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Short-lived climate pollutants and public health risks: A review

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Abstract
Climate change has resulted in a significant disruption in global ecosystem bringing natural disasters quite frequently than ever before. The emission of Green House gases and other gases and particles have deteriorated human, plant and ecosystem's health. Of those gases and particles, short-lived climate pollutants (SLCPs) are a class of pollutants that have an atmospheric lifetime shorter than carbon dioxide (CO_2), often persisting for only days or weeks (longer for methane); but exert a severe climate warming effect. Important examples include black carbon, ground-level ozone, methane and hydro fluorocarbons which have a global warming potential (GWP) far more than CO_2. These pollutants affect the cardio-respiratory system causing acute myocardial infarction, venous thromboembolism, stroke and chronic obstructive pulmonary disease. The World Health Organization (WHO) has estimated the annual deaths attributable to ambient and household air pollution to be 3.7 and 4.3 million respectively. They also affect the crops by reducing the rate of photosynthesis, altering the nutrient composition and decreasing the yield, thereby producing a negative impact on food security and nutrition. The United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) have evaluated the potential impact on climate change and health by finalizing 16 mitigation actions out of nearly 2000 existing ones and determined that their full implementation by 2030 will result in a reduction of 0.6˚C in the global mean temperature, prevention of 2.5 million annual premature deaths and protection of 52 million tons of crops/ year by 2050. The World Health Organization (WHO) is giving more emphasis on reduction of vehicular emission, rapid mode of transport, cleaner and efficient fuel alternatives and promotion of plant-based nutritious food. So, the reduction of SLCP emission can have important near-term climate benefits while also contributing to global public health.

Keywords: short-lived climate pollutants; black carbon; ozone; methane; mitigation

Introduction

The climate all over the globe has been affected severely by human activities that have resulted in ecosystem degradation and decline in food production affecting the livelihood of people and health of human beings and animals [1]. The emission of greenhouses gases (GHG) due to anthropogenic activities contribute significantly towards global warming. In 2015, at the United Nations Climate Change Conference (UNCCC) in Paris, 195 countries agreed to reduce the emissions of greenhouse gases including carbon dioxide (CO_2) with an aim to achieve a 2˚C decrease in global mean temperature [2]. In order to achieve this target, along with CO_2 reduction, efforts have to be given to reduce the concentration of certain other atmospheric pollutants that remain in the atmosphere for a very small period of time, but account for up to 40-45% of global warming [3]. These climate pollutants are known as short-lived climate pollutants (SLCPs) whose longevity in the atmosphere varies from some days to some years. The global warming potential (GWP) of SLCPs are much more pronounced than CO_2. A 0.6˚C decrease in global temperature could be achieved by 2050 if policy efforts are given towards reduction of SLCP emission. If we can implement the SLCP emission mitigation actions along with CO_2 mitigation actions, it would be a "win-win" situation [3] in coming years.

Air pollutants in the atmosphere remain attached to particulate matters (PM) which are composed of a variety of solid and liquid particles of both anthropogenic and natural origin [4] and their composition varies with time and place of origin [5]. The important PMs are the PM_{10} and $PM_{2.5}$ which have an aerodynamic diameter less than 10 µm and 2.5 µm respectively.

There are a number of mechanisms by which air pollutants exert the adverse health effects, especially the cardiovascular diseases [6, 7].

Repeated exposure to fine PMs (e.g. diesel exhaust (300 µg/mm^3) may result in thrombus formation in blood vessels [8] due to dysregulation of endogenous fibrinolytic mechanisms. Alterations in the autonomic control of the heart due to exposure to the PM have also been documented [9] which is mainly attributable to the activation of pulmonary neural reflex arcs and direct effects of pollutants on cardiac ion channels [10].

Short-lived climate pollutants (slcps)

Short-lived Climate Pollutant (SLCP) is defined as "a gas or particle that has a climate warming effect and with an atmospheric lifetime shorter than carbon dioxide, often persisting for only days or weeks (longer for methane and hydrofluorocarbons)" [3]. The important pollutants included under SLCPs are black carbon (BC), methane (CH_4), tropospheric ozone (O_3) and hydrofluorocarbons (HFCs).

Black Carbon (BC)

Black carbon (BC) is a product of incomplete combustion of fossil fuels, solid biomass and agricultural waste (stubble burning) or even during wildfires [11]. It is commonly known as 'soot' and is composed of 5-15% of fine PM [12]. More formally, BC is defined as an ideally light-absorbing substance composed of carbon [13]. Black carbon persists in the atmosphere for a few days and is removed mainly by deposition. The concentration of BC is directly proportional to the areas close to the source of emission, such as near roadways with heavy traffic and inside households where solid fuel is used for cooking. BC can travel to long distances, including transcontinental "brown clouds" [11].

Despite its short persistence, the GWP of BC is nearly 3200 over a 20-year period; which means, it is around 3200 times more potent in causing global warming than CO_2 on a per-unit basis during the same time period [14]. BC has been one of the important contributors to the radiative forcing (difference in the amount of solar energy received by earth and reflected back into the space) over the last ~250 years, of which, approximately 60% has been attributable to fuel combustion (fossil fuel or bio-fuel), about 30% to other biomass burning, and the rest to the deposition on snow and ice [15].

Global emission

Out of 8000 KT of BC emitted globally (4800 KT from energy related burning and 2800 KT from open biomass burning), 77% comes from developing world [16]. On a global scale, East Asia (largely China) contributes 32% of global anthropogenic BC emissions, whereas the contribution from India is around 12% [17]. PM_{10} concentration of majority of the metropolitan cities around the world have gone well beyond the WHO recommended level of 20 μg/m^3.

BC in relation to ambient air pollution

BC may act as a "universal carrier" of toxic components of PM that bind to BC particles after emission in the atmosphere [18]. Both short-term and long-term exposure to PM has resulted in systemic inflammation, vascular dysfunction, cardio-respiratory diseases, lung cancer [10, 19]. Health risks from long-term exposure to $PM_{2.5}$ are more pronounced than those from short-term exposure. The epidemiological evidences depict that the change in risk per unit increase in exposure is generally larger at lower levels. With an increase of 10 μg/m^3 concentration of PM in long-term exposure, all-cause mortality increases by about 2.8% [20].

In terms of total health impact, the burden of disease from ambient (outdoor) $PM_{2.5}$ was estimated at 3.7 million deaths globally in 2012, of which, 16% of deaths due to lung cancer, 11% due to chronic obstructive pulmonary disease (COPD), 29% due to heart disease and stroke and approximately 13% due to respiratory infections [21]. The mortality due to ambient air pollution can go up to a staggering 91% in low and middle-income countries, especially the South-East Asian countries and Western Pacific regions [22].

BC in relation to household air pollution

Household air pollution refers to air pollution inside or near the household due to burning of solid fuels for cooking, lighting or space heating. The annual global mortality accounted to household air pollution has been estimated to be 4.3 million [21], of which, one-third of mortality was attributable to COPD; one-quarter due to stroke; 17% from lung cancer in adults [23] and 15% from ischemic heart disease. Children under five years of age have been found to exhibit acute lower respiratory tract infections, still births, stunted growth, low birth weight, delayed cognitive development as well as death in certain cases due to household air pollution [21]. Household air pollution is responsible for about 12% of outdoor combustion-derived $PM_{2.5}$ globally due to use of solid cooking fuels [24]. Average personal exposures to household air pollution due to solid cooking fuels have been estimated at 204 μg/m^3, 337 μg/m^3 and 285 μg/m^3 for men, women and children respectively, which are 20 times more than WHO guideline levels [25] (Table 1). A reduction of only 10 μg/m^3 in the concentration of BC may result in 1.6% and 15% decrease in the incidence of myocardial infarction and overall air pollution-related mortality respectively.

Table 1: WHO air quality guideline for particulate matter [21]

PM type	WHO standards	Indian National Ambient Air Quality Standards [26]
PM_{10} annual	20 μg/ m^3	60 μg/ m^3
PM_{10} 24-hr mean	50 μg/ m^3	100 μg/ m^3
$PM_{2.5}$ annual	10 μg/ m^3	40 μg/ m^3
$PM_{2.5}$ 24-hr mean	25 μg/ m^3	**60** μg/ m^3

BC as carcinogen and mutagen

The carcinogenic effect of BC as reported by various international organizations working on toxicopathology and carcinogenicity of chemicals is summarized in table 2. In an experimental investigation, mutational changes in hypoxanthine phosphoribosyltransferase (*hprt*) gene were reported in alveolar epithelial cells in rat following inhalation exposure to BC [27] which led to chronic inflammation and release of genotoxic oxygen species. BC does not directly interact with DNA, but at higher concentrations, a secondary genotoxic mechanism was responsible for the mutagenic effect [28].

No mutagenic have been found in Ames test (*in vitro* test for gene mutation in bacteria) [28] because of its insolubility in aqueous solution. Again, organic solvent extracts of black carbon containing traces of polycyclic aromatic hydrocarbons (PAHs) have been used to study the mutagenic effects, but a reduction in the bioavailability of the compound was observed which may be due to very tight molecular bonding between PAHs and BC [29].

Table 2: Carcinogenic potential of black carbon

Organizations	Reports
International Agency for Research on Cancer (IARC), Paris, France	Possibly carcinogenic to humans
American Conference of Governmental Industrial Hygienists (ACGIH) Ohio, United States	Not Classifiable as a Human Carcinogen
European Centre for Ecotoxicology and Toxicology of Chemicals, Belgium	Suspect carcinogen
National Toxicology Program (NTP), US dept of health and human services	Not a carcinogen
Occupational Safety and Health Administration (OSHA), USA	Not a carcinogen
National Institute for occupational Safety and Health (NIOSH), USA	PAH contamination levels >0.1% (1000 ppm) : suspect carcinogen

Impacts of BC on Climate

There are three main interactions between the BC and climate- direct effect, snow albedo effect and aerosol-cloud interaction effect. First, BC contributes to warm the atmosphere by absorbing solar radiation (direct effect). Second, BC is carried by wind and precipitates over snow and ice, thereby darkens the surface, reduces reflectivity and thus increases absorption (snow albedo effect), thereby making the Arctic vulnerable. Third, the interaction of BC with clouds affects cloud stability, precipitation, and reflectivity (aerosol-cloud interaction effects). BC is the second most important contributor to climate change after CO_2 [16] with a net climate forcing of +1.1 Wm^{-2}. In addition this, the climate effect may increase the likelihood of extreme weather, which is often associated with high mortality during that period.

Ground-level Ozone (O_3)

Ground-level ozone is also known as 'smog' which is formed by the chemical interaction of certain primary air pollutants/ ozone precursors like carbon monoxide, methane, nitrous oxides and other volatile organic compounds in the presence of sunlight. Vehicular traffic contributes significantly towards ozone formation through emission of NO_x, VOC to the tune of 56% and 45% respectively [3]. NO_2 in particular appears to be responsible for large disease burdens, with exposure linked to premature mortality and morbidity from cardiovascular and respiratory diseases. Ground-level ozone concentrations are estimated to have increased 2.5 times than pre-industrial era (~1750s). The ground level ozone concentration guideline values are given in table 3.

Table 3: Ground level ozone concentration guidelines

Organizations	Guideline Value (over an 8-hr period)
United States Environment Protection Agency (US EPA)	137.42 µg/ m^3
World Health Organization (WHO)	100 µg/ m^3
European Union (EU)	110 / m^3

Mechanism of action of ozone

Ozone (O_3), upon inhalation reacts to antioxidants, lipids and proteins in the airway epithelium lining fluid (AELF) and produces respective ozonization products. These products activate immune cells, thereby promoting oxidative degradation of membrane lipids, formation of protein adducts and disruption of the structural integrity of membrane proteins. There is also formation of pro-inflammatory precursors within cells by activating various phospholipases (PLA_2, PLC and PLD). Ozone may also directly interact with cholesterol and phospholipids in epithelial cells membranes of respiratory tract, which may further increase the production of lipid ozonized products. Pro-inflammatory mediators are released from injured epithelial cells which attract and activate immune cells, further amplifying lung inflammation [30]. These toxic circulating mediators can alter the blood-brain barrier (BBB) function and may reach the brain. Ozone can induce oxidative stress in the brain through the olfactory pathway which travels from the olfactory bulbs to deeper parts of brain. Both pathways and their associated ozone mediators may lead to oxidative stress and inflammation in some brain areas like cortex, hippocampus and striatum which can contribute to the development of the Alzheimer Disease-like brain defects depending on the ozone inhaled dose and exposure frequency [30].

Fine particles are able to accumulate in the olfactory bulbs when we get exposed to high levels of air pollutants, including particulate matter and heavy metals, potentially leading to deposition in the olfactory mucosa producing local inflammation, neuropathology, cytotoxic and cell stress responses [31] and may be transported farther to the olfactory cortex and other brain regions [32, 33]. Ozone may also exhibit a similar mechanism of inducing local inflammation [34], though the effects of individual pollutants are difficult to access due to co-exposures.

Health effects of Ozone

There is a causal relationship between exposure to ground-level ozone and reduced lung function, inflammatory responses, increased airway reactivity, cardiovascular effects, asthma and total mortality [35, 36]. The severity of adverse health conditions varies according to location and season, but the increase in hospital admissions is normally about 1-6% for every 80 µg/m^3 increase in the 1-hour maximum ozone concentration (or equivalent change in the 8-hr maximum or 24-hr average) [35]. Children, athletes and people working outdoors are highly susceptible whereas, people with pre-existing respiratory disease, older people and people with certain genetic polymorphisms are at increased risk to ozone-related health impacts. Ambient ozone exposure has resulted in approximately, 150000 deaths in 2010, an increase of about 6% over 1990 [37].

Methane (CH_4)

Methane, emitted by anthropogenic activities, is one of the important Green House gases accounting up to 16% of Green House effect with an atmospheric lifetime of about 12 years. Enteric fermentation from the livestock accounts up to 47% of the methane emission [38]. Methane is also responsible for formation tropospheric ozone. The GWP of methane over a 20-year period is 84 times that of CO_2 [39].

Health effects of Methane

Methane acts as an asphyxiant, at high concentrations it may displace oxygen supply, especially in confined spaces [40] indirectly causing suffocation and loss of consciousness. Some other signs include general weakness, headache, dizziness, nausea, vomiting and incoordination.

Hydrofluorocarbons (HFCs)

Hydrofluorocarbons (HFCs) are man-made fluorinated green-house gases with an atmospheric lifetime of about 15 years. Although the contribution of HFCs towards global warming is less than 1%, but the GWP of HFC-134a is estimated to be 3710 over a 20 year period [39].

Health effects of HFCs

Accidental spillage/ leakage from refrigerators and recyclers of electronic appliances are the major sources of HFCs for humans, although the occupational exposure to HFCs is documented to be moderate [41]. Inside the body, HFC is oxidized by the cytochrome-P-450 system to trifluoracetic acid (TFA) which is a toxic metabolite. The most significant responses during heavy exposure are incoordination, laboured breathing, darkening of eyes, frothing from nose, unresponsiveness, cyanosis and convulsions [41].

Indirect health impacts of SLCPs
Food security and nutrition
Ozone and BC can hamper plant growth and development as well as agricultural productivity. BC reduces the amount and quality of solar radiation available for photosynthesis [42]. Ozone significantly decreases photosynthetic rates by 20%, RUBISCO activity by 19%, stomatal conductance by 22%, Chlorophyll content by 40% and wheat yield by 24-34% [43]. It also causes physiological stress in plants, alters chemical composition and the quality of harvested products, thereby reducing the feed value for ruminants [44, 45]. The Indo-Gangetic plain is at highly vulnerable to the ground level ozone.
Combined effects of climate and air pollution reduced India's wheat yield by as much as 36% in 2010 [42], mostly attributable to the direct effects of SLCPs. It has been estimated that, total wheat, maize and soybean yield may decline by 17%, 21% and 24% for China and by 53%, 20% and 11% for India by 2050 due to enhanced ozone levels alone [46], which will indirectly affect the nutrition.

Temperature
Associations of temperature with health related events (morbidity and mortality) have been well documented [47]. Higher risks are observed not only during temperature extremes, but also from short-term changes in ambient temperatures [48]. Temperature-mortality relationship depends on population characteristics, health service provision as well as short-term & long-term exposure and the prevailing climate [49].

Natural hazards and disasters
Rising global temperature can accelerate the glacial and snow melting which is directly proportional to the increased risk of natural disasters, particularly flooding. Direct impacts include injuries and drowning during flooding, indirectly by loss of agriculture, infrastructure, disruption in public health and sanitary system, shortage of safe and wholesome drinking water and food, disrupted livelihoods and an increased risk of water-borne disease outbreaks.

SLCP mitigation options
The role of UNEP and WMO
The United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) evaluated the potential impact of nearly 2000 existing SLCP mitigation actions and determined that, full implementation of only 16 of those actions- nine for BC and seven for CH_4 could provide 90% of the climate benefit [3]. Mitigation actions for CH_4 alone will result in about 60% reductions in future climate warming and remainder could be achieved from BC mitigation actions [48].
As far as health benefits are concerned, if all the 16 SLCP-mitigation options are implemented by 2030 to their full potential; then we can experience approximately 2.4 million avoided premature deaths and 52 million tons of avoided crop losses from 4 major crops annually as well as a 0.5°C reduction in the mean global temperature by 2050 [48]. The Asian countries like India, Pakistan, Afghanistan, China, Bhutan and Nepal will experience 1.2 million avoided deaths from outdoor air pollution and a 15.4 million ton increase in staple crop production per year [48].

Kigali Amendment to Montreal protocol (October, 2016)
In Kigali, the capital of Rwanda, an amendment to Montreal Protocol was made to phase down the production and usage of HFCs in which the developed countries should phase down the use of HFC by 85% till 2036 and the developing countries by 2045 [50] so as to achieve a 0.5°C reduction in global temperature by the end of this century.

Role of the WHO
The WHO has been working constantly on the health and environmental effects of SLCPs and chalked out the following four broad areas as a part of its mitigation approach.
1. Reduction in vehicular emission by implementing higher efficiency standards
2. Policies and investments to build rapid transit medium
3. Provision of clean and efficient fuel energy to approximately 2.8 billion low-income households
4. Encouraging people to consume healthy, nutritious and plant-based foods

Analyzing the above four areas, Dr. Maria Neira, WHO Director, Department of Public Health, Environmental and Social Determinants of Health has rightly said, "The health benefits that may be obtained from these strategies are far larger than previously understood, and they can be enjoyed immediately and locally."
A global campaign named 'Breathe Life', led by the WHO, Climate and Clean Air Coalition (CCAC), UNEP and The World Bank raises awareness about the health risks of SLCPs and protecting health and the climate by improving the air quality. "The Madrid Call for Fast Action on Super Pollutants" has been prepared during the COP25 (2-13 December, 2019) at Madrid, Spain which draws attention to the urgent need for cutting emissions of SLCPs, including methane, fluorocarbons and black carbon.

Conclusion
Short-lived climate pollutants (SLCPs) remain in the atmosphere for much shorter duration than longer-lived climate pollutants such as CO_2, but in terms of their global warming potential their efficacy is thousands times more than that of CO_2. The impacts of SLCPs are especially strong over the short term future. These SLCPs have various direct and indirect detrimental impacts on human health which includes cardio-respiratory illnesses, stroke and neonatal mortality; on agriculture, notably the loss of crop production and on ecosystems, in the form of various types of natural hazards and disasters. Mitigation actions have been formulated to reduce their emission, the implementation of which can make an immediate beneficial impact on climate, thereby improving the public health and agricultural productivity in near term future.

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