

Urban Air Pollution and Human Health: A Review

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Abstract

Rapid and unplanned industrialization and urbanization leading to an increase in air pollutants in the urban areas is not a new phenomena. Findings of several pieces of research have shown that at every stage of life beginning from the effect on developing embryo till an older age. A strong relationship has been reported between urban air pollutants with a wide variety of diseases like respiratory diseases, cardiovascular diseases, adverse effects on the nervous system, endocrine system, prevalence of diseases like diabetes, premature births, etc. Highly susceptible groups are the children and elderly, making this problem a serious concern worldwide. Inhalation of an increasing amount of particulate matter with a variety of toxic chemicals adhered to its surface and gaseous pollutants emitted from various sources initiate complex chemical reactions in the body giving rise to several diseases. The particles move through the upper respiratory tract showing its effect in the form of pulmonary inflammation, chronic obstructive pulmonary disease (COPD), moving further affects the heart rate variability (HRV), Ischemic heart disease, crosses the Blood-brain barrier (BBB) leading to mental and behavior disorder as well as insulin resistance leading to diabetes. The health impacts of poor air quality are serious which require urgent attention. This comprehensive review article aims to provide comprehensive information that can be useful for environmentalists, researchers, engineers, and policymakers for incorporating the data for implementing robust action to combat the problem of increasing urban air pollution.



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Introduction


Urban air pollutants comprise vehicular emissions, industrial emissions, and emissions due to developmental activities. They are known to cause several ill effects on human health and the

environment. Atmospheric ultrafine particles with pollutants bound on its surface can enter our body, which can penetrate deep into the respiratory and circulatory system, causing damage to lungs, heart, brain, and other vital organs. Global data

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for AOD (aerosol optical depth) collected for 189 megacities to evaluate the air quality status revealed that Indian subcontinent cities, Middle East, and North China are the most polluted cities due to their largest population growth which leads to more anthropogenic emissions as compared to Europe, the north-east of US, and South-East Asia countries.¹ World health organization (WHO) reported 6.5 million deaths (approximately 12% of total deaths) annually, worldwide via exposure to indoor and ambient air pollution. Therefore approximately 92% of the world's population is living in an area, where the annual mean concentration level of fine particulate matter (PM_{2.5}) diameter ranges from (0.1-2.5 µm) exceeds the WHO standards i.e. 10 µg/m³.²

The concentration of various pollutants like Sulphur Dioxide (SO₂), Nitrogen Dioxide (NO₂), Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM), ozone (O₃), Benzene, Carbon Monoxide (CO), Lead (Pb) and Hydrocarbons (HCs) increases with an increasing rate of urbanization, industrialization, and vehicular emissions, burning of fossil fuels, agricultural activities, domestic practices as well as natural sources such as forest fire and wind erosion.^{3,4} Particulate matter is one of the prominent air pollutants from the six major criteria air pollutants, which is positively linked with degradation of the environmental condition such as climate change, fog formation, cloud dynamics, acid rain, reduced visibility, affecting radiation budget in addition to causing adverse impact on human health causing mortality and morbidity.^{5,6,7} The effect of Particulate matter (PM) depends on the aerodynamic size of aerosol which is classified as coarse particulate matter (PM₁₀) with aerodynamic diameter 10µm and fine particulate matter (PM_{2.5}) with aerodynamic diameter 2.5 µm based on transportation potential in the atmosphere or inhaling capacity via respiratory system.⁸ Inhalation of fine particulate matter through the olfactory region or oral cavity leads to several health problems. Deposition in various region of lungs i.e. head tracheobronchial (TB) and pulmonary region^{9,10} and cause several disorders like asthma, chronic obstructive pulmonary disease, and even cancer⁷ Further it also causes Cardiopulmonary mortality and metabolic disorder like diabetes.^{11,12} The deposition of particulate matter inside the human body depends on the duration of exposure to particulate matter in ambient air in addition to various

other factors such as nostril shape, weight, age, gender, ventilation, and exercise level.¹³ Inhalation of ultrafine particles deposited in the lungs can cause alveolar inflammation and several hematological disorders like coagulation of blood, plasma viscosity, fibrinogen, plasminogen activator inhibitor, can not only cause cardiovascular diseases but can also cause inflammatory reactions.¹⁴ Ambient fine particulate matter PM_{2.5} are ranked fifth to cause mortality in 2015 at the global level.¹⁵ Fine particulate matter size ≤ 2.5 µm when inhaled get deposited in the airway path and alveolar surface and trigger adverse effect on human health according to U.S. Environmental Protection Agency.¹⁶ Exposure to polycyclic aromatic hydrocarbons (PAHs) in humans via the respiratory tract, digestive tract, and skin, cause cancer in several organs like lungs, skin, esophagus, colon, pancreas, bladder, and breast in women.¹⁷

PM_{2.5} is also known to induce apoptosis due to the production of reactive oxygen species (ROS) as a result of the induction of endoplasmic reticulum (ER) stress and activation of unfolded protein response (UPR) in the lung and liver cells. Double-strand RNA-activated protein kinase-like ER kinase (PERK) leads to phosphorylation of translation initiation factor eIF2α and induction of C/EBP homologous transcription factor CHOP/GADD153 in turn production of ROS.¹⁸ A wide range of ill health effects due to short-term and long-term exposure to a mixture of air pollutants have been observed in urban populations throughout the world for a very long time. The present paper is an attempt to compile comprehensive data related to the adverse effects of air pollutants on various systems of the human body, which would help to form bases for further research.

Methodology

Database Sources

A comprehensive review of literature has been conducted by searching database in Web of Science and Google Scholar by using keywords such as sources and composition of particulate matter, respirable particulate matter (RPM), fine particulate pollution, the effect of particulate on the cardiovascular system, respiratory system, nervous system, reproductive health and prevalence of diabetes. Physiological mechanism related to the effect of air pollutants on different organs of the human body was also searched using specific

keywords like effect on lung capacity, the effect of PM on myocardial muscles, nervous system, air pollutants and reproductive health and physiology of air pollutants causing diabetes. Research articles explaining the mechanism of the effect of pollutants at the cellular level were thoroughly studied to explain the effects on various organs.

Selection of articles

A total of 483 articles were found while searching with the above-mentioned keywords which were thoroughly studied. Out of the total 483 articles, 126 articles were found to be suitable for inclusion in the review paper which critically explain the mechanism of the adverse effect of air pollutants on the various organ of the human body. The Rest of the 357 articles were excluded as they were not found eligible based on their scientific outcome required for the present review article.

Effect of Air Pollutants on Various Systems of the Human Body

Effect on Respiratory System

Every single human being is exposed to a variety of ambient air pollutants daily to a greater or lesser extent, whereas human health is affected at every stage of life from birth to death.¹⁹ Keeping in view the increasing levels of pollutants in the air, several long-term and short-term studies have been done worldwide to correlate the effect of various air pollutants with human health. Short term exposure to particulate matter has been found to increase hospital admissions due to respiratory illness where PM₁₀ and PM_{2.5} are found to be positively associated with chronic obstructive pulmonary disease (COPD) and asthma. Women and older age individuals (more than 65) are more vulnerable to PM_{2.5}.²⁰ It is well documented that traffic-related air pollution (TRAP) aggravates the condition of an asthmatic person. Studies have also shown an increase in new-onset asthma in both children and adults as a result of oxidative stress and immune dysregulation caused due to exposure to TRAP which includes a mixture of pollutants like Particulate matter, sulfur dioxide, nitrogen dioxides, and ozone.^{21,22,23,24,25,26,27,28,29,30,31} Exposure to traffic-related air pollutants for long duration have shown a significant association with risk the of Systemic lupus erythematosus (SLE), a multi-systemic chronic autoimmune disease.³² Inhalation of fine particulate matter is found to increase airway inflammation in childhood-onset

systemic lupus erythematosus (CSLE) patients³³ Chemical species of fine particulate matter (PM_{2.5}) and gaseous pollutants comprising Elemental carbon (EC), Organic carbon (OC), SO₂, NO₂, and CO exerts prolonged inflammatory and thrombotic responses, whereas fine particulate matter (PM_{2.5}) leads to an immediate autonomic imbalance in vulnerable individuals.³⁴ Traffic-related air pollution is also known to have the potential to disrupt the functioning of the endocrine system in adolescents^{35,36} and acute pulmonary edema and mortality with the exposure to elevated levels of nitrogen dioxide.³⁷ Particle deposition in the lungs is dependent on the aerodynamic size of the particle and the region of deposition depends on the lung anatomy and pattern of airflow in the respiratory system.³⁸ Fine particles with a size between 0.2-5µm can be transported easily to the airways and accumulate in the alveoli whereas coarse particles with a size above 5µm are restricted to the upper respiratory tract. Inhalation of ultrafine carbon particles adversely affects the pulmonary diffusing capacity due to the physiologic effects of particulates in the interstitium³⁹ whereas inhalation of Ultrafine particles for 1 h can cross the epithelial barrier and reach the main lung tissue compartment in the cytoplasm and the nucleus of the cell to adversely affect the pulmonary diffusing capacity.⁴⁰ Due to the capacity to damage cells and disrupt their function, ambient air pollutants are found to be group 1 human carcinogen.⁴¹ While moving towards the alveoli, it produces several diseases in the respiratory system in addition to lung cancer.^{42,43} The high potential of the fine particulate matter to cause a wide range of diseases can be attributed to their larger surface area related to their mass which helps in more adsorption of pollutants and reactive metals on their surface making them more toxic.^{44,45} Thus higher concentration of fine particles in ambient air leads to more toxic effects in the body. As fine particles (< 2.5µm) have a probability of penetrating deeper into the lungs, they cause severe adverse health effects as these particles have a higher burden of toxins⁴⁶ Chronic obstructive pulmonary diseases (COPD) is presently the fourth most leading cause of death worldwide in adults older than 50 years.⁴⁷ Several research studies have shown a strong association between long term exposure to air pollutants and increased lung cancer and mortality rate among the population. There is a strong association between vehicular exhaust and

increased risk of lung cancer among people who never smoke a cigarette than ex-smoker or current smokers.⁴⁸ Heavy metals emitted from industries and mining processes also lead to lung dysfunction and later it can cause lung cancer.⁴⁹ In addition to particulates, secondary aerosols mainly nitrate (emitted from the combustion of fossil fuel, road transportation, space heating, aircraft, and ammonia oxidation from agriculture) and sulphate (sources include emission from the power plant, industrial emissions, oceans, plant, soil, and volcanic activities) cause an increased risk of respiratory illness in children.⁵⁰ Sulfur dioxide a water-soluble irritant gas that induces bronchoconstriction and mucus secretion which leads to airway cellular injury and subsequent proliferation of mucus-secreting goblet cells.⁵¹ Due to its damaging effect on the bronchioles, long term exposure even at a concentration lower than 1 ppm is known to cause a higher incidence of bronchitis.⁵² sulfuric acid as fine aerosols formed in the atmosphere shows adverse effects on various cells of the respiratory tract (e.g. phagocytes and epithelial cells) due to its high specific acidity and deposition deeper along the respiratory tract leading to bronchitis.⁵³ Similarly nitrogen dioxide induces

several adverse health effects on the respiratory system and general functioning of the body. Acute exposure to ambient Nitrogen dioxide leads to impaired diffusion capacity of lungs, restrictive and obstructive ventilatory defects, and hypoxemia⁵⁴ Cortisol, a steroid hormone responsible for the regulation of immune and inflammatory responses in the airways⁵⁵ released at abnormal levels from the adrenal gland in the adolescents due to Chronic exposure to nitrogen dioxide and other traffic-related air pollutants⁵⁶ Leading to respiratory system dysfunction. Penetration of gasses into the lungs depends upon the water solubility factor. Gases that are highly water-soluble like SO₂ do not penetrate unless the concentrations are very high whereas insoluble gasses such as NO₂ and ozone penetrate deep inside the lungs and reach the smallest alveoli^{57,58} leading to severe damage. Inhalation of carbon monoxide gas reduces the oxygen level in blood and form carboxyhemoglobin by reacting with hemoglobin, therefore less hemoglobin is left to transport oxygen from the lungs to other parts of the body which results in dizziness, unconscious, and tiredness.⁵⁹ Table 1 summarizes the significant effects of air pollution on the respiratory system.

Table 1: Effects of air pollutants on the respiratory system

Effects	Cause	Reference
Oxidative stress and immune dysregulation causing Asthma	Long term exposure to traffic -related air pollutants (TRAP)	21,22,23,24,25,26,27,28,29,30,31
Risk of Systemic lupus erythematosus (SLE), a multi-systemic chronic autoimmune disease.		32
Disruption in the functioning of the endocrine system in adolescents		35, 36
Asthma due to Chronic obstructive pulmonary diseases (COPD)		47
Lung cancer in nonsmokers		48
Bronchoconstriction and mucus secretion leading to airway cellular injury and subsequent proliferation of mucus-secreting goblet cells	Exposure to SO ₂	51

Effect on the Cardiovascular System

Air pollution leads to more than two-third of mortality particularly due to ischemic heart disease and cerebrovascular disease.⁶⁰ The major cause of all cardiovascular diseases is oxidative stress (raised levels of blood malondialdehyde) leading to dysfunction of the cardiac system. Chronic exposure to enhanced levels of fine particle matter impairs vascular function, which can lead to myocardial infarction, arterial hypertension, stroke, and heart failure.^{2,61} Several epidemiological studies have reported atherothrombosis, thrombotic stroke, and thromboembolism due to exposure to air pollution, especially PM.⁶² Due to exposure to air pollutants excessive clotting is caused leading to thrombotic occlusion of arteries resulting in cardiovascular dysfunction. This process of thrombotic occlusion of arteries was studied by blood markers of pro-thrombotic pathways which have been linked to PM exposure, including fibrinogen, tissue factor, von Willebrand factor (vWF), P-selectin and decreases in activity of fibrinolytic pathways responsible for clot breakdown.^{62,63} Studies have shown that even short term exposure to ultrafine particulate matter is associated with heart rate variability⁶⁴ leading to adverse effects on the cardiovascular system. An increase in the concentration of particulate matter increases the risk of ischemic and Myocardial infarction and stroke.^{65,66,67,68}

Three biological pathways associated with ambient particulate matter and its adverse effect on the cardiovascular system have been identified.^{19,61}

1) Pro-inflammatory mediators or vasoactive molecules are released from lung cells due to the inhalation of particles leading to the systemic chain reaction. This chain reaction cause changes in vascular function and induction of a pro-coagulation state with thrombus formation, ischemic response, and an increase of atherosclerotic lesions.

2) Changes in the autonomic nervous system or heart rhythm are caused due to particle deposition in the pulmonary system. This imbalance in the autonomic nervous system or heart rhythm is caused by stimulating pulmonary neural reflexes or by inducing oxidative stress leading to inflammation in the lungs cardiac arrhythmias and instability of a vascular plaque is further caused by alterations in autonomic tone.

3) Chemical constituents adhered to ultrafine particles and particulate matter are translocated in the blood leading to endothelial dysfunction and vasoconstriction, increased blood pressure, and platelet aggregation. Studies conducted near an area with high vehicular density with increased air pollutants like PM_{2.5}, NO₂, and O₃ have also shown an increase in the risk of pregnancy-induced hypertensive disorders.⁶⁹ Cardiorespiratory morbidity and mortality have also been found to be linked with the particulate matter with an aerodynamic diameter in the range of 10µm to less than 2.5 µm. An increase in 10µg/m³ of PM_{2.5} for the same day is found to increase 0.47% cardiovascular mortality and 0.5% respiratory mortality whereas 0.27% and 0.56% increase in cardiovascular and respiratory mortality respectively were reported for an increase in 10µg/m³ of PM₁₀ for same-day.⁷⁰ The acute and chronic exposure to ambient particulate matter (PM_{2.5}) lead to a direct effect on the cardiovascular system whereas (UPFS) ultrafine particulate matter gets circulated from lungs to the heart or cause indirect injury by inducing systemic inflammation and oxidative stress, abnormal blood clotting function, vascular dysfunction, and nervous system dysfunction which lead to cardiovascular and nervous system dysfunction.⁷¹ Children and old age people are more susceptible to the adverse effects of air pollution. Studies have shown that Heart rate variability (HRV) is reduced when the individual between the age of 53 to 87 yrs is exposed to elevated levels of fine particulate matter PM_{2.5} and ozone.⁷² Increased pulse pressure (PP) and systolic blood pressure (SBP) is strongly associated with exposure to PM_{2.5} and the association is stronger in people highly exposed to road traffic.⁷³ People living near major roads have an increased risk of cardiopulmonary mortality.⁷⁴ Fine particulates, due to their higher penetration capacity are more harmful as compare to coarse particles. Short term exposure to fine particulate matter PM_{2.5} as low as for few hours to week can lead to cardiovascular disorders leading to mortality as well as certain nonfatal events whereas long term exposure for several months to a few years increases the risk of mortality to a greater extent and reduces the life span.⁶¹ Long term exposure to PM_{2.5} is strongly associated with ischemic heart diseases, mortality, and increased risk of Systolic blood pressure, diastolic blood pressure, pulse pressure, and hypertension.^{75,76} Vehicular exhaust leads to an increase in the concentration

of organic carbon in $PM_{2.5}$ which directly affects human health by decreasing the artery diameter up to 0.09 mm.⁷⁷ Long term exposure to road traffic noise and Particulate matter in residential areas has the potential to cause hypertension and Diastolic

blood pressure. An increased concentration of $PM_{2.5}$ by $1\mu g/m^3$ leads to a 15% high frequency of hypertension.⁷⁸ Table 2 summarizes the diseases caused due to exposure to air pollutants.

Table 2: Effects of air pollutants on the cardiovascular system

Effects	Cause	Reference
Impairment of vascular function, leading to myocardial infarction, arterial hypertension, stroke, and heart failure	Chronic exposure to enhanced levels of fine particle matter	67, 65, 66, 68, 61
Atherothrombosis, thrombotic stroke, and thromboembolism		62
Excessive clotting of blood leading to thrombotic occlusion of arteries resulting in cardiovascular dysfunction		
Heart rate variability		64
Risk of pregnancy-induced hypertensive disorders		69
Increased pulse pressure (PP) and systolic blood pressure (SBP)		73

Effect on Nervous System

UFPM (Ultra Fine Particulate Matter) of size less than $0.1\mu m$ is most effective in causing severe health effects (Table 3) due to its nanometer-size due to which it can easily penetrate and accumulate in the lungs and cause a detrimental effect beyond the respiratory tract.^{79,80,81} The most prominent effects caused by air pollution are oxidative stress and neuro-inflammation cause developmental neurotoxicity and may contribute to the etiology of neurodevelopmental disorders, including autism spectrum disorder.⁸² From the upper respiratory tract particulate matter is transferred to the brain leading to brain inflammation, disrupt normal brain activities and pathological function, decline neurocognitive abilities, and finally, it cause mental and behavioral disorders, and risk of Alzheimer's and Parkinson's diseases.^{83,84,85,86,87} The increased concentration of air pollution leads to olfactory bulb dysfunction by accumulating the ultrafine particulate matter in the Olfactory Bulbs basement membrane and endothelial cytoplasm.⁸⁸ From the total air passing the nasal

chamber, 5-20% air cross the olfactory region⁸⁹ thus is affected by respiratory frequency affecting the PM olfactory deposition. As substantial time is spend outdoors by children as compare to adults and have high respiratory frequency to their body size, the olfactory deposition could be higher in them.^{90,91} As their brains are in the developing stage⁹² and have less developed defensive barriers to avoid particles entering in lungs,⁹¹ UFPM crosses the olfactory epithelium and get accumulated in the brain.⁹³ Short term exposure to the high concentration of PM_{10} and $PM_{2.5}$ increases hospital admissions for mental and behavioral disorders more in the winter season due to increased concentration of pollutants as a result of less dispersion as compared to the summer season.⁹⁴ Furthermore, coarse and fine particulate matter, as well as nitrogen dioxide, is associated with depressive symptoms and depression in elderly women⁹⁵ in addition to sleep disorder symptoms in elderly people exposed to traffic-related pollutants like PM_{10} , $PM_{2.5}$, NO_2 , SO_2 , and O_3 .⁹⁶ Particulate matter with aerodynamic size less

than 10 μ m (PM₁₀) is also known to be associated with the increased risk of multiple sclerosis.⁹⁷ an inflammatory demyelinating disorder of the central nervous system. Nano-size particles are found to injure endothelial cells and damage the

BBB (Blood Brain Barrier) due to the reduction in microvascular endothelial cell viability, alteration of mitochondrial potential, Increased oxidative stress, and decreased tight junction protein expression.⁹⁸

Table 3: Effects of air pollutants on Nervous system

Effects	Cause	Reference
Oxidative stress and neuro-inflammation causing developmental neurotoxicity, and etiology of neurodevelopmental disorders, including autism spectrum disorder	Exposure to particulate pollutants	82
A decline in the neurocognitive abilities leading to mental and behavior disorders, and risk of Alzheimer's and Parkinson's diseases		82, 83,84,85,86
Multiple sclerosis, an inflammatory demyelinating disorder of the central nervous system.		97
Injury of endothelial cells and damage the BBB (Blood Brain Barrier)		98
Depressive symptoms and depression in elderly women Exposure to nitrogen dioxide		95

Air pollution and Diabetes

According to the American Diabetes Association,⁹⁹ Diabetes is a group of metabolic diseases that are identified as a high blood sugar level (hyperglycemia) occurring due to abnormal insulin secretions. Diabetes is a global concern and presently there are more than half a million children under the age of 14 who are suffering from type 1 diabetes and 415 million adults with the age group of 20-79 years are suffering from this non-communicable disease and 193 million adults are undiagnosed.¹⁰⁰ In 2017 there were 451 million adults (18-99 years) worldwide reported by International Diabetes Federation¹⁰¹ suffering from diabetes and estimated to rise by 693 million in 2045. The diabetes scenario of the Indian population is not so different from the whole world, due to its genetic profile like sedentary lifestyles, abhorrent eating habits, insomnia, and high-stress levels.¹⁰² In addition to the above-mentioned causes long-term exposure to PM_{2.5} and NO₂ is found to be positively associated with increased risk of diabetes mortality.¹⁰³ There are several clinical studies done

to estimate the relationship between diabetes and ambient air pollutants like PM_{2.5}, black carbon, O₃, and NO₂.^{104,105,106,107} Different physiological and biochemical changes are induced in the human body due to exposure to air pollutants leading to diabetes (Table 4). Long-term exposure to air pollution leads to reduced insulin secretion as a result of impaired β -cell functioning and also decreases insulin-dependent glucose uptake which induces insulin resistance.¹⁰⁸ Oxidative stress and systemic inflammation are shown to be caused as a result of insulin resistance and β -cell dysfunction due to exposure to air pollutants indicating a significant correlation between type 2 diabetes and air pollution.¹⁰⁹ Studies using several biomarkers have suggested a correlation between insulin resistance and the development of diabetes^{110,111} Altered HOMA IR indicating reduced metabolic insulin sensitivity is found even at sub-acute periods of exposure to PM_{2.5} leading to the genesis of diabetes mellitus.¹¹² Clinical studies were performed on rodents revealed that a high concentration of fine particulate matter

(PM_{2.5}) induces impaired glucose tolerance, HOMA-IR index indicating Insulin sensitivity was also found higher in exposed mice as compared to unexposed mice.¹¹³ Further, the effect of PM₁₀ on lipids was found to be higher at low temperatures, whereas the effect of SO₂ and NO₂ was found to be higher at high temperatures.¹¹⁴ Increased concentration of ambient air pollutants such as black carbon, NO₂, and O₃ leads to increased systemic inflammation in older adults suffering from diabetes, hypertension, and obesity.¹¹⁵ Studies have also shown that women are more susceptible to DM (Diabetes Mellitus) as compare to males when exposed to traffic-related pollution.^{114,116} Some studies have also identified a correlation between PM_{2.5} (Particulate matter), NOx (Nitrogen oxides), SO₂ (Sulphur dioxide), and O₃ (ozone) with gestational diabetes. Oral glucose tolerance test (OGTT) indicating gestational diabetes in non-diabetic pregnant women exposed to PM_{2.5}, where maternal exposure to SO₂ and NOx in the first few weeks of pregnancy is correlated with gestational diabetes mellitus (GDM).^{117,118,119} Exposure to traffic-related air pollutants and PM_{2.5} leads to abnormal glycemia during pregnancy and positively correlated with impaired glucose tolerance (IGT).¹²⁰ Long term exposure to air pollutants such as PM₁₀ and NO₂ are strongly correlated with an increased level of serum glucose and glycosylated hemoglobin (HbA1c), which indicates the increased risk of

type 2 diabetes mellitus in the middle age urban population.¹²¹ Evidence also suggests that exposure to air pollutants especially traffic-related air pollutants such as NO₂ may lead to an increased risk of type 2 diabetes mellitus¹⁰⁵ and have the strongest effect on diabetes etiology.¹²² It has been also found that exposure to a very high concentration of particulate matter (PM₁₀) is interdependent with the occurrence of type 2 diabetes mellitus and hypertension.¹²³ In patients with non-insulin-dependent diabetes mellitus, increased concentrations of low-density lipoprotein cholesterol decreased concentrations of high-density lipoprotein cholesterol, as well as increase triglyceride concentration, causes Coronary artery disease and high blood pressure.¹²⁴ Air pollutants such as PM₁₀, SO₂, and NO₂ are correlated with increased levels of lipids such as triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), total cholesterol (TC), and high-density lipoprotein cholesterol (HDL-C) among type 2 diabetes patients. This creates an imbalance in the cholesterol levels and increases Systolic and diastolic Blood Pressure^{114,125} aggravating the patient's health conditions. A higher risk of Diabetic retinopathy has also been reported in patients with Diabetes mellitus.¹²⁶ Thus it is evident that diabetes can affect a person of any age and can also cause additional health issues.

Table 4: Influence of air pollutants on the cause of Diabetes

Effects	References
Impaired β -cell functioning and decreased insulin-dependent glucose uptake inducing insulin resistance	108
Increased level of serum glucose and glycosylated hemoglobin (HbA1c) indicating an increased risk of Type 2 diabetes mellitus	121
Impaired glucose tolerance	114
Diabetic retinopathy	126

Conclusions

The various outcomes of the clinical studies conducted to evaluate the effect of air pollutants on human health have been discussed in this review article. (Table 1,2,3 and 4) represents the key highlights of the effect of the findings of

air pollutants on human health. Systemic lupus erythematosus (SLE), a multi-systemic chronic autoimmune disease, excessive clotting of blood leading to thrombotic occlusion of arteries resulting in cardiovascular dysfunction, multiple sclerosis, an inflammatory demyelinating disorder of the central

nervous system and Impaired β -cell functioning and decreased insulin-dependent glucose uptake inducing insulin resistance are few of the major reported systemic damage due to exposure to urban air pollutants. Keeping in view the array of diseases caused due to air pollution it is evident that strategies for pollution prevention is the most neglected aspects of the development plans of any region. Thus implementation of stringent pollution control strategies can prove to be beneficial in providing multiple benefits, both short-term and long-term, for the protection of human health, the economy, and the environmental components for societies at every level of income group. This review paper can form a base for further studies related to the health impacts of various air pollutants with changing atmospheric chemistry due to the inclusion of a variety of new air pollutants in the atmosphere including ultrafine particles. Keeping in view the present scenario, future research can be

conducted correlating the health effects due to air pollution with changing climatic conditions globally.

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Conflict of Interest

The author(s) declares no conflict of interest.

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