

There has been evidence, though limited, from studies conducted primarily in Europe and North America which suggest a higher risk of morbidity and mortality related to air pollution as a result of economic deprivation. Exposure to air pollution has been found to be dependent upon the socioeconomic status of an individual. People at a lower socioeconomic status experience higher levels of exposure to air pollution[32,35], and can be more susceptible to air pollution induced health impacts by several other factors such as health and nutritional status, and access to medical services which are themselves related to the socioeconomic status of individuals. Published research as well as the stakeholders interviewed for this report are therefore of the view that there is a need for more studies which quantify the role of socio-economic disparities in air pollution exposure, to bring to light what is a latent environmental justice issue.

IV. Economic effects of air pollution in developing country contexts

According to a study conducted jointly by the World Bank and the Institute of Health Metrics and Evaluation on the economic cost of air pollution, 8.5% of India's GDP was lost due to air pollution in terms of the welfare costs and the lost labour incomes in the year 2013[9]. This study, while a good start in quantifying the economic burden of air pollution in India, only captured lost productivity and welfare costs associated with premature mortality. The healthcare costs associated with treating air pollution induced diseases, it could be argued, could be significant in a country where 60 million dip below the poverty line each year due to catastrophic expenditure on health, primarily on treatment of chronic diseases and purchase of medicines[101]. There are, of course, economic benefits as a result of longer lives. A population that lives longer is able to contribute to the country's economy for longer. Unhealthy air also makes people less productive due to higher rates of sickness and hospitalization further justifying the need to study the economic impacts of air pollution in quantifiable terms through systematic epidemiological methods[102].

Stronger evidence on the economic impacts could also drive both health and environmental policymaking, to ensure that the upstream determinant and the downstream curative aspects are effectively addressed.

V. Detailed studies of the composition of air pollution and of the relative contribution of various sources and their health impacts

It is important to understand the chemical speciation of particulate matter to recognise the varied health effects of the individual components of PM. For instance, even though $PM_{2.5}$ may comprise of silica, ammonia, sulphates, and black carbon among other constituents, the association of black carbon with health outcomes is far stronger. It is, therefore, important to study the composition of particles as well as the sources of those pollutants, evidence for which is currently lacking in the research being conducted on air pollution in India. Currently, in global and national estimates, $PM_{2.5}$ is considered as a uniform substance, whereas the composition varies at local, national and regional scales. This variance in the composition of $PM_{2.5}$ ensures that the estimates of the health burden, while reasonably accurate at large scales, cannot provide the basis for strong action locally[100]. There is also a smaller pool of evidence for the health impacts of gaseous pollutants such as ground-level Ozone, which is currently included in the estimates of the GBD.

VI. Development of the evidence base in tier 2 and 3 cities

In India, research on air pollution exposure has been conducted in major cities such as Delhi, Chennai, Mumbai and a few in industrial town or areas where there is a higher concentration of particulate matter and a higher risk of exposure to air pollution. However, research studies conducted in areas other than the metropoles would be able to build the evidence base for the effects of air pollution and the kinds of measures that can be taken to counter the same.

Another consideration should also be the rapid industrialization of tier 2 and 3 cities as part of the government's 'Smart Cities' plan. Since these cities are being developed and being looked at as the industrial and commercial hubs of the future, it is important to think about the impact of this on air pollution in these areas so that effective steps can be taken to tackle the same.

The same is also true for the Indo-Gangetic plain (IGP) where there exists a combination of urban and industrial pollution, agricultural and cooking fires and temperature inversion. In the IGP, during the winter, due to temperature inversion, cold air settles and traps pollution near the surface whence it becomes extremely hazardous to human health.

VII. Alignment with National Health Programs and Priorities

The National Health Policy document of the Union Ministry of Health and Family Welfare released in early 2017 for the first time listed air pollution exposure as a priority area for action. It outlined alignment of policy across sectors to ensure that the burden of air pollution is reduced in the coming years. There is, however, a mismatch even within the health ministry in terms of its funding allocation towards the diseases that are a direct result of air pollution exposure. Currently, national health programmes are disease-specific verticals, with a large chunk of the funding targeted to maternal and child health, immunization, and control of infectious diseases. Chronic Diseases, which are the primary pathway through which air pollution impacts manifest, are afforded a fraction of the funding provided to the other disease verticals, with no mechanism for follow-up and treatment of patients diagnosed with chronic cardio-metabolic or cardiopulmonary diseases. While the Steering Committee report of 2015 advised the Government to reorient its funding towards addressing these diseases, action is yet to be taken at any discernible scale. The immediacy of this need is reinforced when one looks at the fraction of attributable risk of various chronic diseases to air pollution in India, compared to countries of similar economic status and aspiration (table 4 below). While the Government of India has adopted the Sustainable Development Goal targets aimed at reducing mortality and morbidity associated with air pollution exposure, no discernible pathway currently exists to achieve these.

Strengthening the evidence base on air pollution could also play a key role in aligning priorities across other sectors which are the primary contributors to emissions. If some of the above highlighted lacunae such as localized evidence, source-specific or pollutant-specific contributions, and work on the economic impacts is carried out, it can serve as a tool for advocacy with other sectors. While the Ministry of Health is working to establish a multi-sectoral platform to address these issues in partnership with the Ministry of Environment and several other relevant Ministries and Departments, it currently lacks strong advocacy tools besides national and regional estimates. The lack of advocacy reflects in policy documents such as the Smart Cities vision document, National Energy Policy and others, which either ignore air pollution altogether, or provide a cursory mention of the issue. There exists no clear roadmap to achieve air quality standards commensurate with a reduced burden of disease, and the strengthening of the health evidence base can bolster arguments for doing so in an inclusive and holistic manner.

	BRAZIL		RUSSIA		INDIA		CHINA		SOUTH AFRICA	
	% of total DALYs	**Risk factor attribution (%)**	**% of total DALYs**	**Risk factor attribution (%)**	**% of total DALYs**	**Risk factor attribution (%)**	**% of total DALYs**	**Risk factor attribution (%)**	**% of total DALYs**	**Risk factor attribution (%)**
Ischemic heart disease	6.72	15.36	16.97	15.61	7.28	38.61	7.48	30.87	2.93	23.4
Lower respiratory infections	2.85	15.4	2.04	16.17	4.48	62	1.4	46.08	3.78	34.37
Chronic obstructive pulmonary disease	2.17	18.98	1.2	19.31	4.63	55.74	4.47	46	1.41	31.71
Cerebrovascular disease	4.53	11.5	9.18	11.32	3.62	34.16	10.11	26	2.33	19
Tracheal, bronchus and lung cancer	1.21	10.55	2.07	11.22	0.4	46.29	3.72	34.54	0.71	22.91

Table 4: Percentage of total DALYs and risk factor attribution to air pollution in BRICS countries

(Source: GBD 2015[103])

4. Barriers to Change

Section 3 outlined gaps in the research evidence base in India, and identified several areas in which it could be strengthened to better inform policymakers. There are, however, several challenges in terms of the availability, accessibility, and quality of data, both on air pollution and health outcomes that need to be addressed to ensure that studies are conducted with the highest scientific validity. It is also important to ensure that this data is accessible not just to policymakers and academics, but to the general public in an easily understandable format such that awareness on the harmful effects of air pollution exposure is expanded. Greater and greater amounts of data on air quality are now being generated through various low-cost monitoring networks, supplementing the government's own national monitoring program. There are questions, however, on the quality of this data, and thereby its validity. Similar constraints remain in availability and accessibility of health data, both from the public and private sectors, where digitization is not common, and data on many outcomes associated with air pollution exposure are not even collected at this point in time. Where it is collected, there are challenges in the quality of the data, either due to the lack of training provided to physicians on encoding it, or simply the mammoth effort required in digitizing data that lies in registers and reams of paper. In this section, we have attempted to document some of the challenges prevalent in carrying out effective and scientifically sound research on air pollution and health in India, while also identifying pathways to change in those respective areas to ensure better availability, accessibility, quality, and use of data to better inform research, advocacy and communication efforts. Challenges also remain on the awareness front, where little work has been done till date on understanding the public perception around air pollution and health.

4.1 Access to quality health outcome data and health management information system issues

4.1.1 Health outcome data

The Indian healthcare system is mixed in nature – healthcare providers are both private and public. A high proportion of healthcare delivery occurs in the private sector in urban areas, while access to government provided healthcare is high in rural areas. Health outcome data sources then are also both public and private. Public sources for data include government-managed databases, population-based surveys and health management information systems. Private sources primarily include hospital-based patient records and private diagnostic centres.

Avenues of health data outside government and private health records, as suggested by experts, include longitudinal cohorts in research projects, records from private practitioners, insurance claims, emergency ambulance calls. Potential future sources to collect primary data can include data collected from activity trackers and wearable devices. There is, of course, a strong need to develop and put in place a comprehensive sentinel surveillance system (urban and rural) for regularly collecting health and environment data.

4.1.2 Public sources

4.1.2.1 Health Management Information System

The National Rural Health Mission (NRHM) of the Indian government, later rechristened the National Health Mission (NHM), was launched in 2005 to address the health needs of the country's population. In order to support health services at all levels with accurate and up-to-date health data, the Health Management Information System (HMIS) was conceptualized as a digital initiative within the NHM and launched in 2008. The HMIS portal is envisioned as the provider of all public health related information collected under national programmes, capturing data right from the district level and sharing it at the state and central levels.

Key indicators documented within the HMIS include child health, immunization, maternal health and family planning. This data is available at the sub-district and district levels. In addition to the health data itself, the "status of data reporting" by health facilities and districts is available. CHCs are also graded based on available infrastructure at the health facility and services being provided (criteria considered: HR availability, infrastructure, drugs and supplies, service availability, etc.)

4.1.2.2 Surveys

The central government through the Ministry of Health & Family Welfare, Ministry of Statistics & Programme Implementation, Office of the Registrar General & Census Commissioner (Ministry of Home Affairs), with support from organizations such as International Institute of Population Sciences and NIMHANS, conducts population-based surveys. These are a rich source of health data which have been used to collect data on wide-ranging topics such as "fertility, mortality, family planning, maternal and child health, and some other aspects of health, nutrition and health care in India.[104]"

The National Family Health Survey (NFHS) is a nationally representative large-scale and multi-round survey conducted across India. Started in 1992-93, the fourth and latest NFHS was conducted in 2015-16. The survey covers population and household profile, literacy, marriage and fertility, infant and child mortality, family planning, MCH, immunization, feeding and nutrition practices, childhood diseases, nutritional status of adults, anaemia, blood sugar, hypertension, HIV knowledge, women's empowerment, tobacco use, and alcohol consumption. The District Level Household Survey (DLHS) was launched in response to need for district-level data on RCH programme[104]. Four rounds of the DLHS have been completed as of 2012-13. The Annual Health Survey (AHS) was conducted in tandem with the 4th round of the DLHS in states with low levels of development. The recently conducted National Mental Health Survey (2015-16) documents the prevalence, pattern and outcomes of mental disorders in India. The evidence based on mental health outcomes associated with air pollution has been sparse so far. With this milestone survey, there is a possibility of developing this further.

4.1.3 Databases

4.1.3.1 Civil Registration System

Provisions under the Registration of Births and Deaths Act (1969) introduced the Medical Certification of Cause of Death (MCCD). Since the early 1970s, the Office of the Registrar General publishes cause-specific mortality (MCCD) reports annually. The data is tabulated in accordance with the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10), after being collected from State- and UT-level Offices of the Chief Registrars of Births and Deaths.

4.1.3.2 Integrated Disease Surveillance Programme (IDSP)

The IDSP provides comprehensive decentralized state-based surveillance for epidemic prone diseases to detect early warning signals at the district, state and national levels. Data is collected in a standardized manner and computerized. These are reported weekly, with up to 90% districts reporting weekly data, at present. Aside from weekly outbreak data, there is access to monthly disease alert surveillance reports.

4.1.3.3 Disease registries (Cancer, Stroke and Cardiac Events)

The Indian Council for Medical Research has run the National Cancer Registry Programme under the National Centre for Disease Information and Research for over three decades. The objectives of the NCRP include generating reliable data, epidemiological studies, help design, plan, monitor and evaluate cancer control activities and develop training in cancer registration and epidemiology. At present, there are 29 Population Based Cancer Registries (PBCRs) as well as Hospital Based Cancer Registries (HBCRs). The data is verified, digitized, and accessible online.

The National Centre for Disease Informatics and Research set up the National Stroke Registry in India with the aim to generate reliable data on stroke (magnitude, incidence) and understand patterns of care among stroke patients. Specific methods to set up a Population Based Stroke Registry haven't been finalized yet and the Hospital Based Stroke Registry is also in the planning stages. However, registration of stroke patients began in January 2013[105]. Future plans include creating registries for cardiovascular diseases and diabetes.

4.1.4 New initiatives

The Global Burden of Disease initiative is a worldwide effort to provide a comprehensive quantification of morbidity and mortality from diseases, injuries, and risk factors at the global, national and regional levels. At present, only national level estimates are available for India. The state-level estimates are underway and are yet to be released. Additionally, it doesn't cover all health outcomes. The GBD initiative is a useful decision-making tool for policymakers.

4.1.5 Private sources

4.1.5.1 Hospital-based data

Some of the private hospital chains in India maintain a digitized health information system from registration to clinical data. Chains such as Apollo, Max Health, Sankara Nethralaya have implemented electronic health records (EHR) systems to manage patient records. However, this data is rarely exchanged between hospitals[106]. There is very little literature on maintenance of patient clinical data by private clinics and hospitals. Exchange platforms between private sector players are lacking.

The recently released National Health Policy (2017)[101] has a component on health management information. Within this, goals include ensuring district-level electronic database of information on health system components and strengthening health surveillance and establishing registries for diseases of public health importance by 2020, establishing federated integrated health information architecture, Health Information Exchanges and National Health Information Network by 2025. The Policy recognizes the significance of technology in healthcare delivery and proposes the setup of a National Digital Health Authority and integrating the health information system. The recently launched Digital India initiative under the present government aims to transform India into a "digitally empowered society and knowledge economy"[107]. Within this flagship programme, the e-health initiative will involve integration for patient's EHR in a 'digital locker' – can be easily shared with public and private sector doctors. The NITI Aayog's Action Plan on Health & Family Welfare includes a proposal to develop an Integrated Health Information Platform (IHIP) to enable interoperable EHR which can have pan-India access[108].

4.1.6. Quality and Utility of Health Data

There are multiple national-level surveys conducted by different ministries that cover health indicators and outcomes. Data can often overlap across surveys and should be checked. A step in this direction includes the discontinuation of the Annual Health Survey, one of the reasons is to avoid duplication[109]. From the upcoming cycle, the DLHS will be collapsed under the NFHS. In addition to these, it would be valuable to coordinate with international agencies that monitor and report such indicators[110]. Methods may differ, rendering data incomparable. By standardizing data collection nationally and coordinating with international agencies, comparison across key variables will become possible. This would be valuable not just to ensure quality survey data but also data from databases and disease registries.

There is need for expanding the health outcomes and indicators that are covered under various surveys, databases and registries. The overall health profile of India reflects a rise in chronic diseases but there is very less current data available on these. For instance, the HMIS portal focuses heavily on MCH reporting, while is little to no data on chronic diseases and health outcomes. Extension of HMIS beyond MCH reporting may provide a rigorous evidence base to design policy and monitor performance and quality of health services[111]**.** The NFHS provides information on important emerging health and family welfare issues, but collects data on limited risk factors. The NFHS, conducted at irregular intervals, does not adequately reflect specific patterns of health facilities and consumption.

Whatever data is reported, delays in making this publicly available poses a barrier to informing policy-making and designing interventions[112]. Dandona et al. point out a delay ranging from 9 to 22 months in releasing NFHS and DLHS data. For instance, in the IDSP website, not all state-level websites are linked to the main programme website (only 14 states). Information is better accessible on the main website than on state-level websites. MCCD reports are only available for years 2008 to 2014 for online access. However, efficiency of documenting this is uneven across the country and not all States and UTs have reported data. For instance, medically certified deaths as a percentage of total deaths in 2015 for states varied from 1.4% in Jharkhand to 100% in Goa, with a national average of 22%. Medically certifiable deaths are classified into eight leading cause-groups, including diseases of the respiratory system, diseases of the circulatory system, and neoplasms (cancers). As of 2015, MCCD data was limited to select hospitals (private and public) in mostly urban settings; the reports may therefore not be representative of pan-India patterns[113]. Updated health information should be communicated as early as possible after data collection. It is possible that physicians are not trained to code according to ICD 10, leading to a lapse in quality of data. Use of verbal autopsy for collecting data could be valuable.

Inputs from experts also suggest that hospital based data is not easy to source and access; even when government hospitals provide access, private hospitals may be reluctant. Lack of a system to access and analyses hospital-based information is a barrier. Long administrative procedures involved may also be a deterrent. Parameters recorded in hospital data, when available and accessible, are insufficient for conducting epidemiological studies. Additionally, often a lot of demographic and clinical information is not coded properly for use in studies. The Steering Committee on Air Pollution and Health Related Issues recommended that the Ministry of Health & Family Welfare collected data on daily hospital admissions and air-pollution related mortality through a few chosen sentinel urban hospitals[10].

4.2 Access and Quality of Air Pollution Data

Data sources for ambient air pollution (AAP) includes a mix of government-run monitoring networks as well as private low-cost monitoring networks. The Central Pollution Control Board's National Air Quality Monitoring Programme (NAMP) is a nation-wide ambient air quality monitoring network. It can be considered a primary data source, used widely by experts as well. Data sources for HAP are characterized primarily by epidemiological research studies.

4.2.1 Household Air Pollution – data sources

Burning of solid cooking fuels is a primary source of household air pollution (HAP), which occurs due to a combination of incomplete combustion and use of traditional cookstoves. Hundreds of toxic pollutants are released when solid fuels are burnt on traditional chulhas, contributing to nearly one-third ambient $PM_{2.5}$ concentrations[78]. HAP, unlike AAP is not routinely monitored and information on exposures can be attributed to individual research studies[35,114–116]. Given the location of HAP exposures, it is impractical to have real-time, large-scale monitoring systems similar to AAP.

While there is no routine monitoring of HAP, there are over 200 studies that have characterized HAP exposures (solid-fuel usage)[10]. This has been done using questionnaire-based assessments, long-term field based measurements and personal exposure measurements. Since the 1980s, there is more detailed information on HAP exposures in India with measurement of short-term household concentrations and exposures. Aside from these studies, national-level household surveys collect data on solid-fuel usage, cooking patterns, etc. which provide a proxy for household exposures. Experts agree that there is some data on exposures but there is limited correlation with specific health outcomes. There is a need for more detailed measures of exposure to HAP other than solid-fuel usage, which already has a solid evidence base.

4.2.2 Ambient Air Pollution – data sources

There is an ever-expanding network to monitor ambient air quality. This involves a combination of real-time and manual monitoring undertaken by central and state government agencies. In addition, there are some autonomous low-cost monitoring networks as well.

4.2.2.1 Monitoring by Government Agencies

The National Air Quality Monitoring Programme (NAMP) is a nation-wide network operated, maintained and disseminated by the Central Pollution Control Board (CPCB) of India. NAMP is a primary source of ambient air quality in India and has 629 stations, covering 264 cities/towns in 29 states and 5 UTs. SO_2, NO_2, PM_{10} are monitored for 24 hours, twice a week, by the Central Pollution Control Boards, State Pollution Control Boards, Pollution Control Committees and National Environmental Engineering Research Institute. However, the NAMP's extensive network doesn't monitor $PM_{2.5}$ data. Additionally, the geographical spread of NAMP stations covers more urban than rural areas. In effect, rural areas are under-monitored for ambient air quality. Air quality management then needs to take this into consideration as source contributions cannot be deduced. However, several studies report satellite data, or emissions inventories in addition to satellite data, which can supplement the dearth of $PM_{2.5}$ monitoring as well as air quality in rural areas[117,118]. The CPCB also has a Continuous

Ambient Air Quality Monitoring Stations (CAAQMS) network which is less extensive than the NAMP. This samples data every 5 minutes but reports an hourly average for NOx, SO_2, CO, O_3, PM_{10}, $PM_{2.5}$. Some stations also collect VOCs like Benzene, Xylene, Toluene. It covers 14 states and has 66 stations. All monitoring is split between industrial, residential and background sites in order to provide an accurate picture of ambient exposure.

CPCB and state pollution control boards maintain historic air pollution measurements database in their web portals. NAMP database provides 24 hour averaged pollutants levels from 1987 to 2015. While, CAAQMS database provides 5 min averaged pollutant levels from 2008 to the present day. Further, CPCB also displays real-time pollutant levels on its portal and display boards installed at monitoring stations for public viewing. CPCB, however, limits access to industrial stack emissions database and pollutants data from monitoring stations installed within various major industries.

4.2.3 Low-cost monitoring networks

There are several low-cost networks that are monitoring air quality in India. These include:

- India Spend's #Breathe - http://api.indiaspend.org/dashboard/
- India Open Environmental Data Project - http://openenvironment.indiaopendata.com/#/dashboard/ It's an association of various Indian companies, enthusiasts, research institutes and academic departments, all with a keen interest in putting open data into mainstream.
- Global Particulate Matter Network - http://spartan-network.weebly.com/
- Open AQ has integrated Spartan network's data - https://openaq.org/#/?_k=vfwezg However, they only have one location in India – Kanpur.
- Hindustan Times - http://airquality.hindustantimes.com/

While these networks are useful in generating awareness, data produced by such networks would not be conducive to research. Assessing performance of low-cost sensors under low- and middle-income country (LMIC) conditions such as those in India requires further studies and is still under evaluation[119]. LMIC conditions are characterized by higher pollutant concentrations, high temperatures, and humid conditions. As a result, sensor devices require frequent calibration, suffer from drift and its readings may be influenced[120]. These are reported to be unfavourable for reliable and long-term performance of low-cost sensors[119,121–123]. Low-cost particulate sensors are basically nepholometers. The contamination of its laser chamber predominantly occurs under higher pollutant concentrations which often results in their poor performance in LMICs [124]. Low-cost gas pollutant sensors majorly work on oxidation/reduction reactions of sensing materials which are usually highly sensitive to higher operating temperatures and humid conditions that are typically found in LMICs[123].

There are several technical challenges associated with using low-cost sensors in LMICs. A major challenge is reliability of data. Collocation against standard references under diversified environmental conditions is required to derive robust correction factors for low-cost sensor measurements in LMICs[125]. Other challenges include improvement of sensitivity, stability and longevity[123]. They attain saturation at slightly higher concentrations that usually exist in ambient environments of LMICs[124]. For instance, low-cost sensors are observed to be levelled off at concentrations above 100 µg/m3 when measured in LMIC cities - Hyderabad, India and Xi'an, China[119,124]. At present, a majority of low-cost sensors are designed to monitor pollutants up to few hundreds of parts per billion (ppb) levels. However, due to the existence of several pollutants in levels lower than these limits, the existing lower detectable limits need to be improved[123]. Poor agreement with reference sensor measurements and inconsistent correction factors among the different units of same models are the other non-trivial technical challenges linked with LC sensors in LMICs[119].

4.2.4 Quality of data

The CPCB's quality assurance and quality control efforts include visits to monitoring stations, review meetings, analytical quality control, and training programmes. It also conducted a study on "Calibration and evaluation of ambient air quality monitoring stations in India[126]."

Despite such efforts and a growing air quality monitoring network, gaps in data collection and erroneous readings due to mis-calibration pose an obvious barrier to reliable air quality data. For instance, during winter 2015 (characterized by high pollutant concentrations), $PM_{2.5}$ data was recorded only 29% of the time across 11 monitors run by the CPCB and DPCC[127].

To understand missing data points and inconsistencies in particulate matter monitoring and reporting, we analysed data of the CPCB and Delhi Pollution Control Committee (DPCC). There is a wide variability in the percentage of dates these stations were functional, i.e. monitoring $PM_{2.5}$ in over 2500 days, from 2% to 71%. In the days that these stations were functional, data availability has been as low as 44%. Available $PM_{2.5}$ data spurious often. For instance particulate matter data from the IHBAS station (North east Delhi) indicate $PM_{2.5}$ levels greater than PM_{10} levels for more than 1000 days (>40%) in the last 7 years. Similar absurd trends were also observed in the data from other stations such as IGI (South west Delhi). Given the missing data points within the time span analysed, as well as within the period these stations were functional, the data is not representative of the city. The inconsistencies in data monitored and reported then do not give an overall picture of different industrial, rural and residential areas in the city. For efficient air quality management, representative data from continuous monitoring is essential. The table below provides an analysis of the data availability for stations in Delhi monitoring PM2.5 over the years 2010-2016 which we carried out for a study at PHFI.

S. No.	Station Name	No. of days analysed (2010-2016)	No. of days functional (2010-2016)	% of functional days	No. of days for available data	% of days data available	No. of days $PM_{2.5}$ <0	No. of days $PM_{2.5}$>5000
1	Anand Vihar	2557	638	24.95%	579	90.75%	NIL	NIL
2	Delhi Technological University	2557	59	2.30%	56	94.91%	NIL	NIL
3	Dwarka	2557	645	25.22%	566	87.75%	NIL	NIL
4	IGI Airport	2557	1760	68.83%	1150	65.34%	NIL	NIL
5	IHBAS	2557	1827	71.45%	1521	83.25%	NIL	63
6	ITO	2557	59	2.30%	59	100%	2	NIL
7	Mandir Marg	2557	633	24.75%	533	84.20%	NIL	NIL
8	Punjabi Bagh	2557	635	24.83%	597	94.01%	NIL	NIL
9	RK Puram	2557	1350	52.79%	595	44.07%	NIL	NIL
10	Shadipur	2557	650	25.42%	617	94.92%	NIL	NIL

Table 5: Analysis of CPCB & DPCC data for missing data points (2010-2016)

(Source: Central Pollution Control Board Continuous Ambient Air Quality Monitoring System)

Quality control of monitored air quality is essential for reporting accurate data. Research studies conducted by several institutions using the same data or sub-sets of it from the period when the car-rationing "Odd-Even" scheme was operational in Delhi, presented differing interpretations[128–130]. This resulted in differing opinions on the success or failure of the scheme. Kumar et al (2017) studied the two time periods during which the "Odd-Even" scheme was operational in Delhi by analysing data from fixed site monitoring stations. Depending on the periods compared, PM concentrations could be viewed as reduced or increased. Data analysis revealed that while the trials resulted in cleaner air during certain hours, overnight emissions from heavy goods vehicles persisted and could have potentially made the morning hours ineffective. In such a scenario, standardization of pollution-measuring instruments and resulting calibration as per standards becomes important[131].

With an expanding network of air quality monitoring across the country, caution needs to be taken with regard to maintenance of monitoring stations and resulting erroneous data. In December 2015, the CPCB's monitoring facility collected air quality data at the Indian Institute of Technology Madras (IIT-M) campus and reported the value of $PM_{2.5}$ to be almost eight times higher than the prescribed standard.

IIT-M has an enviable green cover and previously recorded values have never exceeded prescribed limits in this area. Upon investigation of this error in readings, it was found that residual effects from the Chennai floods played a role as "some of the electrochemical sensors had been affected by moisture and internal oxidation during the floods." Power outage and voltage fluctuations corrupted software[132]. It was also reported that a private company outsourced with the responsibility to maintain monitoring stations didn't turn off the link with the network while stabilizing the equipment[133]. This raw and incorrect data was uploaded to the real-time CAAQM website without validation and caused the media to take notice. IIT-M had issued an official statement noting that the data uploaded by the CPCB for that period could not be relied upon and was misrepresentative of the air quality in that area. In another instance in April 2017, the Maharashtra Pollution Control Board (MPCB) brought up issues with the air quality data published by SAFAR for Mumbai. SAFAR data showed air as toxic which the MPCB discounted, with officials citing calibration lags in the former's data as it didn't account for Mumbai's humidity and wind speed among others. SAFAR officials maintained that there are no quality issues[134].

According to expert input for this paper, the quality and quantity of air quality data available in the public domain needs improvement, across urban and rural areas. Quality data is very sparse for rural areas in the country, and $PM_{2.5}$ monitoring must also be expanded. Further, current data doesn't reflect dose-response information for individual chemical components of $PM_{2.5}$, which would be useful in conducting epidemiological studies. While the quality of data is improving in urban areas, the network needs to be further expanded across all cities and states in the country. This would make the task of understanding the nature and distribution of population exposures less challenging.

Aside from data quality, other challenges identified in this space include finding the right collaborators and unavailability of current data. Procuring access to recent data is usually troublesome. This data is often not uniform temporally and spatially, has considerable missing data points and virtually no monitoring for certain important parameters. Often data is not available at a single source and therefore, compiling data for analysis poses a challenge. A lack of reliable time-series data makes it difficult to carry out epidemiological studies health risks including dose-response.

4.3 Awareness of health risks of air pollution exposure

Awareness among the general public about air pollution and health risks associated with it has generally been low in India. High pollution levels in Beijing see people wearing air filter masks, which hasn't necessarily been the case in New Delhi[135,136]. The first wave of air pollution episodes saw expats and Indian elites adopting air filter masks[137]. Following Diwali celebrations in 2016, the national capital saw a prolonged aftermath of poor air quality. Subsequently, sales of air purifiers and filter masks sored in the national capital region[138,139]. Parents concerned for their child's health in particular paid attention to these options[140]. This could also be seen as a function of class; urban upper-middle classes were better equipped in knowledge and resources to seek solutions to poor air quality, in comparison to urban poor classes[141]. However, awareness is now picking up[141,142].

There are few research studies that have explored perceptions, awareness and knowledge on air pollution and its health impacts in India as well as any developing countries. Niphadkar et al (2009) conducted a study to assess awareness among urban residents on indoor air pollution and associated respiratory diseases in Mumbai in 2009. They found the population (patients and control population) studied was grossly unaware about indoor air pollution (through a questionnaire with a scoring mechanism in place). Their results didn't show any statistically significant difference among those with higher educational qualifications.[3]

Rao et al (1999) conducted interviews to assess perceptions of effects of environmental pollutants (including air pollutants) in Hyderabad, Andhra Pradesh and identified the need for "aggressive environmental education."[143]

Ramaswami et al (2016)[144] studied social and infrastructural factors affected MSW burning at the neighbourhood level. They found that despite being aware of the health risks, waste-handlers continued to burn MSW – it was low on their priorities. However, awareness about the legal ban was low among handlers and residents.

Clean Air India Movement (CLAIM) conducted Citizens' Awareness and Attitude Survey found that most people believe it's the government's responsibility to clean the air. The survey found participants lacking in knowledge about the ways in which vehicles contribute to pollution[145,146]. Expert inputs received also reflected poor knowledge among the general public; they may know air pollution is harmful to health but they lack clear understanding of how it is harmful and what the long term effects are.

The National Air Quality Index (AQI) was launched in October 2014 by the Union Minister for Environment, Forestry and Climate Change. As "one number-one colour-one description", the AQI was put forth as a tool which communicated near real-time (AQI CPCB) air quality in simple and understandable terms for the common man[147,148]. There isn't published literature available to measure the extent to which the ministry's efforts have been successful in boosting public awareness about air pollution exposure and associated health risks. The AQI itself is accessible online (hosted on Central Pollution Control Board website), on display boards in public areas, and through a mobile application- Sameer[149,150]. The union Ministry for Environment, Forestry and Climate Change announced the intent

[3] Sources responsible for indoor air pollution were categorized into factors, each of which was assigned marks based on potential to cause ill-health. Participants - asthmatic patients and control subjects - were scored for every correct answer, with a threshold for pass and fail.

to launch a "massive people-oriented awareness campaign", to check air pollution in 2015[151]. However, there have been no follow-up articles on activities undertaken towards this.

Initiatives by concerned citizens led to action on air quality and garnered heightened media attention which contributed to awareness among the public. For instance, a Public Interest Litigation was filed behalf of three toddlers by their parents which petitioned the Supreme Court to take action against the dangerous levels of air pollution[146]. Subsequently, in November 2016, in response to this PIL, the Supreme Court ordered a blanket ban on sale and stocking of firecrackers in the national capital region[139].

Addressing deficiencies in data can drive change

Several of the barriers listed above are ones that can be surmounted with coordinated effort across central and state governments with appropriate external support provided by relevant agencies. Of all the barriers, however, addressing the deficiencies in data may be the most important in ensuring all aspects of air quality and health going forward, be it plugging gaps in the research evidence, or raising awareness of the health impacts with the general public. For instance, strengthening the MCCD reporting system in public and private hospitals, coupled with the implementation of digitized records could go a long way in addressing one off the key recommendations of the Steering Committee on air pollution, which was the establishment of sentinel surveillance sites. These sites were to serve as outposts, generating daily, monthly and annual evidence on the health impacts of air pollution, through rigorous data collection in facilities, coupled with air quality data from the CPCB's monitoring network. The availability of such data could lead to a sea change in behaviour especially around episodic pollution events, with advisories issued on the basis of the current status of health impacts through hospital admissions, outpatient visits, and deaths. Similarly, the availability of better quality air pollution data, delivered through various media to the public could raise awareness manifold than where it is currently. The current approach from an academic's perspective is skirting around these challenges to generate effective and sound research outputs. Addressing the issue long-term, and in a sustainable way both in letter and in spirit, will require a data revolution on air quality of a kind that is currently not on the horizon.

5. Conclusions and Way Forward

With the multiplicity of sources, modes of exposure and complexity of outcomes associated, there is no easy solution to address the problem of air pollution in India. Addressing it will require an evidence-informed, multi-sectoral approach to policymaking that aims to maximize exposure reductions[10]. While several aspects of a health-centric air pollution policy are currently under consideration, there are aspects of the issue that require more creative thinking and solution development. In previous sections, we have outlined the scale of the issue and barriers to effective action on air pollution. Taking those into consideration, we outline below suggestions for areas of intervention to address what is now a key risk factor not just to India's health but also to its economy.

5.1 Leveraging existing resources to carry out large scale health impact studies

Our review, as well as others conducted in recent years, has shown that while there is a strong evidence base for household exposures, the evidence base for ambient exposures require significant strengthening. In particular, the evidence base for pregnancy outcomes, cardio-pulmonary diseases, cardio-metabolic diseases, inter-generational effects, require further examination. While there is considerable global evidence already available for these health outcomes, these studies were conducted in comparatively low exposure settings that are vastly different from the annual average exposure to particulate pollutants experienced in India. This is reflected in the Integrated Exposure-Response (IER) curves developed for the Global Burden of Disease comparative risk factor assessment[7,152].

As stated in Cohen et al. (2017), the lack of long-term cohort studies of $PM_{2.5}$ associations with mortality in countries with high levels of pollution like India, ensures that the magnitude of the excess relative risk associated with higher levels of $PM_{2.5}$ remains uncertain. Work is underway in several cohorts in China and these are likely to publish in the next 1-2 years on the impact of $PM_{2.5}$ on cardio-metabolic and cardio-pulmonary diseases. In India, at the time of writing this white paper, there were only a handful of long-term studies underway, mostly focused on outcomes associated with household air pollution such as the TAPHE study in peri-urban and rural Chennai, the APPLE study in Bengaluru, and the CHAI study in peri-urban Hyderabad. Given the differences in sources of pollution across developed, and even developing countries, it is essential to carry out long-term exposure studies. There is also a paucity of evidence on the impact of early life or pre-natal exposures including pre-term births, low birth weight in babies, developmental outcomes in children, and inter-generational effects.

While cohort studies can be expensive to establish and operationalize, there is of course the possibility of leveraging existing resources to reduce costs considerably. There are several birth cohorts that have been functioning for over a decade in the country, utilizing data from which could provide valuable evidence on early life exposures, developmental outcomes, and inter-generational effects. There are also cohorts that have been designed exclusively to study cardiovascular epidemiology, and the data from these as well could be utilized. Some studies that could be utilized in such an evidence generation effort include the Pune Maternal Nutrition Study (PNMS), New Delhi Birth Cohort (NDBC), Prospective Urban Rural Epidemiology (PURE) study, and others. Given the paucity of funding for biomedical research in India, and the vast resources needed to establish new long-term studies, it would be wise to utilize existing cohorts as much as possible in the development of the evidence base on air pollution and health impacts.

5.2 Impact evaluation of policy interventions

The increased media attention afforded to air pollution over the last two years has led to several policy initiatives led either by the judiciary or the legislative. Many of these have resulted from directives issued by the Supreme Court of India and the National Green Tribunal, a result of either suo motu action taken by the courts, or public interest litigations filed by concerned citizens. While the directives issued by the courts have led to action locally in Delhi, and increased awareness among citizens, the science behind some of those decisions is questionable at best in terms of improving air quality in the region. Some examples of this include:

a. A directive from the Supreme Court to divert non-destined trucks from entering Delhi. State governments were instructed to direct these trucks around the capital using peripheral highways instead, increasing their travel time in the region[153].
b. The National Green Tribunal's ban on diesel vehicles over 10 years from plying in the National Capital Region[154].
c. The Delhi Government's "Odd-Even" scheme for road rationing on heavily polluted days.

Subsequent research has shown that the odd-even scheme was questionable in its efficacy[155], but several other initiatives undertaken by the legislative or the judiciary, including the ones listed above, have not been subjected to scientific scrutiny either pre- or post-implementation. Effective policy implementation requires accountability by means of monitoring and evaluation, and till date, there is very little work published on the efficacy of various actions taken over the last 20 years to improve air quality in India, either in the short or long term, bar perhaps the introduction of Compressed Natural Gas vehicular fuels in Delhi[156,157]. It would also be relevant to examine the impact on health outcomes of these policy interventions. There have been several recent efforts undertaken locally in the national capital region such as the Graded Response Action Plan, and other efforts to reduce emissions nationally such as revised emissions standards for brick kilns, and thermal power plants. Examining the impact of these regulations on mortality and morbidity would be essential to judge the efficacy of the policy framework and implementation.

5.3 Low-cost monitoring & citizen science for data collection

As covered in earlier sections, there exist several constraints in the quantity and quality of regulatory-grade air quality data available in the country. While the CPCB has focused on improving the status by installing continuous ambient air quality stations in around 35 cities till date, this coverage is hardly representative of the cities where the air quality is currently measured, let alone the entire country. Vast swathes of urban India remain covered only through the NAMP, through which data is collected manually twice a week, and there is effectively no monitoring in rural India. With no discernible effort being made by many SPCBs in expanding this capacity, the availability of data on particulate and gaseous pollutants looks to remain inadequate in the medium term. This lack of data poses a serious challenge both from a research and advocacy perspective.

Organizations have aimed to plug the gap in monitoring by establishing their own low-cost monitoring networks with sub-$1000 particulate and gaseous sensors, including IndiaSpend[158], and others have aimed to aggregate the available data for easier access and understanding, such as the Hindustan Times[159], and the Smokey Bot[160]. There are challenges however with using low-cost sensors including their performance in changing temperature and humidity patterns, their decay over time, and the need for regular re-calibration[161]. Concerns over data accuracy, calibration and decay can be mitigated to some extent by ensuring regular collocation with regulatory grade instruments to develop accurate correction factors, and frequent maintenance. Once this is done, data generated by a low-cost sensor can be a useful guide in documenting trends in air pollution (particulate or gaseous). These sensors, when accurate, can also play a role in developing a more granular exposure profile at a community level, something that isn't possible with ambient air quality monitors. These granular exposure profiles can then be utilized to identify exposure hotspots for immediate action.

The growing use of smart watches and activity trackers also presents an opportunity for both improved health data collection as well as personalized messaging around air quality. Tools like research kit, from Apple, enable researchers to access large swathes of data that is anonymized and can be utilized for epidemiological studies. Coupling this data with the increasingly complex and granular exposure models that are being developed opens up new possibilities in air pollution epidemiology. Additionally, there could well be smartphone and smartwatch apps that could be developed going forward, which could provide, based on your own medical history, personalized health advisories related to air pollution (e.g. reducing outdoor exposure on a bad air quality day for a hypertensive person), or to even suggest commuting routes with better air quality. While the possibilities in this space only continue to grow with the large amounts of data being collected on a regular basis, ethical issues around the collection and utilization of these data will need to be examined in great detail.

5.4 Localized evidence generation

Our analysis of the health evidence shows us that many of the studies conducted on ambient air pollution exposure are limited to the metros such as Delhi and Mumbai, with little work carried out in tier 2 and 3 developing towns, or in polluted industrial hotspots. This is also reflected in the media coverage of the air pollution issue, which has been Delhi-centric for the most part. There is a need to develop an evidence base in tier 2 and 3 towns as well as in industrial hotspots for the following reasons:

a. The Indian Government's smart cities program lists many tier 2 and 3 cities which currently have no monitoring capacity whatsoever. Many of these cities are already industrial hubs where increased investment and population growth will only result in poorer air quality, and the resultant impacts on health. Developing short-term, impactful studies on health in rapidly industrializing tier 2 and 3 towns will aid in air quality becoming a serious consideration in their master plans and future development. Studies conducted here need not be large in scale or complex in design. Even simple, time-series or cross-sectional studies could have tremendous impact, with the data for these already available to some extent.

b. The responsibility for enforcement of regulations on air quality lie with the SPCBs, and thus far, many have yet to take any serious action on worsening air quality. This is due to several factors including a lack of technical capacity, and the legal framework in which they operate[162]. That said, few states, if any, have actually developed an action plan to meet the NAAQS, and that calls into question their efficacy as regulators. As recently as December 2016, the NCR Planning Board, under the Chairmanship of the Union Minister for Urban Development, requested all 5 NCR states[163] to submit action plans for air pollution, with none having done so yet. Development of a local evidence base can aid in advocacy with the SPCBs to meet the NAAQS and take stronger action on polluting industries.

c. The CPCB, through the Comprehensive Environmental Pollution Index (CEPI), has classified several industrial hubs in the country as severely or critically polluted. Many of these sites have not just high particulate levels, but also high levels of volatile organic compounds and ozone, given the nature of the industries present. The populations living around these clusters are often below the poverty line, and have little to no access to health facilities that can treat the symptoms of air, water and chemical pollution. Given that there is a moratorium on new development hubs classified as critically polluted, and since these industries are often the direct targets stack emissions standards, developing evidence on local impacts can ensure effective implementation of emissions standards, and provide a basis for an environmental justice movement. It can also ensure that already overloaded ecosystems do not bear the burden of additional industrial pollution.

The development of localized evidence is more important than ever as it is an enabler for decentralized action. The federal nature of India's government ensures that much of the attention remains on Delhi, while the power is really with State governments. Ensuring that they are held accountable in the enforcement of existing regulations, and have a forward thinking approach in the management of air quality, can only be done by developing local evidence that can showcase the current or potential health impacts of populations living there. The focus till date has been on pushing action from the top down, but perhaps a reorientation in approach would be more effective going forward.

5.5 Awareness generation through strategic communications

As documented in Section 4 of this report, there is little evidence of the awareness of air pollution health risks in India. Anecdotal evidence collected through our various field visits in urban and rural India informs us that while the public may be aware that exposure to air pollution leads to symptoms such as watery eyes, coughing and shortness of breath, there is little awareness of links to respiratory and cardiovascular illnesses, and mortality associated with air pollution exposure. Indeed, this isn't limited to the general public, as seen in a brief Knowledge-Attitude-Practice survey carried out by PHFI in 2015 (unpublished), with around half of the physicians interviewed reporting that they either do not view air pollution as a risk factor for ill health, or when they do, don't view it as a modifiable risk factor that needs to be considered in diagnosis or in advice to patients. Studies on perceptions and awareness need to be conducted on a larger scale to generate solid evidence, but in the meantime, there is much work that can be done with the information in hand. These include:

a. Awareness generation and behavior change communication amongst rural communities still using biomass cookstoves. Studies[164–166] have shown that the issue of stacking continues to be a challenge in reducing rural exposures from biomass cooking fuels. One of the proposals outlined in the Ministry of Health and Family Welfare Steering Committee Report to address this issue was to utilize the levers of the public health system to disseminate information about the health effects of biomass fuels, and the benefits of using cleaner fuels for cooking. The information was to be developed and disseminated through the network of frontline health workers who are currently engaged with the National Health Mission. The development of material in vernacular languages, training of ASHA workers and dissemination of this information in partnership with the Central and State Ministries of Health would be a great step forward in reducing rural exposures from cooking and heating.
b. Engaging organizations working on mobilization and strategic communications to carry out a large scale public awareness campaign. Air pollution is not on the list of priority issues that citizens are concerned about on a daily basis. Creating broad based awareness of the impact of air pollution on health, and identifying pathways for action at an individual and community level can both empower citizens to take action as well as demand their right to clean air.

c. Engaging the physician community through capacity building and advocacy. Medical professionals are trusted interlocutors with the general public and the lack of awareness within the medical community of the health impacts of air pollution and implications in terms of clinical diagnosis and disease management is a lacuna that needs addressing. Developing and integrating material on environmental exposures into the medical curriculum, and supplementing the knowledge of current practitioners through short-term training programmes would go a long way in addressing the knowledge-action gap with both physicians and their patients. Experiences from the US and Australia have also shown the importance of a unified voice from the health sector speaking on issues of environmental pollution.

5.6 Governance and evidence for effective policymaking

The multi-sectoral nature of the problem naturally requires that solutions consider multiple angles of the problem before development of policy. Practice, however, differs from theory on this aspect, with siloed decision-making on policies that have impacts across sectors an inevitable consequence of established frameworks for inter-sectoral collaboration. An example of this would be the lack of consideration provided to health in environmental policy related to critically polluted areas or on emissions standards. Considerations of the impact on health are the basis on which these policies are framed, but the lack of participation from health sector representatives is telling of the nature of the process followed. While an initial effort is being made in India by the Ministry of Health and Family Welfare, through its Standing Committee on Air Pollution that is to be established, much needs to be done to mainstream inter-sectoral collaboration on air pollution policymaking. Work on best practices followed elsewhere could aid in this effort, but what could also do so is outlining the economic case more strongly, thereby strengthening the convening power of the health sector.

As outlined in Section 3, while there have been a few studies conducted on the economic burden associated with air pollution exposure, all of these studies only account for lost productivity due to premature mortality. None of them take into account the costs associated with treatment and management of air pollution-derived diseases. In a country where over 70% of expenditure on health is out of pocket, with the vast majority of that expenditure spent on medicines for treatment of chronic diseases, the potential impact of air pollution on the impoverishment of many hundreds of thousands every year is not overstated[167]. Since the National Commission on Macroeconomics and Health in 2005, there has not been any comprehensive costing studies carried out to estimate the burden of poor health on families around the country. Proxies are developed through surveys such as the NSSO, but precise calculations of the health costs could prove to be a powerful argument for more stringent policy development and implementation. The factoring in of these new costs could also provide better numbers for benefit-cost analyses of policies and interventions.

Finally, in the last few weeks, there have been stories in the media speaking about the financial challenges associated with the uptake of the Prime Minister's rural LPG scheme. These need to be studied in detail to identify opportunities for more effective policy, but carrying out work to examine not just the behavioural but also the financial barriers to adoption of cleaner fuels where supply is available would be an area to consider given the scale and speed of interventions being deployed.

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