Islamic Republic of IRAN
Ministry of Health and Medical Education

Tehran University of Medical Sciences

Institute for Environmental Research
Tehran University of Medical Sciences

National Institute for Health Research

Air quality in Iran and its effects on health in 2017

2019 (Winter)

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National Institute for Health Research

In the Name of God

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About the Content

This report, prepared in collaboration with the National Institute for Health Research (NIHR) and the Institute for Environmental Research (IER), Tehran University of Medical Sciences (TUMS), reviews air quality in Iran and its effects on health compared to other countries. In addition to a national report, a report on air quality in Tehran city and its effect on health is also presented. The most recent data presented at the international and national scientific centers have been employed in this review.

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Abbreviation

AQI	Air Quality Index
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
GBD	Global Burden of Disease
GEMM	Global Exposure Mortality Model
IER	Integrated Exposure Response
IHD	Ischemic Heart Disease
LC	Lung Cancer
LRI	Lower Respiratory Infections
NCDs	Non-Communicable Diseases
PAF	Population Attributable Fraction
PM	Particulate Matter
ppm	Part Per Million
SO_2	Sulfur Dioxide
WHO	World Health Organization


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Summary of the report

Air pollution is a significant factor affecting health, ranking 8th risk-factor at global level and 7th in Iran with the highest number of deaths [1, 2]. Air pollution has been shown to have a significant share in the non-communicable disease (NCD) burden. After smoking, it is the second cause of deaths due to NCDs, associated with an increased risk of developing acute and chronic diseases and mortality.

There are various pollutants in air, the most important of which are particulate matter (PM). PM with the aerodynamic diameter of 10 µm or less can enter the lower parts of lungs, whereas those with the aerodynamic diameter of 2.5 µm or less can pass the lung barrier and enter the blood flow. Thus, the most important outdoor air pollutant used to express the quality of air is the concentration of PM with the aerodynamic diameter of 2.5 µm or less ($PM_{2.5}$).

The annual mean population-weighted $PM_{2.5}$ exposure concentration of outdoor air in Iran is about 48 µm/m^3, which is relatively lower than its global mean concentration (51 µg/m^3). This value is about 4.8 times higher than the level recommended by the World Health Organization (WHO), i.e. 10 µg/m^3, and almost four times the national standard (12 µg/m^3). In terms of mean concentration of PM, Iran ranks the 152nd from among 195 countries of the world. Mean global concentration of $PM_{2.5}$ was increased by 17% in 2016 compared to its level in 2010, and this trend was increasing in Iran as well; the mean annual concentration of $PM_{2.5}$ was increased by approximately 8% in 2016 compared to 2010 in Iran.

Based on the most recent estimate, in 2018, about 8.9 (7.5-10.3) million deaths in those aged above 25 years were attributed to exposure to outdoor air, of which about 77% (6.9 million) resulted from five causes: ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), lung cancer (LC), and lower respiratory infections (LRI).

Studies have estimated that, in Iran, about 75 (62-86) thousand deaths are attributed to exposure to ambient air $PM_{2.5}$. In fact, about 24% of all-cause mortality in those aged above 25 years in Iran are attributed to exposure to PM, i.e. of every four deaths in Iran, one is due to exposure to ambient air $PM_{2.5}$. Moreover, 39, 32, and 58% of all cases of mortality caused by IHD, COPD, LRI, and about 36% of cases of mortality caused by LC in Iran are attributed to $PM_{2.5}$ exposure.

Results of examining the trend of changes in air pollutant concentration from 2006 to 2017 and the quantification of their effects on health in Tehran, performed by the Institute for Environmental Research (IER) of Tehran University of Medical Sciences (TUMS), indicate that PM concentration had an increasing trend from 2006 to 2011, and the maximum mean concentration of $PM_{2.5}$ over the past 12 years has occurred in 2011, equal to 38 µg/m^3. Then, the PM concentration had a decreasing trend from 2012 to 2015, reaching about 30 µg/m^3. However, in the past two years (2016 and 2017), mean annual concentration of outdoor $PM_{2.5}$ in Tehran was increased compared to its corresponding value in 2015. This indicates that policies and programs for reducing air pollution in Tehran have not been successful.

Furthermore, results of this study demonstrated that, in Tehran, not even one day was classified as "good" (AQI=0-50) from 2011 to 2017 based on the air quality index (AQI), but the number of days in which AQI was "moderate" (AQI=51-100) was increased from 2011 to 2015, and the number of days with the AQI of "moderate" reached 80 in 2015, with the rest of the days having an unhealthy air quality. In 2017, AQI was "moderate" in 20 days, "unhealthy for sensitive groups" in 237 days, "unhealthy" in 107 days, and "very unhealthy" in 1 day.

Results of studies suggest that air pollution has a considerable share in the number of attributed deaths. If air quality is not improved in Iran, this share will increase considering the increase in the share of the elderly in the future population. Since, after smoking, air pollution is the second cause of death due to NCDs, it is essential that it be viewed as an inseparable part of NCD control programs.

Introduction

Air pollution is the most important environmental risk factor for health [3]. Although it affects all countries, those residing in low-income countries are affected by it the most. Research shows that air pollution has a significant share in the non-communicable disease (NCD) burden. After smoking, it is the second cause of deaths from NCDs, associated with an increased risk of developing acute and chronic diseases and mortality [4]. Based on the most recent air quality data published in 2018 by the World Health Organization (WHO), the mean concentration of outdoor air pollutants is above the WHO guideline in approximately 97% of cities with a population of over 100,000 in middle- and low-income countries. This percentage is about 49% in high-income countries [5-7]. As air quality is deteriorated, the risk of heart attack, cardiovascular diseases, lung cancer (LC), and chronic and acute respiratory diseases increases. In addition to outdoor air, indoor air pollutants are a serious risk factor for the health of about three billion people worldwide who use solid fuels for cooking and heat.

There are various pollutants in air, the most important of which is particulate matter (PM). PM concentration is one of the most important indicators for air pollution. The main components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral particles, and water. In other words, PM comprises a complex combination of solid and liquid mineral and organic particles suspended in the air [8]. PM with the aerodynamic diameter of 10 µm or less can enter the lower parts of lungs, whereas that with the aerodynamic diameter of 2.5 µm or less can pass the lung barrier and enter the blood flow. Research suggests that exposure to PM can increase the risk of cardiovascular diseases, respiratory diseases, and LC. There is ample evidence on the close tie between increased concentration of PM and increased mortality. When PM is reduced, the cases of death are also decreased, indicating that the health of a major portion of population improves if air pollution is reduced [7].

Summary of the report

In this section, information on the concentration of $PM_{2.5}$ in air in Iran and other countries is presented based on credible national and international documents.The most up-to-date credible international study on the $PM_{2.5}$ exposure concentration has been conducted by Shaddick et al. (2018) [9] whose results are discussed below.The data resulting from this study are also used by the Global Burden of Disease (GBD) group and the WHO.

The most important outdoor air pollutant used worldwide for expressing air quality is small particulate matter ($PM_{2.5}$). Air quality monitoring stations are active to inform the public about the concentration of outdoor air pollutants in cities. To estimate the concentration of air pollutants where there is no station or in the distance between stations, satellite models are used in addition to the data of monitoring stations. Accordingly, results of the most recent studies published in 2018 estimating the concentration of outdoor air $PM_{2.5}$ in 195 countries have been published, estimating the mean population-weighted $PM_{2.5}$ exposure concentration. In fact, these weighted values have been calculated based on the concentration of $PM_{2.5}$ in outdoor air by considering the population size in each region. Figure 1 illustrates mean population-weighted $PM_{2.5}$ exposure concentration in Iran and some other countries.

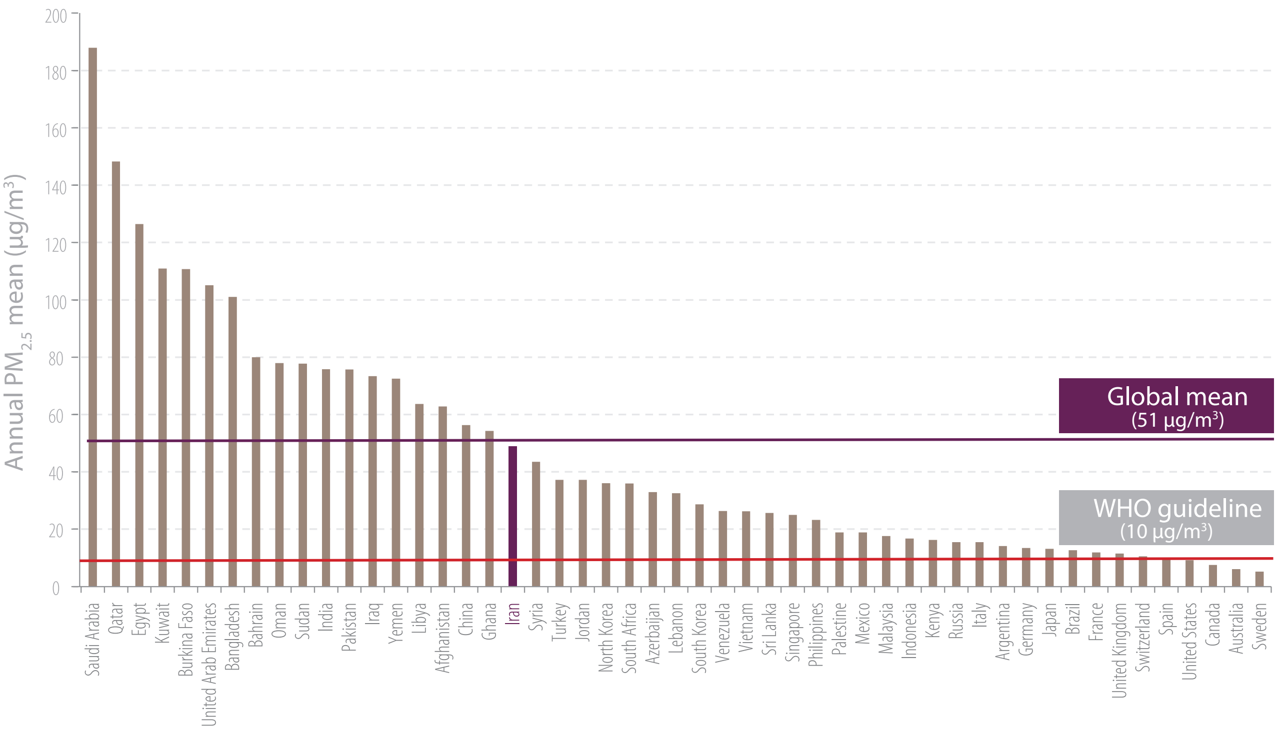


Figure 1. Annual mean population-weighted PM2.5 exposure concentration of outdoor air in different countries [9].

Figure 1 depicts the mean annual population-weighted outdoor air $PM_{2.5}$ exposure concentration in different countries. Results suggest that those residing in almost all countries, except for Canada, USA, Sweden, Australia, Finland, Norway, Iceland, and Greenland, are exposed to a high concentration of PM, higher than the limit recommended by WHO (10 µg/m^3), demonstrating the global nature of the problem. Based on the most recently published data in 2018, the mean annual $PM_{2.5}$ concentration equaled 51 µm/m^3, with the highest value in Saudi Arabia (188 µg/m^3) and Qatar (148 µg/m^3). The mean annual population-weighted $PM_{2.5}$ exposure concentration is 48 µm/m^3 in Iran, slightly below the mean global concentration (51 µg/m^3); in terms of mean concentration of PM, Iran ranks the 152nd from among 195 countries of the world. The quality of outdoor air is better in Iran compared to China, India, and the mean for the Middle East (62 µg/m^3). A comparison of mean $PM_{2.5}$ exposure concentration in Iran with WHO recommendation shows that those residing in Iran are exposed to a 4.8 times higher PM than the WHO limit, a value which is about 4 times higher than the national standard (12 µg/m^3).

Effects of air pollution on health at global level

In this section, information on the health-related effects attributed to $PM_{2.5}$ exposure in Iran and other countries is presented based on credible international documents.The most up-to-date credible international study has been conducted by Burnett et al. (2018) [5] whose results are discussed below.

Several studies have reported that exposure to air pollution, even at very low concentration, can have numerous negative effects on health, including the exacerbation of asthma attacks, hospitalization, LC, and death. Researchers who estimate the health-related effects of air pollution using epidemiological studies employ various models and software programs to quantify the effects of air pollution on health. A valid method used worldwide, also applied by the GBD and WHO to estimate the health-related effects attributed to air pollution is the integrated exposure-response (IER). Based on the latest report, the number of deaths at global level attributed to outdoor air $PM_{2.5}$ has been estimated at 4.2 million, which is reported to be 33,000 in Iran [6, 10]. However, considering the limitation of the IER model, researchers developed the most recent air pollution effect quantification model entitled global exposure mortality model (GEMM) in 2018, and estimated the number of deaths attributed to outdoor $PM_{2.5}$. Based on this method, which is the most valid model so far, the number of deaths attributed to outdoor air $PM_{2.5}$ is 8.9 million at global level and about 75,000 in Iran. Below, results of the deaths attributed to outdoor air $PM_{2.5}$ in Iran and globaly are presented, by age groups and causes of mortality. Based on the literature, the five leading causes of death attributed to air pollutionare ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), LC, and lower respiratory infection (LRI). The number of deaths attributed to the long-term exposure to outdoor air $PM_{2.5}$ at global level by age groups and causes of death is presented in Table 1 and Figure 2.

It is evident that, based on the latest estimation in 2018, about 8.9 (7.5-10.3) million deaths at global level have been attributed to exposure to outdoor $PM_{2.5}$ for those aged above 25 years, of which about 6.9 million cases were due to the five mentioned causes, i.e. 78% of all- cause mortality attributed to $PM_{2.5}$[5]. Approximately 50% of the cases of deaths attributed to air pollution result from IHD and stroke, about 22% from COPD and acute LRI, and 6% from LC. Results of global studies show that about 1.4 million deaths attributed to air pollution can be prevented if the concentration of outdoor air $PM_{2.5}$ is reduced by 20% [5].

Table 1. Number of deaths attributed to ambient air $PM_{2.5}$ at global level by the causes of mortality and age groups [5].

Age Groups	Number of deaths attributed to $PM_{2.5}$ resulting from each cause						All causes
	IHD	Stroke	COPD	LRI	LC	Other causes	
25-29	21,756	14,402	2,874	16,964	1,369	45,077	102,442
30-34	39,179	18,964	3,759	17,893	2,469	50,097	132,362
35-39	57,855	24,835	5,510	20,462	3,898	63,870	176,430
40-44	92,370	41,333	8,988	23,027	9,348	85,700	260,766
45-49	144,272	71,644	16,849	28,906	20,659	114,908	397,239
50-54	201,432	99,671	29,936	37,894	34,933	145,897	549,762
55-59	257,597	122,534	49,898	47,485	48,318	167,398	693,231
60-64	341,918	176,685	91,668	64,111	76,911	211,711	963,003
65-69	341,226	186,677	121,476	73,804	74,142	201,850	999,175
70-74	375,992	201,506	162,993	94,749	71,790	199,397	1,106,428
75-79	362,161	203,255	178,384	113,494	63,626	208,481	1,129,401
≥80	744,608	343,182	367,818	338,030	80,002	530,796	2,404,436
All age groups	**2,980,365**	**1,504,688**	**1,040,154**	**876,818**	**487,466**	**2,025,183**	**8,914,675**

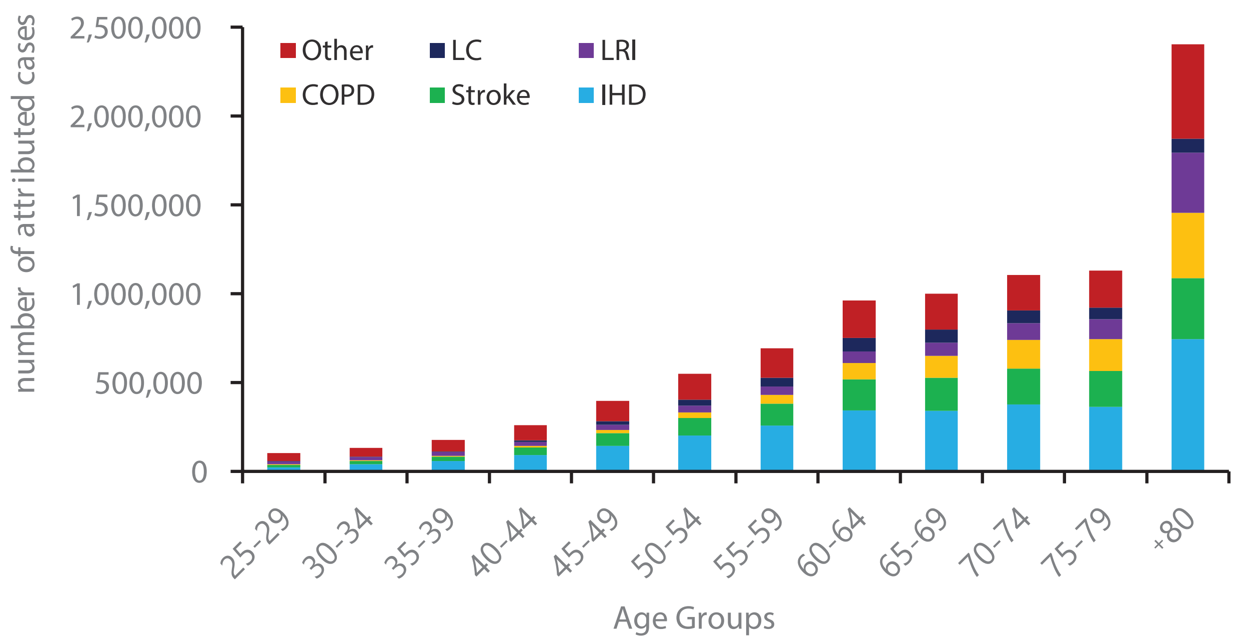


Figure 2. Number of deaths attributed to ambient air $PM_{2.5}$ by the causes of mortality and age groups at global level [5].

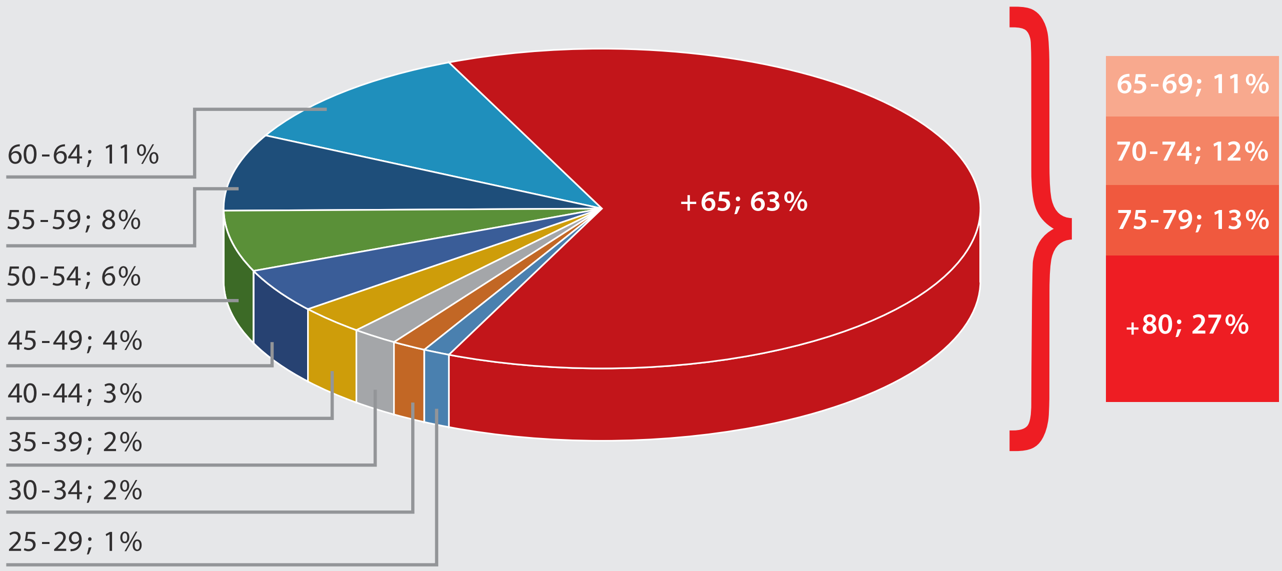


Figure 3.Portion of each age group from all-cause mortality attributed to ambient air $PM_{2.5}$ at global level [5].

Figure 3 illustrates the portion of each age group from all-cause mortality attributed to outdoor air $PM_{2.5}$ worldwide. Based on Figure 3, as age increases, the portion of cases of death attributed to air pollution also increases. In other words, only 12% of deaths attributed to PM occur in those aged 25 to 50 years, while this value is 52% in those aged 70 years and above. Moreover, the age group of 80 years and above has the largest share (27%) of all cases of mortality.

Table 2 gives the population attributable fraction (PAF) of all cases of death attributed to air pollution due to the five identified causes. PAF refers to the percentage of any outcome attributed to outdoor $PM_{2.5}$, or the portion of each health-related outcome which can be prevented if $PM_{2.5}$ is controlled/eliminated. Based on the table below, about 20% of all-cause mortality in those aged above 25 years worldwide is attributed to exposure to PM, i.e. of every five cases of death, one is due to exposure to ambient air $PM_{2.5}$. Furthermore, about one-third of all cases of death due to strokes and COPD are attributed to $PM_{2.5}$, while this value has been estimated at 46% for LRI. Based on the global estimate, about 28% of all cases of death due to LC have been attributed to outdoor air $PM_{2.5}$ exposure.

Table 2. PAF of the causes of death attributed to the long-term exposure to ambient air $PM_{2.5}$ at global level in people aged above 25 years [5].

Cause of death	PAF for outdoor air $PM_{2.5}$ (%)
All-cause mortality	20
IHD	34
Cerebrovascular diseases (stroke)	24
COPD	33
LRI	46
LC	28

Estimation of the effects of air pollution on health in Iran

Results of the estimation of health-related effects of air pollution in Iran are given in Table 3 and Figure 4. It is evident that, based on the latest estimation in 2018, about 75 (62-86) thousand deaths in Iran have been attributed to exposure to outdoor $PM_{2.5}$ of which about 60,000 cases were due to the five mentioned causes, i.e. 80% of all cases of death attributed to $PM_{2.5}$ [5]. In other words, a large number of premature deaths in Iran can be prevented if air quality is improved. Results related to Iran indicate that IHD and LC have the largest and smallest share of all cases of death attributed to air pollution (52% and 3%, respectively), a figure similar to the global one. In other words, the highest number of deaths attributed to $PM_{2.5}$ exposure in Iran and the world results from IHD.

Table 3. Number of deaths attributed to ambient air $PM_{2.5}$ in Iran by the causes of mortality and age groups [5].

Age Groups	Number of deaths attributed to $PM_{2.5}$ resulting from each cause						All causes
	IHD	Stroke	COPD	LRI	LC	Other causes	
25-29	360	105	23	94	17	437	1,036
30-34	654	146	35	111	33	473	1,452
35-39	895	196	43	106	47	445	1,732
40-44	1,360	274	56	108	69	347	2,215
45-49	2,376	426	98	136	132	305	3,474
50-54	3,245	639	158	191	198	480	4,912
55-59	4,028	888	226	242	272	726	6,383
60-64	4,878	1,220	327	337	347	1,103	8,212
65-69	4,186	1,151	327	345	294	1,202	7,505
70-74	4,271	1,340	395	475	297	1,555	8,332
75-79	4,833	1,696	530	698	294	2,211	10,261
≥80	7,866	2,891	1,069	1,955	336	5,477	19,593
All age groups	**38,951**	**10,972**	**3,287**	**4,799**	**2,336**	**14,761**	**75,106**

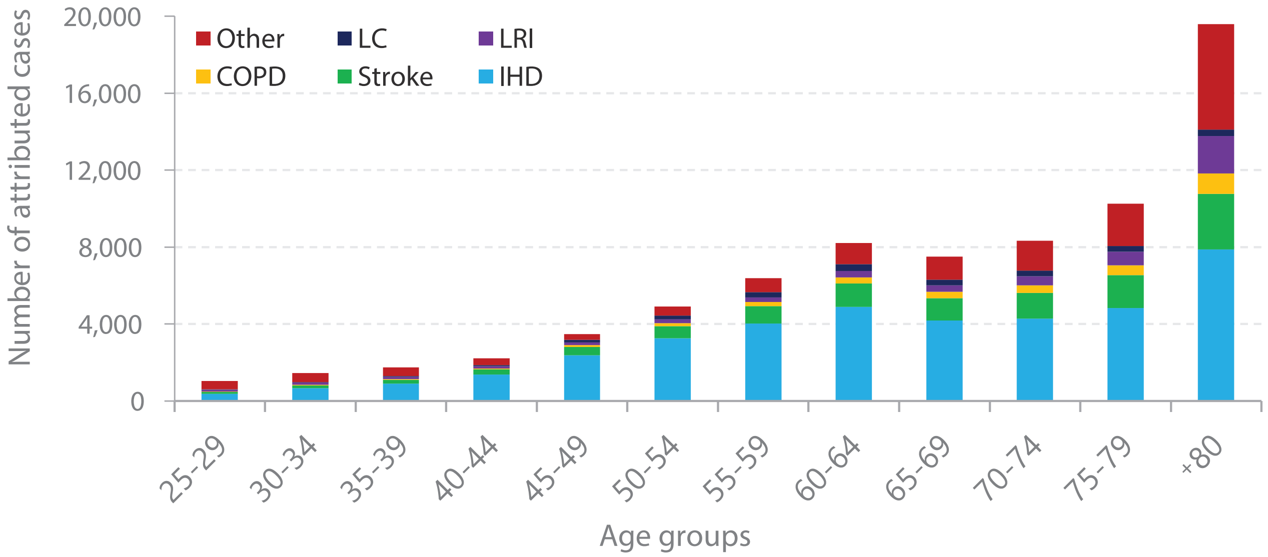


Figure 4.Number of deaths attributed to ambient air $PM_{2.5}$ in Iran by the causes of mortality and age groups [5].

Figure 5. Portion of each age group from all-cause mortality attributed to ambient air $PM_{2.5}$ in Iran [5].

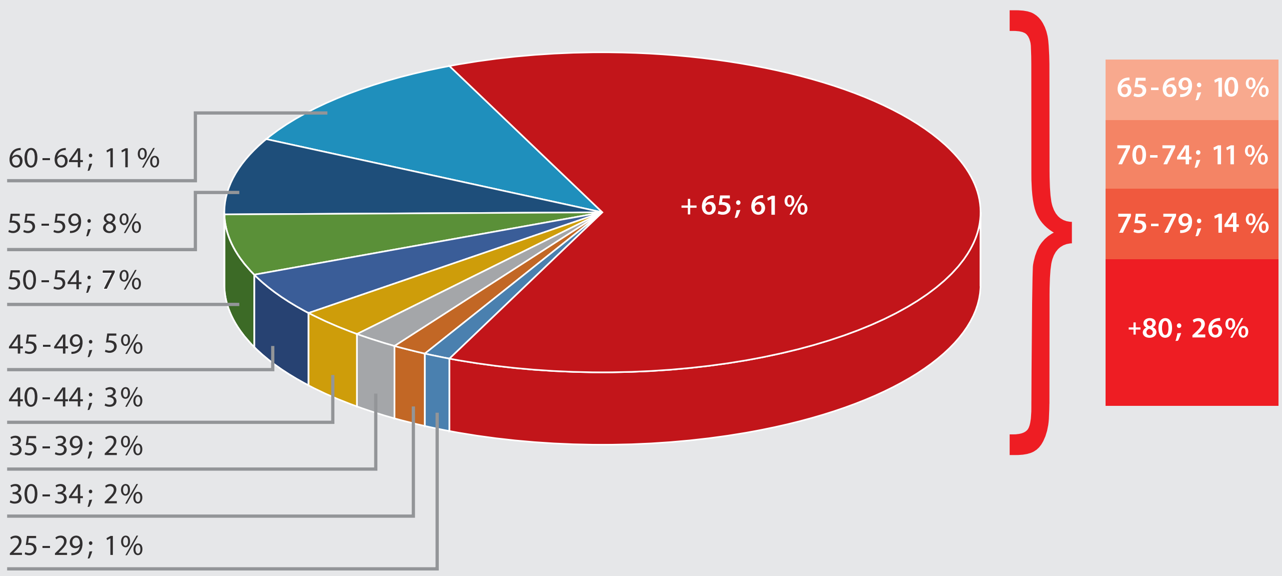


Figure 5 depicts the portion of each age group from all-cause mortality attributed to outdoor air $PM_{2.5}$ in Iran. Based on results, by increasing age, the share of deaths attributed to $PM_{2.5}$ is also increased. In other words, only 13% of all cases of death attributed to air pollution in Iran occur in those aged 25 to 50 years, while this value is about 51% in those aged above 70 years. Moreover, the share of cases of death in Iran attributed to air pollution is 28% in those aged 25 to 60 years, while this value is 26% in those aged 80 years and above.

Table 4 gives the PAF of all cases of death attributed to air pollution in Iran due to the five identified causes. Based on the table below, about 24% of all-cause mortality in those aged above 25 years in Iran are attributed to exposure to PM, i.e. of every four cases of death, one is due to exposure to outdoor air $PM_{2.5}$. Furthermore, 39, 32, and 58% of deaths due to IHD, COPD, and LRI are attributed to $PM_{2.5}$. Based on the estimations in Iran, about 36% of all cases of death due to LC have been attributed to outdoor air $PM_{2.5}$ exposure.

Table 4. PAF of the causes of death attributed to the long-term exposure to ambient air $PM_{2.5}$ in Iran in people aged above 25 years [5].

Cause of death	PAF for outdoor air $PM_{2.5}$ (%)
All-cause mortality	24
IHD	39
Cerebrovascular diseases (stroke)	26
COPD	32
LRI	58
LC	36

Age-standardized number of deaths (in every 105 people) attributed to outdoor $PM_{2.5}$ in various countries based on the latest study in 2018 is given in Figure 6. Results of this study show that the mean global number of deaths attributed to outdoor $PM_{2.5}$ equals 121 in every 100,000 age-standardized population, a value equal to 95 in Iran, which is below the mean global value. The main reason for this is the large young population in Iran compared to the mean global value. Based on Figure 6, the number of deaths attributed to outdoor $PM_{2.5}$ per age-standardized 100,000 people mainly depends on the age pyramid in different countries. This value is higher than Iran in many developed countries such as Germany (124) and Japan (111), whereas the concentration of $PM_{2.5}$ in these countries is about one-third that in Iran.

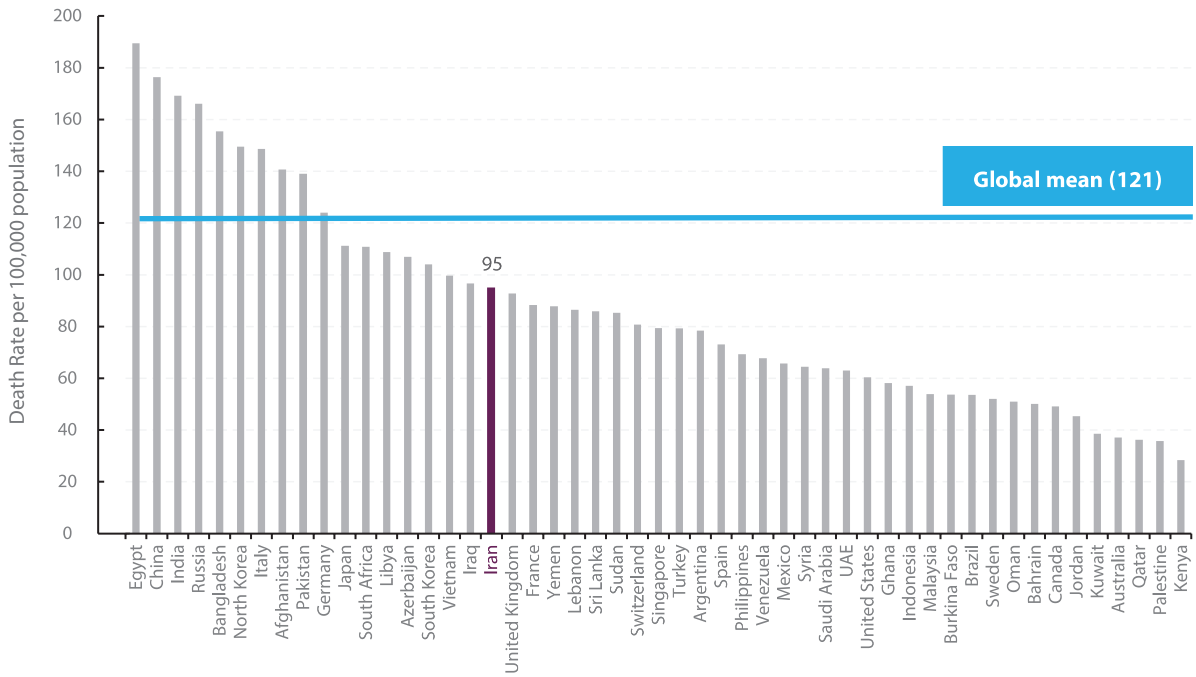


Figure 6. Age-standardized number of deaths attributed to ambient air $PM_{2.5}$ per 100,000 population [5].

Changes in particulate matter concentration in 2016 compared to 2010

Table 5 presents the changes in $PM_{2.5}$ concentration in 2016 compared to 2012 in Iran and other countries. Based on this table, the mean global concentration of $PM_{2.5}$ was increased by 17% in 2106 compared to its level in 2010, and this trend was increasing in Iran as well; the mean annual concentration of $PM_{2.5}$ was increased by approximately 8% in 2016 compared to 2010 in Iran.

Table 5.Percentage of change in $PM_{2.5}$ concentration in 2016 compared to 2010 [9].

Country	Percentage of change in $PM_{2.5}$ concentration in 2016 compared to 2010	Country	Percentage of change in $PM_{2.5}$ concentration in 2016 compared to 2010
Afghanistan	24.1	Mexico	-12.8
Argentina	0.5	North Korea	19
Australia	2.4	Oman	29.7
Azerbaijan	33.7	Pakistan	19.7
Bahrain	19.5	Palestine	5.8
Bangladesh	21.8	The Philippines	-0.3
Brazil	12.9	Qatar	22.6
Burkina Faso	101.5	Russia	0.2
Canada	3.0	Saudi Arabia	38.2
China	-1.8	Singapore	37.7
Egypt	42.9	South Africa	23.1
France	-3.2	South Korea	15.2
Germany	1.1	Spain	2.0
Ghana	74.1	Sri Lanka	-6.0
India	14.7	Sudan	32.1
Indonesia	14	Sweden	0.6
Iran	7.8	Switzerland	-6.0
Iraq	-6.8	Syria	15.8
Italy	6.3	Turkey	22.9
Japan	9.9	UAE	43
Jordan	7.5	UK	-4.5
Kenya	-2.1	USA	0.6
Kuwait	7.0	Venezuela	10.7
Lebanon	20.0	Vietnam	-4.0
Libya	9.1	Yemen	16.2
Malaysia	12.8	Global Mean	17.0

Reduction in particulate matter concentration and increased life expectancy

In this section, information on the relationship between reduced exposure to outdoor air $PM_{2.5}$ and increased life expectancy in Iran and the world is presented based on credible international documents. The most up-to-date credible international study has been conducted by Apte et al. (2018) [11] which results are discussed below.

As noted previously, exposure to $PM_{2.5}$ is a serious risk factor for early mortality, also decreasing life expectancy. Based on the literature, exposure to outdoor air $PM_{2.5}$ in 2016 reduced the mean global life expectancy from birth by one year. It is also estimated that, if the outdoor concentration of $PM_{2.5}$ is decreased globally to the limit in WHO guideline (10 μg/m³), the mean global life expectancy can be increased by 0.6 years (0.1-0.2 years). In fact, this increase in life expectancy due to the reduction in outdoor air $PM_{2.5}$ to the WHO limit equals the increase in life expectancy resulting from the eradication of lung and breast cancer [11].

Table 6 presents the amount of life expectancy increase in various countries in case of reducing outdoor air $PM_{2.5}$ to the WHO limit. Based on these results, if outdoor air $PM_{2.5}$ concentration is decreased to 10 μg/m³ in Iran, life expectancy at birth will be increased by 0.5 year.

Table 6. Increase in life expectancy (years) in case of reduced $PM_{2.5}$ concentration of outdoor air in various countries to the level of the annual WHO guideline (10 μg/m³) [11].

Country	Increase in life expectancy (years) in case of meeting the WHO limit	Country	Increase in life expectancy (years) in case of meeting the WHO limit
Afghanistan	1.03	Mexico	0.15
Argentina	0.11	North Korea	0.60
Australia	0.00	Oman	0.72
Azerbaijan	0.56	Pakistan	0.99
Bahrain	0.58	Palestine	0.23
Bangladesh	1.33	The Philippines	0.37
Brazil	0.09	Qatar	0.73
Burkina Faso	1.01	Russia	0.16
Canada	0.00	Saudi Arabia	1.08
China	0.76	Singapore	0.35
Egypt	1.27	South Africa	0.42
France	0.03	South Korea	0.24
Germany	0.07	Spain	0.01
Ghana	0.70	Sri Lanka	0.28
India	1.02	Sudan	0.93
Indonesia	0.16	Sweden	0.00
Iran	0.51	Switzerland	0.01
Iraq	0.80	Syria	0.48
Italy	0.08	Turkey	0.45
Japan	0.06	UAE	1.01
Jordan	0.41	UK	0.05
Kenya	0.12	USA	0.01
Kuwait	0.96	Venezuela	0.30
Lebanon	0.33	Vietnam	0.33
Libya	0.64	Yemen	0.85
Malaysia	0.22		

Air quality status in Tehran and its effects on health

Air pollution in metropolises is a major challenge faced by officials in Iran. Tehran, as the largest metropolis in Iran with a population of over 8 million, has long been dealing with unhealthy air. In this section, the results of a study quantifying the effects of air pollution on health in Tehran annually published by the Institute for Environmental Research (IER) of Tehran University of Medical Sciences (TUMS) are presented [12]. Results of this study comprise two main parts: 1) trend of changes in air pollutant concentration, and 2) estimation of air pollution effects on health using the software program offered by WHO entitled AirQ+ v1.3. Quantification of health-related effects of air pollution in Tehran has been performed annually by the IER since 2010. To examine the trend of changes in outdoor air pollutant concentration in Tehran, the raw data of air pollutant concentration were obtained from 21 air quality monitoring stations affiliated with the Tehran Air Quality Control Company from 2006 to 2018 from the company's website. After processing the raw data using valid methods and removal of outliers, the resulting data were analyzed [13, 14].

Trend of changes in outdoor air pollutant concentration in Tehran

Examination of the trend of changes in air pollutant concentration has always served as the most important indicator for evaluating air pollutant reduction policies and programs worldwide. Results of the trend of changes in outdoor SO_2, $PM_{2.5}$, and CO concentration in Tehran are depicted in Figures 7-9. As the concentration of $PM_{2.5}$ in Tehran has been measured since 2011, the values of $PM_{2.5}$ concentration from 2006 to 2011 has been estimated based on the $PM_{10}/PM_{2.5}$ ratio obtained from the data of 2012-2018, i.e. 0.38 [13]. Based on Figure 7, the trend of changes in outdoor air $PM_{2.5}$ concentration in Iran has been decreasing and increasing in the past 12 years. This value had an increasing trend from 2006 to 2011, with the maximum value in the past 12 years observed in 2011 (38 µg/m³). Afterwards, this trend was decreasing until 2015, reaching about 30 µg/m³. Results demonstrate that, in the past two years (2016-2017), the mean annual outdoor air $PM_{2.5}$ concentration in Tehran has increased compared to its corresponding value in 2015. Based on results, the mean annual $PM_{2.5}$ concentration in 2017 (32.9 µg/m³) has increased by 7.5 and 4.5% compared to the values in 2015 and 2016, indicating that policies and programs for reducing air pollution in Tehran have not been completely successful.

Based on WHO guidelines and the national standard, the mean annual level of $PM_{2.5}$ must be below 10 and 12 µg/m³, respectively. However, the mean annual outdoor air $PM_{2.5}$ concentration in Tehran has always been higher than the WHO limit and national standard in the past 12 years; even the 10thpercentile of annual concentration has been higher than these limits, and those residing in Tehran have always been exposed to high levels of PM which is an actual carcinogenic.

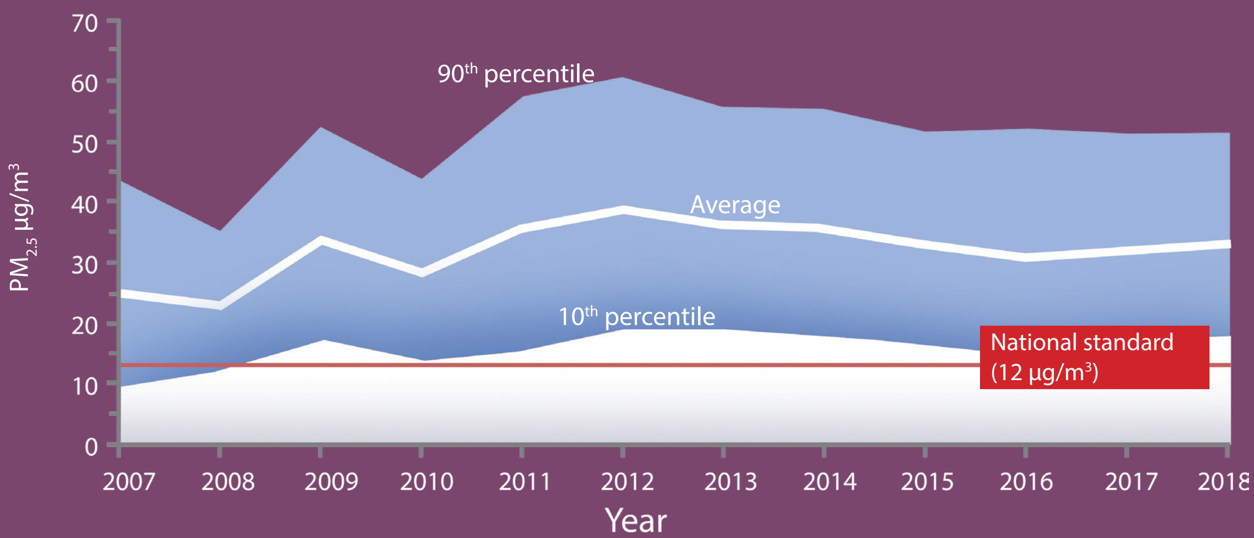


Figure 7.Trend of changes in the annual $PM_{2.5}$ concentration of outdoor air in Tehran from 2006 to 2017 [12].

The trend of changes in outdoor air SO_2 concentration in Tehran in the 12 years end to 2017 is illustrated in Figure 8. Results demonstrate that changes in the annual SO_2 concentration from 2006 to 2017 has had a considerable decreasing trend, except for 2008; this value reached about 7 ppb in 2017 from 64 ppb in 2006 (a 90% reduction). A major reason for this reduction is the reduction in sulfur in the fuel consumed by vehicles. In other words, the decreasing trend of annual outdoor air SO_2 concentration in Tehran points to the success of the program aiming to reduce sulfur in vehicle fuel.

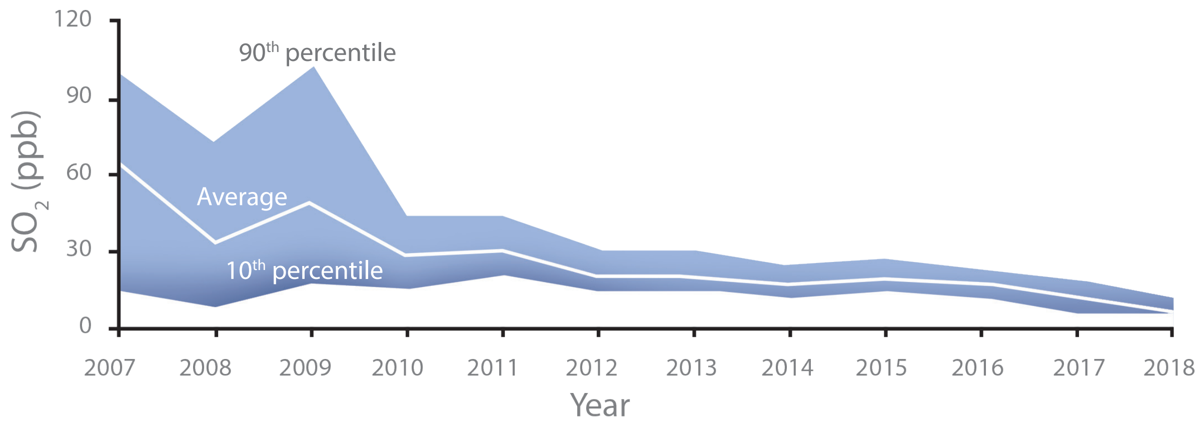


Figure 8.Trend of changes in the annual SO2 concentration of outdoor air in Tehran from 2006 to 2017 [12].

The trend of changes in outdoor air CO concentration in Tehran in the mentioned time period is illustrated in Figure 9. Based on results, the trend of changes of annual CO concentration has been decreasing from 2006 to 2017. This value reached 2.5 ppm in 2017 from 4.5 ppm in 2006 (a 44% reduction). The major cause for this reduction is the conversion of a large number of carbureted into injector cars, thereby limiting CO emission.

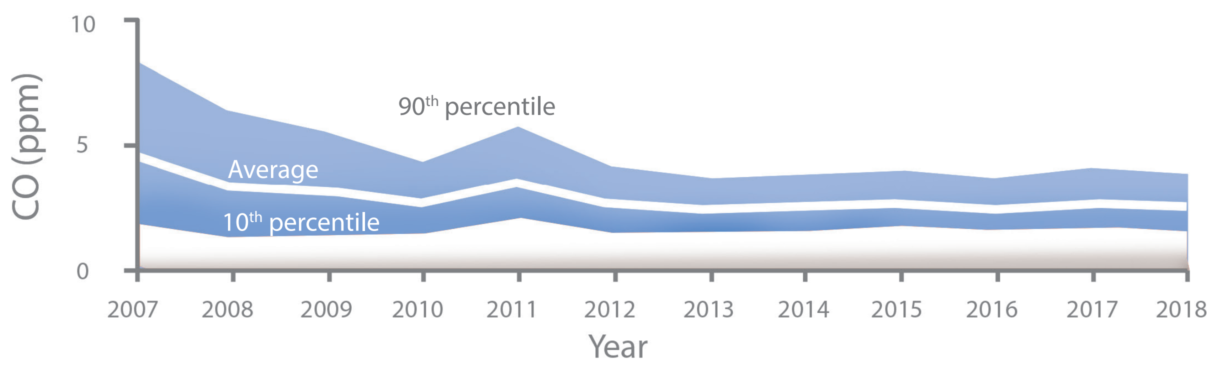


Figure 9.Trend of changes in the annual CO concentration of outdoor air in Tehran from 2006 to 2017 [12].

Trend of changes in air quality index in Tehran over 12 years up to 2018

The managers monitoring air quality in large cities convert the data related to air quality into the air quality index (AQI) and publish the data for the use of the public. Therefore, AQI is a key tool for learning about air quality, health-related effects of air pollution, and protection methods against air pollution. In general, AQI is an index for daily reporting the air quality. This index notifies the public of the air quality and its health-related effects. In other words, AQI discussed the health-related effects resulting from exposure to polluted (unhealthy) air. For ease of interpretation, AQI is classified into six categories of "good", "moderate", "unhealthy for sensitive groups", "unhealthy", "very unhealthy", and "hazardous" [15].

The trend of changes in AQI from 2006 to 2017 in Tehran is given in Figure 8. This figure shows the status of daily AQI in each year based on credible methods of AQI calculation. Results indicate that, from 2011 to 2015, not even one day was classified as "good" (AQI=0-50) in Tehran, but the number of days in which AQI was "moderate" (AQI=51-100) was increased from 2011 to 2015, and in 2015, the number of days with the AQI of "moderate" reached 80, with the rest of the days having an "unhealthy" air quality. In 2017, AQI was "moderate" in only 20 days and "unhealthy" in the remaining 345 days. In other words, in 2017, AQI was "unhealthy for sensitive groups" for 237 days, "unhealthy" for 107 days, and "very unhealthy" for 1 day [12].

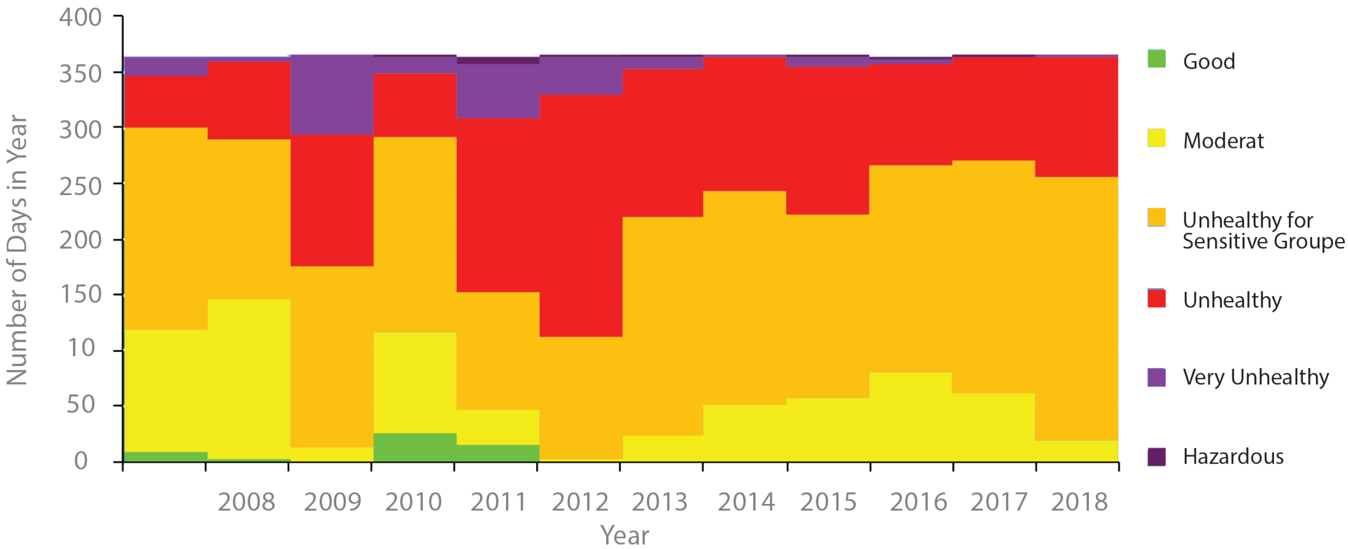


Figure 10. Trend of changes in the daily air quality index in Tehran from 2006 to 2017 [12-13].

Spatial distribution of outdoor air pollutant concentration in Tehran

Figure 9 depicts the Spatial distribution of mean annual outdoor air $PM_{2.5}$ in Tehran in 2017. Based on this figure, mean annual level of this carcinogenic factor has been above the WHO and national limit in all credible stations across Tehran. Results of the place distribution of $PM_{2.5}$ concentration in Tehran show that the minimum values were observed in Districts 2 (Sa'adatabad), 15 (Masoodiyyeh), 8 (Golbarg), 1 (Aghdasiyyeh), and the maximum values were observed in Districts 13 (Piroozi), 11, and in vicinity of Sharif University. In other words, mean annual concentration was twice in Piroozi compared to Sa'adatabad [12].

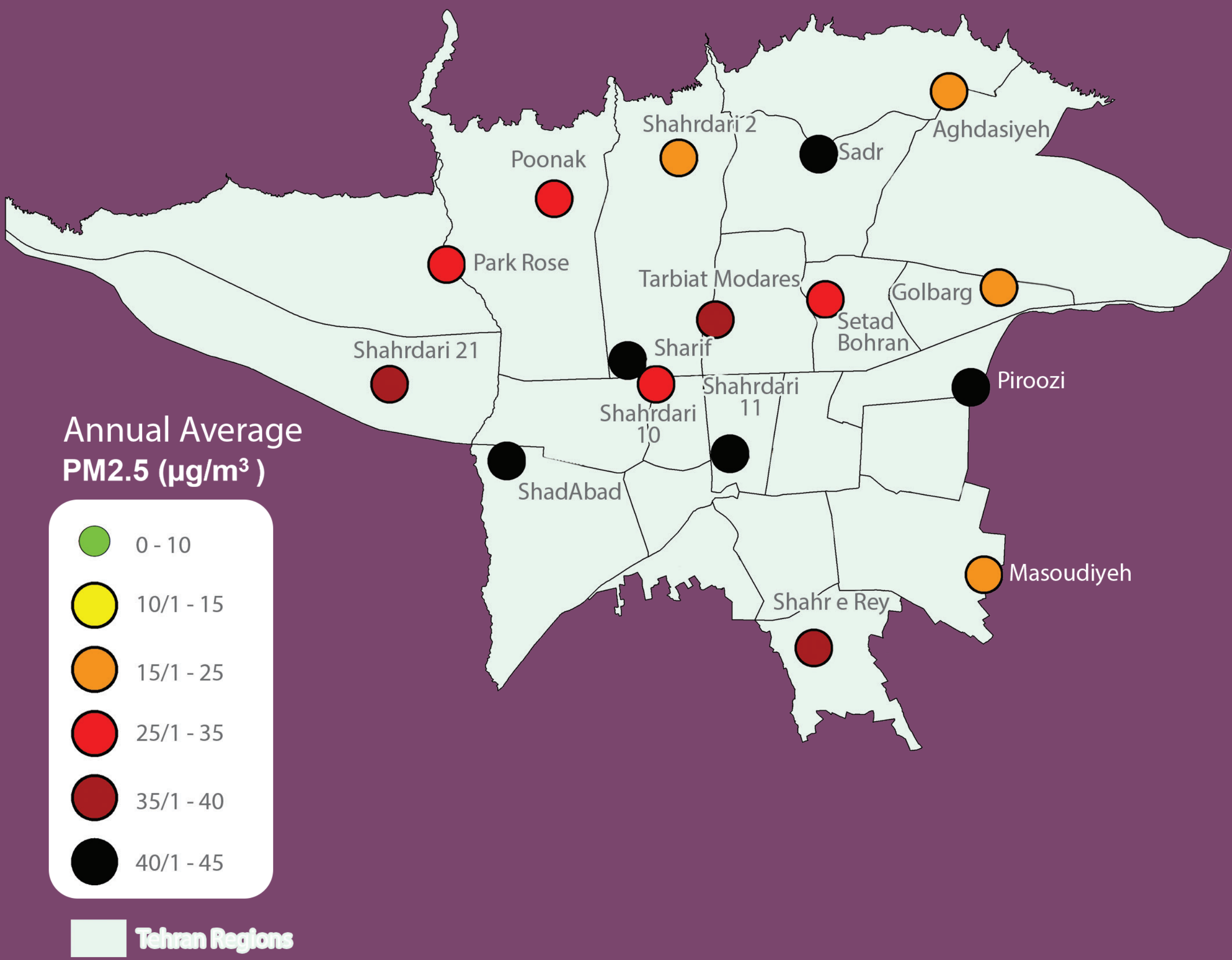


Figure 11. Spatial distribution of the annual mean $PM_{2.5}$ concentration of air quality monitoring stations of Tehran in 2017 [12].

Quantification of the effects of air pollution on health in Tehran

The health-related effects attributed to outdoor air pollutants in Tehran in 2017 were estimated by the Institute for Environmental Research, Tehran University of Medical Sciences using the latest version (1.3) of AirQ+ designed by WHO. Results of this quantification is presented in Table 10.

Based on Table 7, in 2017, the number of deaths attributed to $PM_{2.5}$ in adults (aged above 25 years) in Tehran equaled (95% CI) 3238-6359; if this concentration was reduced to 10 µg/m^3 (WHO guideline), 4878 deaths could be prevented. In other words, about 10 (6-13) percent of all deaths in those aged above 25 years in Tehran are attributed to outdoor air $PM_{2.5}$ in concentrations above 10 µg/m^3. Moreover, results of this study show that the highest number of deaths attributed to air pollution were due to IHD in those aged above 25 years (Figure 10).

Table 7. Health-related effects attributed to air pollution as a result of long-term exposure in Tehran in 2017 by the causes of mortality [12]

Health-related outcome	Age group	Number of deaths		
		Middle limit	Lower limit	Upper limit
Death caused by all factors	≥25 years	4878	3238	6359
Due to COPD	≥25 years	602	330	896
Due to IHD	≥25 years	3002	1542	4528
Due to stroke	≥25 years	595	259	1006
Due to LC	≥25 years	133	78	190
Due to ALRI	<5 years	7	5	9

AirQ+ v1.3 uses the relations presented by IER in order to quantify the effects of air pollution, not the GEMM relations reported in September 2018 for estimating the global effects of air pollution at the national level in different countries. The number of deaths resulting from air pollution estimated by the GEMM method worldwide is much higher than the value estimated by IER relations. Based on this study, the ratio of the number of deaths attributed to outdoor air $PM_{2.5}$ by IER to GEMM equals 0.45 [5]. Thus, it is expected that the number of deaths attributed to outdoor air $PM_{2.5}$ in Tehran be estimated at about 10,000 using the GEMM method, which is equal to 20% of all cases of death in Tehran.

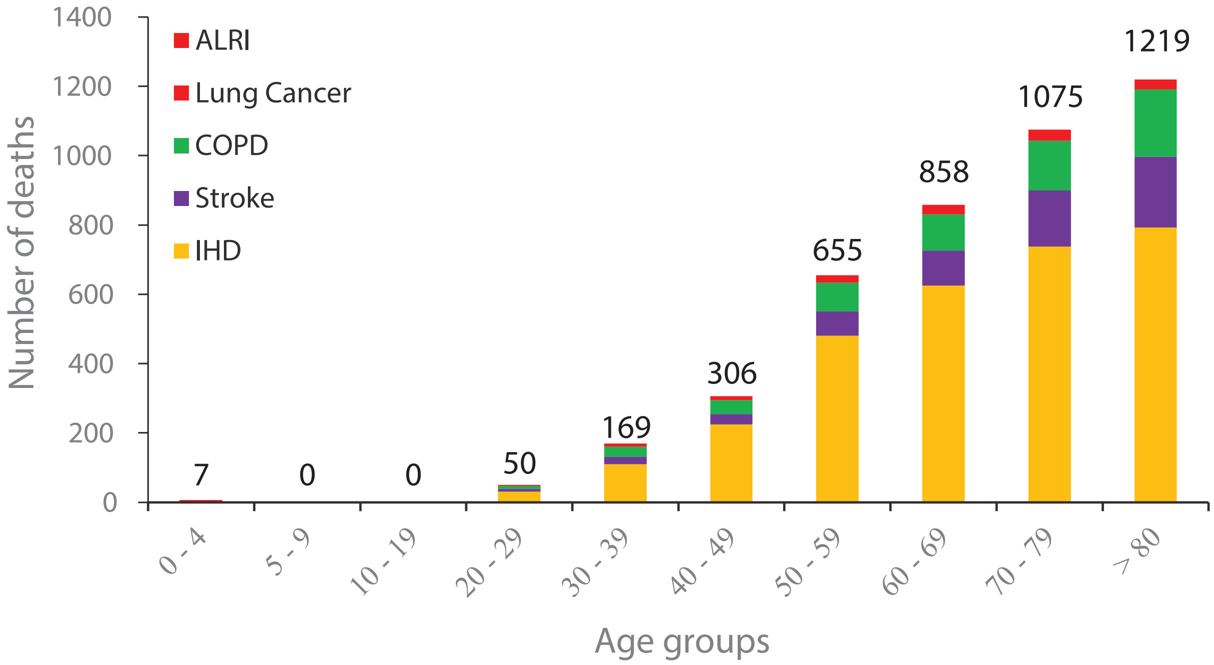
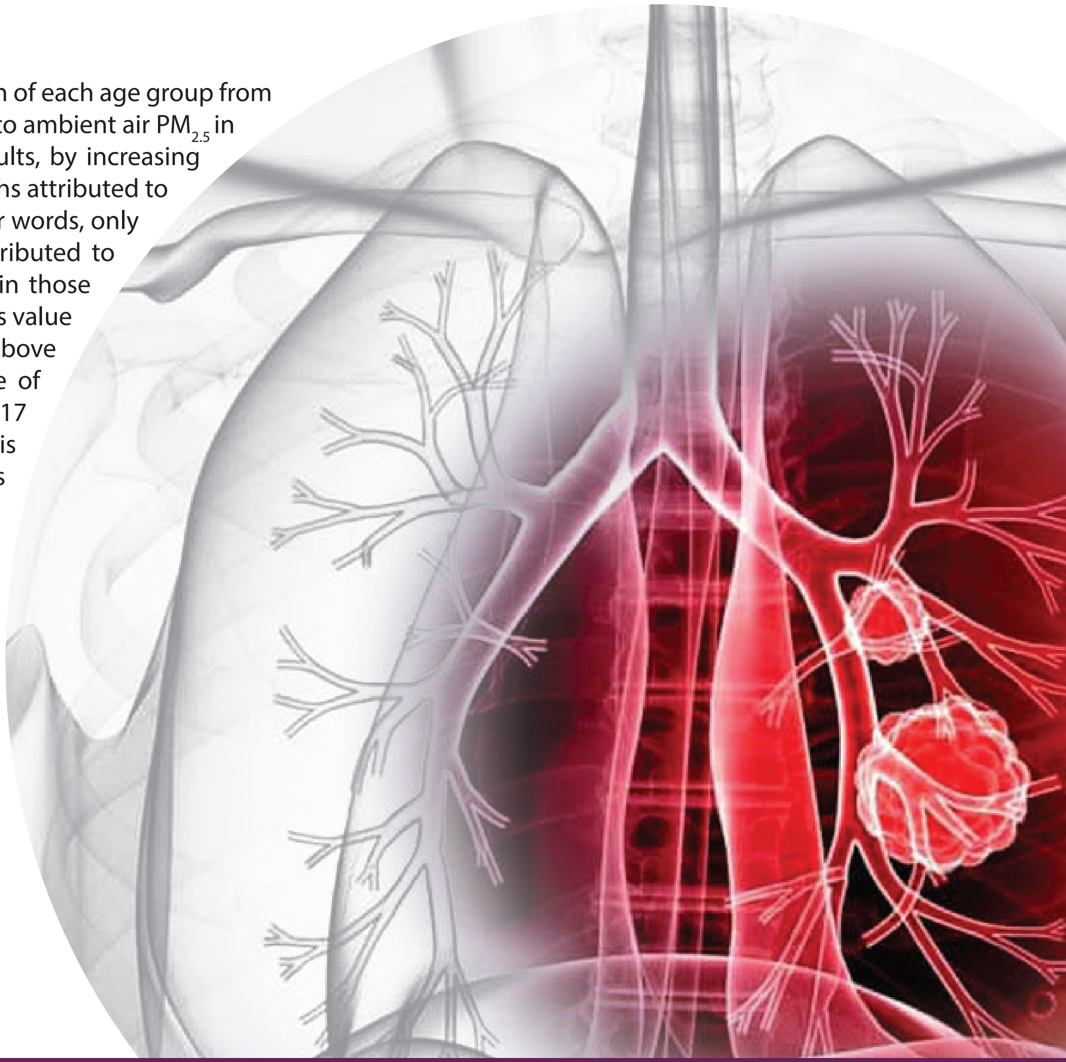


Figure 12. Number of deaths attributed to air pollution in Tehran in 2017 by the causes of mortality and age groups [12].

Figure 11 depicts the portion of each age group from all-cause mortality attributed to ambient air $PM_{2.5}$ in Tehran in 2017. Based on results, by increasing age, the share of cases of deaths attributed to $PM_{2.5}$ is also increased. In other words, only 12% of all cases of death attributed to air pollution in Tehran occur in those aged below 50 years, while this value is about 52% in those aged above 70 years. Moreover, the share of cases of death in Tehran in 2017 attributed to air pollution is 28% in those aged 80 years and above.



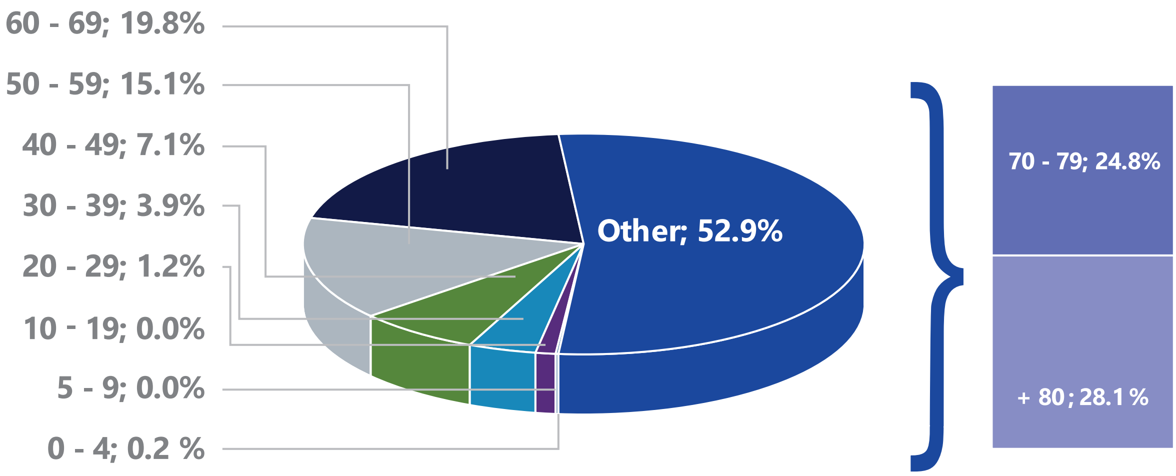


Figure 13. Percentage of deaths attributed to air pollution in Tehran by age groups [12].

Conclusion

Results of air quality and the health-related effects of air pollution in Iran and other countries point to the considerable role of this risk factor in the incidence and burden of NCDs. Also, due to the increase in outdoor air pollutants and, consequently, their effects on health in Iran and many other countries, it is vital to plan and implement scientific and practical programs. If programs based on credible scientific evidence are proposed and implemented, the concentration of air pollutants can be gradually decreased, thereby reducing many NCDs in society and increasing life expectancy and quality of life.

Suggestions

First suggestion

Based on the data presented in this report, air pollution is the 8^{th} risk factor at global level and the 7^{th} in Iran, with the largest number of deaths. Based on the literature, this factor ranks higher in the Middle East compared to the global mean due to dust storms. Maybe it is time that WHO and the Iranian Ministry of Health and Medical Education give serious attention to the control of air pollution as a major risk factor for NCD; besides, suitable measures for air pollution have to be adopted at the global and national level, and the NCD control program of WHO should pay special attention to air pollution.

Second suggestion

Since the Second Development Plan, the Iranian government and the Islamic Consultative Assembly have attempted to decrease air pollution in large and industrial cities with little success. In this nearly 20-year period, numerous programs have been developed and implemented by the government, all of which considering all the theoretical solutions effective in air pollution reduction; in other words, the solutions proposed by these programs were not ranked based on cost-effectiveness. Considering the heavy costs incurred by these programs, the progress made by comprehensive air pollution reduction plans has been limited due to the serious limitations in the country's economic power, with different sectors constantly competing over the budget. Now, based on cost-effectiveness analysis, the economic power of the country must be focused on solutions with maximum effectiveness, instead of focusing on components which might theoretically reduce air pollution. For instance, investment on the development of a healthy public transport system and elimination of old vehicles from this system may be effective. Of course, high-ranking solutions must be selected based on research.

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Appendix 1

Definitions

PM_{10}: Particulate matter in the air with the aerodynamic diameter of 10 µm and less

$PM_{2.5}$: Particulate matter in the air with the aerodynamic diameter of 2.5 µm and less

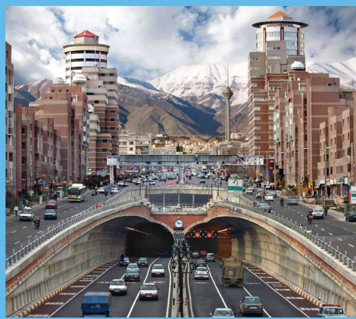
population-weighted $PM_{2.5}$: Mean $PM_{2.5}$ concentration weighted by the population residing in a region

IER (Integrated Exposure-Response): Exposure-response relation used for the estimation of health-related effects of air pollution

GEMM (Global Exposure Mortality Model): Global exposure-mortality model for the estimation of health-related effects of air pollution

Population Attributable Fraction (PAF): Percentage of a health-related outcome which can be prevented if the risk factor is eliminated

Air quality index (AQI): An index for daily reporting the air quality in which the concentrations of pollutants are converted into air quality index to be understood more easily by the public



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