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Original Article

Characteristics of the Ozone pollution and its Health Effects in India

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ABSTRACT

Surface level ozone is one of the important air pollutants. It is formed by the reaction of atmospheric pollutants in the presence of sunlight. The surface ozone shows temporal and spatial variations in the country. The levels are maximum during summer and minimum in monsoon seasons. The levels are maximum during daytime and minimum during night or early morning. In India, surface ozone levels are above the recommended threshold of 8 hour average of 100 μg/m^3 for air quality monitoring at various stations. Exposure to high levels of surface ozone causes number of health problems. Short term exposure causes drop in lung function measures and it also affects the lung's mucociliary function thereby increasing the susceptibility to bacterial infections. With increase in surface ozone levels, there is likelihood of an increase in risk of hospital admissions for Chronic Obstructive Pulmonary Diseases (COPD) and the number of cardiovascular and respiratory deaths. In children, increase in ozone concentration is associated with increase in hospital admissions and unscheduled asthma medications. The high levels of surface ozone are becoming a threat to people's health and so surface ozone levels have to be monitored and steps taken to reduce their levels.

Key words: Surface Ozone, Pollution, Respiratory, Cardiovascular Diseases, India

Key Messages: Surface level ozone is an important air pollutant causing cardiovascular and respiratory diseases. The levels are above the recommended threshold at various stations in India. Surface ozone has to be monitored and steps taken to reduce their levels.

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INTRODUCTION

Outdoor air pollution is a major environmental health problem. Exposure to air pollution leads to increased risk of respiratory diseases like acute respiratory infections and chronic obstructive pulmonary diseases; and cardiovascular diseases, such as stroke and ischemic heart disease. According to World Health Organization, one in eight total global deaths occurs as a result of exposure to air pollution.[1] Over 3.5 million people die each year from outdoor air pollution. Low- and middle-income countries, especially the Western Pacific and South-East Asian countries account for about 88% of those premature deaths.[1] According to a recent study by the Organization for Economic Co-Operation and Development (OECD), in India, the cost of air pollution to society in 2010 was estimated at US$ 0.5 trillion.[2] Ozone is one of the air pollutants of major concern globally. Higher levels of ozone in the air can affect human health, leading to breathing problems, asthma exacerbation and reduced lung function. Several studies have also shown that daily mortality and heart diseases increase with exposure to high levels of ozone.

MATERIALS AND METHODS

Literature search was carried out in PubMed, WHO website and Google Scholar. Inclusion criteria used were: articles published from 1980 to 2014 concerning ozone and its health effects with special reference to India, in any language and of any design. Articles on ozone layer and ozone depletion were excluded. Cross-references of articles included in the review were also searched. Key words used during the search were surface ozone, health effects, air pollution, mortality, morbidity, seasonal variations and ozone standards. All relevant articles were critically analysed and the contents were extracted into broad thematic areas for further interpretation.

RESULTS AND DISCUSSION

During the search a total of 55 relevant articles were identified and analysed. The results are presented below in the pre-identified thematic areas.

Ozone

Ozone is a colorless gas composed of three atoms of oxygen. It occurs both in the Earth's upper atmosphere and at ground level. The ozone layer occurs

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naturally in the upper atmosphere (the stratosphere), 6 to 30 miles above the Earth's surface. This protective ozone layer shields the Earth from the sun's ultraviolet rays. But manmade chemicals are gradually destroying this layer, resulting in a "hole in the ozone" over the north and south poles. The tropospheric or ground level ozone lies in the Earth's lower atmosphere is an important photochemical pollutant. This surface ozone (O_3) is formed when pollutants like as Volatile Organic Compounds (VOCs) and oxides of nitrogen chemically react in the presence of sunlight. As a result, the highest levels of ozone pollution occur during periods of sunny weather. Cars, power plants, industrial boilers, refineries, chemical plants, and other sources emit these pollutants. Once formed, ozone is scavenged by NO and a "photo stationary state" is formed where concentrations of NO, NO_2 and O_3 are all inter-related. But the presence of CO and VOCs can disturb this steady state relationship by producing peroxy radicals and resulting in an increased ozone concentration.[3]

Due to the worldwide increase in the burning of fossil fuels, atmospheric CO_2 concentrations are currently rising at approximately 0.5% per year and surface ozone values are increasing at a rate of 0.32% per year.[4] Ozone can be transported over long distances by wind and due to this even rural areas can experience high ozone levels. High ozone concentrations have also been observed in cold months, with high levels of local VOC and NO emissions. Smog is primarily made up of ground level ozone combined with other gases and particle pollution. Surface ozone is also a greenhouse gas which contributes to climate change.

Characteristics of ozone pollution

Factors influencing ozone concentration

Many meteorological factors influence ozone concentration. Solar irradiation and temperature influence the speed and amount of photochemical production of ozone. Vertical temperature gradient influences the vertical mixing in the atmosphere and thereafter the ozone concentration near the ground. Surface winds control the concentrations in mountain valleys and coastal areas. Aloft winds are responsible for the transport of ozone and its precursors. Precipitation decreases the ozone concentration by means of wet deposition. Relative humidity chemically controls the ozone concentration and diurnal meteorological variations cause diurnal variation of ozone concentrations.

Ozone Guidelines

In 1997, the United States Environmental Protection Agency (EPA) proposed adding an ozone standard of 80 ppb based on the daily 8-hour maximum concentration. WHO Air Quality Guidelines for Europe (WHO AQG, 2000) had set the guideline value for ozone levels at 120 μg/m^3 for an 8-hour daily average. But studies have shown health effects at concentrations below 120 μg/m^3. So WHO Air Quality Guidelines AQG in 2005 reduced the cut-off from 120 μg/m^3 to 100 μg/m3 (daily maximum 8-hour mean).[5] In the year 2009, for the first time, India included ozone under its Revised National Ambient Air Quality Standards (NAAQS).[6] According to this, the mean concentration of ozone in ambient air must be less than 100 μg/m^3 for any 8 hour period of monitoring and less than 180 μg/m^3 in hourly monitoring. This should be complied with 98% of the time in a year and in 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.[7]

Variations in Ozone level

The ground level ozone levels are not constant. It varies from country to country and even within a country varies from region to region. Monthly measurements at 50 stations in Asia, Africa, South America, and Europe showed that the median ozone concentrations were maximum at Waliguan Mountain, China (45ppb) and minimum at Petit Saut, French Guiana (8ppb). The highest ozone values were found in the mid-latitudes, with Northern hemisphere values exceeding the Southern hemisphere levels, and the lowest values found in the tropical regions.[8] In India, in addition to regional variation, ozone shows diurnal (or daily) and seasonal variations as shown in Table 1. The ground-level ozone is maximum during summer and minimum during monsoon seasons. In

Table 1: Characteristics of ground level ozone in India

Factor		Stations
Maximum level of Ozone		
Season	Summer	Dayalbagh[9], Debaji[10], Gadanki [AP][11], Pant Nagar[12], Thumba[13], Anantpur[14,15], Mittal[16], Nainital[17], Maharashtra[18], Kannur[19], Nainital[17], Tranquebar[20], Mohal [Kulu valley][21], Pune, Bandipur and Nilgris[22]; Chennai[23], Thumba[13], Mittal[16], Pune, Bandipur and Nilgris[22], Anantpur[9,24]
	Winter	Debaji[10], Dayalbagh[9], Gadanki [AP][11], Varanasi[25], Tranquebar[20], Kannur[19], Mt.Abu[26], Anantpur[15], New Delhi[27], Pant Nagar[12], Ahmadabad[28]
	Autumn	New Delhi[27], Pant Nagar[12], Mt. Abu[26]
	Spring	Gadanki[11], Pantnagar[12]
Diurnal	Noon	Chandrapur District[29], New Delhi[30] Kannur[19], Tranquebar[20], Anantpur[29], Dayalbagh[9]
	Evening	Allahabad[31], Anantpur[15], Thumba[13]
	Daytime	Anantpur[24], Pune, Bandipur and Nilgris[22], Mohal [Kulu valley][21], Dayalbagh[9], New Delhi[27], Gadanki[11], Anatpur[32]
Minimum level of Ozone		
Season	Monsoon	Kannur[19], Anantpur[24,32], Varanasi[25], Pune, Bandipur and Nilgris[22], Anantpur[32], Nagercoil[33], Dayalbagh[9], New Delhi[27], Ahmedabad[28], Nainital[17], Anantpur[14]
	Winter	Mohal [Kulu valley][21], New Delhi[27]
	Post monsoon	Dayalbagh[9], Tranquebar[20]
Diurnal	Morning	Chandrapur District[29], Kolkata[34], Anantpur[14,15], Kannur[19], Anantpur[24], Mohal [Kulu][21], Tranquebar[20]
	Night	Kolkata[34], Kannur[19], Tranquebar[20], Dayalbagh[9]
	Evening	Anantpur[14,15], Anatpur[32], Mohal [Kulu] [21]

most parts of the country, the levels are maximum either during daytime or noon and minimum during night time or early morning.

Highest ozone levels in India

In India, the highest level of ground level ozone has been reported in number of individual studies. But the regional variations of ozone are difficult to document as these studies are done at different stations in varying time points and have used different measures to report the highest level. Still in many locations the 8 hourly ozone levels exceeded the recommended 100 μg/m3 as shown in Table 2.

Health effects of Ozone: global literature

Pathological and functional changes in the lung

Ozone has been shown to alter epithelial permeability of the lung after 18-20 hours of exposure.[38] The lung's mucociliary function is also acutely stimulated by ozone.[39] These effects can increase susceptibility to bacterial respiratory infections. Exposure to ambient levels of ozone for 6.6 hours has been shown to increase the markers of inflammation like the Neutrophils (PMNs), Prostaglandin E2 (PGE2), fibronectin, Interleukin-6 (IL-6), and Lactate Dehydrogenase (LDH), alpha-1 antitrypsin in the lungs, and decrease phagocytosis via the complement receptor.[40] Short-term exposures to ambient-level O_3 concentrations cause drop in lung function measures such as lung volume and expiratory flow rates, forced vital capacity and specific airway conductance.[41] The APHEA (Air Pollution and Health, a European Approach) project in 1997 by Andersen *et al* in 6 European cities showed there was an increase in hospital admissions for Chronic Obstructive Pulmonary Diseases (COPD) for all ages for a 50 μ/m^3 change in ozone (RR=1.04).[42]

Table 2: Highest ozone level recorded at various stations in India

Location	Level of ozone [μg/m^3]
Chennai[23]	106
New Delhi[27]	> 160#
Pantnagar[12]	100
Ahmedabad[28]	<160#
Hyderabad[35]	198 in 2002 and 180 in 2003
Kolkata[34]	96
Chandrapur district[29]	50
Pune[36]	120
Anantapur[24]	104 ± 20
Mt Abu[26]	Background = 66 Continental levels =96
Pune, Bandipur, Nilgiris[22]	Annual average = 54
	Other Measures
Anantapur[32]	Annual average ozone mixing ratio =35.9
Anantpur[15]	Yearly mean mixing ratio^ = 35.9 ± 8.8
Delhi[30]	Threshold exceeded for 45 days /yr
Agra[37]	AOT 40 index* Summer- 840 ppb.h Winter- 2430 ppb.h

Note:

#The level of ozone is expressed as μg/m3 by multiplying ppb by a factor of 2

*Accumulated exposure over a cut-off threshold of 40 ppb

^Mixing ratio is defined as the ratio of the number of molecules of a particular trace gas to the number of molecules of all the other gases present in a given volume of air

Mortality

A meta-analysis of time series studies and panel studies by WHO in 2004 showed that there was a 0.44% increase in daily mortality per 10 ppb change in 1-hour maximum ozone concentration.[43] Similarly a meta-analysis of 50 time-series analyses by Levy *et al* in 2001 showed a 0.39% change in daily mortality per 10 ppb change in daily 1-hour maximum ozone.[44] The APHEA project in 15 European cities by Touloumi *et al* in 1997 showed that increases of 50 μg/m^3 in O_3 (1-hour maximum) was associated with a 2.9% increase in the daily number of deaths.[45] The APHEA 2 project by Gryparis *et al* in 23 cities/areas for 3 years since 1990 showed that an increase in 1-hour ozone concentration by 10 μg/m^3 was associated with a 0.33% increase in the daily number of deaths, 0.45% in the number of cardiovascular deaths, and 1.13% in the number of respiratory deaths.[46]

Child health

Young children are sensitive to O_3, because significant lung development continues in the postnatal period.[47] Burnett *et al* demonstrated that in children under 2 years of age, there was a 6.6% increase in hospital admissions per 10 ppb change in 1-hour daily maximum ozone (RR = 1.348).[48] Thurston *et al* showed that among children aged 7 to 13 years in summer asthma camps in New York City, an increase in the 1-hour daily maximal ozone concentration from 84 to 160 ppb was associated with increased unscheduled medications administered per day.[49] The health effects of ozone are summarised in Table 3.

Health effects of Ozone: Indian literature

Studies on health effects of ozone from India are limited. Gupta *et al* demonstrated a significant increase in daily hospital admission for respiratory diseases with elevated levels of ozone.[50] Kumar *et al* conducted a cross-sectional study in Punjab and showed that levels of ozone were found to be higher in an industrial town than in the a non-industrial town and that residence in the industrial town was associated with increased chronic respiratory symptoms like cough, phlegm, breathlessness, or wheezing (OR= 1.5) and spirometric ventilatory defect (OR = 2.4).[51] Jayaraman *et al* in Delhi showed that a 10-microgram rise in O_3 led to increase in respiratory morbidity (RR = 1.03).[52]

Control of ozone pollution

Through global climate policies, it is estimated that in the time horizon up to 2050, a decrease of ozone concentrations might save nearly 20,000 cases of premature death per year.[53] The annual monetary value of health benefits from reducing ozone concentration was estimated to be $10 per person per microgram per cubic meter reduction.[44] Steps that are needed to reduce ground-level ozone are as follows:

Legal framework and monitoring of Ozone levels

In India, National Air Quality Monitoring Program (NAMP) is a nationwide program executed by Central Pollution Control Board (CPCB) to monitor the ambient air quality through a network of over 340 stations across the country. Under NAMP, only four air pollutants namely Sulphur dioxide (SO2), Oxides of Nitrogen, Suspended Particulate Matter (SPM) and Respirable Particulate Matter (RSPM) are regularly monitored.[54] Surface ozone is regularly monitored by the CPCB through automatic monitoring stations in New Delhi and few other stations. Nevertheless, surface ozone level must also be regularly monitored throughout the country and particularly in rural neighborhoods surrounding large cities as ozone levels are likely to be high in these neighborhoods, particularly because agriculture production is known to be adversely affected by high ozone concentrations.

Automobile manufacturing and auto fuel industry can introduce several measures to reduce emissions of precursor pollutants including Vapor

Table 3: Health effects of increased surface ozone

Effects	Experimental Studies	Epidemiological Studies
Acute effects	-Alters epithelial permeability of the lung -Stimulates mucociliary function of the lung -Increase in PMNs, PGE2, LDH, IL-6, alpha1 antitrypsin, and decrease phagocytosis via the complement receptor	-Increase in hospital admissions for COPD -Increase in daily mortality -Increase in the daily number cardiovascular (0.45%) and respiratory (1.13%) deaths . -Increase in hospital admissions in children -Increased unscheduled asthma medications in children
Chronic effects	-Increased susceptibility to bacterial respiratory infections	

Recovery Control, which are systems that control VOC vapour releases during the refuelling of motor vehicles, timely engine turnover, and adoption of cleaner and lower emitting new engines. Similarly, coal-burning power plants can adopt clean coal technology to reduce emissions. Urban planners and policy makers can support the cause through improving public transport, reduce congestion on roads, reduce idling time and incentivize use of hybrid or electric vehicles.

To reduce vehicular pollution, Honorable Supreme Court of India has ordered the states to strictly implement Emission Norms and to switch over to clean fuels like Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG). Emission standards for the industries are notified under Environment (Protection Act) 1986 to check pollution. The states have given an action plan to the Supreme Court, in which they have given commitment to monitor that the industries are using cleaner fuel, developing green belt and installing pollution control devices.

Role of individuals and NGOs in controlling Ozone level

The public can also reduce ozone levels by conserving energy at home and at work; by reducing vehicle by walking, cycling or using public transportation whenever possible, following gasoline-refueling instructions, keeping motor vehicle engines properly tuned and making sure that tires are properly inflated.[55]

CONCLUSIONS

The ground level ozone measured at various stations across the country exceed the threshold limit. Ground level ozone is a health hazard – leading to respiratory and cardio vascular diseases and their exacerbations and adding to the cost of health care of an already strained health system. Policy changes are required to reduce the generation of ground-level ozone and to monitor the ambient levels and health effects. Further studies have to be conducted to measure the mortality and morbidity due to this pollutant in India and the cost of inaction.

CONFLICT OF INTEREST

None

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