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Mortality and morbidity economic burden due to $PM_{2.5}$ and ozone; an AirQ+ modelling in Iran

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ABSTRACT:

Introduction: Attributable health impacts of air pollution result in economic costs to societies. In this study, the WHO AirQ+ model was used to estimate the health impacts and health-related economic costs of $PM_{2.5}$ and O_3 in Karaj, the fourth largest city in Iran, from March 2015 to March 2016.
Materials and methods: For $PM_{2.5}$, long-term mortality due to ischemic heart disease (IHD), lung cancer, chronic obstructive pulmonary disease (COPD), and morbidity such as acute lower respiratory infection (ALRI), and short-term cardiovascular and respiratory hospitalizations were calculated. For ozone, short-term mortality and hospitalizations due to cardiovascular and respiratory diseases were estimated. The human capital method (HCM) was used to monetize the mortality impact attributed to selected air pollutants. Direct and indirect costs of morbidity were estimated using available local data on the costs related to cardiovascular and respiratory diseases.
Results: The total number of IHD, COPD, LC and ALRI deaths attributed to $PM_{2.5}$ in selected age groups was 576. The total number of cardiovascular and respiratory deaths attributed to O_3 was 46 cases. For hospitalization, the aggregate cardiovascular and respiratory hospital admissions for both pollutants were 552. The total economic loss due to mortality and morbidity from selected health endpoints was approximately 44 million USD.
Conclusion: Despite the limitations, such methodologies can be useful for policy-makers. Therefore, there is a compelling need to conduct cost of illness's studies in other areas.

Introduction

Air pollution is a major cause of adverse health impacts and economic loss [1-3]. In recent years, high concentrations of ambient air pollutants are observed in Iranian cities, especially Metropolitans [4, 5]. According to the World Health Organization (WHO), Iranian cities are among the most polluted cities in the world with respect to

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particulate matter. Many studies have been conducted to estimate the attributable health impacts of air pollution in Iran [4]. Despite these published reports [3], no study had yet been performed to estimate the monetary value of economic losses the result from air pollution driven illness in Iran. Such studies provide governmental authorities and policy-makers with the costs of inaction with respect to implementing pollution control measures [6].

Studies about costs of illness (COI) are economic analyses that calculate the direct and indirect costs of a given disease. The output is expressed in monetary terms, and measures the total financial burden of the disease to society [7]. Two main approaches are used to estimate the costs of illness, including the prevalence and incidence approaches. The prevalence approach calculates the total cost of a disease incurred in any given year. The incidence based approach estimates the lifetime costs of cases first diagnosed in a specific year [8].

COI are classified into three categories: intangible, indirect, and direct costs. However, due to the difficulties in measurement, intangible COI have rarely been calculated [9]. The direct COI include both the healthcare and non-healthcare costs such as diagnosis, treatment, and rehabilitation, transportation, household expenditures, relocating, property losses, etc. The direct COI of communicable or acute diseases are lower than those of chronic diseases [10]. Finally, indirect COI are related to the losses in productivity due to morbidity and mortality, borne by the individual, family, society, or the employer. This type of costs is mainly because of social welfare losses due to diseases. Several methods have been developed to estimate indirect COI, including human capital method (HCM), friction cost method, and willingness to pay method [9].

HCM is the most common approach, and requires less input data in comparison to the other methods. This approach is suitable for countries or cities with limited information. In this method, the productivity losses related to health impacts are a function of the 'market value' of that individual's future contribution to production in a society. Therefore, HCM calculates the human capital as the present value of each individual's future earnings under the assumption that his/her future earnings are representative of his/her productivity [9, 11].

To calculate the monetary losses resulting from air pollution, the number of attributable deaths or hospital admissions must be estimated. Several models have been developed to quantify air pollution's health impacts, such as AirQ 2.2.3, BenMAP, AirQ+, etc. [12-16]. Among these models, AirQ+ is the latest WHO-developed software based on previous AirQ 2.2.3. This model, through an ecological approach, calculates the air pollution health impacts on a specific population relatively of one year of study. It is designed to include both long- and short-term exposures and has been validated for the six classic air pollutants to six classic air pollutants (CO_2, NOx, SOx, O_3, PM_{10} and finally $PM_{2.5}$) as described by Conti and colleagues [12]. The concentration–response functions used in the software are based on the systematic review of all available studies up to 2013 and their meta-analysis [17].

Several prior studies have been carried out to estimate the monetary costs of air pollution to society. Researchers estimated avoided cases of health impacts and economic losses due to PM in Shanghai. They used the BenMAP (Benefits

Mapping and Analysis Program) of US EPA to quantify the number and economic value of air pollution-related deaths and illnesses [18]. In addition, economic losses were monetized using different methods such as HCM, WTP, etc. [18]. Another study in China investigated direct and indirect costs of exposure to $PM_{2.5}$ in 30 Chinese provinces [19]. In total, many of economic impact evaluations of air pollution have been carried out in China [20-22].

Currently there aren't studies of the monetary value of the health impacts of air pollution in Iran, so our study is the first to estimate the economic and health impacts of $PM_{2.5}$ and O_3 in Karaj from March 2015 to March 2016.

Materials and methods

Location and time

Karaj is the capital of Alborz Province (Iran) and is the fourth-largest city of Iran, after Tehran, Mashhad, and Isfahan. Karaj is a great industrial city and has a population of about 1.6 million and is located at 35°50′08″ N and 51°00′37″ E. The study period, 21st March 2015 to 19th March 2016, was chosen based on the availability of air pollution monitoring data.

Data

The AirQ+ model requires 24 h averages (or annual mean concentration) and sum of Ozone Means Over 35 ppb (SOMO35) values for $PM_{2.5}$ and O_3, the at-risk population, the baseline incidence rate for the given health endpoint, a cut-off value of concentration for consideration, and relative risk (RRs) values [13]. Hourly concentrations of $PM_{2.5}$ and O_3 were obtained from Department of Environment (DOE) of Karaj. DOE data derive by a network of three fixed monitoring stations. Age- and cause-specific numbers of deaths and hospital admissions were acquired from Organization for Civil Registration, and Karaj University of Medical Sciences. Karaj University of Medical Sciences provided the costs related to cardiovascular and respiratory hospitalizations. All other monetary values were obtained from the Central Bank of Iran, the Ministry of Labour and Social Affairs, the Statistical Center of Iran, and the World Bank [23].

Validation of monitoring stations

24- and 8-h averages were calculated for $PM_{2.5}$ and O_3, respectively. Since, there are three air quality monitoring stations in Karaj, the WHO criteria were used to validate monitoring stations and exclude the invalid ones [24]. The first criterion is that over 50% and 75% of the measured 1 h data must be valid to obtain 24 and 8 h average $PM_{2.5}$ and O_3 values, respectively. The ratio between the number of valid data for the two seasons of each year cannot be greater than 2 [24]. After exclusion of invalid stations, only one valid station was available for each of the two pollutants, and 24 and 8 h averages of the valid station were calculated for $PM_{2.5}$ and O_3, respectively. The SOMO35 value was calculated from 8-hour averages of ozone as recommended by WHO [13, 25, 26].

Cause-specific health endpoints

For $PM_{2.5}$, long-term mortality due to ischemic heart disease (IHD, ICD-10: I20-I25) among individuals older than 25 years old, lung cancer (LC, ICD-10: C34.90) among individuals older than 30 years old, chronic obstructive pulmonary disease (COPD, ICD-10: J40 – J47) among individuals older than 30 years old, and acute lower respiratory infection (ALRI, ICD-10: J20-J22) among children younger than 5 years old were calculated. In addition to long-term health impacts of $PM_{2.5}$ on mortality, the number of $PM_{2.5}$ short-term hospital admissions for cardiovascular and respiratory diseases were estimated.

For O_3, short-term mortality caused by cardiovascular and respiratory diseases were estimated. Furthermore, short-term hospitalization attributed to cardiovascular and respiratory diseases were calculated by AirQ+ model.

Cost of illness

The cost of hospital admissions was divided into two main categories-direct and indirect. The direct cost was calculated by multiplying the number of cardiovascular/respiratory hospital admissions to the capital costs of care and treatment of cardiovascular/respiratory diseases during one year. These values were obtained from the governmental hospitals of Karaj. Indirect costs were estimated by multiplying the number of cardiovascular/respiratory hospital admissions by the work time missed (assumed 10 days for each patient in the year) and daily minimum wage (8.47 USD). Other indirect costs were neglected due to the lack of any monetary information.

The costs of deaths were estimated using HCM. Initially, the years of life lost (YLL) were calculated using the following equation:

$$YLL= LE- X \quad (1)$$

Where, LE is life expectancy taken from the WHO report. X is the age at which each attributable death occurred, and was estimated using the age-specific number of cardiovascular/respiratory deaths in Karaj. Average YLL per capita was obtained for cardiovascular and respiratory deaths 12.85 and 16.28 years, respectively. In addition, the average YLL per capita for cardiovascular mortality among people >25 years old, and respiratory mortality among people <5 and >30 years old were 12.28, 73.16, and 12.33 years, respectively. Total monetary losses due to cardiovascular/respiratory deaths were calculated by following equation:

$$T=YLL*N*GDP \quad (2)$$

Where, N is the number of cardiovascular/respiratory deaths, and GDP is the gross domestic product per capita. The value of GDP of Iran was obtained from World Bank's report, and its value per capita was calculated to be 5376 USD [23].

Results and discussion

Table 1 shows the input data for AirQ+ analyses. The incidence rates of health outcomes per 100,000 population are presented in this Table. The annual mean of $PM_{2.5}$ and the value of SOMO35 were 31.90 $\mu g/m^3$ and 10435.23, respectively.

The annual mean concentration of $PM_{2.5}$ and O_3 during the March 2015-March 2016 were calculated 31.9 and 35.3 $\mu g/m^3$, respectively. Table 2 presents the number of cardiovascular and respiratory deaths and hospital admissions attributed to short- and long-term exposure to $PM_{2.5}$ and O_3. Central values of health impacts were used to estimate economic losses of given air pollutants. Table 3 presents the results of calculations related to economic losses of selected cause-specific mortality and morbidity attributed to $PM_{2.5}$ and O_3 in Karaj during March 2015

Table 1. Population, incidence rates, and $PM_{2.5}$ and ozone values as input for AirQ+

Parameter	Value
Population	2,024,765
Population > 25	1,210,786
Population > 30	960,116
Population < 5	172,430
BI for IHD *	198.63
BI for COPD *	21.70
BI for LC *	6.99
BI for ALRI *	12.17
BI for Cardiovascular mortality	119.72
BI for Respiratory mortality	22.92
BI for Cardiovascular hospitalization *	490.53
BI for Respiratory hospitalization *	51.36
Cut-off value for $PM_{2.5}$ and O_3 (μg/m^3)	10
Annual mean of $PM_{2.5}$ (μg/m^3)	31.90
SOMO35 *	10435.23
Number of valid days for ozone	296

* BI: baseline incidence rate per 100,000 population; IHD: ischemic heart disease; COPD: chronic obstructive pulmonary disease; LC: lung cancer; ALRI: acute lower respiratory infection; SOMO35: sum of means over 35 ppb.

Table 2. Number of cause-specific mortality and hospitalization due to $PM_{2.5}$ and O_3

Exposure	Endpoint	Mortality/morbidity (CI %95)	
		$PM_{2.5}$	O_3
Long-term	IHD [a]	534 (367-775)	-
	COPD [a]	27 (12-44)	-
	LC [a]	11 (2.6-17)	-
	ALRI [a]	4.2 (3-5.4)	-
Short-term	Cardiovascular mortality	-	41 (11-71)
	Respiratory mortality	-	4.7 (0-11.3)
	Cardiovascular hospitalization	190 (36-344)	305 (173-432)
	Respiratory hospitalization	41 (0-86)	16 (2.6-30)

[a] Ischemic heart disease (IHD) among individuals >25 years old, lung cancer (LC) among individuals >30 years old, chronic obstructive pulmonary disease (COPD) among individuals >30 years old, and acute lower respiratory infection (ALRI) among children <5 years old.

Table 3. The economic losses of deaths and hospital admissions due to exposure to $PM_{2.5}$ and O_3

Pollutant	Endpoint	YLL [b]	Economic losses (USD)			Total (USD)
			Mortality	Morbidity		
				Direct	Indirect	
$PM_{2.5}$	IHD [a]	6557.5	35,253,228	-	-	35,253,228
	COPD [a]	332.91	1,789,724	-	-	1,789,724
	LC [a]	135.63	729,147	-	-	729,147
	ALRI [a]	292.6	1,573,018	-	-	1,573,018
	Cardiovascular	-	-	321,290	16,101	337,391
	Respiratory	-	-	18,204	3,474	21,678
	Total (USD)	-	39,345,117	339,494	19,575	39,704,186
O_3	Cardiovascular	526.9	2,832,346	515,755	25,846	3,373,947
	Respiratory	81.4	437,606	7,104	1356	446,066
	Total (USD)	-	3,269,952	522,859	27,202	3,820,013
Total economic losses (USD)		-	42,615,069	862,353	46,777	43,524,199

[a] Ischemic heart disease (IHD) among individuals >25 years old, lung cancer (LC) among individuals >30 years old, chronic obstructive pulmonary disease (COPD) among individuals >30 years old, and acute lower respiratory infection (ALRI) among children <5 years old.
[b] Years of life lost (YLL) was calculated by multiplying the YLL per capita to the number of deaths of each health outcome.

to March 2016.

The total number of IHD, COPD, LC and ALRI deaths attributed to $PM_{2.5}$ in selected age groups was 576 cases. Total number of cardiovascular and respiratory deaths attributed to O_3 was 46 cases. In case of hospitalization, the aggregate of cardiovascular and respiratory hospital admissions for both pollutants was 552 cases.

Long-term exposure to $PM_{2.5}$ in Karaj was estimated to induce mortality with an economic loss of about 39.3 million USD. Short-term exposure to O_3 is estimated to cause deaths with economic loss of approximately 3.3 million USD. The total economic loss of hospital admissions due to short-term exposure to both pollutants was calculated to be more than 0.9 million USD.

Aim of this study was to estimate the economic and health impacts of $PM_{2.5}$ and O_3 in Karaj from March 2015 to March 2016. The economic cost of air pollution's impact on mortality was estimated using HCM. In addition, the costs of morbidity were estimated using available local data on the expenses related to cardiovascular and respiratory diseases. Economic losses due to air pollution in Iran have been never studied before. Alternatively, many studies have been conducted estimating the health impacts of air pollution in Iranian cities [27-32]. However, no previous study has been performed regarding air quality in Karaj. Therefore, there are no previous city-based results to compare with.

According to WHO, the attributable number of ALRI, COPD, lung cancer, and IHD due to $PM_{2.5}$ concentrations in Iran were 600, 434, 1460, and 16484 cases in 2012. The total YLL in whole population for ALRI, COPD, lung cancer, and IHD were estimated 54425, 8513, 37894, and 422105 years, respectively [33]. In another study by the World Bank, the total number of deaths in Iran caused by $PM_{2.5}$ was estimated to be 21680 in 2013. The comparable impact in 1990 was reported to be 17035. In addition, the total welfare losses from exposure to $PM_{2.5}$ in 2013 was 30599 million USD, which was about 2.48% of the Iranian GDP. The total lost labor output due to exposure to $PM_{2.5}$ in 2013 was estimated 1471 million USD, which is equal to 0.12% of Iran's GDP [3].

Many similar studies have been conducted in cities and countries of the world. For example, the monetary benefit due to implementation of China's Class II air quality standards in Shanghai was investigated. The results estimated that the avoided cases of all-cause mortality, hospital admissions, emergency department visits, and outpatient visits had an estimated monetary value of 170-1200, 20-43, 5.6-15, and 21-31 million Yuan (1 US dollar=4.2 Yuan Purchasing Power Parity) [18]. Another study was conducted to estimate the monetary value of total output losses resulting from reduced working time caused by diseases related to $PM_{2.5}$ across 30 Chinese provinces in 2007. The results indicated that the total economic losses were 346.26 billion Yuan (about 1.1% of the China's national GDP) based on the number of affected employees whose work time in years was reduced because of mortality and morbidity [19].

A study carried out in Singapore estimated the economic cost of PM_{10} on health. The selected health endpoints included mortality and morbidity due to respiratory health admission, emergency room visits, restricted activity days, lower respiratory illness in children, asthma attacks, respiratory symptoms and chronic bronchitis. The authors reported that the economic cost of PM_{10} in Singapore was 3662 million USD, which was about 4.31% of Singapore's 1999 GDP [34]. The economic cost of premature mortality due to exposure to $PM_{2.5}$ and ozone in India was estimated to be 640 (350–800) billion USD in 2011, which was a factor of 10 higher than total expenditure on health by public and private expenditure [35].

The results of the present study and other referenced studies show that air pollution forces large economic losses to national economies. Governments can prevent these losses by designing and implementing air quality management strategies and plans to control the extent of air pollution [36]. The costs of such actions can be recovered by the potential gain in public health [9]. However, cost of illness studies have been the cause of much debate among economists [8].

Several arguments have been proposed against the cost of illness studies. First, identification of an area of high expenditure does not mean inefficiency and waste. An inefficient allocation of resources exists when those resources could generate more benefits in other situations. The efficiency of expenditure can be evaluated, when there is an understanding of the benefits (or health outcomes) achieved. Second, the cost savings from using cost of illness calculations are possibly overestimated, due to new and previous cases of incidence. Third, the costs of prevention could be much higher, and such studies provide no information on prevention costs. Another argument is that high costs can not necessarily be treated by existing medical technology. However, despite these limitations, the results of such studies can be used as a useful estimate for policy-makers to better understand the air pollution/public health relationships [7, 8]. In addition, other kinds of studies are required to prepare control actions. For example, source apportionment of pollutants can be helpful to concentrate on high-priority sources and sectors [37].

Conclusion

In this study, the AirQ+ model was used to estimate some short- and long-term health impacts of $PM_{2.5}$ and O_3 concentrations in ambient air of Karaj during March 2015 to March 2016. Economic costs of mortality were estimated using human capital method. In addition, costs of morbidity were estimated using available local data on the expenses related to cardiovascular and respiratory diseases. The results showed that the economic impact of air pollution on health is significant. Governments can prevent this by implementing actions to control ambient air pollution. Although, there is limitations to these studies, their results can be useful for policy-makers as an initial approximation. Therefore, there is a compelling need to conduct cost of illness's studies in other cities of Iran. By providing more input data, future studies should be focused on conducting economic evaluations, such as cost-effectiveness analyses, which assesses both costs and outcomes.

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Competing interests

The authors declare that there are no competing interests.

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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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