



## **Air Pollution, Its Mortality Risk, and Economic Impacts in Tehran, Iran**

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### **Abstract**

**Background:** Air pollution in Tehran is widely recognized as a serious environmental challenge, posing significant threats to the health of the resident population. Improving air quality will be difficult for many reasons, including climate and topography, heavy dependence on motor vehicles for mobility, and limited resources to reduce polluting emissions. Consequently, it is useful to have information regarding the scale of the health threat and the economic value of reducing that threat.

**Methods:** This paper integrates information on air quality, population, economic valuation, and health science to assess the most serious impact of fine particle pollution on humans, which is increased mortality risk, and provides estimates of the costs of present pollution levels, both in terms of risk and in terms of economic value relative to attaining air quality standards.

**Results:** Mid-range results indicate that mortality risk for the population aged 30 and over would be reduced from 8.2 per 1,000 residents annually to 7.4 per 1,000 and that the estimated annual economic benefits of this reduced risk would be \$378.5 million, if health-based World Health Organization-recommended annual average PM<sub>2.5</sub> standards were met.

**Conclusions:** The potential public health benefits of reducing particulate air pollution are significant, and will increase with growing population.

**Keywords:** Air pollution, Mortality, Iran

### **Introduction**

Tehran is among cities ranked high for severe fine particle air pollution globally, with more than a third of the year characterized by unhealthy air pollution levels. This is partly the result of topography and meteorology, as the city is bound by the Alborz Mountain range to the north, and frequently capped by a thermal inversion that traps the polluted air. However, heavy reliance on motor vehicles for transportation is also part of the problem. It is estimated that vehicular emissions represent from 70 to 85 percent of total particulate emissions in the region (1-3). Considering vehicular emissions of sulfur dioxide and nitrogen oxides that contribute to secondary particulates as well as primary particulates, ambient fine particle concentrations are even more closely correlated with vehicle emissions. Further,

most of the approximately 2 million motor vehicles in Tehran are more than 20 years old and many lack catalytic converters (4, 5).

Over the past decade, the government has taken some actions to address the problem. It has promoted the conversion from gasoline to compressed natural gas engines in taxis and buses, and has tried to raise public awareness about the dangers of air pollution by installing Pollution Indicator Boards throughout the city. Efforts have been made to reduce fuel subsidies and increase the use of public transportation. Still, experts say that it will take several years before the increase in Tehran's pollution can be reversed or even slowed. At the same time, population growth continues to increase the size of the population at risk. In the meantime, these high

pollution levels continue to cause a wide range of adverse health outcomes, ranging from relatively minor effects such as eye irritation and cough, all the way to the most serious effect—premature death.

The central research question that this paper addresses is what benefits could be realized in the greater Tehran area if mortality risk were reduced as a result of attaining air quality standards for fine particle pollution, PM<sub>2.5</sub>. To address this question, air quality data from 14 monitors were used to represent air quality concentrations across the city, and population was mapped to the nearest monitor in order to estimate annual exposure. Concentration-response functions derived from the extensive literature on PM<sub>2.5</sub> levels and mortality risk were then used to estimate the change in risk and the implied reduction in premature deaths. Finally, a Tehran-specific value of mortality risk reduction was used to estimate the economic benefits of attaining health-based annual average PM<sub>2.5</sub> standards.

Tehran is ringed on the north by the Alborz Mountains, which trap pollutants blown across the region by winds blowing predominantly from the west and

south (4). On about 250 days a year there is an inversion layer (6, adding vertical trapping to the effect of the mountains and producing a stagnant mass of pollutants. In short, emissions do not readily disperse, meaning that emissions reductions are the only effective approach to reducing human exposure. The health-based annual average PM<sub>10</sub> standard of 50 µg/m<sup>3</sup> is violated at all of the monitors in the 22 districts of greater Tehran (Table 1). At the highest monitors, concentrations are nearly two times higher than the standard. Monthly averages are generally high in the autumn and low in spring, reaching maximums in September and minimums in late March and early April. Levels also tend to be lower on Fridays, which are holidays (4). Because concentrations of PM<sub>2.5</sub> are more strongly associated with elevated mortality risk, we converted PM<sub>10</sub> levels to PM<sub>2.5</sub> using an outdoor ratio of 0.271 (7). This shows that the United States federal annual average standard for PM<sub>2.5</sub> of 15µg/m<sup>3</sup> is violated at all but one monitoring station, and the more stringent World Health Organization (WHO)-recommended standard of 10µg/m<sup>3</sup> is violated at every station.

**Table 1:** Tehran Population and Pollution Data

District No.	Total Population	Population > 30	Ann. Ave. PM10	Ann. Ave. PM2.5
1*	379,962	179,646	82.82	20.705
2	650,000	307,320	74.44	18.61
3	300,000	141,840	75.30	18.825
4*	663,166	313,545	90.39	22.60
5*	677,085	320,126	72.80	18.20
6*	242,049	114,441	67.69	16.92
7*	308,445	145,833	109.58	27.395
8*	378,725	179,061	83.40	20.85
9	65,000	30,732	64.22	16.055
10*	282,308	133,475	85.70	21.425
11*	280,000	132,384	73.06	18.265
12*	248,048	117,277	97.50	24.375
13	239,686	113,324	89.30	22.325
14	394,478	186,509	89.30	22.325
15*	694,678	328,444	95.12	23.78
16*	332,230	157,078	89.97	22.49
17	256,022	121,047	105.40	26.35
18	250,000	118,200	79.00	19.75
19*	249,786	118,099	89.90	22.475
20	378,445	178,929	58.42	14.605
21	326,000	154,133	64.10	16.025
22*	138,970	65,705	72.66	18.165
Total	7,735,083	3,657,147		

\* = monitor location/Sources: Office of the Mayor, Tehran Municipality, Tehran, Iran (population data); Air Quality Control Company (AQCC), Tehran, Iran (pollution data)

In spite of growth in heavy industry, motor vehicles dominate particulate pollution emissions. Estimates of how much of the emissions inventory is attributable to vehicles varies, although all sources agree they are the majority. Nearly 75% of Tehran's pollution derives from vehicles (1) and mobile sources are 80–85% of the source (2). Vehicles emit 69% of primary particulate emissions (3). There are approximately two million vehicles in Tehran, ranging from bicycles to heavy trucks. Of these, roughly, one million are passenger cars averaging 20 years in age, and more than 600,000 are motorcycles (4). Reducing particulate exposure will of necessity require some combination of reduced vehicle use, cleaner fuels, and cleaner vehicles. Notably, on Friday holidays and during the Nowruz holidays in March when people leave the city and commuting traffic falls, particulate levels also fall. There is also diurnal variation in concentrations, with two daily peaks during prime commute hours on workdays.

Approximately 8 million people live in the greater Tehran area (Table 1). Rapid urbanization over the past several decades has contributed to a significant increase in population and associated emissions. On workdays the population increases by about one million additional people (7), increasing the number exposed to elevated pollution levels. Of the total population, about 3.66 million (or 47.3%) are age 30 or older, the population of interest for increased risk of mortality.

The regulatory framework is somewhat complex. Pursuant to the Clean Air Act passed by parliament in 1995, several organizations are involved in air quality management. While the Department of Environment (DOE) was designated by the Environmental Act of 1973 as the body responsible for reducing air pollution, the Municipality of Tehran is also involved in monitoring air quality and proposing solutions through the Air Quality Control Company (AQCC), which was established in 1993. The DOE and AQCC operate real time monitoring stations. While other organizations, such as the Ministry of Health and the Ministry of Oil, also operate monitoring stations, they are discontinuous. Most of the available monitoring stations in Tehran are roadside stations. One recent activity of AQCC has been to improve coordina-

tion of data collection and to make air quality data more widely available. A 10-year air pollution master plan for Tehran was initiated in 2000, although there has been something of a gap between the plan and implementation (7).

The objective of this research was to estimate the change in mortality risk and the associated economic value that would result from reducing fine-particulate-related mortality if air quality improved from current levels to the U.S. federal and WHO annual average standards.

## Materials and Methods

To quantify the expected changes in premature mortality risks associated with reduced exposure to  $PM_{2.5}$ , we used a variation of the basic exponential concentration-response (C-R) function developed in the U.S. EPA's first comprehensive analysis of the costs and benefits of the Clean Air Act (8), and widely used in benefit assessments since. Specifically, the traditional functional form used is as follows:

$$\Delta H = H_0(e^{\beta \Delta P} - 1)$$

where:  $\Delta H$  = the change in the number of cases (of a particular health outcome);

$H_0$  = the number of baseline cases (of the health outcome);

$\Delta P$  = the change in ambient pollution concentrations; and

$\beta$  = an exponential "slope" factor derived from the health literature pertaining to that specific health outcome.

In most of the recent health literature, "relative risk" (RR) factors are reported, which relate change in pollution levels to the increased odds of developing various health effects. These risk factors are related to the  $\beta$  in the EPA concentration-response function in the following manner:  $\beta = (1 + \text{Increased Odds}) / (\text{Change in Pollution})$ .

Since we estimated and valued the *change in risk* of premature mortality, and not the total number of averted premature deaths, the basic C-R function was modified slightly. The  $H_0$  term—number of baseline cases—is typically calculated as the death rate multiplied by total population. Here, therefore, by simply dividing both sides of the equation

by the baseline population, we converted the C-R function as follows:

$\Delta\text{Death Rate} = \text{Baseline Death Rate} (e^{\beta\Delta P} - 1)$ , where  $\beta$  and  $\Delta P$  are defined as above. In the next section, we describe the specific health studies used to develop our mortality  $\beta$  values.

The scientific literature that assesses associations between  $\text{PM}_{2.5}$  and premature mortality in adults has expanded rapidly over the past 15 years, with significant implications for benefits assessment (9). Several large-scale multi-city studies extended or reanalyzed earlier studies (10-14) as well as a California-specific study that focused on the Los Angeles basin (15). To estimate  $\text{PM}_{2.5}$ -related mortality for a developing region such as Tehran requires determining which of these studies is most appropriate for conditions in the region. In general, studies are preferred that are peer reviewed, cover longer periods, are more recent, include larger samples, account for confounding, and were conducted in locations that have the greatest similarity to the study population. Following the professional consensus, and based on the reasons further discussed below, we relied on a combination of several studies to estimate our adult mortality effects for Tehran.

One study (13) meets all of the essential criteria noted above for the choice of a C-R function. A large-scale, longitudinal cohort study follows a large nationally representative population (ages 30 and older) across 61 American cities over a 16-year follow-up period from a base of 1979-1983. Extending the follow-up period to 16 years increases the mortality data set by a factor of three compared to earlier studies. Based on this cohort study, the increase for all-cause mortality associated with annual average  $\text{PM}_{2.5}$  is 6% per  $10\mu\text{g}/\text{m}^3$ . We note that a recent report for the WHO (16) on the global analysis of outdoor air pollution-generated health effects also bases its primary health risk estimates on this study.

Another study (15) is based on the Los Angeles area population subset from the national cohort. The authors found a substantially higher association between  $\text{PM}_{2.5}$  and mortality, with a 17% increase in all-cause mortality for every  $10\mu\text{g}/\text{m}^3$  increase in the pollutant. While this is quite a large difference, contrasted with the 6% increase found

in the national study, there are sound reasons to conclude that the results may better represent the Tehran population. One reason is that the authors used a detailed intra-urban exposure measure supported by 23  $\text{PM}_{2.5}$  monitors across the region, in contrast with the national cohort studies that compare inter-urban exposure and have much less spatial resolution. Another is that in the Jerrett study traffic-generated primary particles have a greater association with observed effects, and traffic in the Tehran area accounts for a large portion of particulate emissions, as noted earlier.

Research in this area has expanded considerably over the past two decades, strengthening scientific confidence that the effect of fine particulate exposure on mortality is "real," and at the same time exploring the risk factors that vary significantly from study to study. In 2006, the U.S. EPA sponsored an expert elicitation as part of the process of determining what risk factor should be used in risk assessments conducted to inform policy decisions. Twelve experts provided responses, with a significant majority choosing a relative risk factor at or above 1.10. None recommended a value lower than 1.06 (17, 18).

Given the differing strengths of the primary underlying health studies, and the conclusions from the expert elicitation, for our mid-range (base) case we used a weighted average of  $\text{RR}=1.06$  and  $\text{RR}=1.17$ . We assigned greater weight (two-thirds) to the lower risk because of the national scope of the underlying study, resulting in a relative risk factor of 1.10 and a C-R  $\beta$  of 0.009531. We also included a low estimate, based solely on the Pope et al. study (10), generating a  $\beta$  value of 0.005827. Then, based on the similarities between the Los Angeles and Tehran areas, we also calculated an alternative, high estimate, based on the higher relative risk. This results in a C-R  $\beta$  value of 0.0157. (We note that this value is reasonably close to the pollution/health factor implied by a recent Iranian health assessment. (2). finally, to calculate the pollution-related changes in risk of death, we used a city-specific, 30 years and older, death rate of 8.206 per 1,000. This was estimated by adjusting Iran's overall death rate for the age cohort considered and for the Tehran area itself, where life expectancy exceeds the national average slightly (19).

For the purposes of this research, we were interested in how best to value relatively small changes in mortality risk. However, if we can estimate how much mortality risk might be reduced as a result of meeting the health-based air quality standards, thereby reducing some number of premature deaths, why estimate monetary values at all? The social choice to control pollution sources in order to improve air quality and health is a high priority in many heavily polluted cities, but resources are limited. A sense in economic terms of the scale of gains from successfully implementing pollution control policies and programs thus provides useful perspective.

The basis for valuation of environmental improvements begins with the premise that, within limits, society accepts individual choices as valid, and as reflecting the actual value that individuals place on their choices. Social value—the information important to policy-makers—is then simply the sum of value to individuals. For the purposes of this research, we need to know the value to individuals in Tehran of reducing fine particle-related mortality risk to the resident population.

One means to estimate value involves the use of surveys. This method is referred to as contingent valuation (CV) because people are asked to determine what something would be worth to them as if they were able to purchase or sell it. CV has become a significant source of values over the past two decades, as the methodology has matured and become more accepted, and as policy-makers has become more reliant on economic valuation in decision-making. The survey approach is expensive to administer and the validity of values derived from this method depends on careful design and application of the survey instrument. Nonetheless, CV measures are in many cases well supported and add useful information to benefits assessment (20). When available, CV results for willingness to pay (WTP) are generally viewed, based on appropriateness and validity, as the preferred measure of the value of environmental improvements.

Premature mortality is the most significant effect of exposure to unhealthful levels of air pollution that can presently be quantified. Consequently, determining a socially appropriate value to attach

to reducing the risk of premature mortality is a crucial part of any benefit assessment. It is very important to keep in mind that we are not valuing the life of any identifiable individual, but rather the value of reducing a very small risk over a large population enough so that some people would live longer than would otherwise have been the case.

To assess the value to society of reducing the risk of premature death associated with elevated levels of air pollution, we want a value that is based on risk of a similar scale (in this case, a very small annual risk) and is based on the preferences of people similar to the population at risk from pollution exposure. The need therefore arises to match the degree of risk and population characteristics as closely as possible to factors such as age and income. Ideally, we use values derived from the population in the region of interest.

In the case of greater Tehran, a CV study recently estimated monetary values for the avoidance of certain health symptoms (2). Specifically, a survey instrument was developed to obtain WTP estimates for eight commonly occurring symptoms (including cough, shortness of breath, headache, sore throat, and eye irritation), but more importantly, the survey also estimated a monetary value of individual WTP to reduce the probability of dying prematurely. Specifically, the current death rate in Iran was given to the survey respondents. They were then asked their willingness to pay to have the death rate decrease by one in one thousand.

Overall, nearly 3,000 surveys were completed from residents of Tehran. Based on these surveys, the mean bid for a one in 1,000 reduction in the probability of dying prematurely is 350,720 Rials. We converted this 2002 value to U.S. dollars, using a 2002 implied Purchasing Power Parity (PPP)-based exchange rate (2,000 Rials = \$1 US) and update to 2010, using an Iranian inflation factor of 2.966, both obtained from the International Monetary Fund (21,22). Our estimate of the annual value of a 1/1,000 reduction in the probability of premature mortality for each individual in the exposed population is thus \$520.12.

## **Results**

By applying the epidemiological (C-R) functions to pollution and population levels for the 22 districts of Tehran, we were able to quantify the expected reduction in risk of mortality (as well as the expected number of statistical lives saved) from standard attainment. We report results for the two levels of annual PM<sub>2.5</sub> standards previously described: 15µg/m<sup>3</sup> and 10µg/m<sup>3</sup>. Table 2 reports both the decrease in mortality risk and the estimated number of averted deaths attributable to meeting the air quality standards, for each of our six cases. Starting with a baseline mortality risk of 8.206 per 1,000, the expected reduction in risk ranges from 0.269 to 1.264 per 1,000, which also translates into between 984 and 4,622 premature deaths averted. Our mid-range case, based on the weighted average of health studies, generated mortality risk reductions of 0.794 per 1,000 (from 8.206 down to 7.412) for the 10µg/m<sup>3</sup> standard and 0.434 per 1,000 (from 8.206 down to 7.772) for the less stringent 15µg/m<sup>3</sup> standard. These risk reductions correspond to the avoidance of 2,905 and 1,588 premature deaths, respectively.

**Table 2:** Mortality Risk Reduction from Meeting Air Quality Standards in Tehran

	Low β	Mid β	High β
<b>Standard = 10µg/m<sup>3</sup></b>			
Decrease in mortality risk	0.496	0.794	1.264
Averted deaths	1,814	2,905	4,622
<b>Standard = 15µg/m<sup>3</sup></b>			
Decrease in mortality risk	0.269	0.434	0.699
Averted deaths	984	1,588	2,558

Applying our estimated WTP for mortality risk of \$520.12 to these risk reductions generated an overall annual economic benefit in a range between \$511.7 million and \$2.404 billion (Table 3). For the mid-range case, we projected overall benefits of \$1.51 billion and \$0.83 billion, for the 10µg/m<sup>3</sup> and 15µg/m<sup>3</sup> standards, respectively. To put all of these dollar figures into perspective, we note that they represent between 0.35% and 1.63% of estimated Tehran GDP (22). The two mid-range benefit figures are 1.025% and 0.56% of Tehran’s estimated GDP.

**Table 3:** WTP for Mortality Risk Reduction from Meeting Air Quality Standards in Tehran (millions of US \$)

	Low β	Mid β	High β
<b>Standard= 10µg/m<sup>3</sup></b>			
Total Benefits	\$ 943.47 (0.64%)	\$ 1,510.3 (1.025%)	\$ 2,404.3 (1.63%)
<b>Standard= 15µg/m<sup>3</sup></b>			
Total Benefits	\$ 511.7 (0.35%)	\$ 825.5 (0.56%)	\$ 1,330.0 (0.90%)

\*Numbers in parentheses denote % of Tehran GDP

Table 4 shows that on a city-wide average basis, these annual benefits range from \$139.91 (1.32% of GDP per capita) to \$657.43 (6.20% of GDP per capita), with a mid-range value of \$225.73 (2.13% of GDP per capita) for the 15 µg/m<sup>3</sup> standard case.

**Table 4:** Per Capita Mortality Risk Reduction Benefits of Meeting Air Quality Standards in Tehran (US \$)

	Low β	Mid β	High β
<b>Standard = 10µg/m<sup>3</sup></b>			
Per Capita Benefits	\$ 257.98 (2.43%)	\$ 412.98 (3.90%)	\$ 657.43 (6.20%)
<b>Standard = 15µg/m<sup>3</sup></b>			
Per Capita Benefits	\$ 139.91 (1.32%)	\$ 225.73 (2.13%)	\$ 363.56 (3.43%)

\*Numbers in parentheses denote % of Tehran GDP per capita

While we report results for mortality risk reductions based on three separate C-R functions, we note that the highest risk is likely a better fit for Tehran than for urban centers where pollution levels are not as strongly dominated by vehicular emissions because of the way that study measures exposure nearer roadways and the fact that most air quality monitors in Tehran are also along roads. That is, while the higher relative risk factor might over-represent exposure in regions where vehicles are not such major contributors to fine particles,

or where fewer people live near major arterials, it is less likely to do so in Tehran. The resulting benefit estimates thus expand to \$2.404 billion (1.63% of city GDP) and \$1.33 billion (0.90% of city GDP) for the 10 and 15 $\mu\text{g}/\text{m}^3$  standards. Corresponding per capita figures are \$657.43 (10 $\mu\text{g}/\text{m}^3$  standard) and \$363.56 (15 $\mu\text{g}/\text{m}^3$  standard), which represent 6.20% and 3.43% of per capita GDP. Clearly, failure to attain health-based air quality standards poses a significant threat to public health in the Tehran region, as demonstrated by this assessment of the pollution-induced changes to mortality risk.

## Discussion

Elevated concentrations of fine particulates are widely recognized to pose a significant public health risk to exposed populations. Thus, given the size of the population in and around Tehran, and the degree to which health-based air quality standards are exceeded, the potential public health benefits of reducing particulate pollution are significant. The results presented here demonstrate both a reduction in mortality risk of 0.794 and significant economic value from reducing this risk. Policies to reduce the collective risk and implementation of policies such as, for example, options delineated in the ten-year plan, would produce public health gains by either measure. This will also likely require greater cooperation among disparate agencies of government, both for information sharing and policy coordination. Of course, information on the value of environmental improvements in developing regions is still rather limited. Further investment in monitoring air quality and in contingent valuation studies is likely to yield useful policy-relevant information.

We close with several observations. First, since we focused solely on particulate pollution, our estimates are conservative. Recorded levels of many other pollutants in Tehran known to be strongly associated with a variety of adverse health effects, including sulfur dioxide, ozone, and nitrogen dioxide, are well above health-based standards. Second, our focus on premature mortality ignored a number of other fine particle consequences (and thus the resulting benefits of cleaner air). These omissions include non-fatal, pollution-related

morbidity health benefits—hospital admissions, days of restricted activity, and lost days of work and school. They also include an array of non-health, pollution-related benefits, such as reductions in damage to materials, agriculture, and ecosystems, and improvements in visibility. Finally, we note that with Tehran's air pollution and population projected to increase over the next few years, the resulting health damage will also increase. This suggests that even the realizable particulate-related mortality health benefits from successful air pollution control may be larger than those presented here.

## Ethical considerations

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

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