Environ Sci Pollut Res (2017) 24:6399–6413
DOI 10.1007/s11356-016-8264-y

TREND EDITORIAL

Airing 'clean air' in Clean India Mission

T. Banerjee[1] · M. Kumar[1] · R.K. Mall[1] · R.S. Singh[2]

Received: 28 March 2016 / Accepted: 13 December 2016 / Published online: 30 December 2016

Abstract The submission explores the possibility of a policy revision for considering clean air quality in recently launched nationwide campaign, Clean India Mission (CIM). Despite of several efforts for improving availability of clean household energy and sanitation facilities, situation remain still depressing as almost half of global population lacks access to clean energy and proper sanitation. Globally, at least 2.5 billion people do not have access to basic sanitation facilities. There are also evidences of 7 million premature deaths by air pollution in year 2012. The situation is even more disastrous for India especially in rural areas. Although, India has reasonably progressed in developing sanitary facilities and disseminating clean fuel to its urban households, the situation in rural areas is still miserable and needs to be reviewed. Several policy interventions and campaigns were made to improve the scenario but outcomes were remarkably poor. Indian census revealed a mere 31% sanitation coverage (in 2011) compared to 22% in 2001 while 60% of population (700 million) still use solid biofuels and traditional cook stoves for household cooking. Further, last decade (2001–2011) witnessed the progress decelerating down with rural households without sanitation facilities increased by 8.3 million while minimum progress has been made in conversion of conventional to modern fuels. To revamp the sanitation coverage, an overambitious nationwide campaign CIM was initiated in 2014 and present submission explores the possibility of including 'clean air' considerations within it. The article draws evidence from literatures on scenarios of rural sanitation, energy practises, pollution induced mortality and climatic impacts of air pollution. This subsequently hypothesised with possible modification in available technologies, dissemination modes, financing and implementation for integration of CIM with 'clean air' so that access to both sanitation and clean household energy may be effectively addressed.

Keywords Aerosol · Climate change · Clean energy · Health · Sanitation · Swachh Bharat

Responsible editor: Philippe Garrigues

✉ T. Banerjee
tb.iesd@bhu.ac.in; tirthankaronline@gmail.com

R.K. Mall
rkmall@bhu.ac.in

R.S. Singh
rssingh.che@itbhu.ac.in

[1] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221005, India

[2] Department of Chemical Engineering and Technology, Indian Institute of Technology (BHU), Varanasi, India

Introduction

Increase in global population with considerable environmental footprint has put unprecedented impacts on Earth's carrying capacity and natural resources. Although, general concern for environmental sustainability has improved considerably over the last few decades, implementing the concept at grass-root level still remains a challenge. Access to proper sanitation and clean energy is a distant dream for many rural households. Like many other countries, India is still grappling with fundamental issues like sanitation, hygiene and access to clean energy especially for rural communities. Therefore, taking the pledge for a cleaner environment, under auspicious guidance of Prime Minister Narendra Modi, entire India voluntarily took the biggest-ever cleanliness drive called "*Swachh Bharat Mission*" or Clean India Mission (CIM). The CIM is unique in many aspects as it is projected as a massive mass movement of the entire country. The nationwide campaign was launched on the birth Anniversary of Mahatma

Gandhi (October 2, 2014) and aspire to achieve a 'Clean India' by his 150th birthday anniversary in 2019. The entire campaign includes 4041 towns for cleaning streets, roads and other places of public interests for the development of an aesthetic environment. Inclusion of people from almost every hierarchical domain of the society i.e. students, government employees, social workers coupled with celebrities makes the mission entirely novel. The entire mission appears to be a drive for promoting awareness among individuals along with improvement of municipal machinery for effective solution to household sanitation by spending nearly US$ 9.7 billion, 100 times more than the India's Mars Orbiter Mission (MUD 2014; isro.gov.in). Entire mission addresses social transformation by eliminating open defecation and manual scavenging, induce behavioural changes in promoting healthy sanitation practises, create awareness on sanitation, public health issues and participation.

Present submission explores the scope for possible inclusion of 'clean air' concept within 'Clean India Mission', so that people may well be informed regarding adverse health impacts of air pollutants and thereby, encouraged to use clean fuel for domestic consumption. Existing policies and legislations till now appeared insufficient in regulating population exposure to airborne toxic chemicals. The system gets additionally complicated through inclusion of different short-lived pollutants which substantiate associated health risks. Implications of airborne particulates and trace gases on human health have been investigated extensively (Apte et al. 2015; Kumar et al. 2015a; WHO 2014a; Schmale et al. 2014). In most instances, airborne particulates composed of organic and elemental carbon; salts of sulphates and nitrates originate from improper burning of biomass and fossil fuels contribute significantly in deteriorating human health. It has been argued by Schmale et al. (2014) of possible prevention of 2 million premature deaths (by 2040) through consideration of clean air, while it is also vowed on avoiding 40 million additional deaths (by 2030) only by reducing methane, black carbon (BC) and other pollutant emitted from household cooking. Globally, exposure to air pollution is held responsible for causing one in eight premature deaths (7 million deaths in 2012) particularly associated to heart diseases and stroke (Fig. 1). Most of these premature deaths were associated to indoor air pollution (61.4%, 4.3 million deaths in 2012; WHO 2014a) emitted from cooking over conventional fuels while ambient air pollution was held responsible for 3 million additional premature deaths (WHO 2016). Indoor air pollution was also accountable for 50% of children deaths under age five (WHO 2014a). Conventional household energy practises are responsible for emitting toxic levels of air pollutants which pose health risks in terms of exposure, high risks of burns, poisoning and additionally contribute to outdoor pollution. In a current estimate, 53% global woody harvested biomass are used as wood fuel for heating and to meet energy demands, while for India, the estimate is over 90% (FAOSTAT 2013). Further, globally around 3.0 billion people

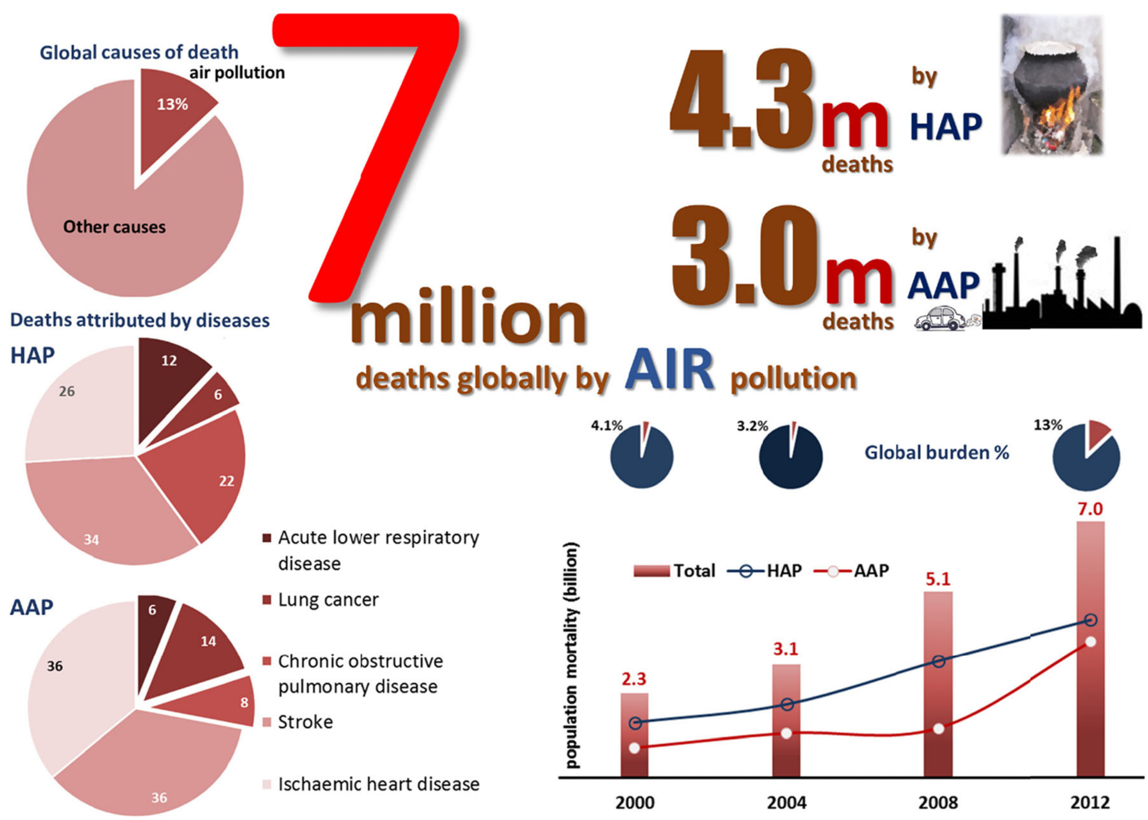

Fig. 1 Global death attributable to air pollution Note: *HAP* household air pollution, *AAP* ambient air pollution. Data for AAP-induced and total mortality for 2008 is estimated. The *pie chart* represent the global burden of disease (%) in corresponding years (source: WHO, 2007; 2008; 2009; 2014a, 2016)

use open fires and biomass stoves while in India, approximately 700 million population (60% of entire population) consider solid biofuels and traditional cook stoves for domestic cooking (WHO 2014a; CEEW 2015).

The report on WHO global burden of disease identifies South-East Asia and Western Pacific region accounting major proportion of global mortality associated to household (HAP, 47% of global mortality, 3.3 million deaths; WHO 2014a) and ambient air pollution (AAP, 27%, 1.9 million deaths; WHO 2016). Only in South East Asia, exposure to AAP is responsible in causing 0.79 million premature deaths (11% of global mortality), while 1.7 million (40%) deaths are linked to HAP, mostly by stroke or ischaemic heart diseases (Fig. 2). In addition to this, global monetary loss due to air pollution can be as high as \$225 million in a year (World Bank 2016). Anthropogenic emissions in the form of smoke, particulates and harmful trace gases interact with key physiological functions with varying degrees of toxicological impacts. Airborne particulates mainly in finer range ($PM_{2.5}$) are of special concern due to its critical roles in inducing mortality. A 31% rise in death tolls attributed to ambient $PM_{2.5}$ has been reported within last 2 decades (1990 to 2013). Fine particulate associated risk of mortality was also projected to increase in 2013 (5.3% deaths) compared to 1990 (4.7% deaths; World Bank 2016). Entire South Asia acts as a potential reservoir of $PM_{2.5}$. Exemplifying the Indo-Gangetic Plain in South Asia is burdened with high aerosol loading with annual $PM_{2.5}$ concentration of 81 ± 55 μgm^{-3} for 2014–2015 (AOD_{550}: 0.5 to 1.4; Murari et al. 2015, 2016; Kumar et al. 2015b; Sen et al. 2014). It is well argued that reducing airborne particulate from 70 to 20 $\mu g/m^3$ may contribute 15% reduction in air pollution related mortality within the region (WHO 2014a). Apart from mortality, many other physiological disorders induced by airborne particulates include decreased semen quality (Zhou et al. 2014), chronic kidney disorder (Gresham et al. 2014), dry eye syndrome (Bhatnagar et al. 2014), peptic ulcers with probability of developing gastric ulcers (Lai et al. 2014), skin cancer (Goldsmith 1996) and intestinal disorder (Beamish et al. 2011). Children are also highly susceptible to the impacts of aerosols due to incomplete development of their immune systems (Bateson and Schwartz, 2007).

Violation of air quality standards often resulted from unsustainable policies and practises. This ultimately create the scope of constituting proactive policy trade-offs or synergies (Bhatt et al. 2015). Exemplifying, implications of CIM objectives require installation of a proper and scientific solid waste treatment facilities, which in current scenario only managed by open unregulated combustion at waste collection site or by open disposal without considering possible environmental consequences. This is a typical case for Delhi and other Indian municipalities, where burning of solid waste is considered to be a significant factor for ambient air pollution (firepost.com 2016). So in certain aspects the fate of CIM may possibly turn in deteriorating ambient air quality. In this context, we explore the possibility of policy revision by incorporating 'clean air' within CIM to achieve an effective and achievable solution. The article strongly recommends few mechanisms for inclusion in CIM except which its vision to have a 'Clean India' may not be achievable in factual sense. We recommend a quick revival of the mission with an enhanced scientific planning, institutional organization and expertise by considering 'clean air' within CIM.

Clean India mission: scopes

CIM has been implemented with a vision to eradicate manual scavenging, elimination of open defecation, generate and transfer knowledge of sanitation, induce behavioural changes regarding healthy sanitation practises and to install scientific waste management system (MDWS 2014; MUD 2014; Fig. 3). Within these broad perspectives, some defined objectives include subsidized construction of sanitary latrines for families below poverty line, renovation and conversion of dry latrines into low-cost sanitary latrines, development of community sanitary complexes in villages facilitated with hand pumps and bathrooms, development of sewerage system in villages, awareness campaign, health education to induce behavioural changes, encouraging participation of

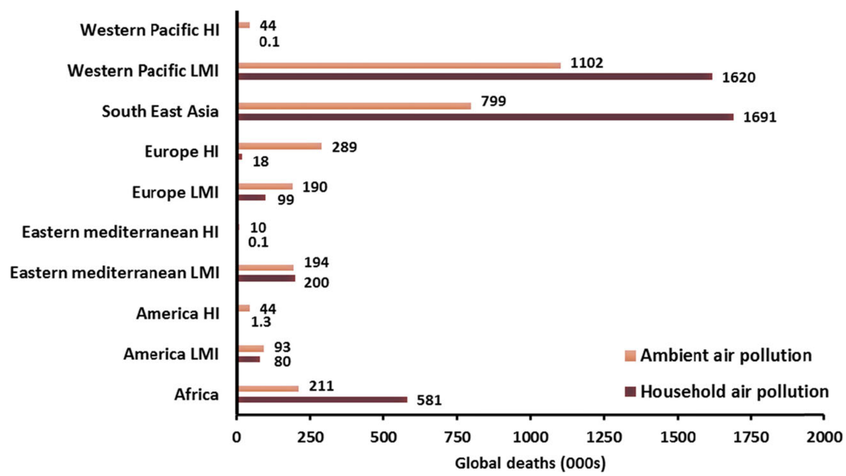

Fig. 2 Regional distribution of premature death due to household and ambient air pollution Note: *LMI* low- and middle-income, *HI* high-income (modified from WHO, 2014a, 2016)

Fig. 3 Components of Clean India Mission

private sector for capital expenditure and providing operation and maintenance costs for sanitation facilities. These objectives are proposed to be achieved in a stepped mode with complete sanitation till year 2019.

The entire campaign has been executed under the jurisdiction of Ministry of Drinking Water and Sanitation (Swachh Bharat Mission-Gramin; SBM-Gramin) and Ministry of Urban Development (Swachh Bharat Mission-Urban; SBM-Urban) with proper financial obligations for each phase of mission implementation. A total of Rs. 62,009 crore (US$ 9.7 billion) was earmarked for implementation of SBM (Urban) with proposed central assistance of Rs. 14,623 crore and Rs. 4874 crore will be contributed by states as State/ urban local bodies (ULB) (MUD 2014). Specific infrastructural guidelines have been provided for each CIM component most notably including structures for household, community and public toilets, solid waste management, communication to general public for behavioural change and capacity building for states and ULB (Fig. 4). SBM-Urban is governed by three-tier mission management structure at national, state and ULB level. In national level, National Advisory and Review Committee (NARC) for project monitoring and supervision, SBM National Mission Directorate (NMD) for project formulation in support to State Mission Directorates and within state level, a High Powered Committee (HPC) and SBM State Mission Directorate is made functional for proper execution (Fig, 4; MUD 2014). For SBM-Gramin scheme, National Scheme Sanctioning Committee (NSSC) was constituted to approve or revise the Project Implementation Plan (PIP), while a five-tier implementation mechanism was involved for proper project functioning from nation to village level (MDWS 2014). A specific monitoring and evaluation plan has also been proposed for the entire campaign with the provision of concurrent monitoring of project status using community level participation.

Past initiatives for sanitation

Different environmental cleanliness drives in terms of sanitation programmes with apparently identical objectives were periodically introduced in India. The first of its kind Rural Sanitation Programme was launched in 1954 during first five-year plan (1951–1956). However, the programme achieved limited accomplishment due to non-availability of qualified work-force and supporting materials. It was also overambitious as rural sanitation coverage were subsequently revealed to be merely 1% by Census of India-1981 (MDWS 2014; Fig. 5). Incidentally, during celebration of the first International Drinking Water Supply and Sanitation Decade (1981–1990), Government of India introduced the Central Rural Sanitation Programme (CRSP, in 1986) with objective of improving quality of life by providing sanitation facilities among the household below poverty lines, to eradicate manual scavenging and to create mass awareness (MDWS 2014). However, such infrastructure oriented and supply driven

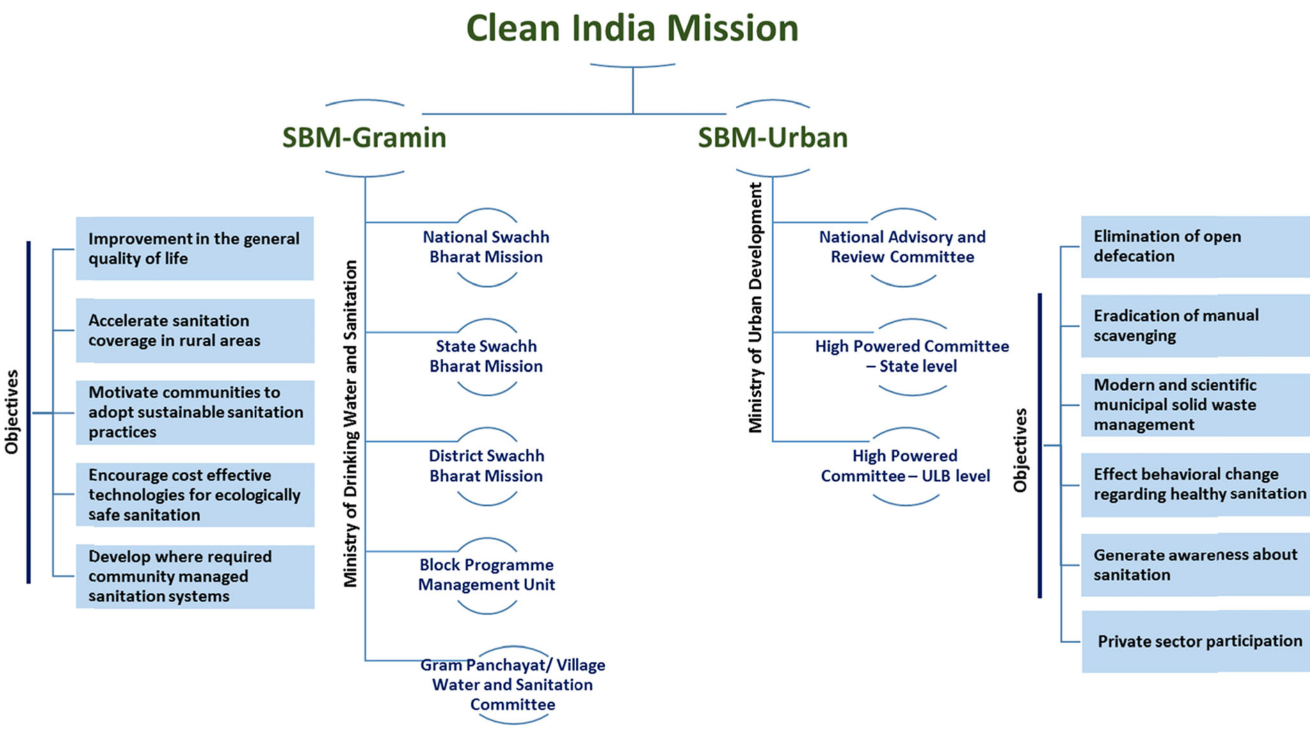

Fig. 4 Objectives and implementing agencies for Clean India Mission

programme was failed to deliver as sanitation coverage hardly exceeded 10% of rural population (Census 1991).

Entire programme was re-launched with the name of Total Sanitation Campaign (TSC) in 1999 to specifically eradicate open defecation process until 2010. The key intervention areas of TSC were improving awareness, education and communication, improving hygiene and capacity building for effective change in behaviour with involvement of community based organizations, co-operatives, women, self-help groups and NGOs. In the first 6 years of TSC implementation (1999–2005), entire focus was to remove the practises of open defecation and creating awareness, while from 2006 onwards, TSC includes solid and liquid waste management as separate components (GOI 2013). TSC has proclaimed to achieve rural sanitation coverage of 68% (in 2011) (GOI 2012). However, in a recent report by Planning Commission, 27% of rural household was found having any sanitation facilities while only 14% of Gram Panchayats were using solid waste management system (GOI 2013). The failure of TSC was further revealed in Census of India 2011 which account merely 31% (in 2011) of rural sanitation coverage (GOI 2012b) in contrast to 22% during 2001 (Hueso and Bell 2013; Census 2001) (Fig. 5). Subsequently, in order to revamp the rural sanitation, Nirmal Bharat Abhiyan (NBA) was launched in 2012 as successor of TSC. Encouragement of cost effective and appropriate technologies for ecologically safe and sustainable sanitation was the main target (GOI 2011). The concept of NBA included incentive based community managed environmental sanitation system. Further, convergence with MNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) leads to an even more construction-oriented programme. NBA also failed to deliver for multiple reasons and therefore, subsequently modified and re-launched as Swachh Bharat Mission or Clean India Mission on October 2, 2014.

Proper sanitation in India still remains a distant dream in rural households due to long term ignorance and lack of administrative planning. Most of the sanitary programmes were remain ignorant of actual ground implementation additionally burdened with minimum political priorities, technocratic and paternalistic inertia, improper monitoring and corruption (Huesoa and Bell 2013). While CIM is certainly a creditable move, its feasibility is uncertain as some key issues were not properly addressed. Ignorance of proper monitoring system, motivation of implementing agency, technocratic governing machinery and universal corrupt behaviour are possibly the key issues need to be resolved for effective implementation of the program.

Integrating *Clean Air* within CIM: necessity

We understand that CIM necessitate some essential changes in its basic structure, especially to consider clean air quality within the present mission. The statistics of air pollution in most of the Indian geographical regions reported by many agencies and researchers justify the concern. The essential requirement of 'clean air' within CIM is based on some specific scientific observations which are explained hereafter.

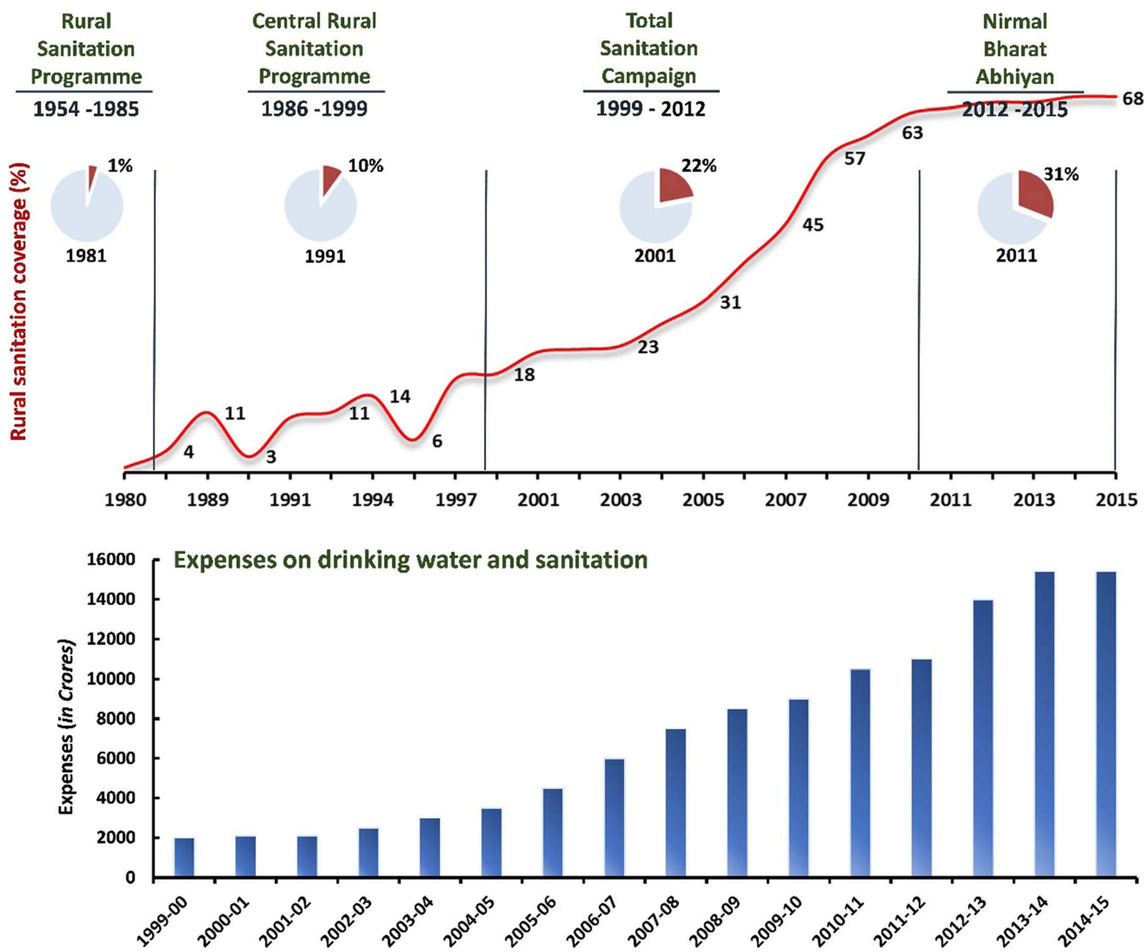

Fig. 5 Rural India sanitation coverage and annual expenses on drinking water and sanitation Note: *Line diagram* represents India's rural sanitation coverage (%) according to published government reports while the *pie chart* corresponds to data reported in India's census. Expenses on drinking water and sanitation represent all of India (i.e. both urban and rural regions) (source: Census, 1991, 2001, 2011; GOI, 2013)

Air pollution from household fuel combustion

The effects of indoor air quality on human health has been widely acknowledged (WHO 2016; Kumar et al. 2015a). Emission potentials of household fuels depend on number of factors most importantly type of fuels, moisture content, associated impurities, combustion temperature, ventilation, residence time and level of mixing. Combustion of fuels proceeds through a sequence of steps. Ideally fuels first enter into vapour phase either directly or by devolatilization processes and combustion initiates in a flame or distributed reaction zone to generate energy and associated by-products. For complete combustion, presence of stoichiometric oxygen with adequate residence time at a sufficiently high temperature is required, except which this may generate numerous hazardous chemicals depending on exact combustion and fuel conditions prevailed (Banerjee and Srivastava 2012).

In most instances, biomass and crop residues subject to burning consist of high level of moisture which compromise the maximum burning temperature and thereby potentially emit numerous un-burnt hydrocarbons, most of which are carcinogenic. Fuels also differ in associated contaminants like in coal (ash, sulphur, arsenic, mercury), kerosene (sulphur), biomass (nitrogen, ash, chlorine) (WHO 2014b). Burning of solid household fuels potentially emits respirable particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), carbon di-oxide (CO_2) and unburnt hydrocarbons. Average emission factors for household fuels for laboratory or simulated kitchen measurements are illustrated in Fig. 6 (WHO 2014b and references therein). In presence of chlorine, burning of biomass and household trash may generate dioxins and furans (Banerjee and Srivastava 2012). Coals also associated with emissions containing sulphur, arsenic, silica, fluorine, lead and mercury. Several gas phase pollutants also generated from biofuel burning which are carcinogenic (benzene, formaldehyde), probably carcinogenic (1,3-butadiene), and possibly carcinogenic (styrene) to human (Zhang and Smith 2007).

In a current estimate, approximately 60% of population in India use solid biofuels and traditional cook stoves for cooking (WHO 2014a). However, the situation is much

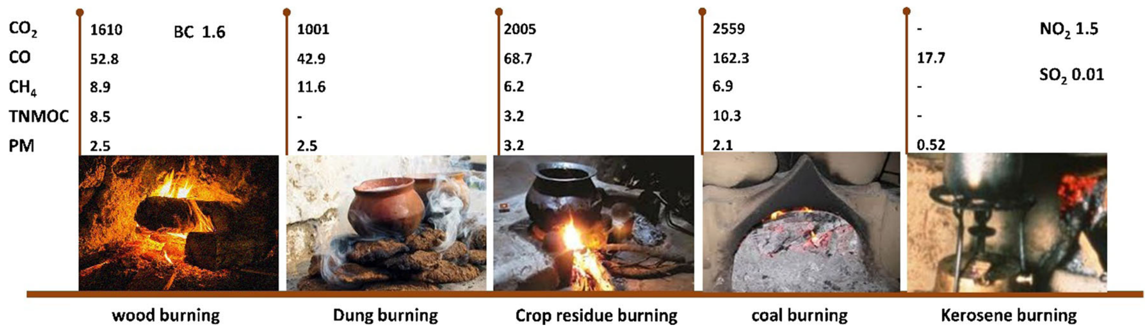

Fig. 6 Emission factors for household fuels under laboratory or simulated kitchen experiments. Note: All the emission factors carry identical unit (g/kg) except kerosene (mg/gm). The emission factors were available from WHO (2014b) except for kerosene (Lam et al., 2012 and references therein)

disastrous for rural India where 87% of households rely on solid fuels for domestic cooking with predominate share of firewood (63%), crop residue (13%) and dung cake (11%) (Census 2011) (Fig. 7b). In India, households using modern fuels with reduced emission potential are extremely rare. The conversion of solid fuels to modern fuels has been slow in the rural sector with a decrease of 8% in 2009–2010 compared to 1993–1994 (Fig. 7c-d) (DGDA 2013). Total number of LPG consumers of public sector oil marketing companies as on April, 2015 stands 181 million representing approx. 15% of population (MPNG 2015). Till year 2011, LPG penetration within domestic sector accounts 19.6% of rural households (for urban: 83.8%). This clearly signify the enormous potential of introducing clean energy to rural household either through providing clean fuels and/ or through providing combustion-biomass stoves.

Air pollution and public health

Epidemiological studies and systematic reviews have well established the association of enhanced mortality, hospital admissions, acute respiratory infections and cardiovascular diseases with deteriorating air quality (Kumar et al. 2015a; WHO 2014a; Singh and Banerjee 2016). Recent satellite images coupled with field observations has revealed global distribution of airborne particulates and identified very few global hotspots, including Indo-Gangetic plains in South Asia,

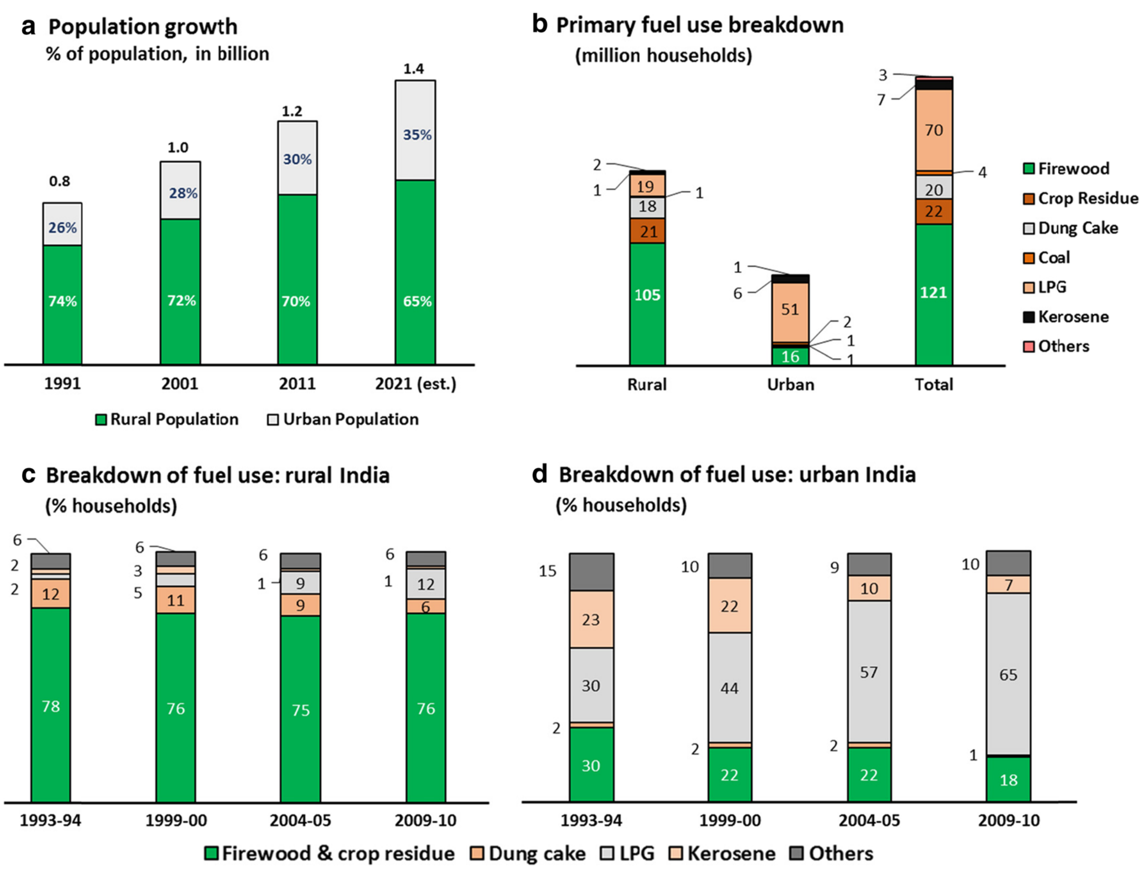

Fig. 7 India's population growth and breakdown of primary fuel use in rural and urban sectors. (Source: DGDA, 2013; Census, 2011)

South-East Asia, Central America, Eastern Africa and eastern China. Indo-Gangetic alluvial plain has long been identified having huge aerosol burden mostly characterized by the presence of mineral dust, organic aerosols and elemental carbon produced through combustion of fossil fuels, biomass burning and road dust re-suspensions (Banerjee et al. 2015; Kumar et al. 2015b, 2016; Murari et al. 2016; Sen et al. 2014, 2016). To recognize the spatial nature of air pollution impacts, a comparative figure including India's population density (for 2011), distribution of aerosol columnar loading in terms of aerosol optical depth (average AOD for 2011–2015) and premature mortality as a function of ambient fine particulates (for 2010) are presented in Fig. 8. The spatial nature of premature mortality attributable to fine particulates (Fig. 8c) has been developed by Apte et al. (2015) considering high-resolution aerosol loading information coupled with cause-specific integrated exposure-response function. Figure 8 identifies entire India having high aerosol loading while IGP solely recognized with exceptionally high population density, aerosol loading and thereby high pollution induced mortality. Except IGP, rest of the region exhibit somewhat reduced susceptibility. Over the IGP, particulate induced premature mortality was considerably high due to high exposure and low socio-economic resilience. However, modest improvements in regional air quality will possibly result in large avoided mortality owing to nonlinear concentration-response relationship and population demography (Apte et al. 2015). Therefore, considerable improvements in terms of regional energy practises and air quality are required. According Apte et al. (2015), India and china are required to offset average fine particulate levels by ~20–30% over the next 15 years only to balance attributable mortality from ageing population. Effects of air pollution in population mortality are not extensively documented especially over IGP as very few evidences are found in literature database. Figure 9a explains the major risk of mortality in India indicating a total of 1.66 million annual deaths solely due to air pollution. Household air pollution (1.04 million deaths) emerged as the second leading risk of mortality well comparable to blood pressure (1.20 million) and smoking (1.02 million) (Cohen 2013). Additionally, air pollution induced excess premature mortality over few urban habitats is reported in Table 1. Figure 9b introduces major categories of air pollution induced mortality in India specifying both ischemic heart disease and stroke as predominant risks.

It emerged that although air pollution is responsible for a major proportion of premature deaths in India, the government is yet to intervene to the primary sources of pollution. There are numerous evidences of achieving critical level of pollution in ambient atmosphere and associated health impacts over several cities and urban habitats. Cardio-vascular diseases are widely linked with air pollution while from last few decades these are mainly attributed to finer particulates. Health issues associated with air pollution clearly indicate that even after implementation of stringent legislations, pollution and its impacts are quite significant. This probably indicates the essentiality of a nationwide air quality management campaign towards popularizing clean energy and dissemination of improved cook stoves especially to rural households. Extended provisions of including these aspects in CIM will not only help in reduction of premature mortality but also help in generating rural employment.

Air pollution and clean fuel

In India, dependence of rural household on traditional fuels is exceedingly high. The Ministry of New and Renewable Energy (MNRE) through a Special Project on Cook stove (in 2009–10) initiated the process of developing various types of biomass based improved cook stoves for rural households.

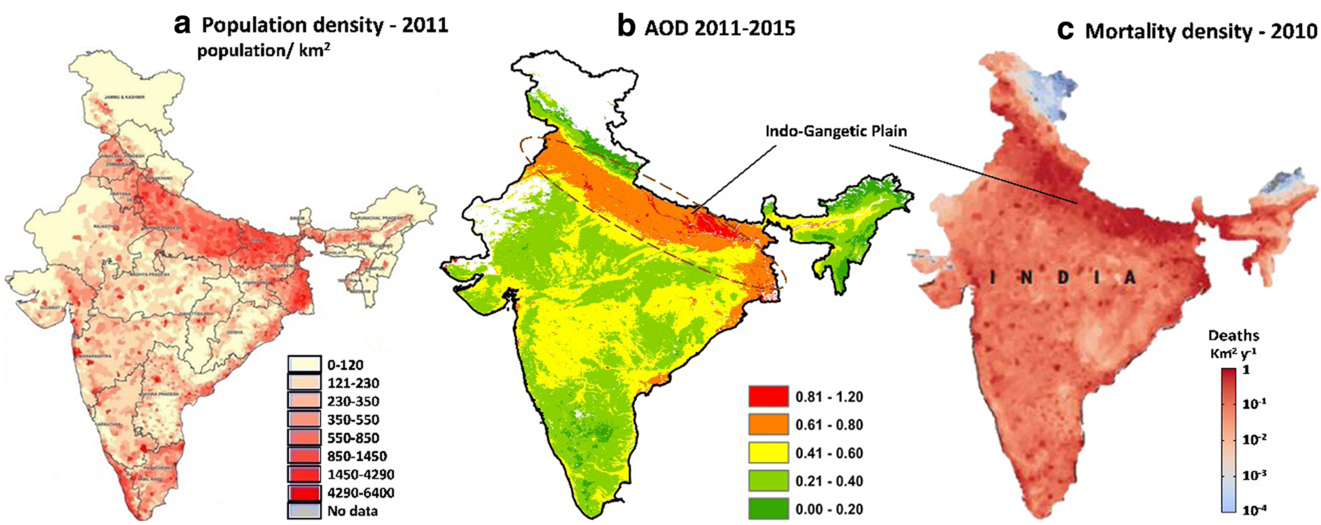

Fig. 8 Comparison of (a) population density, (b) distribution of aerosols loading and (c) premature mortality as a function of ambient fine particulates. Note: Population density map is the curtsey of GEOCONCEPT Group, Chennai. AOD 2011–2015 represents 5 years of average AOD derived from Aqua-MODIS. Premature mortality as a function of ambient fine particulates is curtsey of Apte et al., (2015)

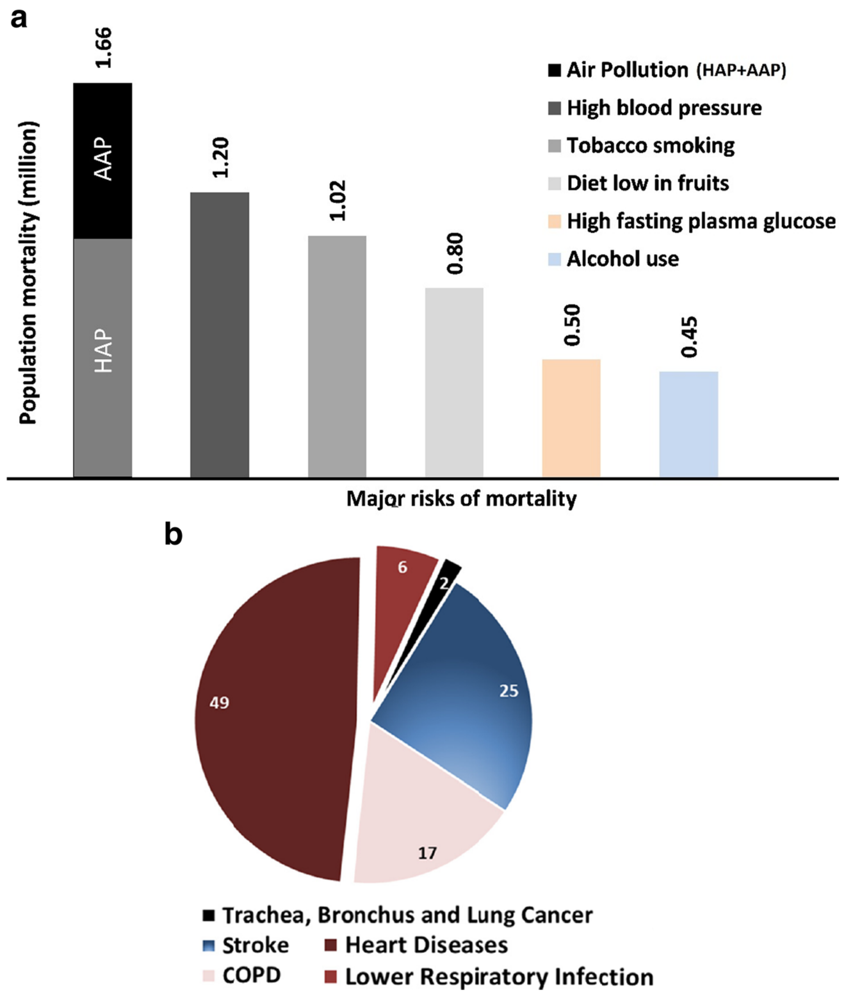

Fig. 9 Premature mortality in India (a) major risks (b) mortality due to air pollution (in percentage). (Modified from Cohen, 2013)

Ministry also emphasized means for expanding the network for deployment of improved biomass cook stoves for rural people. The National Biomass Cookstoves Initiative (NBCI) was launched in 2009 by MNRE to initiate state-of-the-art testing, certification and monitoring facilities and strengthening R&D program. Switching from less efficient biomass burning to cleaner and more efficient stoves have great potentials both in terms of environmental and societal benefits. Such understanding has resulted in many initiatives to develop various forms of improved cook stoves. Exemplifying, project *surya* was implemented over selected regions (Himalayan, IGP and Southern India) to reduce the impacts of biomass burning, reductions in BC, methane and ozone and to replace the conventional cook stoves by clean and sustainable cooking technologies. Five thousand households were provided cleaner technologies like solar cookers and other energy efficient stoves. These improved stoves were environmental friendly with a reported reduction of major ions associated

Table. 1 Air pollution induced excess premature mortality over few cities

Excess mortality (Number/million/Year)	Delhi (Gurjar et al. 2010)	Mumbai (Maji et al. 2016)	Pune (Maji et al. 2016)	Karachi (Gurjar et al. 2010)	Dhaka (Gurjar et al. 2010)
Cardiovascular	3500	724	449	5200	7000
Respiratory	1600	121	78	2100	2100
COPD	-	34	20	-	-
Hospital Admissions (Respiratory)	-	1519	901	-	-
Hospital Admissions (Cardiovascular)	-	582	348	-	-
Hospital Admissions COPD	1500	-	-	2100	2100
Total	10,500	1192	733	15,000	14,700

with biomass burning (~32%) with maximum reduction in sulphate aerosols (47%) and sulphur dioxide (55%) compared to conventional cook stoves (Singh et al. 2014). However, such success stories are limited mainly due to improper distribution networks, distribution costs and lack of infrastructure to provide after-sale services (Freeman and Zerriffi 2015).

Air pollution and agriculture

Trace gases and airborne particulates potentially impact on human nutrition by reducing both quality and quantity of crop yield. Negative effects of air pollution on crops and food production are evident within several regions of the world. Various short-lived climate pollutants (SLCPs, like tropospheric ozone, black carbons, methane, HFCs) originate from incomplete fuel combustion of biomass and cow dung, have indirect effects on crop productivity through its impacts on insolation (by BC and sulphate), surface temperature (by ozone and BC) and precipitation (by BC). Over the past half century, efforts have been made on estimating impacts of elevated temperature, trace gases and aerosols on quality and quantity of agriculture yield (Lobell and Field 2007). According to IPCC (2014), globally averaged land and ocean surface temperature has enhanced by 0.85 °C (0.65 to 1.06 °C) over 1880 to 2012. There is a medium confidence that change in climate will negatively affect wheat (Lobell et al. 2012) and maize production (Lobell et al. 2013) for many regions, while for rice (Pathak et al. 2003) the potential yield is expected to decrease. Burney and Ramanathan (2014) estimated 36% reduction in wheat and 20% reduction in rice production (over 1980–2010) by combined effect of various long-lived greenhouse gases (CO_2, N_2O) and SLCPs in India.

Ground-level ozone is also linked with reduction in crop yield often extended to 90% with 2–3 times more crop losses over other air pollutants (Felzer et al. 2007). Globally projected yield loss (for 2030 over 2000) due to surface ozone is significantly varied among wheat (5–26%), soybean (15–19%) and maize (4–9%) with an accounted annual global loss of \$17–35 billion USD_{2000} (Avnery et al. 2011). The projected yield and associated economic loss is even more drastic over Indian subcontinent. Debaje (2014) estimated ozone induced relative losses from 5 to 11% for winter wheat and 3–6% for rabi rice for 2002–2007. Highest crop losses were also predicted over IGP region having relatively high O_3 concentrations (>80 ppmv) especially during crop growing seasons (Shukla et al. 2017).

Apart from variations in crop yield, several investigators found significant changes in nutritive values of various crops, especially for C_3 plants (rice, wheat, soyabean) and legumes. A significant proportion of global population depend on C_3 crops and legumes for zinc and iron, while globally an estimated two billion people suffer from these nutrient deficiencies (Tulchinsky 2010), resulting annual loss of 63 million life-years (Caulfield and Black 2004). Myers et al. (2014) reported that enhanced CO_2 fertilization will possibly be associated with lower zinc (wheat: 9%; rice: 3%; maize: 5%; soybean: 5% reduction); iron (wheat: 5%; rice: 5%; maize: 6%; soybean: 5% reduction) and protein content (wheat: 6%; rice: 7%; maize: 5% reduction; soybean: 0.3% increase). However, to recognize the impacts of air pollutants on food security require more specific studies in Asian countries where very limited researches have been conducted.

Air pollution and environmental sustainability

Numerous international researches, arguments and scientific publications support inextricable linkages of atmospheric pollution and human health (Kumar et al. 2015a; WHO 2014a). Air pollution induced climate modifications in terms of radiative forcing (Kumar et al. 2017), precipitation, and monsoon cycles are often centre of discussions (Banerjee and Srivastava 2011; Ramanathan and Carmichael 2008). Air pollutant's association with food security pose considerable direct threat to sustainability in terms of economic and social crisis (Burney and Ramanathan 2014). Pollutant's interaction with incoming solar radiation and microphysical properties of cloud possibly threatens hydrological cycle (Ramanathan and Carmichael 2008). Complexities associated with air pollution are now not only restricted to scientific communities but are outspread to every individual by its direct and indirect socio-economic impacts. Approximately 1 billion people in South, South-East, and East Asia is expected to face risks of water scarcity, declined agricultural productivity, risks of various climate extremes like floods and droughts. Further, combination of land-use changes and modified climatic conditions are expected to degrade biodiversity which ultimately burden ecosystem functionality (Banerjee and Srivastava 2010).

Given these situations, environmental sustainability necessitates new approaches for integrating pollution management having socio-ecological considerations in association with climate adaptation and mitigation policies. The cost involved in managing air pollution has to be included in policy formulations and both policy trade-off and synergies need to be considered simultaneously (Banerjee et al. 2017). Region specific requirements are specifically required to be considered for mainstreaming air pollution policies into sustainable development strategies. However, the means to achieve such integration may differ considerably and therefore, extensive discussions and planning are required. In these contexts, we recommend few policy interventions which are worth to consider in continuation to CIM.

CIM with *Clean Air*: recommendations and way forward

Population, social hierarchy, political motivation, financial provision, socio-economic resilience and inequities often create hurdles in effective implementations of any awareness programme. Socio-economic determinants including discrimination of economically weaker group of people, illiteracy, lack of information about government policies and role of middlemen are important factors that additionally constrains the effective implementations of any policy. In India, inequities in distribution and consumption of energy resources apparently vary on the basis of regions and socio-economic conditions. Ganeshan and Vishnu (2014) reported the inequities in energy consumption on the basis of income and regions using Gini coefficient and Lorentz curve. A high Gini coefficient for clean sources of energy i.e. LPG (0.50–0.72) and electricity (0.22–0.42) depicted the high evidences of energy inequity in rural areas with low per capita income. Urban areas with higher per capita income were characterized with relatively lower Gini coefficient for LPG (0.17–0.41). For unclean traditional fuels over rural areas, the trends were somewhat different like in case of firewood (−0.07 to 0.14) and kerosene (−0.10 to 0.15). This indicates the existing inequities in rural areas for having access to clean fuels. However, over the last few decades there are efforts to reduce social inequities for distribution of energy resources. Government of India has recently approved a visionary project as 'Pradhan Mantri Ujjwala Yojna' for distributing 50 million free LPG connections to the citizens below poverty line. Till the preparation of the manuscript, around 11.6 million LPG connections have already been distributed covering nearly 647 districts throughout India (pmujjwalayojana.com).

Model for cleaner environment require provisions for addressing local needs, scope of modification and broader societal implementation. A system for government-society-science trilogue will also help to address complications arise even at a grass-root level. Both CIM and access to clean energy have number of commonalities especially in terms of creating mass awareness, inducing behavioural changes in habituating such practises, capacity augmentation for providing access to clean fuels, cook stoves, household toilets, waste management systems and ultimately improvising public sector participation (Fig. 9). Although, both CIM and 'clean air' addresses two different aspects, considering synergies both in policy formulation and execution will definitely derive maximum benefit for the rural people. In this context, for effective inclusion of 'clean air' concept within CIM, some key recommendations and policy interventions are addressed below (Fig. 10).

Access to clean fuel

Access to clean fuel in improving health and living conditions of rural people has well been established. Policy makers have understood such linkages and are continuously endeavouring to improve the status of energy access. However, rural demography speaks in contrasting way as significant proportion of rural households in India do not have access to clean fuel and therefore, bound to use biomass based fuels. In most of the cases, rural households depend on biomass and dung cake due to its easy availability and lower price. This clearly suggests that India has to go a long way to address rural energy needs. Even the latest Census of India (2011) indicates that access to clean energy is lagging far behind compared to access to electricity. There are ample opportunities to introduce clean fuels for the rural household by adopting a proper distribution network. However, rural distribution networks for LPG or for alternative fuels are extremely limited and even cost of subsidized fuel can deter the poorest households. In most instances, rural households are slow

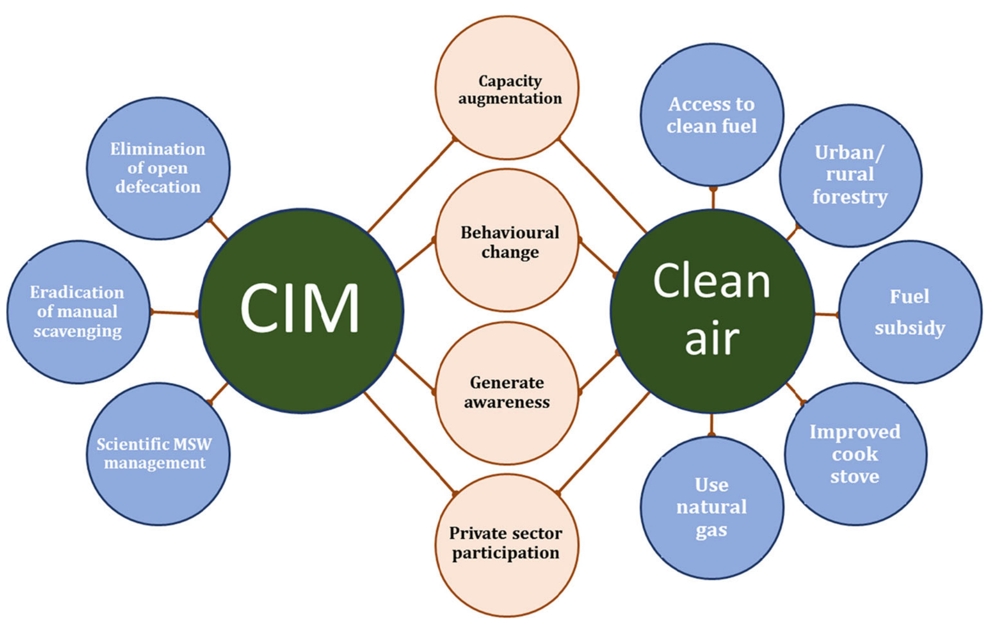

Fig. 10 Possibilities for combined implementations of CIM and clean air

in adapting alternative fuel due to a combination of both, shortage in supply and lower affordability.

Therefore, there is an urgent need to bridge this gap by means of employing proper distribution network and effectively regularizing the energy cost so that rural people have easy access. On this account, the PMUY may be clubbed effectively with SBM-Gramin with the provisions of encouraging cost effective and appropriate technologies for ecologically safe and durable sanitation facilities along with clean domestic fuel. The availability and access to cleaner fuels should also be administered with strict regulations in its distribution and use. Despite of several government interventions, India ranks 4th in contribution to global carbon budget with 6.3% of the global carbon emissions (Quéré et al. 2016). Therefore, promotion of cleaner fuels should also be handled with stringent regulations. Additionally, it is practically impossible to restrict the use of traditional fuel which can only be handled with a synergy of stringent regulations as well as with compatible alternatives. The key governmental interventions which may limit the use of existing unclean traditional fuels may be (i) promoting more efficient use of existing traditional fuels and (ii) encouraging people to switch to clean fuels and clean technologies. However, the success of such interventions may vary spatially and depends on local circumstances and economic conditions.

Ensure awareness and induce behavioural change

The consensus and awareness of using clean fuels is minimum among rural households which make it extremely difficult to remain choice of interest. Most of the rural people are unaware of adverse health effects of conventional fuels and therefore, raising awareness about potential health benefits of cleaner fuels will definitely facilitate its public acceptance. Although general awareness on education, drinking water, sanitation, electricity and vaccination has considerably increased in recent years (CEEW 2015), rural people still prioritize on using freely accessible conventional fuels over cleaner ones.

Another interesting characteristic signature of rural households in India is to partially adopt the cleaner fuels irrespective of affordability. Many rural and even urban households prefer to use multiple energy sources, like kerosene with biomass or cow dung cake. Thereby, both cleaner and polluted fuels coexist which jeopardize the benefits arise from using cleaner fuels. This highlights the fact that in certain cases, inability to switch to cleaner fuels is not a financial obligation, but it is people's interest and unawareness which drive them for such behaviour. Therefore, inducing behavioural changes of local people should be an integral part of CIM. Awareness and promotional campaign are required to educate people on potential health benefits of cleaner fuels, kitchen ventilation, improved cook stoves and also for sanitation practises.

Effective subsidized fuel scheme

Fuel price subsidies for kerosene and LPG have often found ineffective and unsustainable in expanding the clean fuel markets for rural households (World Bank 2003). Exemplifying, fuel price subsidy for LPG accumulates disproportionately to the urban population as 32% of urban household enjoy the subsidized LPG connection while LPG account only 19% of rural household. Therefore, the advantages of introducing subsidized LPG has only confined to urban areas and benefits never reached to target population.

In absence of any electrification, kerosene serves as a reliable and affordable source of electricity to poor non-electrified households. However, kerosene subsidy also appears to have a large leakage, mainly in terms of diversion to the black market, prominently to the automotive diesel sector. Implementation of strict rules and penalization of defaulters can discourage such practises. Globally, success story of subsidized kerosene is extremely limited while sizable subsidy also induces massive fiscal deficit (World Bank 2003). However, in a recent move, Government of India introduced direct transfer of kerosene subsidy to individuals which has potentials to eliminate pilferage and kerosene black-marketing.

Promoting improved cook stove

Improved fuel efficient cook stoves provide multiple benefits like reduced emissions, reduced biomass consumption, empowerment of rural women, improvement of rural sanitation and human health (Freeman and Zerriffi 2015). Initiated way back in 1970s to address global energy crisis, distribution of improved cook stoves has been started to address a number of potentially relevant issues like societal welfare, rural empowerment, climate change and also sustainable development. Under Indian National Program for Improved Chulas, 30 million improved cook stoves were distributed within 1980s to 1990s with a minimum of 50% subsidy. Recently, Ministry of New and Renewable Energy launched National Biomass Cookstoves Initiative in 2009 under which pilot scale projects were considered for demonstration of community size and domestic biomass cook-stoves. By providing additional subsidies these cook stoves can be made popular among rural people. There are also provisions for manufacturing such cook stoves by private sectors. This can be promoted by facilitating greater partnerships and sharing knowledge between stakeholders, developing acceptable and achievable standards, promoting awareness and providing wide financing options. Provision for providing seed money at initial development stage may also appears attractive to stakeholders.

Use of natural gas

In India use of natural gas as a household fuel is extremely limited, although given to the recent discoveries of large gas fields it seems potentially feasible. India pose 1488 Billion Cubic Meters (BCM) of proven natural gas reserves as of April, 2015 with an annual production of about 33.7 BCM (MPNG 2015). While the production capacity at source is estimated to be higher, India lack substantially in gas pipeline distribution network. Establishing a proper distribution network for the rural people appears a distant dream but, distribution of natural gas may well be considered for urban and peri-urban region. It is worth to consider an option as natural gas appears to be cleanest commercially viable household fuel.

Promoting urban/ rural forestry

Enhanced green cover has potentials to reduce key atmospheric pollutants. Both at rural and urban level, plantation of green trees can have a pivotal role in providing environmental safety thereby helps local governments to achieve environmental, social and ethical sustainability goals. Although, promoting rural forestry will not contribute in reducing indoor pollution level, but its broader implication may integrate community rights by maximizing the environmental benefits. Improving urban green cover is a complicated job for urban setting in India due to large impervious lands and haphazard land use. Most of the metropolitan cities in India are facing similar types of experiences with a major share of impervious land. India stands 3rd in the total impervious surface area after China and United States with 81,221 Km^2 of impervious surface area (Elvidge et al. 2007). In this situation, roof top greening can provide better results for controlling airborne particulates, precursor gases and other air toxics. There are hypothesis of potenatilly reducing massive pollutant load by introducing green roofing over a city. Deutsch et al. (2005) using UFORE model estimated the removal of nearly 58MT of pollutants including aerosols with 100% green roofing in Washington. Implementations of such practises are therefore strongly recommended in India.

Conclusions

Present scenarios of India's rural sanitation and access to clean household fuel were explored. Sanitation coverage and access to clean fuels for rural households were found miserably poor which induce negative health impacts both in terms of human morbidity and mortality. We found nationwide campaign 'Clean India Mission' for improving sanitation and waste management as ambitious but pose potential to improve rural sanitation and general hygiene. However, there are possibilities worth exploring on concurrent implementation of 'clean air' concept imbedded with CIM so that mission objectives may achieve in a factual sense. India share predominate proportion of global population without having any access to clean household fuels. In absence of a clean energy source, indoor air pollution has been considered as an important contributor to health hazard. We found evidences of minimum governmental interventions for popularizing and disseminating the alternative sources of clean energy to rural people. Therefore, driven by the necessities, we explored the likelihoods of concurrent implementation of CIM with 'clean air'. Both CIM and 'clean air' potentially address number of similar attributes like mass awareness, behavioural changes, capacity augmentation, reduce social inequities and public sector participation. Number of sectors with possible coherence, technological adaptation, dissemination modes, financing, and scope of implementation were explored so that both sanitation and access to clean household energy may effectively be addressed.

Conclusively, we recommend effective policy revision to disseminate clean energy especially to rural people and periodical assess human health impacts of air pollution with highest degree of importance. The fundamental objective behind such policy revival is to adopt anticipatory steps for establishing specific air pollution control measures to minimize the health impacts. Expenditure on treatment of air pollution induced diseases and number of premature mortality can be significantly reduced if priorities are set to effectively control pollution at source level. At the same time, need for reconstitution of state economic policies is recommended for improved and dedicated dissemination of clean alternative source of energy to rural people.

References

Apte JS, Marshall JD, Cohen AJ, Brauer M (2015) Addressing global mortality from ambient PM2.5. Environ Sci Technol 49:8057

Avnery S, Mauzerall DL, Liu J, Horowitz LW (2011) Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O3 pollution. Atmos Environ 45:2297–2309

Banerjee T, Srivastava RK (2011) Assessment of the ambient air quality at the integrated industrial estate-Pantnagar through the air quality index (AQI) and exceedence factor (EF). Asia Pac J Chem Eng 6: 64–70

Banerjee T, Srivastava RK (2010) Estimation of the current status of floral biodiversity at surroundings of integrated industrial estate-Pantnagar, India. International Journal of Environmental Research 4(1):41–48

Banerjee T, Murari V, Kumar M, Raju MP (2015) Source apportionment of airborne particulates through receptor modeling: Indian scenario. Atmos Res:164–165 167–187

Banerjee T, Srivastava RK (2012) Plastic waste management and resource recovery in India. International Journal of Environment & Waste Management 10(1):90–111

Banerjee T, Kumar M, Singh N (2017) Aerosol, climate and sustainability. Reference module in earth systems and environmental sciences. Elsevier, Encyclopaedia of Anthropocene. doi:10.1016/B978-0-12-409548-9.09914-0

Bateson TF, Schwartz J. (2007) Children's response to air pollutants. J Toxic Environ Health A 71(3):238–243

Beamish LA, Alvaro R, Vargas O, Wine E (2011) Air pollution: an environmental factor contributing to intestinal disease. J Crohn's Colitis 5:279–286

Bhatt D, Mall RK, Banerjee T (2015) Climate change, climate extremes and disaster risk reduction. Natural Hazard 78(1):775–778

Bhatnagar K, Sapovadia V, Gupta D, Kumar P, Jasani H (2014) Dry eye syndrome: a rising occupational hazard in tropical countries. Med. J. D.Y. Patil Univ. 7 (1).

Burney J, Ramanathan V (2014) Recent climate and air pollution impacts on Indian agriculture. Proc Natl Acad Sci U S A 111(46):16319–16324

Caulfield LE, Black RE (2004) Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attribution to Selected Major Risk Factors Ezzati, M., Lopez, A. D., Rodgers, A. & Murray, C. J. L. (Eds) (World Health Organization, 2004) Vol. 1, Ch. 5 .

CEEW (2015) Access to clean cooking energy and electricity survey of states. Council on Energy, Environment and Water. Delhi.

Census (1991) Census of India, 1991. http://www.censusindia.gov.in/DigitalLibrary/Tables.aspx, accessed on December, 2015.

Census (2001) Census of India, 2011. http://www.censusindia.gov.in/DigitalLibrary/Tables.aspx, accessed on December, 2015.

Census (2011) Census of India, 2011. Available at http://www.census2011.co.in.html, accessed on November, 2015.

Census of India (2011) The Registrar General & Census Commissioner, India, New Delhi, Ministry of Home Affairs, Government of India. http://www.censusindia.gov.in/2011 common/census_2011.html.

Cohen AJ (2013) Global Burden of Disease 2010. In: Global burden of disease 2010. New Delhi India: 2013. Available from: http://www.cseindia.org/userfiles/global_burden_aaron.pdf. Accessed 20 Nov 2016.

Debaje DB (2014) Estimated crop yield losses due to surface ozone exposure and economic damage in India. Environ Sci Pollut Res 21:7329–7338

Deutsch B, Whitlow H, Sullivan M, Savineau A (2005) Re-greening Washington, DC: A Green Roof Vision Based on Quantifying Storm Water and Air Quality Benefits. (Available from www.greenroofs.org/resources/greenroofvisionfordc.pdf; accessed 14 February 2016).

DGDA, (2013). Global Alliance for Clean Cookstoves: India Cookstoves and Fuels Market Assessment. Dalberg Global Development Advisors. (Available from http://cleancookstoves.org/resources_files/india-cookstove-and-fuels-market-assessment.pdf; accessed on January, 2016).

Elvidge CD, Tuttle BT, Sutton PC, Baugh KE, Howard AT, Milesi C, Bhaduri BL, Nemani R (2007) Global distribution and density of constructed impervious surfaces. Sensors 7:1962–1979

Felzer BS, Cronin T, Reilly JM (2007) Impacts of ozone on trees and crops. CR. Geoscience 339:784–798

FAOSTAT 2013. ForesSTAT. Food and Agriculture Organization Statistics Division (FAOSTAT). (Available from http://faostat.fao.org/site/626/default.aspx#ancor, 2013, Accessed 07 Dec 2013).

Firstpost.com Air pollution . Gurugram admin imposes Section 144 to check waste burning. Avilable at http://www.firstpost.com/india/air-pollution-gurugram-admin-imposes-section-144-to-check-waste-burning-3092170.html (Accessed on November 11, 2016).

Freeman OE, Zerriffi H (2015) Complexities and challenges in the emerging cook stove carbon market in India. Energy for Sustainable Development 24:33–43

Ganesan, K., Vishnu, R. (2014) Energy Access in India - Today, and Tomorrow. CEEW Working Paper 2014/10, Council on Energy, Environment and Water, New Delhi.

Gurjar BR, Jain A, Sharma A, Agarwal A, Gupta P, Nagpure AS, Lelieveld J (2010) Human health risks in megacities due to air pollution. Atmos Environ 44:4606–4613

GOI (2011) Towards Nirmal Bharat. Rural Sanitation and Hygiene Strategy 2010–2022. Department of Drinking Water and Sanitation, Ministry of Rural Development, Government of India, Delhi.

GOI (2012) Census of India 2011. Houses, Household Amenities and Assets. Latrine Facility. Government of India, Delhi.

GOI (2013) Evaluation Study on Total Sanitation Campaign. Planning Commission, Government of India.

Goldsmith LA (1996) Skin effects of air pollution. Otolaryngol Head Neck Surg 114:217–219

Gresham JB, Morgenstern H, Saydah S, Williams D, Powe N (2014) Understanding the county-level variability in the prevalence of diagnosed chronic kidney disease (CKD) in the medicare population across the United States (US). 142nd APHA Annual Meeting and Exposition. http://isro.gov.in/pslv-c25-mars-orbiter-mission.

Huesoa A, Bell B (2013) An untold story of policy failure: the total sanitation campaign in India. Water Policy 15:1001–1017

IPCC (2014) Climate change: The physical science basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Kumar M, Singh RS, Banerjee T (2015a) Associating airborne particulates and human health: exploring possibilities. Environ Int 84:201–202

Kumar M, Tiwari S, Murari V, Singh AK, Banerjee T (2015b) Wintertime characteristics of aerosols at middle indo- Gangetic plain: impacts of regional meteorology and long range transport. Atmos Environ 104:162–175

Kumar M, Singh RK, Murari V, Singh AK, Singh RS, Banerjee T (2016) Fireworks induced particle pollution: a spatio-temporal analysis. Atmos Res 180:78–91

Kumar M, Raju MP, Singh RK, Singh AK, Singh RS, Banerjee T (2017) Wintertime characteristics of aerosols over middle indo-Gangetic plain: vertical profile, transport and radiative forcing. Atmos Res 183:268–282

Lai HK, Wong CM, Tsang H, Thach TQ, Thomas G, Chan K et al (2014) Long-term exposure to particulate matter air pollution and hospital admissions for peptic ulcer disease. UEG J 2

Lam NL, Smith KR, Gauthier A, Bates MN (2012) Kerosene: a review of household uses and their hazards in low- and middle-income countries. Journal of Toxicology and Environmental Health, Part B 15(6):396–432. doi:10.1080/10937404.2012.710134

Lobell DB, Field CB (2007) Global scale climate-crop yield relationships and the impacts of recent warming. Environ Res Lett 2:014002

Lobell DB, Hammer GL, McLean G, Messina C, Roberts MJ, Schlenker W (2013) The critical role of extreme heat for maize production in the United States. Nat Clim Chang 3:497–501

Lobell DB, Sibley A, Monasterio JIO (2012) Extreme heat effects on wheat senescence in India. Nat Clim Chang 2(3):186–189

Maji KJ, Dikshit AK, Deshpande A (2016) Human health risk assessment due to air pollution in 10 urban cities in Maharashtra, India, cogent environmental. Science 2:1193110

MDWS (2014). Guidelines for Swachh Bharat Mission Gramin. Ministry of Drinking Water and Sanitation, Government of India.

MPNG (2015). Indian Petroleum and Natural Gas Statistics. Government of India, Ministry of Petroleum & Natural Gas, Economics and Statistics Division, New Delhi.

MUD (2014) Guidelines for Swachh Bharat Mission (SBM). Ministry of Urban Development, Government of India.

Murari V, Kumar M, Barman SC, Banerjee T (2015) Temporal variability of MODIS aerosol optical depth and chemical characterization of airborne particulates in Varanasi, India. Environ Sci Pollut Res 22:1329–1343

Murari V, Kumar M, Singh N, Singh RS, Banerjee T (2016) Particulate morphology and elemental characteristics: variability at middle indo-Gangetic plain. J of Atmos Chem 73:165–179. doi:10.1007/s10874-015-9321-5

Myers SS, Zanobetti A, Kloog I, Huybers P, Leakey ADB, Bloom AJ et al (2014) Increasing CO2 threatens human nutrition. Nature 510:139–142. doi:10.1038/nature13179

Pathak H, Ladha JK, Aggarwal PK, Peng S, Das S, Singh Y et al (2003) Trends of climatic potential and on-farm yields of rice and wheat in the indo-Gangetic Plains. Field Crop Res 80:223–234

Quéré CL, Andrew RM, Canadell JG, Sitch G, Korsbakken JI, Peters GP et al (2016) Global carbon budget 2016. Earth Syst Sci Data 8(605–649):2016

Ramanathan V, Carmichael G (2008) Global and regional climate changes due to black carbon. Nat Geosci 1:221–227

Schmale JD, Shindell E, Chabay VS, Lawrence M (2014) Air pollution: clean up our skies. Nature 515:335–337

Shukla K, Srivastava PK, Banerjee T, Aneja VP (2017) Variation of ground-level and columnar ozone at middle indo-Gangetic plain: impacts of seasonality and precursor gases. Environmental Science and Pollution Research. doi:10.1007/s11356-016-7738-2

Sen A, Ahammed YN, Arya BC, Banerjee T et al (2014) Atmospheric fine and coarse mode aerosols at different environments of India and the bay of Bengal during winter-2014: implications of a coordinated campaign. MAPAN-Journal of Metrology Society of India 29(4):273–284

Sen A, Ahammed YN, Banerjee T, Chatterjee A, Choudhuri AK, Das T (2016) Spatial variability in ambient atmospheric fine and coarse mode aerosols over Indo-Gangetic plains, India and adjoining oceans during the onset of summer monsoons, 2014. Atmospheric Pollution Research, 7(3): 521–532. doi:10.1016/j.apr.2016.01.001

Singh VK, Sairam R, Raviteja PL, Naresh A, Suresh R (2014) Performance evaluation of biomass cooking devices in household environment with various solid biomass fuel. International Journal of Energy Science 4(1):24–27

Singh N, Banerjee T (2016) Airborne Toxicants & Human Health: causes and consequences. Curr Sci 110(5):1108

Tulchinsky TH (2010) Micronutrient deficiency conditions: global health issues. Public Health Rev 32:243–255

WHO (2007) Indoor air pollution: National Burden of Disease Estimates. World Health Organization. (http://www.who.int/indoorair/publications/nationalburden/en/, accessed 2 March 2016).

WHO (2008) The Global Burden of Disease: 2004 Update. World Health Organization. (http://www.who.int/indoorair/publications/nationalburden/en/, accessed 2 March 2016).

WHO (2009) Global health risks: Mortality and burden of diseases attributable to selected major risks. World Health Organization. (http://www.who.int/healthinfo/global_burden_disease/, accessed on 10 February, 2016).

WHO (2014a) Burden of disease. World Health Organization. (http://www.who.int/gho/phe/outdoor_air_pollution/burden_text/en/, accessed on 10 February, 2016).

WHO (2014b) WHO Indoor Air Quality Guidelines: Household fuel Combustion: Emissions of Health-Damaging Pollutants from Household Stoves. World Health Organization. (http://www.who.int/indoorair/guidelines/hhfc/en/, accessed 22 March 2016).

WHO (2016). Ambient air pollution: a global assessment of exposure and burden of diseases, 2016. WHO Document production services, Geneva, Switzerland. (who.int/phe/health_topics/outdoorair/databases/en/, accessed 30 November 2016).

World Bank (2003). India: access of the poor to clean household fuels. Energy Sector Management Assistance Programme (ESMAP); no. ESM 263 / 03. Washington, DC: World Bank.

World Bank (2016). The Cost of Air Pollution Strengthening the Economic Case for Action. The World Bank and Institute for Health Metrics and Evaluation, University of Washington, Seattle.

Zhang JJ, Smith KR (2007) Household air pollution from coal and biomass fuels in China: measurements, health impacts, and interventions. Environ Health Perspect 115(6)

Zhou N, Cui Z, Yang S, Hana X, Chenb G, Zhoua Z et al (2014) Air pollution and decreased semen quality: a comparative study of Chongqing urban and rural areas. Environ Poll 187:145–152 http://www.pmujjwalayojana.com