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Review article

Air pollution health research priorities for India: Perspectives of the Indo-U.S. Communities of Researchers

Terry Gordon[a], Kalpana Balakrishnan[b], Sagnik Dey[c], Sanjay Rajagopalan[d], Jonathan Thornburg[e], George Thurston[a], Anurag Agrawal[f], Gwen Collman[g], Randeep Guleria[h], Sneha Limaye[i], Sundeep Salvi[i], Vasu Kilaru[j], Srikanth Nadadur[g,*]

[a] Department of Environmental Medicine, New York University School of Medicine, Tuxedo, NY, 10987, United States of America
[b] Department of Environmental Health Engineering, Faculty of Public Health, Sri Ramachandra University, Porur, Chennai, 600116, India
[c] Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India
[d] Department of Internal Medicine, Case Western Reserve University, 11100 Euclid Ave, Cleveland, OH 44106, United States of America
[e] RTI International, Research Triangle Park, NC, United States of America
[f] CSIR Institute of Genomics and Integrative Biology, Delhi University, New Delhi, India
[g] Division of Extramural Research and Training, National Institute of Environmental Health Sciences, Research Triangle Park, NC 27709, United States of America
[h] All India Institute of Medical Sciences, New Delhi, India
[i] Chest Research Foundation, Pune, India
[j] Office of Research and Development, U.S. E.P.A., Research Triangle Park, NC 27711, United States of America

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1. Basis for document on air pollution research gaps in India

This white paper represents the culmination of over 2 years of efforts and bilateral dialog between scientists at Indian governmental agencies, U.S. federal agencies, and academic institutions in India and the U.S. to develop strategies to mitigate air pollution-related health effects and to promote collaborative research initiatives to accelerate a scientific knowledge base that may help accomplish this goal. A series of virtual meetings initiated by the National Institute of Environmental Health Sciences (NIEHS) led to the formation of a Communities of Researchers (CoRs) organized around three themes of health research, exposure assessment, and training. Virtual meetings and visits of U.S. scientists at laboratories in India were held over 18 months. The CoRs were successful in identifying gaps in research in the three theme areas and providing research recommendations that were discussed at length at a joint Indo-US Workshop to "Explore Bilateral Research Opportunities to Address Air Quality and Health Issues" in New Delhi, India on November 8–10, 2016. This workshop was jointly sponsored by NIEHS and the Indo-US Science and Technology Forum (IUSSTF) with additional support provided by the Centers for Disease Control (CDC) and the Research Triangle Institute (RTI) and US Embassy, New Delhi, India. The information gathered through all these efforts, including the bilateral workshop, provided the direct basis of this document. The workshop participants also thoroughly reviewed the recent Indian Ministry of Health and Family Welfare report (MHFW (Ministry of Health and Family Welfare), 2015), that provided a comprehensive account on the status of air quality-related health issues in India, and targeted actions aimed at providing the largest exposure reductions (instead of traditional approaches to air quality management) to address the substantial national health burden that can be attributed to both ambient and household air pollution in India (Sagar et al., 2016).

A core group of eight scientists representing each CoRs, through multiple conference calls and exchange of information, developed a set of charge questions for broader discussion at the workshop in New Delhi with the participation of about 100 scientists in the areas of health, exposure and education. The questions were based on the previously identified gaps in knowledge to facilitate a focused discussion around the defined themes of exposure assessment and air pollution

* Corresponding author.
E-mail address: nadadurs@niehs.nih.gov (S. Nadadur).

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health research. Each breakout group consisted of approximately 40 scientists that separately and together deliberated on the major questions. An additional goal was to identify potential opportunities for collaboration and exchange of expertise between the U.S. and India. These collaborations would integrate exposure and health outcomes analyses to demonstrate the health burden due to high levels of air pollution in the Indian population at large. Discussions were also aimed at developing a focused set of research priorities with shared expertise that may be jointly supported by the U.S. and India and identifying critical needs in training and capacity building with advanced technical expertise in air pollution exposure assessment, modeling, and population health research.

2. Background

According to the global air pollution observatory maintained by World Health Organization (http://www.who.int/gho/phe/outdoor_air_pollution/en/), 13 of the world's 20 cities with the highest annual levels of particulate matter < 2.5 μm in diameter ($PM_{2.5}$) are in India, with its capital city New Delhi leading cities within India. Given the challenges in regulation, increasing economic activity, and industrialization across the country, a progressive worsening of ambient air pollution (AAP) in these Indian cities is nearly certain. To add to this burden of AAP, nearly 76% of rural households are dependent on solid biomass as cooking fuels and thus experience household air pollution (HOAP) exposures that greatly exceed World Health Organization (WHO) Air Quality Guideline (AQG) levels (Balakrishnan et al., 2013).

The report on Global Burden of Disease (GBD) estimates 2 million premature deaths annually in India due to AAP and HOAP exposure (GBD (Global Burden of Disease), 2016). This places air pollution near or at the top of the list of all known risk factors for ill health in the country, above high blood pressure, smoking, child and maternal malnutrition, and risk factors for diabetes. However, given the current demographics in India skew towards a more youthful population, there may be a masking of the cumulative cardio-pulmonary effects of air pollution exposures, that will only be observable as latent effect decades later. If $PM_{2.5}$ levels were to remain constant at current levels, it would suggest that the per-capita mortality attributable to $PM_{2.5}$ in India would increase by 21% in the year 2030, aided and abetted by a dramatic increase in the age > 50 population. To even keep $PM_{2.5}$-attributable mortality rates (deaths per 100,000 people per year) constant, the average $PM_{2.5}$ levels would need to be reduced by 20–30% over the next 15 years, particularly to reduce the increases in $PM_{2.5}$-attributable mortality in the elderly. Thus, significant improvements in indoor and outdoor air quality are required to produce a significant reduction in $PM_{2.5}$-attributable mortality in India (Apte et al., 2015).

The strategic direction for air quality improvement in India is hampered by the lack of adequate inventories on emissions and uncertainty in the pollution mixture in ambient air (Garaga et al., 2018). It is likely that both factors differ from what is observed in developed economies of the West. Source emissions can differ significantly in composition, but only limited research in India has addressed the role of $PM_{2.5}$ source and composition on adverse health effects. Initial results suggest that emissions from fossil fuel combustion are of greater health consequence, per μg/m^3 of $PM_{2.5}$, than from biomass or windblown sources (Thurston and Balmes, 2017). However, emissions from indoor cooking using biomass contribute to approximately one-quarter of the mass of ambient $PM_{2.5}$ pollution in the country, suggesting India-specific solutions are needed to additionally address these sources (Chafe et al., 2014). In India, exposure to ambient and household air pollution forms a continuum, owing to the significant penetration of AAP indoors and the substantial contribution of HOAP to outdoor levels. Thus, indoor and outdoor sources cannot be considered in isolation or examined in a compartmentalized manner, but rather as a continuum (Balakrishnan et al., 2014) with a common impact on health outcomes and common approaches to measure, quantify, and control diverse sources that contribute to this problem.

The risk of exposure to air pollution occurs in both rural and urban populations, however, the routine monitoring of air quality, in India and many countries across the globe, is nearly exclusively confined to urban centers (Garaga et al., 2018). This makes the task of understanding the nature and distribution of nationwide population exposures much more difficult. Another important aspect relates to the spectrum of exposures. In India, exposure to locally strong sources such as biomass cooking, trash burning, street food carts, and small industries contribute to large spatial gradients in exposures that are poorly captured by outdoor ambient levels measured at central sites (Pant et al., 2016). Given the high levels of ambient $PM_{2.5}$ in metropolitan areas, where the contributions of HOAP may be dissimilar compared to rural settings, derived exposure-response relationships will be different and need to be addressed adequately in estimating health impacts at the national level (i.e., the $PM_{2.5}$ mixtures are likely to vary significantly between urban and rural populations, and one can also expect the exposure-response relationships to also vary between these two populations). Further considerations in India include additional exposures to air toxics and heavy metals, which are highly prevalent in urban industrial clusters. Several toxic pollutants are co-emitted along with PM and contribute to adverse health risks (Pant et al., 2016; Guo et al., 2017). A comprehensive environmental health assessment should consider factors such as toxicity, emissions volume, potential population exposed, exposure pathways, and health outcomes.

3. Air pollution sources, concentration, and exposure scenarios in India

This section provides a background summary on AAP and HOAP exposures relative to the major sources and emissions in India. Understanding of the unique exposure profiles to air pollution is critical to better understanding of the magnitude of health effects attributable to air pollution and provision of recommendations.

3.1. Ambient air pollution (AAP)

The rapid growth in the industrial, power, and transportation sectors nationally, combined with growth in urbanization, both planned and unplanned, have contributed to the rapid increase in AAP levels in India. Together, the substantial growth in the number of automobiles and coal-based power production are expected to significantly contribute to the worsening of air quality in the next decade in India. For more than half of the cities included in the National Air Quality Monitoring Program (NAMP), two critical measures, $PM_{2.5}$ and PM_{10} (daily and annual levels), routinely exceed Interim Target-1 levels (75 and 150 μg/m^3 for daily and 35 and 70 μg/m^3 annually, respectively), as designated by the WHO.

The assessment of the contribution of emission sources to air pollution is inadequate in India, and limited data are available for sulfur dioxide (SO_2), nitrogen oxides (NOx), and carbon monoxide (CO). Although a decline in the levels of SO_2 has been observed in many cities, these levels are still unhealthy. While the monitoring of ambient air pollution has increased, at least in major cities, there are substantial gaps in monitoring in large parts of the country, especially in rural locations (http://www.cpcb.nic.in/RealTimeAirQualityData.php). Given the critical need to provide a national map of air pollution, remote sensing methodologies are increasingly relied upon and felt to be critical to provide exposure-health effects data and to develop source apportionment information vital to assessment of intervention strategies. Indeed, satellite modeling of aerosol optical depth (AOD) has demonstrated a stark picture of AAP in both urban and rural areas. The Indo-Gangetic Plain registered critical levels of $PM_{2.5}$ (mean annual $PM_{2.5}$ > 50 μg/m^3) attributable to multiple ambient sources, the use of biomass and coal for household cooking and heating needs, and the burning of agricultural residue (Dey et al., 2012).