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Research Article

Investigation of air pollution and health effects as per dose-response functions and prioritizing responsibility of pollutants based on Multi-Criteria Decision Making computations: A case study

Mohammad Gheibi[1]*, Benyamin chahkandi[2], Zahra Kian[3], Amir Takhtravan[4] and Reza Aghlmand[1]

[1]Department of Civil Engineering, Ferdowsi University of Mashhad, Iran

[2]Department of Civil Engineering, University of Tehran, Iran

[3]Department of Chemical Engineering, Amir Kabir University of Technology, Tehran, Iran

[4]Department of Civil Engineering, Brigand University of Technology, Brigand, Iran

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***Corresponding author:** Mohammad Gheibi, Research Associate, Department of Civil Engineering, Ferdowsi University of Mashhad, Iran, Tel: +989152198721; Fax:+985137110979;
E-mail: Mohammadgheibi@ymail.com

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ORCID: https://orcid.org/0000-0003-1987-5790

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Abstract

With the growth of industrialization and urbanization in megacities, some emerging disasters occur such as air pollution mortality, increasing cancer risks, decreasing life expectancy, descending prosperity, and Human Development Indexes (HDI). In addition, with the raising population of cities, the quantity and quality of air pollutions are increased based on vehicle application rate, industrial activities, agricultural efforts and etc. In this research, with the application of Dose-Response Functions in air pollution, some parameters such as chronic disease-based mortality, life expectancy reduction based on chronic and acute effects, and ozone gas health risks are computed in a case study of Mashhad city, Iran. The outcomes have illustrated the life expectancy is reduced in a case study around 8.22 and 8.51 years for men and women, respectively. Plus, the results of statistical health scrutinizing have demonstrated that the mortality of chronic effects based on air pollution emissions is calculated around 20 percentages in the case study. Likewise, with the application of two different methods in Multi-Criteria Decision Making (MCDM) containing Analytic Hierarchy Process (AHP) and ELimination Et Choice Translating Reality (ELECTRE) the responsibility of each pollution is determined. As per the mentioned computations, Particle Matter 2.5 ($PM_{2.5}$) has the most role in increasing the health risk of air pollution in Mashhad City, Iran.

Introduction

Nowadays air pollution is one of the adverse aspects of industrialization and technological advances in cities which is indeed intensified by the growing demand for manufacturing processes in the last several decades [1]. The occurrence of air pollution in densely populated urban areas has been associated with tragic events in the second half of the 20th century in the United States and Europe. The results of time studies in the early 1990s in different parts of the world have shown that even in areas with a low concentration of pollution, the attributed load of diseases to air pollution is very high due to the large coverage of at-risk population and the sensitivity of certain groups of society [2].

A historical review of the injuries and damages caused by air pollution in different cities of the world shows that a rise in pollution can lead to irreparable disasters. Some of the

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mentioned catastrophes are 1. The Meuse Valley of Belgium disaster in 1930 caused by a temperature inversion and SO_2 high concentration resulted in 60 death [3]. 2. London incident in 1952 caused by temperature inversion and accumulation of pollutants which led to 4000 death [4]. 3. Smog phenomena in 2008, Ontario which led to 9500 premature death a year [5]. 4. accumulation of pollutants in 2014 Delhi, caused by a high $PM_{2.5}$ concentration which led to 10500 at-risk premature death [6]. Also, in 2005, an air pollution risk survey in Tehran showed that 1600 people were experiencing severe coughs and other tough signs of illnesses [7]. Such calamities indicate that there is a direct relation between air pollution and casualties [8] Figure 1.

Studies have assessed air pollution impacts on both human and animal health which human section consists of experimental and epidemiological investigations to represent chronic and acute diseases. In a research in 2003 buffalo, the number of death caused by fine particulate matters on a 2-year period and 4 levels of particulate matters was analyzed [10]. In 2013 the impact of pollutants on human health originated from vehicles were analyzed by using dose-response functions, results prioritized the impacts of pollution on human health and, showed that relying on cost-benefit methods in assessing transportation projects would result in neglecting critical impacts [11]. Health Effects Institute (HEI) of Boston in 2013 investigated the influence of air pollution on the reduction of life expectancy and the related number of death in China, which showed 1.2 million early death each year [12]. In 2014 decrease in life expectancy in the USA between 2000 and 2007 was measured by using the regression method and the results showed that $PM_{2.5}$ is the most responsible pollutant for this reduction [13]. Also, in 2015 a survey using field measurement and remote sensing was conducted to assess the amount of decrease in life expectancy and the responsible pollutant in India [14]. Later on, World Health Organization (WHO) analyzed the most 13 polluted cities in India focusing on $PM_{2.5}$ which pointed out that the most reduction of life expectancy is in Delhi with the highest concentration of $PM_{2.5}$. Also in 2015 WHO reported the average amount of $PM_{2.5}$ in the most polluted cities of India, China, Europe, and America which were 46, 40.4, 21.7, and 9.6 µg/m³ respectively [14]. In 2017 an open cohort in the USA using a two-pollutant model of $PM_{2.5}$ and O_3 was conducted and measured the risk of death, associated with the increase of exposure to those pollutants, results showed that all-cause mortalities raised by 7.3% for $PM_{2.5}$ and 1.1% for O_3 [15]. In 2018 the impact of temperature inversion associated with air pollution on human health was explored in Hanoi, Vietnam by collecting data from monitoring centers in the region showing levels of NO_2, SO_2, PM_{10}, and $PM_{2.5}$ and came to the conclusion that acute respiratory and cardiovascular diseases were significantly increased during inversion periods [16]. In 2019 the association of $PM_{2.5}$ and PM_{10} with all-cause diseases among 652 cities in 24 countries was investigated and showed that on average an increase of PM_{10} concentrations by 10 µg/m³ in a 2-day average will result in a higher percentage of daily mortality of some diseases like all-cause, cardiovascular and respiratory by 0.44%, 0.36%, and 0.47% respectively, the same scenario occurred for $PM_{2.5}$ by 0.68%, 0.55% and 0.74% respectively [17]. Again in 2019, the effect of air pollution on human health was analyzed in China by comparing China Dynamic Survey to air pollution data which indicated that an increase in air pollution concentration considerably reduced citizen's health levels [18].

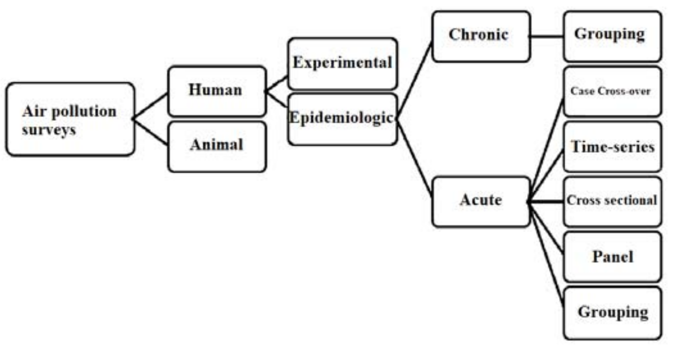

Figure 1: Designs used to investigate air pollution illnesses [9].

Materials and Methods

In the present study, via analytical methods such as dose-response functions, the impact of air pollution on both pathogens and human health has been investigated in a large city of Iran, Mashhad. The steps are described below.

Creating a database

There are 12 air pollution monitoring centers in Mashhad that monitor, measure, and index 5 kinds of pollutants including CO, NO_2, O_3, $PM_{2.5}$, and SO_2 (Figure 2). since there are usually consequent fouls in monitoring equipment, one of the most important matters in collecting and analyzing the measured data is to implement expert methods and engineering judgment according to UNEP criteria [19] in order to modify them. In fact, engineering judgment means amending some data which are not logical. They could easily be recognized and corrected by the experts who are operating monitoring equipment. Hence, collected data were evaluated by brainstorming method twice and those that could not pass UNEP criteria were removed for the next phases.

Brainstorming is a method for decision-making in a group to generate plenty of ideas about any issue which was first improvised in 1942 by Alex Faickney Osborn. The UNEP criteria are availability, validity, amount, range, and comprehensiveness of data. The data used in this research are for the year 2014 with the least possible errors.

Data processing using dose-response functions

Applied studies on dose-response functions provide results based on the concentration of air pollutants and human health. 4 factors are considered in this research, as follows.

Adult mortality (chronic diseases)

In a research in 2014, two different rates presented for the risk of $PM_{2.5}$ per 10 µg.m⁻³ which are 1.04 and 1.06 [20]. Regarding some recent studies [21,22], in the present study,

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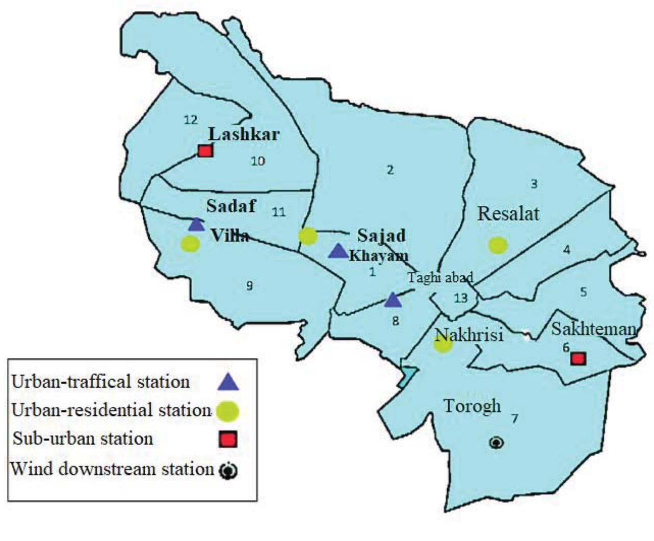

Figure 2: Dispersion map of air pollution monitoring stations in Mashhad.

the average amount of the mentioned figures was considered as 1.05 and the Relative Risk (RR) is defined as follows

$$RR = 1.05 \; for \; 10 \; \mu g \; PM_{2.5} \qquad (1)$$

Decreased life expectancy due to chronic diseases

Researches conducted by the EU on the evaluation of the life expectancy index due to chronic diseases are described in equations number 2 and 3 [23], which are the basis of calculations in the present research.

$$for(PM_{10}, NO_x): \begin{cases} LLE_{max} = 4\times10^{-6}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times(Max[PM_{10}]+Max[NO_x]) \\ LLE_{min} = 4\times10^{-6}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times(Min[PM_{10}]+Min[NO_x]) \end{cases} \qquad (2)$$

$$for(PM_{2.5}, SO_x): \begin{cases} LLE_{max} = 6.7\times10^{-4}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times(Max[PM_{2.5}]+Max[SO_x]) \\ LLE_{min} = 6.7\times10^{-4}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times(Min[PM_{2.5}]+Min[SO_x]) \end{cases} \qquad (3)$$

Which LLE_{max} and LLE_{min} are the maximum and minimum reduction of life expectancy per person per year respectively, and YOLL is the decline in life expectancy (years) due to chronic diseases. Base on the model presented by the EU, equ.2 is recommended as the slope of the dose-response diagram of PM_{10} and NO_x and equ.3 for $PM_{2.5}$ and SO_x. To evaluate the main equation, the superposition method has been used. in other words, a decline in life expectancy is derived from all SO_2, NO_2, $PM_{2.5}$, and PM_{10} impacts on people's health, because each of these 4 pollutants affects the environment at the same time.

Decreased life expectancy due to acute diseases

Based on some researches conducted in 2005 [24] equations 4 and 5 were inferred to determine decreased life expectancy due to acute diseases, both of which have an upper (LLE_{max}) and a lower bound. Final results have been achieved by using superpositioning between the amount of $PM_{2.5}$, PM_{10}, and constant values in equations which showed that the decrease in life expectancy due to acute illnesses is much lower than chronic ones.

$$for(PM_{10}): \begin{cases} LLE_{max} = 3\times10^{-6}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times Max[PM_{10}] \\ LLE_{min} = 3\times10^{-6}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times Min[PM_{10}] \end{cases} \qquad (4)$$

$$for(PM_{2.5}): \begin{cases} LLE_{max} = 4\times10^{-6}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times Max[PM_{2.5}] \\ LLE_{min} = 4\times10^{-6}\left(\dfrac{YOLL}{Person.year.\dfrac{\mu g}{m^3}}\right)\times Min[PM_{2.5}] \end{cases} \qquad (5)$$

Diseases caused by ozone emission

Surveys have shown that with each 10 $\mu g.m^{-3}$ increase of ozone concentration in the air, the relative risk of adult mortality rises by 0.3% [25] also, hospital admission of chronic respiratory diseases (older than 65 years) will grow by 12.5 people per 100,000 [26]. The present research has analyzed some mortality parameters related to ozone emission including intense and quick contact, hospital admission of respiratory diseases, low limitation of daily activity, and using bronchodilators [27].

Prioritizing main pollutants

One of the important goals in monitoring and analyzing air pollution in large cities is determining main air pollutants as the dominant influential factor. This comparison in one year period has created a management perspective that can help to allocate the needed budget and time to treat air pollution. Therefore, according to Table 1, AHP (Analytic Hierarchy Process) and ELECTERE (Elimination and Choice Translating Reality) methods have been implemented to reach maximum approval among all comparisons and prioritizations. It is necessary to say that in judging between different options, comparative parameters, such as intensity of concentration during the year, stability of pollutants (production fluctuations), the variance of pollutant concentrations from the standard amount, distribution pattern in all monitoring centers, and the portion of pollutant responsibility in a year are well-considered.

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Results and discussions

All results according to utilizing dose-response functions in Mashhad are completely discussed below.

Adult mortality

As mentioned in the last sections some data collected in monitoring stations are amended because of and equipment errors based on expert's ideas this data for $PM_{2.5}$ is provided in Table 2 equation.1 tells that per 10 $\mu g.m^{-3}$ increase in $PM_{2.5}$ concentration adult casualties rise by 5 percent. Statistical analysis shows that $PM_{2.5}$ concentration is the highest at Torogh station and the lowest at Mashin Abzar station averagely (annually) with the amount of 41.71 and 17.08 $\mu g.m^{-3}$ respectively. Calculations show that adult mortality due to chronic diseases for Mashhad in comparison with cities without pollution rises by 20.85% at the maximum rate and by 8.54% at the minimum rate. Since the average concentration of $PM_{2.5}$ is 27.6 $\mu g.m^{-3}$ it can be concluded that 13.8% of people in Mashhad on average are at risk of death due to chronic diseases.

In the last two decades, we have witnessed the expansion of the city and the growth of industries around Tehran; the capital city of Iran, according to the annual government report adult mortality due to chronic disease was calculated by 19.02% in 2011. Similarly, the average number of death due to chronic diseases reported in India and China is 20.2% and 23% respectively which means these two countries have a more critical situation than Iran cities. The mortality rate due to chronic diseases in Europe and the United States of America has also been reported by 10.85% and 4.8% respectively which represents a better condition. It should be noted that these calculations are based on an annual average which shows a higher risk and a more critical situation than longer periods. All of the above refers to chronic diseases.

The state of life expectancy according to chronic diseases

Based on the dose-response diagram slope which was previously noted in equations 2 and 3 life expectancy reduces by 6.7×10^{-4} units of $PM_{2.5}$ and SO_2 concentration and reduces by 4×10^{-4} units per each µg increase of NO_2 and PM_{10} concentration. Reported results of PM_{10} concentration have not been confirmed by authentication tests due to large errors in the measurement process. The minimum and maximum amount of $PM_{2.5}$, NO_2, and SO_2 concentration and their influence on the reduction of life expectancy in 2014 have been described in Table 3.

Results show that the appearance of chronic diseases caused by the existing $PM_{2.5}$, NO_2, and SO_2 in the environment decreases life expectancy by 11.39% at maximum and 3.49% at minimum rate.

Based on the 2011 census in Iran, life expectancy has been reported 72.1 years and 74.6 years for men and women respectively. Therefore, according to the described data in 2014 (supposing that the amount of air pollution has been constant for every individual life span and the same as 2014), air pollution has declined the life expectancy by 8.36% at maximum and 2.65% at minimum rate. Similarly, surveys in Tehran, showed that air pollution has reduced life expectancy due to chronic diseases by 27.8 at maximum and 5 years at the minimum in 2013 [28]. Decreased life expectancy data due to chronic diseases in the present research has been compared to others in Table 4.

The state life expectancy according to acute diseases

Researches in 2005, show that acute diseases are mostly caused by PM_{10} and $PM_{2.5}$ [29] and since PM_{10} results were not reliable, decreased life expectancy due to acute diseases in the current research has just been analyzed based on equ.3 and 4 under the effect of $PM_{2.5}$. calculations show that this kind of decreased life expectancy has been occurred by the maximum rate of 0.0175% and the minimum rate of 0.00717% which means the maximum reduction of life expectancy is 0.012 years or 4.38 days. Reviews clear the point that reduction of life expectancy due to acute diseases in comparison with chronic ones is very low which is almost predictable as the small ratio of slope in dose-response diagram of acute diseases in comparison with chronic ones.

The state of diseases caused by ozone emission

Based on validated data in the pollutant monitoring center of Mashhad side effects of ozone emission are described in Table 5. Note that equ.6 is used to convert ozone concentration data into $\mu g.m^{-3}$ since main data are given in ppb [30]. Surveys conducted in 2015 for 5 metropolitan cities in Iran show that Mashhad is the 2nd large city in Iran with the most cumulative mortality with 148 people per day. This information together indicates that Mashhad is in a highly critical situation.

Table 1: Comparison between the AHP and ELECTERE methods to validate initial data.

Method attribute	AHP	Electere
comparison factor	NO_x, SO_x, $PM_{2.5}$, O_3, PM_{10}	NO_x, SO_x, $PM_{2.5}$, O_3, PM_{10}
option	one-year statistics and data	expert opinion and judgment
prioritizing logic	paired data comparison and mathematical logic	Dispersion of indicators and relative relationships
result	allocating suitable weights for risk of each pollutant	allocating suitable weights for risk of each pollutant

Table 2: Maximum and minimum pollution concentration in all stations.

Stations	Nakhrisi	Sakhteman	Sajad	Sadaf	Taghi abad	Mashin abzar	Torogh	Khayam	Resalat	Lashkar	Villa	Shahr
$PM_{2.5}$ maximum concentration	150.5	115.2	116.3	118.9	133.4	46.2	161	104	116.5	92.4	149.4	105.1
$PM_{2.5}$ minimum concentration	1.35	4.2	4.04	3.37	5.c1	1.08	5.82	3.78	5.57	4.59	4.55	4.9
Annual average	27.1	31.3	24.7	24.0	33.9	17.0	41.7	20.3	26.0	23.0	28.0	27.6

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Prioritizing of pollutants in a year

To prioritize pollutants based on dangerous side effects AHP and ELECTERE methods have been used and results are shown in Table 6 which specifies that $PM_{2.5}$ is the first. The weighting method expresses that the difference between SO_2, NO_2, and O_3 weights is so little while the significant weight of polluting is devoted to $PM_{2.5}$. Also, in 2014 scholars showed that $PM_{2.5}$ reduces life expectancy 5 years on average as the most influential pollutant in the environment [31]. Furthermore, reports published by major organizations such as EPA, WHO, and NAAQS specify that $PM_{2.5}$ plays an important role in giving rise to the mortality rate caused by chronic diseases [32] which is emphasized by other researchers too [33,34]. So far, no comprehensive studies have been conducted to determine the type and share of each fixed and mobile pollutants in Mashhad. The present study uses two decision-making ways to determine the priority of risk-causing pollutants, the results of which can be used to control, set special rules and restrictions for each type of them.

Table 3: Upper and lower boundary of $PM_{2.5}$, NO_2 and SO_2 concentration.

Pollutants	$PM_{2.5}$	NO_2	SO_2
Maximum annual average concentration (µg.m^{-3})	41.71 Torogh station	65.31 Sajad station	80.13 Sajad station
Minimum annual average concentration (µg.m^{-3})	17.08 Mashin abzar station	16.54 Sadaf station	25.54 Resalat station

Table 4: Decreased life expectancy due to increase in $PM_{2.5}$ concentration.

Researchers	Year	decreased life expectancy per 10 µg.m^{-3}
Chen	2013	1
Correia	2013	0.35
Hoek	2013	0.73
Laden	2006	1.8
Pope	2002	0.73
Current research	2020	0.61

Table 5: Symptoms caused by ozone concentration growth in Mashhad.

Symptoms	Cnsequences
all ages mortality because of short time contacts with ozone	2.74% rise of relative risk
hospital admission of respiratory diseases (older than 65 years)	increase by 67.6 cases per year per 100000 people
daily activity limitation (18-64 years)	622.5 wasted daily works per 1000 people
using bronchodilators (5-14 years)	days using bronchodilators increased by 1678 per 1000 people
using bronchodilators (older than 20 years)	days using bronchodilators increased by 3951.5 per 1000 people

Table 6: Normalized weights to determine responsible pollutants.

Weighted pollutants	Method	
	AHP	Electere
$PM_{2.5}$	0.48	0.52
SO_2	0.29	0.195
NO_2	0.14	0.175
O_3	0.09	0.11

Conclusion

The city of Mashhad is one of the most important metropolises in terms of religion, trade, and industry. Environmental requirements in large cities are highly dependent on management parameters and highly affect the quality of life of citizens. Besides determining the number of adult mortality due to chronic diseases, showed that a maximum of 20.8% of people in Mashhad is exposed to a high risk of death caused by this type of disease. The present study also found a maximum of 8.22 years for men and 8.51 years for women reduction in life expectancy caused by air pollution. It is necessary to say that the calculated data for mortality and life expectancy in the present study is only caused by air pollution while living in large cities is associated with many pollutions such as polluted water, soil food, etc. The results show a serious warning to city managers and authorities to prevent reaching a critical situation by planning right and implementing long-term policies. Besides, the current situation in Mashhad was investigated using dose-response functions based upon the number of adult mortality due to chronic diseases, the reduction in life expectancy due to acute and chronic diseases, and the side effects of ozone emission. Results showed that adult mortality and decreased life expectancy due to chronic disease are in an undesirable condition. Moreover, using the AHP and ELECTERE method responsible pollutants were prioritized which indicated that $PM_{2.5}$ is averagely responsible for about half of pollution on average in Mashhad.

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