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SOURCES AND EFFECTS OF INDOOR AIR POLLUTANTS: A REVIEW

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Abstract

Exposure to pollutants in the indoor environment is a major global public concern as people spend ≥ 80-90% of their daily time indoors especially at work places homes, hospitals, restaurants, garage, indoor parking, temples, beauty salons, offices, and other enclosed building. This fact makes it important to investigate possible source of indoor air pollutants and to consider their contributions to adverse health effects. Indoor air may be polluted by a variety of pollutants such as Particulate matter (PM), Volatile organic compound (VOCs), Nitrogen oxide (NO_2), Sulfur dioxide (SO_2), Polycyclic aromatic hydrocarbon (PAHs) etc. which vary in chemical composition, reaction capabilities, emission source, disintegration time, and capacity to spread across long or short distances. Indoor air pollutants affect human health in both acute (perceptible) and chronic ways, affecting a variety of systems and organs. It can cause everything from modest upper respiratory irritation to chronic respiratory and heart disease, cardiopulmonary disease, lung cancer, hematological issues, occupational skin and genotoxic repercussions, kidney and liver damage, and even eventual mortality. Short and long term effects of indoor air pollutants on human health are discussed in this paper which would form a basis for further scientific interventions.

Key words: Particulate matter, Indoor Air Quality, Respiratory diseases

INTRODUCTION

With the rapid development of the economy and the efflorescence of population growth, our society requires a large number of resources (e.g., energy, water, and food) to sustain our activities. As a result, there has been a variety of pollution. Air pollution has been a major source of concern around the world among the numerous types of pollution. Pollutants such as particulate matter of various sizes, biological pollutants, and over 400 different organic and inorganic chemical compounds can pollute indoor air, and their concentrations are influenced by a variety of external and interior conditions at different workplaces. Workers are exposed to indoor air pollutants at workplaces like motor garage, commercial kitchens, underground parking, rolling mills, textile mills to name a few. In recent years, there has been a significant movement toward service and knowledge-based industries functioning in an indoor office environment, exposing a bigger population to indoor air pollution [1]. The poor Indoor air quality (IAQ) in addition to causing respiratory illness cause several types of allergies, cancers and even significant reduction in productivity of workers by 10-15% .It is also responsible for damage to valuable objects like books in libraries and historically important objects in museums [2]. Indoor air pollution has been

identified to significantly degrade the quality of human life due to harmful chemicals and other toxic materials which may be ten times more than the outdoor environment due to restricted circulation of air indoors [3]. Air pollution in indoor workplaces can be a major problem because workers spend most of the time in the indoor environment and are exposed to air toxic waste in this environment during their working hour shifts ranging between 8-12 hours. The level of exposure of air pollution at the workplace can be much higher than the outdoor. People who live in a tight energy efficient structure have 46 to 50 percent increased prevalence of upper respiratory infections than those who live in a well ventilated home. The indoor environment influences indoor sources, emissions rates, air exchange rates, penetration of outdoor contaminants into the indoor environment, and pollutant sinks or removal rates on indoor surfaces. The review presents a comprehensive literature related to major indoor air pollutants and their adverse health effects on the exposed population. The literature reported in the paper has been extracted from the research papers obtained by searching the websites Google scholar and Google using keywords like indoor air quality, sources and health effects of particulate matter, Sulphur dioxide, Nitrogen dioxide and polycyclic aromatic hydrocarbons.

Major Indoor air Pollutants

Indoor air pollutants can contaminate the air from different sources including emissions from various household activities like cooking, occupational activities like repairing of cars in garage, commercial kitchens, vehicular exhaust in underground parking and other activities in addition to the air carrying pollutants from the ambient environment. The major indoor air pollutants can be particulate matter of varying size, gaseous pollutants, volatile organic compounds, polycyclic aromatic hydrocarbons, nitrogen dioxide and Sulphur dioxide. These pollutants are present in varying quantities at a particular time with different air circulation patterns in the indoor environment. Exposure to these pollutants, cause various health effects (Table 1) which are summarized in the sections below.

Table 1: Sources and health effects of indoor air pollutants

Pollutants	Sources(indoor)	Health effects	References
PM (particulate matter)	Cleaning, cooking, Smoke, engine exhaust, Vehicle exhaust, Wood stoves, etc.	Reduce lung function, respiratory symptoms, cancer, cardiopulmonary disease, heart rate variability, blood viscosity, destabilization, etc.	Kampa and Catansas 2008; Riedl et al.,2008 ;Valavanidis et al.,2006; Chen et al 2020 ; Silva et al 2020

VOCs (volatile organic compound)	Beauty products, Fuel combustion, Paints, Automotive products, Welding, Finishing, etc.	Respiratory disease, Hematological problems, Cancer Skin irritation, Fatigue, Headache, Dizziness Weakness, Insomnia, Nausea, etc.	Barreto et al.,2009; Nandan et al.,2020; Kampa and Castanas 2008; Nandan et al., 2020 Li et al., 2021).
PAH(polycyclic aromatic hydrocarbons)	Motor vehicle exhaust, fuel stoves, smoking Cooking, dome sting heating, fire places, sanitizers etc.	Eye irritation, Nausea, Vomiting, Diarrhea, Breakdown of red blood cells asthma, lung function, Headaches, Dizziness	Arey and Atkinson 2003; Di Toro et al.,2000; Abdel et al 2016; Ali et al 2019.
SO_2(sulfur dioxide)	Mostly carbon fossil fuels combustion, unvented kerosene stoves, vehicle exhaust, space heaters, domestic coal burning,	Asthma,premature mortality, Irritation (nose, throat, eye) breathingdifficulties, reduced lung function,loss of vision etc.	Shinkura et al 1999;Smith et al.,2000; James et al.2020;Madureira et al., 2020 etc.
NO_2(nitrogen dioxide)	Gas fired appliances (wood stoves, oven unvented gas),Space heaters, unvented kerosene Stoves, tobacco smoke, burning of fuel, emissions from underground parking	Respiratory infections, Loss of appetite, Corroded teeth, Coughing, Wheezing, Breathing problems, Asthma	Berglund et al., 1993; Ponosonby et al.,2001; Adam et al., 2015; Dioron et al 2019 etc.

Particulate matter

Particulate matter, a major hazard, is a complex mixture of solid or liquid particles suspended in the air, some of which are toxic. Particulate matter exposure has been associated to a number of

health outcomes, including mortality, asthma exacerbation, poor lung function, and respiratory and cardiovascular disease hospitalizations. The size, shape, and content of particles can all be different. Particles of a diameter of 10 micrometers or less, such as PM_{10}, $PM_{2.5}$, and ultra-fine particles (UFPs) or $PM_{0.1}$ are inhalable and becomes a major public health issue [4]. Due to their pervasiveness, fine and UFP particles can easily enter deep into the lungs without being filtered, causing a variety of acute and chronic respiratory health consequences [5-7].

Exposure to airborne particulate matter (PM) in the workplace could lead to a variety of health problems [8]. Inhaling PM induces oxidative stress and the generation of reactive oxygen species, leading to hypersensitivity and inflammation of the respiratory epithelium, which can compromise lung function. Long-term chronic exposure can cause lung tissue remodeling, scarring, and fibrosis, which can lead to asthma, bronchitis, chronic obstructive pulmonary disease (COPD), and potentially lung cancer [9-13]. Apart from inflammation, particulate matter causes systemic inflammatory changes that alter blood coagulation [14-16] and increasing the risk of death with exposure beyond the threshold limit. Long-term exposure to fine particle air pollution caused by combustion is a significant environmental risk factor for cardiopulmonary and lung cancer mortality [17,18]. Most toxicological and epidemiological studies focused on inhalation of airborne particulate matter (mainly automobile exhaust particles) because fine respirable particles have a larger link with mortality and adverse respiratory health consequences than other atmospheric gaseous pollutants [19]. Long-term exposure to particle air pollution affects the cardiovascular system, with fine and ultrafine particles from automobile exhaust influencing heart rate variability, blood viscosity, and cardiac arrhythmia, as well as the instability or rupture of atheromatous plaques [20-22].

Sulphates, nitrates, endotoxin, polycyclic aromatic hydrocarbons, and heavy metals are the primary components of PM which are found adhered on the surface of PM originating from a variety of human- made and natural resources contributing to various adverse health effects. Anthropogenic sources also include cigarette smoke, emissions from cooking, wood and other biomass burning in stoves and fire places, cleaning activities with re- suspended dust particles (e.g. sweeping) in addition to penetration of outdoor particles into the indoor environment [23, 24] biological sources of indoor air pollutants including pollens, mold spores, dust mites and cockroaches are also known to cause major health effects.

Volatile Organic Compounds (VOCs)

VOCs are referred to a group of aromatic hydrocarbons including ketones, aldehydes, alcohols acids and eithers with varying functional groups including oxygen, sulfur, nitrogen or phosphorus halogens, with an exception to carbon oxides and carbonates. These show toxicity due to their lipophilic nature enabling them to pass through the biological membrane and causing systemic effects. The toxicity of these compounds depend on their biotransformation within the body [25]. Indoor VOCs concentrations may be at least 10 times higher than outdoor ones, regardless of building location due to emissions from the indoor material in addition to penetration of outdoor VOCs. Indoor VOCs are produced primarily from four sources i) activities including cooking,

smoking, and the use of cleaning and personal care items; ii) indoor chemical reactions; iii) outdoor air penetration occurring due infiltration from windows and door and ventilation systems; and iv) construction materials [26,27]. In addition to above mentioned factors other factors like air exchange rates, age and size, of building, outside VOC levels, and door and window openings can also alter VOCs concentrations. Paint, varnish, wax, and solvent-coated furniture all generate volatile organic compounds (VOCs) [28-30]. Solid wood and wood composite-based furniture items are reported to contribute significantly to VOC emissions, affecting overall indoor air quality. Toluene and xylenes, for example, are common aromatic chemicals that come from combustion (cigarette smoke, heating, and automobile exhaust), fuels, building materials, furniture, and consumer products, all of which can be found in the interior environment. In the many therapies conducted in beauty salons (facial, cleansing, body hydrotherapy, pigmentation, make-up, hair removal, and so on), a large variety of chemical agents are utilized. These items include a huge number of ingredients, including VOCs, methacrylate, phthalates, and formaldehyde. [31-35] adding to the indoor VOC levels. Emissions from wet process of office machinery, interior finishing, and vehicle exhaust from subterranean parking garages were all discovered as substantial sources of VOCs.

The nature and extent of the health effects caused by VOCs depend on their concentration levels and the duration of their exposure. The highly affected population is the children, who are particularly sensitive due to their delayed physical and cognitive development. Inhaled gaseous pollutants not only impact the respiratory system, but they can also cause hematological issues as well as cancer [15]. Depending on whether their exposure is for a short or long amount of time, VOCs can have distinct effects on different systems. The central nervous system and respiratory system are the target systems in short term or acute exposure, causing irritation of the eyes, nose, throat, mucous membranes, headaches, and dizziness. Long term or chronic exposure, on the other hand, is more harmful, damaging systems like the immunological, hematopoietic, central neurological, and respiratory systems. Immunodeficiency affects blood chemistry as a result, and such exposures are linked to leukemia, delayed reaction times, concentration and balance problems, memory loss, peripheral neuropathy, and asthma [36]. VOCs are lipid-soluble chemicals that can pass the blood–brain barrier and cause neurologically harmful health effects, which are common side effects of exposure along with, respiratory ailments, allergies, and malignancies, reported by studies based on occupational risk and animal exposure [37]. Early symptoms of VOCs toxicity may include mucous membrane irritation, headache, dizziness, and nausea.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs (polycyclic aromatic hydrocarbons) are chemical compounds composed primarily of hydrogen and carbon atoms that are structurally coordinated in numerous aromatic rings [38,39]. PAHs with a low molecular weight (2–4 rings) are more volatile and can be found in the gaseous phase, whereas PAHs with a high molecular weight (4–6 rings) vaporize infrequently and are usually found in the particulate phase. They are a type of semi-volatile organic compound (SVOC) generated during incomplete combustion, mainly under conditions with high moisture content, low temperature, and low oxygen concentration [40]. Pyrogenic, petrogenic, and biological activities

are the three main sources of PAHs in the environment. They are common environmental pollutants that are mostly emitted by incomplete combustion of organic materials (coal, air, petrol, and wood) and emissions from human activities like smoking, cooking, and heating with fuel stoves and open fire places [41,42]. Pharmaceuticals, agricultural products, photo graphics products, thermosetting polymers, lubricants, and other chemical processes use PAHs as intermediaries contributing to their environmental concentration. Their natural source in the environment including forest fires, seepage from petroleum or coal deposits, and volcanic eruptions. Incomplete combustion of motor fuels in autos and trucks, incomplete burning of wood and fireplaces, and incomplete combustion of fuel oils in heating systems and even burning of incense sticks in the indoor environment are all examples of inadvertent processes that release them into the environment [40,43]. Shoes, dirt, and infiltrating air that enters the house during cross-ventilation are the other sources of PAHs and environmental contaminants in indoor areas. These PAHs can partition between airborne particles, vapor phase, settling dust, and surface dust, just like other SVOCs.

PAHs can enter the human body by air inhalation, dust ingestion, and skin contact, in addition to food consumption. The partitioning of PAH compounds in the atmosphere between gaseous and particulate phases affects their transit and fate in the atmosphere, as well as how they reach the human body [44]. Due to their high lipid solubility, PAHs can cause disruption in the endocrine system, reproductive system, developmental disorders, neurological diseases, skin allergies, asthma, and premature births. Some PAHs are well-known carcinogens and teratogens, posing a serious threat to human health [45,46]. Their exposure has also been linked to oxidative stress leading to cardiac disease, mutagenicity, teratogenicity, cancer [47,48]. Their effects dependent on the health conditions of individuals and route of exposure, the duration and concentration of PAHs to which they are exposed, and the relative toxicity of the PAHs [49]. Exposure to high levels of PAHs in pollutant mixtures has shown a link to eye discomfort, nausea, vomiting, diarrhea, and skin allergies [50]. Chronic exposure to PAHs has been linked to decreased immune function, kidney and liver damage (e.g. jaundice), cataracts, breathing problems, asthma-like symptoms, lung function abnormalities, and skin irritation. Naphthalene, a kind of PAH, can also cause red blood cell damage as well as bladder and gastrointestinal cancers if inhaled or swallowed in large enough volumes [51-54].

Sulfur dioxide (SO_2)

Sulfur dioxide (SO_2) is a colorless gas and most common oxide of sulfur (SO_x) found both in ambient and indoor atmosphere. SO_2 can enter the indoor air through a number of sources, including vented gas appliances, oil furnaces, kerosene heaters, space heaters, and the burning and heating of high-Sulphur coal. In addition, the amount of SO_2 pollution in the air contributes to the concentration of SO_2 in the home. Higher sulphur oxide concentrations have well-documented harmful effects in humans of all ages [55-58].

SO_2 present in the air, on entering the human body combines with moisture present in the nose, nasal cavity and throat and damages respiratory neurons thereby causing cardiovascular,

respiratory and neurological disorders. Several studies have indicated that even brief exposure to SO_2 levels in the range of 8-12 ppm can produce throat discomfort, and exposure levels of 400-500 ppm can be harmful [59,60]. Moreover, excessive exposure to the SO_2 levels beyond the prescribed limits of World Health Organization's (WHO) has profound harmful impact on persons suffering from asthma, bronchitis, lung disease, and heart disease.

Nitrogen Dioxide (NO_2)

The indicator species for the NOx group of gases is NO_2, which is mostly formed when high-temperature fuels are burned. Petroleum activities, industrial processes, and automotive combustion all release this pollutant. Nitric acid vapor and accompanying particles are produced when NOx combines with ammonia, moisture, and other gases. Indoors, NO_2 is produced by gas stoves, ovens, restaurant cabooses, unvented gas, heaters, unvented kerosene, heaters, and cigarette smoke [61-66]. Indoor NO_2 levels can readily exceed outdoor levels in homes with activities using kerosene heaters, gas stoves or unvented gas space heaters.

The majority of the impacts of NO_2 exposure have been negative [67] NO_2, like O_3, has anatomical targets in the bronchitis and alveoli of the lower respiratory tract. Short-term NO_2 exposure can damage cell membrane, aggravate respiratory problems, especially asthma, by generating respiratory symptoms such as coughing, wheezing, or difficulty breathing and long-term NO_2 exposure can lead to asthma development, decrease in forced vital capacity and increase susceptibility to respiratory infections [68-70]. Asthmatics, children, and the elderly are all more prone to the harmful effect of NO_2 exposure. One of the indirect impacts is edema, or the fluid filling of the intercellular spaces. At dosages of 15 to 25 ppm, eye and nasal irritation, as well as pulmonary discomfort, are common. When NOx reacts with ammonia, moisture, and other substances, nitric acid vapor and associated particles are generated that further deteriorate the human health.

Conclusion

The review includes major air pollutants and their potential sources in the indoor environment and the major health effects caused by these pollutants. The mechanism of effects of pollutants in human body shows that both chronic and acute exposure can induce several diseases including cancers. It can be concluded from the literature that occupational exposure to indoor air pollutants can be a major cause of degradation of health thus appropriate preventive measures should be adopted. Most suitable measure which can be adopted at workplaces and domestic setups can be efficient ventilation and filtration methods, use of proper mask at workplaces and adoption of other safety measures to prevent fugitive emissions. Use of efficient sources of fuel and proper maintenances of equipments at the workplaces can also be a method of reduction of air pollutants. The review can form a basis for further studies related to health effects of indoor air pollutants and aid in interventions related to control of indoor air pollution.

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There is no competing interest among the authors

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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