Review Article

# Effects of air pollution on human health and practical measures for prevention in Iran

**Adel Ghorani-Azam, Bamdad Riahi-Zanjani, Mahdi Balali-Mood**
Medical Toxicology Research Center, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran

Air pollution is a major concern of new civilized world, which has a serious toxicological impact on human health and the environment. It has a number of different emission sources, but motor vehicles and industrial processes contribute the major part of air pollution. According to the World Health Organization, six major air pollutants include particle pollution, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. Long and short term exposure to air suspended toxicants has a different toxicological impact on human including respiratory and cardiovascular diseases, neuropsychiatric complications, the eyes irritation, skin diseases, and long-term chronic diseases such as cancer. Several reports have revealed the direct association between exposure to the poor air quality and increasing rate of morbidity and mortality mostly due to cardiovascular and respiratory diseases. Air pollution is considered as the major environmental risk factor in the incidence and progression of some diseases such as asthma, lung cancer, ventricular hypertrophy, Alzheimer's and Parkinson's diseases, psychological complications, autism, retinopathy, fetal growth, and low birth weight. In this review article, we aimed to discuss toxicology of major air pollutants, sources of emission, and their impact on human health. We have also proposed practical measures to reduce air pollution in Iran.

**Key words:** Air pollution, cardiovascular diseases, environment, human health, respiratory tract diseases, toxicology

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## INTRODUCTION

Air pollution is a major problem of recent decades, which has a serious toxicological impact on human health and the environment. The sources of pollution vary from small unit of cigarettes and natural sources such as volcanic activities to large volume of emission from motor engines of automobiles and industrial activities.[1,2] Long-term effects of air pollution on the onset of diseases such as respiratory infections and inflammations, cardiovascular dysfunctions, and cancer is widely accepted;[3-6] hence, air pollution is linked with millions of death globally each year.[7-9] A recent study has revealed the association between male infertility and air pollution.[10]

Air pollution has now emerged in developing countries as a result of industrial activities and also increase the quantity of emission sources such as inappropriate vehicles.[11-13] About 4.3 million people die from household air pollution and 3.7 million from ambient air pollution, most of whom (3.3 and 2.6 million, respectively) live in Asia.[14] In Iran, as a developing country, the level of air pollutants has increased gradually since the beginning of industrialization in the 1970s, but it has reached a very harmful level in some megacities such as Tehran, Mashhad, Tabriz, Isfahan, Ahvaz, Arak, and Karaj over the past two decades. Iran is the world's third main polluted country in the world, which results in 16 billion $ annual loss.[15] In fact, four of the top ten air-polluted cities are in Iran. Ahvaz is the most air polluted city in the world with microdust blowing in from neighboring countries, and particulate levels three times that of Beijing, and nearly 13 times that of London.[16] Air pollution caused almost 4460 deaths in 2013 only in Tehran although the reality seemed higher and is getting worse every year.[17] Therefore, it is of great importance to describe the problem, particularly its toxic

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**Address for correspondence:** Prof. Mahdi Balali-Mood, Medical Toxicology Research Center, School of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran. E-mail: balalimoodm@mums.ac.ir
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effects on human health and provide recommendations as a basis for environmental guidelines and standard protocols in the field of air pollution in Iran.

The present article is neither a systematic review nor a descriptive, educational study. It is a problem-based descriptive review in which the authors try to explain a problem which is the major health and ecological problem in developing countries like Iran. In this review, we have tried to summarize the toxicology of air pollutants and related diseases with a possible mechanism of action and appropriate management of the patients. Therefore, it shall be useful for the environmental and health professionals particularly policy makers, emergency physicians, and other clinicians who may be involved in air pollution and related diseases. In this paper, we also discuss sources of air pollution and proposed some feasible solutions which may be beneficial for the environmental legislators and decision makers.

## DEFINITIONS

Air pollution is defined as all destructive effects of any sources which contribute to the pollution of the atmosphere and/or deterioration of the ecosystem. Air pollution is caused by both human interventions and/or natural phenomena. It is made up of many kinds of pollutants including materials in solid, liquid, and gas phases.[18] Air pollutions of indoors will not be specifically considered in this article.

The Pollutant Standard Index (PSI) is a numerical value and indicator of pollutants that is normally used to facilitate risk assessment. It is a numeric value between zero to 500.[19] PSI is a guideline for reporting air quality which was first introduced by Thom and Ott in 1974.[20] Hence, it would provide a method of comparing the relative contribution of each pollutant to total risk.[21] The calculation of PSI is based on the concentration of five major air pollutants including particulate matters (PMs), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), and ozone ($O_3$) in the air.

According to Johnson *et al*., "air quality index (AQI) is defined as a measure of the condition of air relative to the requirements of one or more biotic species or to any human need."[22] AQI is divided into ranges, in which they are numbered, and each range is marked with color codes. It provides a number from healthy standard level of zero to a very hazardous level of above 300 to indicate the level of health risk associated with air quality. Based on PSI, air quality is classified into six major indices, which is marked by color codes and each color corresponds to a different level of health concerns. Principally, green is defined as a color indicator for healthy air quality; while yellow, orange, red, purple, and maroon colors indicate as moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous air quality, respectively. These ranges and codes may differ in the different methods of classifications in different countries.[22]

## TOXICOLOGY OF AIR POLLUTION

Effects of air pollutants on living organism will not only be limited to the human and animal health but also include the whole environment. Different geographical conditions, global climate changes, and the environmental variations affect the human health and the environment including the animal life.

### Environmental damages

Ecologically, air pollution can cause serious environmental damages to the groundwater, soil, and air.[23,24] It is also a serious threat to the diversity of life. Studies on the relationship between air pollution and reducing species diversity clearly show the detrimental effects of environmental contaminants on the extinction of animals and plants species.[25] Air suspended toxicants may also cause reproductive effects in animals.[26,27] Acid rain, temperature inversion, and global climate changes due to the emissions of greenhouse gasses to the atmosphere are other major ecological impacts of air pollution.[28]

### Air pollutants and their toxicities

Every material in the air which could affect human health or have a profound impact on the environment is defined as air pollutants. According to the World Health Organization (WHO), particle pollution, ground-level $O_3$, CO, sulfur oxides, nitrogen oxides, and lead (Pb) are the six major air pollutants which harm human health and also the ecosystem. There are many pollutants of suspended materials such as dust, fumes, smokes, mists, gaseous pollutants, hydrocarbons, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and halogen derivatives in the air which at the high concentrations cause vulnerability to many diseases including different types of cancers.[29-32] The most important air pollutants and their toxic effects on different human body organs and related diseases have been briefly described below.

#### *Particle pollutants*

Particle pollutants are major parts of air pollutants. In a simple definition, they are a mixture of particles found in the air. Particle pollution which is more known as PM is linked with most of pulmonary and cardiac-associated morbidity and mortality.[33,34] They have varied in size ranging mostly from 2.5 to 10 μm ($PM_{2.5}$ to $PM_{10}$).

The size of particle pollutants is directly associated with the onset and progression of the lungs and heart diseases. Particles of smaller size reach the lower respiratory tract and thus have greater potential for causing the lungs and heart diseases. Moreover, numerous scientific data have demonstrated that fine particle pollutants cause premature death in people with heart and/or lung disease including cardiac dysrhythmias, nonfatal heart attacks, aggravated asthma, and decreased lung functions. Depending on the level of exposure, particulate pollutants may cause mild to severe illnesses. Wheezing, cough, dry mouth, and limitation in activities due to breathing problems are the most prevalent clinical symptoms of respiratory disease resulted from air pollution.[35-37]

Long-term exposure to current ambient PM concentrations may lead to a marked reduction in life expectancy. The increase of cardiopulmonary and lung cancer mortality are the main reasons for the reduction in life expectancy. Reduced lung functions in children and adults leading to asthmatic bronchitis and chronic obstructive pulmonary disease (COPD) are also serious diseases which induce lower quality of life and reduced life expectancy. Strong evidence on the effect of long-term exposure to PM on cardiovascular and cardiopulmonary mortality come from cohort studies.[38-40]

### *Ground-level ozone*

$O_3$ with the chemical formula of $O_3$ is a colorless gas which is the major constituent of the atmosphere. It is found both at the ground level and in the upper regions of the atmosphere which is called troposphere. Ground-level ozone (GLO) is produced as a result of chemical reaction between oxides of nitrogen and VOCs emitted from natural sources and/or due to human activities. GLO is believed to have a plausible association with increased risk of respiratory diseases, particularly asthma.[41]

As a powerful oxidant, $O_3$ accepts electrons from other molecules. There is a high level of polyunsaturated fatty acids in the surface fluid lining of the respiratory tract and cell membranes that underlie the lining fluid. The double bonds available in these fatty acids are unstable. $O_3$ attacks unpaired electron to form ozonides and progress through an unstable zwitterion or trioxolane (depending on the presence of water). These ultimately recombine or decompose to lipohydroperoxides, aldehydes, and hydrogen peroxide. These pathways are thought to initiate propagation of lipid radicals and auto-oxidation of cell membranes and macromolecules. It also increases the risk of DNA damage in epidermal keratinocytes, which leads to impaired cellular function.[42]

$O_3$ induces a variety of toxic effects in humans and experimental animals at concentrations that occur in many urban areas.[43] These effects include morphologic, functional, immunologic, and biochemical alterations. Because of its low water solubility, a substantial portion of inhaled $O_3$ penetrates deep into the lungs but its reactivity is scrubbed by the nasopharynx of resting rats and humans in around 17% and 40%, respectively.[44,45] On ecological aspect, $O_3$ can reduce carbon assimilation in trees leading to deforestation which may affect global food security in long-term exposure.[46,47]

### *Carbon monoxide*

CO is a colorless and odorless gas, which is produced by fossil fuel, particularly when combustion is not appropriate, as in burning coal and wood. The affinity of CO to hemoglobin (as an oxygen carrier in the body) is about 250 times greater than that of oxygen. Depending on CO concentration and length of exposure, mild to severe poisoning may occur. Symptoms of CO poisoning may include headache, dizziness, weakness, nausea, vomiting, and finally loss of consciousness. The symptoms are very similar to those of other illnesses, such as food poisoning or viral infections.

No human health effects have been showed for carboxyhemoglobin (COHb) levels lower than 2%, while levels above 40% may be fatal. Hypoxia, apoptosis, and ischemia are known mechanisms of underlying CO toxicity.[48] The mechanism of such toxicity is the loss of oxygen due to competitive binding of CO to the hemoglobin heme groups. Cardiovascular changes also may be observed by CO exposures that create COHb in excess of 5%. In the early 1990s, Health Effects Institute performed a series of studies associated with cardiovascular disease to determine the potential for angina pectoris with COHb levels in the range of 2–6%.[49] The results showed that premature angina can occur under these situations but that the potential for the occurrence of ventricular arrhythmias remains uncertain. Thus, the reduction in ambient CO can reduce the risk of myocardial infarction in predisposed persons.

### *Sulfur dioxide*

$SO_2$ is a colorless, highly reactive gas, which is considered as an important air pollutant. It is mostly emitted from fossil fuel consumption, natural volcanic activities, and industrial processes. $SO_2$ is very harmful for plant life, animal, and human health. People with lung disease, children, older people, and those who are more exposed to $SO_2$ are at higher risk of the skin and lung diseases.

The major health concerns associated with exposure to high concentrations of $SO_2$ include respiratory irritation and dysfunction, and also aggravation of existing cardiovascular disease. $SO_2$ is predominantly absorbed in the upper airways. As a sensory irritant, it can cause bronchospasm and mucus secretion in humans. Residents of industrialized regions encountered with $SO_2$ even at lower concentrations (<1 ppm) in the polluted ambient air might experience a high level of bronchitis.

The penetration of $SO_2$ into the lungs is greater during mouth breathing compared to nose breathing. An increase in the airflow in deep, rapid breathing enhances penetration of the gas into the deeper lung. Therefore, people who exercise in the polluted air would inhale more $SO_2$ and are likely to suffer from greater irritation. When $SO_2$ deposits along the airway, it dissolves into surface lining fluid as sulfite or bisulfite and is easily distributed throughout the body. It seems that the sulfite interacts with sensory receptors in the airways to cause local and centrally mediated bronchoconstriction.

According to the Environmental Protection Agency (EPA) of the USA, the level of annual standard for $SO_2$ is 0.03 ppm. Due to its solubility in water, $SO_2$ is responsible for acid rain formation and acidification of soils. $SO_2$ reduces the amount of oxygen in the water causing the death of marine species including both animals and plants. Exposure to $SO_2$ can cause damages to the eyes (lacrimation and corneal opacity), mucous membranes, the skin (redness, and blisters), and respiratory tracts. Bronchospasm, pulmonary edema, pneumonitis, and acute airway obstruction are the most common clinical findings associated with exposure to $SO_2$.[50]

### *Nitrogen oxide*

Nitrogen oxides are important ambient air pollutants which may increase the risk of respiratory infections.[50] They are mainly emitted from motor engines and thus are traffic-related air pollutants. They are deep lung irritants that can induce pulmonary edema if been inhaled at high levels. They are generally less toxic than $O_3$, but $NO_2$ can pose clear toxicological problems. Exposures at 2.0–5.0 ppm have been shown to affect T-lymphocytes, particularly $CD8^+$ cells and natural killer cells that play an important role in host defenses against viruses. Although these levels may be high, epidemiologic studies demonstrate effects of $NO_2$ on respiratory infection rates in children.

Coughing and wheezing are the most common complication of nitrogen oxides toxicity, but the eyes, nose or throat irritations, headache, dyspnea, chest pain, diaphoresis, fever, bronchospasm, and pulmonary edema may also occur. In another report, it is suggested that the level of nitrogen oxide between 0.2 and 0.6 ppm is harmless for the human population.[51]

### *Lead*

Pb or plumb is a toxic heavy metal that is widely used in different industries.[52] Pb pollution may result from both indoor and outdoor sources. It is emitted from motor engines, particularly with those using petrol containing Pb tetraethyl. Smelters and battery plants, as well as irrigation water wells and wastewaters, are other emission sources of the Pb into the environment.[52,53] Evaluation of the blood Pb level in traffic police officers shows that environmental pollution may be considered as a source of Pb exposure.[54] Fetuses and children are highly susceptible to even low doses of Pb.[55] Pb accumulates in the body in blood, bone, and soft tissue. Because it is not readily excreted, Pb can also affect the kidneys, liver, nervous system, and the other organs.[56]

Pb absorption by the lungs depends on the particle size and concentration. Around 90% of Pb particles in the ambient air that are inhaled are small enough to be retained. Retained Pb absorption through alveoli is absorbed and induces toxicity. Pb is a powerful neurotoxicant, especially for infants and children as the high-risk groups. Mental retardation, learning disabilities, impairment of memory, hyperactivity, and antisocial behaviors are of adverse effects of Pb in childhood.[57,58] Therefore, it is very important to reduce the Pb level of ambient air.[59]

Pb exposure is often chronic, without obvious symptoms.[60] It can affect the different parts of the body including cardiovascular, renal, and reproductive systems, but the main target for Pb toxicity is the nervous system.[61] Pb disrupts the normal function of intracellular second messenger systems through the inhibition of N-methyl-D-aspartate receptors. Pb may also replace calcium as a second messenger resulting in protein modification through various cellular processes including protein kinase activation or deactivation.

Abdominal pain, anemia, aggression, constipation, headaches, irritability, loss of concentration and memory, reduced sensations, and sleep disorders are the most common symptoms of Pb poisoning. Exposure to Pb is manifested with numerous problems, such as high blood pressure, infertility, digestive and renal dysfunctions, and muscle and joint pain.

### Other air pollutants

Other major air pollutants that are classified as carcinogen and mutagen compounds and are thought to be responsible for incidence and progression of cancer in human include VOCs such as benzene, toluene, ethylbenzene, and xylene, PAHs such as acenaphthene, acenaphthylene, anthracene, and benzopyrene, and other organic pollutants such as dioxins, which are unwanted chemical pollutants that almost totally produced by industrial processes and human activity.[62-64]

In Table 1, the standard level of some conventional air pollutants is presented in which the values were defined as air quality standards that provide public welfare protection.

As it can be easily understood, fossil fuel consumption shares the largest part of air contamination. Air pollutants can also be classified into anthropogenic and natural according to their source of emission. From anthropogenic aspect, air contamination occurs from industrial and agricultural activities, transportation, and energy acquisition. While from natural contaminant has different sources of emission such as volcanic activities, forest fire, sea water, and so on.[65,66]

## Health hazards

In terms of health hazards, every unusual suspended material in the air, which causes difficulties in normal function of the human organs, is defined as air toxicants. According to available data, the main toxic effects of exposure to air pollutants are mainly on the respiratory, cardiovascular, ophthalmologic, dermatologic, neuropsychiatric, hematologic, immunologic, and reproductive systems. However, the molecular and cell toxicity may also induce a variety of cancers in the long term.[67,68] On the other hand, even small amount of air toxicants is shown to be dangerous for susceptible groups including children and elderly people as well as patients suffering from respiratory and cardiovascular diseases.[69]

## Respiratory disorders

Because most of the pollutants enter the body through the airways, the respiratory system is in the first line of battle in the onset and progression of diseases resulted from air pollutants. Depending on the dose of inhaled pollutants, and deposition in target cells, they cause a different level of damages in the respiratory system. In the upper respiratory tract, the first effect is irritation, especially in trachea which induces voice disturbances. Air pollution is also considered as the major environmental risk factor for some respiratory diseases such as asthma and lung cancer.[70,71] Air pollutants, especially PMs and other respirable chemicals such as dust, $O_3$, and benzene cause serious damage to the respiratory tract.[72-77] Asthma is a respiratory disease which may be developed as a result of exposure to air toxicants.[78] Some studies have validated associations between both traffic-related and/or industrial air pollution and increasing the risk of COPD.[79-81] Treatment of respiratory diseases due to air pollution is similar to the other toxic chemical induce respiratory disorders.

## Cardiovascular dysfunctions

Many experimental and epidemiologic studies have shown the direct association of air pollutant exposure and cardiac-related illnesses.[82-85] Air pollution is also associated with changes in white blood cell counts[86] which also may affect the cardiovascular functions. On the other hand, a study on animal models suggested the close relationship between hypertension and air pollution exposure.[87] The traffic-related air pollution, especially exposure to high levels of $NO_2$, is associated with right and left ventricular hypertrophy.[88,89] In addition to the antidote therapy that exists only for a few cardiotoxic substances like CO, usual treatment of cardiovascular diseases should be carried out.

## Neuropsychiatric complications

The relationship between exposure to air suspended toxic materials and nerve system has always been argued. However, it is now believed that these toxic substances have damaging effects on the nervous system. The toxic effect of air pollutants on nerve system includes neurological complications and psychiatric disorders. Neurological impairment may cause devastating consequences, especially in infants. In contrast, psychiatric disorders will induce aggression and antisocial behaviors. Recent

**Table 1: Standard level of criteria air pollutants and their sources with health impact based on the United States Environmental Protection Agency**

| Air pollutants® | Major source of emission | Averaging time | Standard level | Health impact target organs |
|---|---|---|---|---|
| Particle pollutants | | | | |
| $PM_{2.5}$ | Motor engines, industrial activities, smokes | 24 h | 35 µg/m³ | Respiratory and cardiovascular diseases, CNS and reproductive dysfunctions, cancer |
| $PM_{10}$ | | 24 h | 150 µg/m³ | |
| Ground-level ozone | Vehicular exhaust, industrial activities | 1 h | 0.12 mg/m³ | Respiratory and cardiovascular dysfunctions, eye irritation |
| Carbon monoxide | Motor engines, burning coal, oil and wood, industrial activities, smokes | 1 h | 35 mg/m³ | CNS and cardiovascular damages |
| Sulfur dioxide | Fuel combustion, burning coal | 1 h | 75 µg/m³ | Respiratory and CNS involvement, eye irritation |
| Nitrogen dioxide | Fuel-burning, vehicular exhaust | 1 h | 100 µg/m³ | Damage to liver, lung, spleen, and blood |
| Lead | Lead smelting, industrial activities, leaded petrol | 3 months average | 0.15 µg/m³ | CNS and hematologic dysfunctions, eye irritation |
| Polycyclic aromatic hydrocarbons* | Fuel combustion, wood fires, motor engines | 1 year | 1 ng/m³ | Respiratory and CNS involvement, cancer |

*Air quality standards according to the European Union; ®$PM_{2.5}$ is stand for PM of 2.5 µ or less. $PM_{10}$ is stand for PM of 10 µ or more. PM = Particulate matter, CNS = Central nervous system studies have reported the relationship between air pollution and neurobehavioral hyperactivity, criminal activity, and age-inappropriate behaviors.[90,91] Studies have also revealed the association between air pollution and higher risk of neuroinflammation,[92] Alzheimer's and Parkinson's diseases.[93] Some studies showed that aggression and anxiety in megacities are in close relationship with the high level of air pollutants.[94-96]

## Other long-term complications

Skin is the body's first line of defense against a foreign pathogen or infectious agent and it is the first organ that may be contaminated by a pollutant. The skin is a target organ for pollution in which the absorption of environmental pollutants from this organ is equivalent to the respiratory uptake.[97] Research on the skin has provided evidence that traffic-related air pollutants, especially PAHs, VOCs, oxides, and PM affect skin aging and cause pigmented spots on the face.[98-100]

Theoretically, toxic air pollutants can cause damage to organs when inhaled or absorbed through the skin.[101] Some of these pollutants are hepatocarcinogen chemicals.[102,103] There are some proven data which highlighted the role of air pollutants, especially traffic-related air pollution on the incidence of autism and its related disorders in fetus and children.[104-107] Disrupting endocrine by chemical components of pollutants has been described as a possible mechanistic pathway of autism or other neurological disorders.[93,108] Some studies showed that there are relationships between air pollution exposure and fetal head size in late pregnancy,[109] fetal growth,[110] and low birth weight.[111,112]

Many of the diseases that are linked to immune system dysfunction can be affected by several environmental factors such as poor air quality.[113,114] Poor air quality can cause serious complications in the immune system such as an abnormal increase in the serum levels of the immunoglobulin (Ig); IgA, IgM, and the complement component $C_3$ in humans as well as chronic inflammatory diseases of the respiratory system.[115] Exposure to these immunotoxicants may also cause immune dysfunction at different stages which can serve as the basis for increased risks of numerous diseases such as neuroinflammation, an altered brain innate immune response.[93,116] Air pollutants modify antigen presentation by up-regulation of costimulatory molecules such as CD80 and CD86 on macrophages.[117]

The eye is a neglected vulnerable organ to the adverse effects of air suspended contaminants even household air pollution.[118,119] Clinical effects of air pollution on the eyes can vary from asymptomatic eye problems to dry eye syndrome. Chronic exposure to air pollutants increases the risk for retinopathy and adverse ocular outcomes. In addition, there are now evidence suggesting the association between air pollution and irritation of the eyes, dry eye syndrome, and some of the major blinding.[118,120] According to data, the level of air pollution is linked to short-term increases in the number of people visiting the ophthalmological emergency department.[121,122]

## Air pollution in Iran

Air pollution in Iran as a developing country has recently caused several health and environmental problem. According to a report, the quality of air in Iran, especially in Tehran metropolis is very unhealthy and most of the pollution indices, specifically indices for CO and PM are above the standard and at sometimes at dangerous level.[123] Nonstandard motor engines and other traffic-related sources of air pollution are the most important cause of poor air quality. For example, more than 90% of the CO gas as an important air pollutant is generated by motor vehicles in Tehran.[124] Moreover, reports have shown that more than 80% of air pollution in Iran is attributed to motor vehicles.[125,126] Official reports show that in Tehran, 9.4% of the cars, 22.1% of vans, and 4.7% of taxis are carburetor vehicles. Around 9% of the vehicles in Tehran are responsible for the production of almost 400 tons pollutants annually.[127] Other reports demonstrated that cars are responsible for 80% of air pollution. Unpublished data show that a motorcycle produces air pollution 60 times more than a standard car. Based on reports, annual average of air toxicants including PM 10, $SO_2$, $NO_2$ and $O_3$ in Tehran capital city of Iran with around 8.3 million inhabitants were 90.58, 89.16, 85, and 68.82 $\mu g/m^3$, respectively. These values are more than standards defined by EPA and WHO. Therefore, as expected, air pollution is the main casualty of excess 2194 out of total 47284 deaths in a year. According to a recent report, $SO_2$, $NO_2$, and $O_3$, respectively, have caused about additional 1458, 1050, and 819 cases of total mortality in 2011.[128] According to an official report in 2013, air pollution leaves almost 4,460 deaths annually only in Tehran.[129]

Reports of the World Bank in 2005 show that mortality due to urban air pollution in Iran has led to about 640 million dollars annual losses which contribute to 0.57% of the gross domestic product.[130] Another report has also shown that Iran is the world's third main polluted country in the world, which results in 16 billion $ annual loss for the country.[16] Many regulatory programs including planting projects have been developed to reduce urban air pollution in Iran, but due to lack of enough stewardship and standardization of new technologies including those related to car engines and also nonstandard energy production, no significant output has been obtained so far.[17]

## Practical measures to reduce air pollution in Iran

The industrialization of societies is necessary to develop, but a long-term health problem and ecological impacts of such growth should always be considered prior to imposing a large financial burden on the societies. Therefore, it is suggested to adopt a balance between economic development and air pollution by legislating policies to control all activities resulting in air pollution.[131-133] There are some temporary but not trustworthy strategies to reduce air pollution in Iran. For example, increasing the price of fuels, planting trees around and inside the city, replacing old cars with modern ones, and increasing road taxes and car insurance may reduce the amount of air pollutants, but in order to keep the constancy or even optimization, these strategies should be continued. The most air-polluted capital cities of Asia are Delhi and Tehran.[134] Causes of air pollutions including cheap and low quality of vehicle's fuel particularly gas oil, nonstandard motor engines, inappropriate public transport, overuse of fossil fuel, lack of public awareness and transparency, legislation, and cooperation between different departments and green societies are similar in the two cities. Therefore, urgent and concerted actions at national and international levels are required.

Some mega capital cities in the other countries like London and Tokyo have controlled their air pollutions over the years following appropriate legislations and strict controls, whereas moving the capital cities in India and Pakistan in the last century have not solved the problem of air pollution in the long term in these countries. Therefore, moving capital city will not solve the problem of air pollution and only reduces the problem in the short term. Some recommended strategies to reduce the air pollution in Iran are summarized as the followings:

- Standardization of vehicle's fuel as much as possible and also finding a new source of energy for motor engines has attracted great attention. A great part of emission comes from vehicle exhaust, especially those which use diesel and gasoline. Using other clean source of energy such as compressed natural gas (CNG), liquefied natural gas (LNG), and alcohol is of great interests. Hence, exhorting researchers and also companies in the era of interest to find a way for replacing petrol and other fossil fuels with new suitable power generation sources will be beneficial.[135,136] Expanded of more CNG and LNG stations in big cities of Iran and producing more vehicles using CNG and LNG are recommended
- Standardization of motor engines and manufacturing engines with low fuel consumption is another strategy to reduce the level of air pollutants. Surely, motor vehicles will not use fossil fuel and derivatives anymore in the near future. Recently, some car makers in Japan and Western countries have made electrical cars that use electricity from a battery storage for low speeds which is usually enough for driving inside the cities with traffic and/or controlled speeds. Hence, designing new motor engines, companies of interests should look forward.[137] This might be implemented in Iran in the future
- Improving public transportation systems by using more subways (metro), trams, and electrical bus routes. Reducing the costs for the people who are using such systems is an optimal solution for lowering air pollution.[14] The people and governments will gain profits from reducing air contaminations in the long term, both economically and in cases of health issues.[138-140] At the present, there are only limited metro lines in Tehran, Mashhad, and Esfahan. It is recommended to expand the metro lines in these cities. Trams and electrical buses have unfortunately not been established in Iran. They should be implemented soon in big cities of Iran
- Increasing the cost of fuel in Iran can be considered as an effective solution to reduce the proportion of air contaminants. According to the report by Barnett and Knibbs, higher fuel price is associated with lower air pollution level[141]
- Imposing penalties for polluting industries and implementing low tax policy for clean technologies. Applying more taxes on automobiles in Iran, particularly on those older than 20 years to distinguish between dirty and clean vehicles. The government should establish exhorting plans for car makers and other producers who adhere to environmental standards. Moreover, exhorting plans should be designed for all sources of emissions. These plans may contain discount on taxes or other financial supports for customers and producers
- Since the phenomenon of air pollution was a global issue over the centuries since the industrial revolution, it is proposed to establish an interdisciplinary academic field on air pollution. It is also suggested that more communication and collaboration between specialists in different sciences including toxicology, environmental health, analytical chemistry, mechanics, and applied physics will be performed
- Continuous monitoring of air quality, designing and developing tools to identify the pollutants, finding the origin of the particles, and the use of particulate filter for diesel engines and other nonroad cars are other suggested practical approaches to reduce air pollution
- Extensive media campaign to increase public awareness about air quality, environmental, and public health issues.

Inadequate legislation and also a lack of appropriate policies in Iran result in higher levels of environmental pollution and its impact on the incidence of diseases, which will undeniably impose a heavy financial burden on the community. Increasing risk of diseases due to air contamination has necessitated defining the standard values for air quality and also a normal range for pollutants and daily control of air pollution. Thus, monitoring air quality plays an important role in developing regulatory policies.[142] These should be implemented in all big cities of Iran.

Regulatory programs should apply high taxes per unit of emission not only as a penalty for air polluters but also should give rise to the cost of pollution for them in order to ensure the efficient reduction of pollutants. Final achievement is to reduce the pollution and not only paying the cost of damages by polluters.[143]

Advantages and breakpoints of these strategies should be carefully documented. Tax on vehicles is the most controversial issue in controlling and management of air pollution. It would be helpful providing all necessary facilities including subway, and other transportation systems prior to applying penalties. In other word, taxes should be applied, but public transportation systems should be improved, and also its cost should be reasonable enough.

It is important to balance between all suggested strategies, and discuss all aspects of each plan. Each of these controlling policies has an impact on each other and also on the society. Ideally, an optimum solution for the problem of air pollution is that in which no additional problem resulted from controlling policies impose on the society. Therefore, a suitable controlling policy should contain penalties for each unit of air pollutants' emission. The sources of emission vary from small unit of cigarettes to large volume of emission from motor engines of automobiles and industrial activities.[144]

## CONCLUSIONS AND RECOMMENDATIONS

Air pollutions have major impacts on human health, triggering, and inducing many diseases leading to high morbidities and mortalities, particularly in the developing countries such as Iran. Therefore, air pollutions control is vital and should be on the top of priority list of the governments. The policy makers and legislators in these countries must update all laws and regulations related to air pollutions. Coordination between different departments involving in air pollutions must be leaded by a powerful environmental protection organization. An effective environmental protection organization should have enough budgets for administration, research, development, monitoring, and full control of the environment including air pollution.

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## AUTHORS' CONTRIBUTIONS

AGA, BRZ, and MBM contributed in study concept, design, and critical revision of the manuscript. AGA and BRZ participated in the drafting of the manuscript. MBM contributed in revision and final approval of the manuscript.

## REFERENCES

1. Robinson DL. Air pollution in Australia: Review of costs, sources and potential solutions. Health Promot J Austr 2005;16:213-20.
2. Habre R, Coull B, Moshier E, Godbold J, Grunin A, Nath A, *et al.* Sources of indoor air pollution in New York city residences of asthmatic children. J Expo Sci Environ Epidemiol 2014;24:269-78.
3. Rumana HS, Sharma RC, Beniwal V, Sharma AK. A retrospective approach to assess human health risks associated with growing air pollution in urbanized area of Thar Desert, Western Rajasthan, India. J Environ Health Sci Eng 2014;12:23.
4. Yamamoto SS, Phalkey R, Malik AA. A systematic review of air pollution as a risk factor for cardiovascular disease in South Asia: Limited evidence from India and Pakistan. Int J Hyg Environ Health 2014;217:133-44.
5. Zhang W, Qian CN, Zeng YX. Air pollution: A smoking gun for cancer. Chin J Cancer 2014;33:173-5.
6. Brucker N, Charão MF, Moro AM, Ferrari P, Bubols G, Sauer E, *et al.* Atherosclerotic process in taxi drivers occupationally exposed to air pollution and co-morbidities. Environ Res 2014;131:31-8.
7. Biggeri A, Bellini P, Terracini B. Meta-analysis of the Italian studies on short-term effects of air pollution – MISA 1996-2002. Epidemiol Prev 2004;28 4-5 Suppl: 4-100.
8. Vermaelen K, Brusselle G. Exposing a deadly alliance: Novel insights into the biological links between COPD and lung cancer. Pulm Pharmacol Ther 2013;26:544-54.
9. Kan H, Chen B, Zhao N, London SJ, Song G, Chen G, *et al.* Part 1. A time-series study of ambient air pollution and daily mortality in Shanghai, China. Res Rep Health Eff Inst 2010;(154):17-78.
10. Zhou N, Cui Z, Yang S, Han X, Chen G, Zhou Z, *et al.* Air pollution and decreased semen quality: A comparative study of Chongqing urban and rural areas. Environ Pollut 2014;187:145-52.
11. Chen B, Kan H. Air pollution and population health: A global challenge. Environ Health Prev Med 2008;13:94-101.
12. Molina MJ, Molina LT. Megacities and atmospheric pollution. J Air Waste Manag Assoc 2004;54:644-80.
13. Chi CC. Growth with pollution: Unsustainable development in Taiwan and its consequences. Stud Comp Int Dev 1994;29:23-47.
14. Air pollution: Consequences and actions for the UK, and beyond. Lancet 2016;387:817.
15. WHO. Database: Outdoor Air Pollution in Cities; 2003-2010. Available from: http://www.who.int/phe/health_topics/outdoorair/databases/cities-2011/en/.
16. Mawer C. Air pollution in Iran. BMJ 2014;348:g1586.
17. Shahrabi NS, Pourezzat A, Ahmad FB, Mafimoradi S, Poursafa P. Pathologic analysis of control plans for air pollution management in tehran metropolis: A qualitative study. Int J Prev Med 2013;4:995-1003.
18. Vallero D. Fundamentals of Air Pollution. 4th ed. California, USA: Academic Press; 2007.
19. U.S. Environmental Protection Agency. Metropolitan area trends. Washington, DC: U.S. Environmental Protection Agency; 1996.

20. Thom GC, Ott WR. Air Pollution Indices: A Compendium and Assessment of Indices Used in the United States and Canada. 6th ed. Michigan, USA: Ann Arbor Science; 1976.
21. Cairncross EK, John J, Zunckel M. A novel air pollution index based on the relative risk of daily mortality associated with short-term exposure to common air pollutants. Atmos Environ 2007;41:8442-54.
22. Johnson D, Ambrose S, Bassett T, Bowen M, Crummey D, Isaacson J, *et al*. Meanings of environmental terms. J Environ Qual 1997;26:581-9.
23. Lovett GM, Tear TH, Evers DC, Findlay SE, Cosby BJ, Dunscomb JK, *et al.* Effects of air pollution on ecosystems and biological diversity in the eastern United States. Ann N Y Acad Sci 2009;1162:99-135.
24. Mellouki A, George C, Chai F, Mu Y, Chen J, Li H. Sources, chemistry, impacts and regulations of complex air pollution: Preface. J Environ Sci (China) 2016;40:1-2.
25. Camargo JA, Alonso A. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environ Int 2006;32:831-49.
26. Catcott EJ. Effects of air pollution on animals. Monogr Ser World Health Organ 1961;46:221-31.
27. Veras MM, Caldini EG, Dolhnikoff M, Saldiva PH. Air pollution and effects on reproductive-system functions globally with particular emphasis on the Brazilian population. J Toxicol Environ Health B Crit Rev 2010;13:1-15.
28. Schneider SH. The greenhouse effect: Science and policy. Science 1989;243:771-81.
29. Loomis D, Huang W, Chen G. The International Agency for Research on Cancer (IARC) evaluation of the carcinogenicity of outdoor air pollution: Focus on China. Chin J Cancer 2014;33:189-96.
30. Kjellstrom T, Lodh M, McMichael T, Ranmuthugala G, Shrestha R, Kingsland S. Air and water pollution: Burden and strategies for control. In: Jamison DT, Breman JG, Measham AR, Alleyne G, Claeson M, Evans DB, *et al*., editors. Disease Control Priorities in Developing Countries. 2nd ed. Washington, DC: World Bank; 2006. p. 817-32.
31. Rodopoulou S, Chalbot MC, Samoli E, Dubois DW, San Filippo BD, Kavouras IG. Air pollution and hospital emergency room and admissions for cardiovascular and respiratory diseases in Doña Ana County, New Mexico. Environ Res 2014;129:39-46.
32. Carugno M, Consonni D, Randi G, Catelan D, Grisotto L, Bertazzi PA, *et al.* Air pollution exposure, cause-specific deaths and hospitalizations in a highly polluted Italian region. Environ Res 2016;147:415-24.
33. Sadeghi M, Ahmadi A, Baradaran A, Masoudipoor N, Frouzandeh S. Modeling of the relationship between the environmental air pollution, clinical risk factors, and hospital mortality due to myocardial infarction in Isfahan, Iran. J Res Med Sci 2015;20:757-62.
34. Sahu D, Kannan GM, Vijayaraghavan R. Carbon black particle exhibits size dependent toxicity in human monocytes. Int J Inflam 2014;2014:827019.
35. Bentayeb M, Simoni M, Norback D, Baldacci S, Maio S, Viegi G, *et al.* Indoor air pollution and respiratory health in the elderly. J Environ Sci Health A Tox Hazard Subst Environ Eng 2013;48:1783-9.
36. Guillam MT, Pédrono G, Le Bouquin S, Huneau A, Gaudon J, Leborgne R, *et al.* Chronic respiratory symptoms of poultry farmers and model-based estimates of long-term dust exposure. Ann Agric Environ Med 2013;20:307-11.
37. Gao Y, Chan EY, Li L, Lau PW, Wong TW. Chronic effects of ambient air pollution on respiratory morbidities among Chinese children: A cross-sectional study in Hong Kong. BMC Public Health 2014;14:105.
38. Zhou M, Liu Y, Wang L, Kuang X, Xu X, Kan H. Particulate air pollution and mortality in a cohort of Chinese men. Environ Pollut 2014;186:1-6.
39. Pelucchi C, Negri E, Gallus S, Boffetta P, Tramacere I, La Vecchia C. Long-term particulate matter exposure and mortality: A review of European epidemiological studies. BMC Public Health 2009;9:453.
40. Jerrett M, Finkelstein MM, Brook JR, Arain MA, Kanaroglou P, Stieb DM, *et al.* A cohort study of traffic-related air pollution and mortality in Toronto, Ontario, Canada. Environ Health Perspect 2009;117:772-7.
41. Gorai AK, Tuluri F, Tchounwou PB. A GIS based approach for assessing the association between air pollution and asthma in New York state, USA. Int J Environ Res Public Health 2014;11:4845-69.
42. McCarthy JT, Pelle E, Dong K, Brahmbhatt K, Yarosh D, Pernodet N. Effects of ozone in normal human epidermal keratinocytes. Exp Dermatol 2013;22:360-1.
43. Lippmann M. Health effects of ozone. A critical review. JAPCA 1989;39:672-95.
44. Hatch GE, Slade R, Harris LP, McDonnell WF, Devlin RB, Koren HS, *et al.* Ozone dose and effect in humans and rats. A comparison using oxygen-18 labeling and bronchoalveolar lavage. Am J Respir Crit Care Med 1994;150:676-83.
45. Gerrity TR, Weaver RA, Berntsen J, House DE, O'Neil JJ. Extrathoracic and intrathoracic removal of O3 in tidal-breathing humans. J Appl Physiol (1985) 1988;65:393-400.
46. Fares S, Vargas R, Detto M, Goldstein AH, Karlik J, Paoletti E, *et al.* Tropospheric ozone reduces carbon assimilation in trees: Estimates from analysis of continuous flux measurements. Glob Chang Biol 2013;19:2427-43.
47. Wilkinson S, Mills G, Illidge R, Davies WJ. How is ozone pollution reducing our food supply? J Exp Bot 2012;63:527-36.
48. Akyol S, Erdogan S, Idiz N, Celik S, Kaya M, Ucar F, *et al.* The role of reactive oxygen species and oxidative stress in carbon monoxide toxicity: An in-depth analysis. Redox Rep 2014;19:180-9.
49. Allred EN, Bleecker ER, Chaitman BR, Dahms TE, Gottlieb SO, Hackney JD, *et al.* Acute effects of carbon monoxide exposure on individuals with coronary artery disease. Res Rep Health Eff Inst 1989;(25):1-79.
50. Chen TM, Gokhale J, Shofer S, Kuschner WG. Outdoor air pollution: Nitrogen dioxide, sulfur dioxide, and carbon monoxide health effects. Am J Med Sci 2007;333:249-56.
51. Hesterberg TW, Bunn WB, McClellan RO, Hamade AK, Long CM, Valberg PA. Critical review of the human data on short-term nitrogen dioxide (NO2) exposures: Evidence for NO2 no-effect levels. Crit Rev Toxicol 2009;39:743-81.
52. Balali-Mood M, Shademanfar S, Rastegar Moghadam J, Afshari R, Namaei Ghassemi M, Allah Nemati H, *et al.* Occupational lead poisoning in workers of traditional tile factories in Mashhad, Northeast of Iran. Int J Occup Environ Med 2010;1:29-38.
53. Mousavi SR, Balali-Mood M, Riahi-Zanjani B, Yousefzadeh H, Sadeghi M. Concentrations of mercury, lead, chromium, cadmium, arsenic and aluminum in irrigation water wells and wastewaters used for agriculture in Mashhad, Northeastern Iran. Int J Occup Environ Med 2013;4:80-6.
54. Manuela C, Francesco T, Tiziana C, Assunta C, Lara S, Nadia N, *et al.* Environmental and biological monitoring of benzene in traffic policemen, police drivers and rural outdoor male workers. J Environ Monit 2012;14:1542-50.
55. Farhat A, Mohammadzadeh A, Balali-Mood M, Aghajanpoor-Pasha M, Ravanshad Y. Correlation of blood lead level in mothers and exclusively breastfed infants: A study on infants aged less than six months. Asia Pac J Med Toxicol 2013;2:150-2.
56. Farhat AS, Parizadeh SM, Balali M, Balali M, Khademi GR.

Comparison of blood lead levels in 1-7 year old children with and without seizure. Neurosciences (Riyadh) 2005;10:210-2.
57. Lidsky TI, Schneider JS. Adverse effects of childhood lead poisoning: The clinical neuropsychological perspective. Environ Res 2006;100:284-93.
58. Lidsky TI, Schneider JS. Lead neurotoxicity in children: Basic mechanisms and clinical correlates. Brain 2003;126(Pt 1):5-19.
59. American Academy of Pediatrics Committee on Environmental Health. Lead exposure in children: Prevention, detection, and management. Pediatrics 2005;116:1036-46.
60. Kianoush S, Balali-Mood M, Mousavi SR, Moradi V, Sadeghi M, Dadpour B, *et al.* Comparison of therapeutic effects of garlic and d-penicillamine in patients with chronic occupational lead poisoning. Basic Clin Pharmacol Toxicol 2012;110:476-81.
61. Kianoush S, Balali-Mood M, Mousavi SR, Shakeri MT, Dadpour B, Moradi V, *et al.* Clinical, toxicological, biochemical, and hematologic parameters in lead exposed workers of a car battery industry. Iran J Med Sci 2013;38:30-7.
62. Kansal A. Sources and reactivity of NMHCs and VOCs in the atmosphere: A review. J Hazard Mater 2009;166:17-26.
63. Kameda T, Akiyama A, Toriba A, Tang N, Hayakawa K. Atmospheric formation of hydroxynitropyrenes from a photochemical reaction of particle-associated 1-nitropyrene. Environ Sci Technol 2011;45:3325-32.
64. Schecter A, Birnbaum L, Ryan JJ, Constable JD. Dioxins: An overview. Environ Res 2006;101:419-28.
65. Harrison RM. Sources of air pollution. Air Quality Guidelines Global Update 2005. Copenhagen, Denmark: World Health Organization Regional Office for Europe; 2006. p. 9-30.
66. Hewitt C, Jackson AV. Sources of air pollution. In: Jackson AV, editor. Handbook of Atmospheric Science: Principles and Applications. 2nd ed. Malden, MA, USA: Blackwell Science Ltd.; 2007. p. 124-55.
67. Nakano T, Otsuki T. Environmental air pollutants and the risk of cancer. Gan To Kagaku Ryoho 2013;40:1441-5.
68. Kampa M, Castanas E. Human health effects of air pollution. Environ Pollut 2008;151:362-7.
69. Makri A, Stilianakis NI. Vulnerability to air pollution health effects. Int J Hyg Environ Health 2008;211:326-36.
70. Weisel CP. Assessing exposure to air toxics relative to asthma. Environ Health Perspect 2002;110 Suppl 4:527-37.
71. Brunekreef B, Beelen R, Hoek G, Schouten L, Bausch-Goldbohm S, Fischer P, *et al.* Effects of long-term exposure to traffic-related air pollution on respiratory and cardiovascular mortality in the Netherlands: The NLCS-AIR study. Res Rep Health Eff Inst 2009;(139):5-71.
72. Valavanidis A, Vlachogianni T, Fiotakis K, Loridas S. Pulmonary oxidative stress, inflammation and cancer: Respirable particulate matter, fibrous dusts and ozone as major causes of lung carcinogenesis through reactive oxygen species mechanisms. Int J Environ Res Public Health 2013;10:3886-907.
73. Tam WW, Wong TW, Wong AH, Hui DS. Effect of dust storm events on daily emergency admissions for respiratory diseases. Respirology 2012;17:143-8.
74. Beelen R, Hoek G, van den Brandt PA, Goldbohm RA, Fischer P, Schouten LJ, *et al.* Long-term effects of traffic-related air pollution on mortality in a Dutch cohort (NLCS-AIR study). Environ Health Perspect 2008;116:196-202.
75. Bahadar H, Mostafalou S, Abdollahi M. Current understandings and perspectives on non-cancer health effects of benzene: A global concern. Toxicol Appl Pharmacol 2014;276:83-94.
76. Johannson KA, Vittinghoff E, Lee K, Balmes JR, Ji W, Kaplan GG, *et al.* Acute exacerbation of idiopathic pulmonary fibrosis associated with air pollution exposure. Eur Respir J 2014;43:1124-31.
77. Kelly FJ. Oxidative stress: Its role in air pollution and adverse health effects. Occup Environ Med 2003;60:612-6.
78. Stoner AM, Anderson SE, Buckley TJ. Ambient air toxics and asthma prevalence among a representative sample of US kindergarten-age children. PLoS One 2013;8:e75176.
79. Chung KF, Zhang J, Zhong N. Outdoor air pollution and respiratory health in Asia. Respirology 2011;16:1023-6.
80. Zeng G, Sun B, Zhong N. Non-smoking-related chronic obstructive pulmonary disease: A neglected entity? Respirology 2012;17:908-12.
81. Ko FW, Hui DS. Air pollution and chronic obstructive pulmonary disease. Respirology 2012;17:395-401.
82. Nogueira JB. Air pollution and cardiovascular disease. Rev Port Cardiol 2009;28:715-33.
83. Snow SJ, Cheng W, Wolberg AS, Carraway MS. Air pollution upregulates endothelial cell procoagulant activity via ultrafine particle-induced oxidant signaling and tissue factor expression. Toxicol Sci 2014;140:83-93.
84. Brook RD. Cardiovascular effects of air pollution. Clin Sci (Lond) 2008;115:175-87.
85. Andersen ZJ, Kristiansen LC, Andersen KK, Olsen TS, Hvidberg M, Jensen SS, *et al.* Stroke and long-term exposure to outdoor air pollution from nitrogen dioxide: A cohort study. Stroke 2012;43:320-5.
86. Steenhof M, Janssen NA, Strak M, Hoek G, Gosens I, Mudway IS, *et al.* Air pollution exposure affects circulating white blood cell counts in healthy subjects: The role of particle composition, oxidative potential and gaseous pollutants – The RAPTES project. Inhal Toxicol 2014;26:141-65.
87. Sun Q, Yue P, Ying Z, Cardounel AJ, Brook RD, Devlin R, *et al.* Air pollution exposure potentiates hypertension through reactive oxygen species-mediated activation of Rho/ROCK. Arterioscler Thromb Vasc Biol 2008;28:1760-6.
88. Leary PJ, Kaufman JD, Barr RG, Bluemke DA, Curl CL, Hough CL, *et al.* Traffic-related air pollution and the right ventricle. The multi-ethnic study of atherosclerosis. Am J Respir Crit Care Med 2014;189:1093-100.
89. Van Hee VC, Adar SD, Szpiro AA, Barr RG, Bluemke DA, Diez Roux AV, *et al.* Exposure to traffic and left ventricular mass and function: The multi-ethnic study of atherosclerosis. Am J Respir Crit Care Med 2009;179:827-34.
90. Newman NC, Ryan P, Lemasters G, Levin L, Bernstein D, Hershey GK, *et al.* Traffic-related air pollution exposure in the first year of life and behavioral scores at 7 years of age. Environ Health Perspect 2013;121:731-6.
91. Haynes EN, Chen A, Ryan P, Succop P, Wright J, Dietrich KN. Exposure to airborne metals and particulate matter and risk for youth adjudicated for criminal activity. Environ Res 2011;111:1243-8.
92. Calderón-Garcidueñas L, Mora-Tiscareño A, Ontiveros E, Gómez-Garza G, Barragán-Mejía G, Broadway J, *et al.* Air pollution, cognitive deficits and brain abnormalities: A pilot study with children and dogs. Brain Cogn 2008;68:117-27.
93. Calderón-Garcidueñas L, Solt AC, Henríquez-Roldán C, Torres-Jardón R, Nuse B, Herritt L, *et al.* Long-term air pollution exposure is associated with neuroinflammation, an altered innate immune response, disruption of the blood-brain barrier, ultrafine particulate deposition, and accumulation of amyloid beta-42 and alpha-synuclein in children and young adults. Toxicol Pathol 2008;36:289-310.
94. Rotton J, Frey J, Barry T, Milligan M, Fitzpatrick M. The air pollution experience and physical aggression1. J Appl Soc Psychol 1979;9:397-412.
95. Evans GW. The built environment and mental health. J Urban Health 2003;80:536-55.

96. Jones JW, Bogat GA. Air pollution and human aggression. Psychol Rep 1978;43(3 Pt 1):721-2.
97. Goldsmith LA. Skin effects of air pollution. Otolaryngol Head Neck Surg 1996;114:217-9.
98. Singh B, Maibach H. Climate and skin function: An overview. Skin Res Technol 2013;19:207-12.
99. Vierkötter A, Schikowski T, Ranft U, Sugiri D, Matsui M, Krämer U, *et al.* Airborne particle exposure and extrinsic skin aging. J Invest Dermatol 2010;130:2719-26.
100. Drakaki E, Dessinioti C, Antoniou CV. Air pollution and the skin. Front Environ Sci 2014;2:11.
101. Potera C. More human, more humane: A new approach for testing airborne pollutants. Environ Health Perspect 2007;115:A148-51.
102. Motta S, Federico C, Saccone S, Librando V, Mosesso P. Cytogenetic evaluation of extractable agents from airborne particulate matter generated in the city of Catania (Italy). Mutat Res 2004;561:45-52.
103. Ito Y, Ramdhan DH, Yanagiba Y, Yamagishi N, Kamijima M, Nakajima T. Exposure to nanoparticle-rich diesel exhaust may cause liver damage. Nihon Eiseigaku Zasshi 2011;66:638-42.
104. Roberts AL, Lyall K, Hart JE, Laden F, Just AC, Bobb JF, *et al.* Perinatal air pollutant exposures and autism spectrum disorder in the children of nurses' health study II participants. Environ Health Perspect 2013;121:978-84.
105. Kalkbrenner AE, Daniels JL, Chen JC, Poole C, Emch M, Morrissey J. Perinatal exposure to hazardous air pollutants and autism spectrum disorders at age 8. Epidemiology 2010;21:631-41.
106. Volk HE, Lurmann F, Penfold B, Hertz-Picciotto I, McConnell R. Traffic-related air pollution, particulate matter, and autism. JAMA Psychiatry 2013;70:71-7.
107. Becerra TA, Wilhelm M, Olsen J, Cockburn M, Ritz B. Ambient air pollution and autism in Los Angeles county, California. Environ Health Perspect 2013;121:380-6.
108. de Cock M, Maas YG, van de Bor M. Does perinatal exposure to endocrine disruptors induce autism spectrum and attention deficit hyperactivity disorders? Review. Acta Paediatr 2012;101:811-8.
109. Ritz B, Qiu J, Lee PC, Lurmann F, Penfold B, Erin Weiss R, *et al.* Prenatal air pollution exposure and ultrasound measures of fetal growth in Los Angeles, California. Environ Res 2014;130:7-13.
110. Liu S, Krewski D, Shi Y, Chen Y, Burnett RT. Association between maternal exposure to ambient air pollutants during pregnancy and fetal growth restriction. J Expo Sci Environ Epidemiol 2007;17:426-32.
111. Stieb DM, Chen L, Eshoul M, Judek S. Ambient air pollution, birth weight and preterm birth: A systematic review and meta-analysis. Environ Res 2012;117:100-11.
112. Yucra S, Tapia V, Steenland K, Naeher LP, Gonzales GF. Maternal exposure to biomass smoke and carbon monoxide in relation to adverse pregnancy outcome in two high altitude cities of Peru. Environ Res 2014;130:29-33.
113. Vawda S, Mansour R, Takeda A, Funnell P, Kerry S, Mudway I, *et al.* Associations between inflammatory and immune response genes and adverse respiratory outcomes following exposure to outdoor air pollution: A HuGE systematic review. Am J Epidemiol 2014;179:432-42.
114. Behrendt H, Alessandrini F, Buters J, Krämer U, Koren H, Ring J. Environmental pollution and allergy: Historical aspects. Chem Immunol Allergy 2014;100:268-77.
115. Hadnagy W, Stiller-Winkler R, Idel H. Immunological alterations in sera of persons living in areas with different air pollution. Toxicol Lett 1996;88:147-53.
116. Dietert RR. Distinguishing environmental causes of immune dysfunction from pediatric triggers of disease. Open Pediatr Med J 2009;3:38-44.
117. Saxon A, Diaz-Sanchez D. Air pollution and allergy: You are what you breathe. Nat Immunol 2005;6:223-6.
118. West SK, Bates MN, Lee JS, Schaumberg DA, Lee DJ, Adair-Rohani H, *et al.* Is household air pollution a risk factor for eye disease? Int J Environ Res Public Health 2013;10:5378-98.
119. Klopfer J. Effects of environmental air pollution on the eye. J Am Optom Assoc 1989;60:773-8.
120. Rozanova E, Heilig P, Godnic-Cvar J. The eye – A neglected organ in environmental and occupational medicine: An overview of known environmental and occupational non-traumatic effects on the eyes. Arh Hig Rada Toksikol 2009;60:205-15.
121. Chang CJ, Yang HH, Chang CA, Tsai HY. Relationship between air pollution and outpatient visits for nonspecific conjunctivitis. Invest Ophthalmol Vis Sci 2012;53:429-33.
122. Bourcier T, Viboud C, Cohen JC, Thomas F, Bury T, Cadiot L, *et al.* Effects of air pollution and climatic conditions on the frequency of ophthalmological emergency examinations. Br J Ophthalmol 2003;87:809-11.
123. Khalilzadeh S, Khalilzadeh Z, Emami H, Masjedi MR. The relation between air pollution and cardiorespiratory admissions in Tehran. Tanaffos 2009;8:35-40.
124. Saeb K, Maryam M, Saeed K. Air pollution estimation from traffic flows in Tehran highways. Curr World Environ 2012;7:1-6.
125. Kakouei A, Vatani A, Idris AK. An estimation of traffic related CO2 emissions from motor vehicles in the capital city of, Iran. Iranian J Environ Health Sci Eng 2012;9:13.
126. Ronaghy HA. Major source of air pollution in Iranian cities. J Iran Res Anal 2001;17:56-65.
127. Shafie-Pour M, Tavakoli A. On-road vehicle emissions forecast using IVE simulation model. Int J Environ Res 2013;7:367-76.
128. Naddafi K, Hassanvand MS, Yunesian M, Momeniha F, Nabizadeh R, Faridi S, *et al.* Health impact assessment of air pollution in megacity of Tehran, Iran. Iranian J Environ Health Sci Eng 2012;9:28.
129. Phys.org. Tehran Air Pollution Leaves 4,460 Dead: Health Official; 2013. Available from: http://phys.org/news/2013-01-tehran-air-pollution-dead-health.html.
130. Asadikia H, Oyarhossein R, Saleh I, Rafiee H, Zare S. Economie growth and air pollution in Iran during development programs. J Environ Stud 2009;35:93-100.
131. Xepapadeas A. Economic growth and the environment. In: Mäler KG, Vincent JR, editors. Handbook of Environmental Economics. 1st ed. North Holland: Elsevier; 2005. p. 1219-71.
132. Panwar N, Kaushik S, Kothari S. Role of renewable energy sources in environmental protection: A review. Renewable Sustain Energy Rev 2011;15:1513-24.
133. Dincer I. Renewable energy and sustainable development: A crucial review. Renewable Sustain Energy Rev 2000;4:157-75.
134. Rizwan S, Nongkynrih B, Gupta SK. "Air pollution in Delhi: Its Magnitude and Effects on Health". Indian J Community Med 2013;38:4-8.
135. Goldemberg J, Johansson TB, Reddy AK, Williams RH. Energy for the new millennium. Ambio 2001;30:330-7.
136. Jacobson MZ. Review of solutions to global warming, air pollution, and energy security. Energy Environ Sci 2009;2:148-73.
137. Faiz A, Weaver CS, Walsh MP. Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions. 1st ed. Washington, DC: World Bank Publications; 1996.
138. Wong EY, Gohlke J, Griffith WC, Farrow S, Faustman EM. Assessing the health benefits of air pollution reduction for children. Environ Health Perspect 2004;112:226-32.
139. Hall JV, Brajer V, Lurmann FW. Air pollution, health and economic benefits – Lessons from 20 years of analysis. Ecol Econ 2010;69:2590-7.

140. Haines A, Smith KR, Anderson D, Epstein PR, McMichael AJ, Roberts I, *et al*. Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. Lancet 2007;370:1264-81.
141. Barnett AG, Knibbs LD. Higher fuel prices are associated with lower air pollution levels. Environ Int 2014;66:88-91.
142. Becker R, Henderson V. Effects of air quality regulations on polluting industries. J Polit Econ 2000;108:379-421.
143. Stavins RN, Whitehead B. The Greening of America's Taxes: Pollution Charges and Environmental Protection. 1st ed. Cambridge, MA: Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University; 1992.
144. Holman C. Sources of air pollution. In: Holgate ST, Samet JM, Koren HS, Maynard RL, editors. Air Pollution and Health. 1st ed. London: Academic Press; 1999. p. 115-48.