ORIGINAL ARTICLE

Health Risks Assessment of Criteria Air Pollutants on Shiraz Residents Using AirQ and GAM Models during 2012-2013

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Abstract

Background: Air pollutants have harmful impacts on human health and aggravation of diseases and mortality. This study was conducted to investigate the impact of PM_{10}, NO_2, SO_2, and O_3 on cardiovascular and respiratory mortality and hospital admissions in Shiraz during 2012-2013.

Methods: The health impact of pollutants was quantified using AirQ2.2.3 model provided by WHO Regional *Office*-European Center for Environment and Health. In addition, Generalized Additive Model (GAM) in R was used to investigate the relationship between pollutants and disease and mortality.

Results: According to the results of quantification with *WHO's default values* for Baseline Incidence (BI) and Relative Risk (RR) as well as the number of hospital admissions related to PM_{10} (1,375 cases in 2012 and 874 ones in 2013), it has been observed that respiratory diseases have had the highest health impacts. On the other hand, an assessment using regional *values* for BI and RR indicated that the highest health impacts were related to respiratory diseases due to exposure to O_3 with 134 and 252 cases in 2012 and 2013, respectively. Moreover, significant relationships were observed among PM_{10}, NO_2, and O_3 and respiratory mortality, hospital admissions due to cardiovascular diseases, and hospital admissions due to respiratory diseases in patients aging 65 years and older.

Conclusion: Overall, the results showed that due to different geographical, statistical, and climatic features of each region, WHO's default values for BI and RR cannot be used normally in some cases. Thus, calculated BI and RR values should be used for such cases. However, further research is needed to assess the health impacts of air pollutants in terms of BI and RR specific to the study region.

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Introduction

Air quality is affected by pollutants, such as particulate matter (PM_{10}), nitrogen oxides (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and tropospheric ozone (O_3). Today, the concentration of air pollutants is increasing because of the significant growth in the use of private cars, increased activity of industries, and power plants in urban areas with high population density.[1, 2] Thus, residents of megacities are faced with the problem of increasing air pollutants and health impacts as a result of exposure to pollutants.[3-5] Increased exposure to low concentrations of pollutants leads to harmful effects on human health.[6, 7] Reviews and meta-analyses conducted in Europe, the United States, China, and South Korea have shown the effects of short-term exposure to air pollutants on mortality.[8-11] Some studies in Italy, India, and Egypt have estimated the number of deaths and disease cases caused by short- and long-term exposure to air pollutants.[12-15] According to development programs of future megacities, by increasing traffic and industrial activities, it is essential to assess the health impact of air pollutants on residents of megacities and also investigate the relationship between air pollution and mortality and diseases.

Shiraz is one of the megacities in Iran with a high population density and traffic and increased air pollutants in the recent decades. Thus, this city can be assessed as a model for megacities of Iran and the world in terms of air pollutants. Health impact assessment of air pollution in Shiraz using AirQ software revealed that, considering World Health Organization's (WHO) default values, admissions due to cardiovascular diseases as a result of exposure to PM_{10} comprised 2.3% of all admissions. Additionally, Mohammadi et al. (2016) reported that, based on WHO's Baseline Incidence (BI) of PM_{10}, hospital admissions due to respiratory diseases accounted for 54.6% of all hospital admissions.[16]

Air pollution models represent an important tool in environmental and epidemiological sciences. AirQ developed by WHO, as an instrument for health impact assessment of air quality, evaluates the potential effects of human exposure to a particular contaminant in a given urban area and a specific matter of time.[16, 17] In several studies, health impact assessment of air pollutants has been carried out using *WHO's default values* for BI and Relative Risk (RR). However, these values may be different depending on geographical, statistical, and climatic features of various regions. In the present study, *regional values* for BI and RR as well as *WHO's default values* were analyzed using Generalized Additive Model (GAM). Overall, the present study aims at: a) Assessing health impacts of PM_{10}, NO_2, SO_2, and O_3 pollutants using AirQ and *WHO's default values* for BI and RR, and b) Investigating health impacts of pollutants using AirQ and *regional values* for BI and RR using GAM in R software.

Materials and Methods

Study Region

Shiraz is located in southwestern Iran (29.36 N and 52.32 °E) with a total population of 1.5 million people, an area of 1,268 square kilometers, and an altitude of 1,540 m above the sea level. In the present study, data about air pollutants, including PM_{10}, SO_2, NO_2, and O_3, were collected from two air pollution monitoring stations in Emam Hosein (Setad) square and Darvaze Kazeroon affiliated with Shiraz environmental department. Besides, the daily number of cardiovascular and respiratory deaths was collected from Registration Office of Shiraz Municipality and three hospital admissions due to respiratory and cardiovascular diseases from Shiraz Emergency Medical Services.

Statistical Methods

Correlation Evaluation and RR Calculation

Correlation evaluation and RR calculation were done by applying Poisson regression with a logarithmic link in GAM. The GAM is expressed as the following equation:[10]

$$\text{Log}\,[E(Y)] = \beta_0 + \beta_1 \times \text{pollutant} + S_1(X_1) + \ldots + S_p(X_p) \quad (1)$$

Where Y denotes the number of daily mortality and hospitalizations; E(Y) denotes the number of expected cases; X_i, i = 1,…,p which can be temperature, relative humidity, time, etc.; and S_i, i = 1,…,p denotes smooth functions.

A two-stage analysis was done using GAM on mgcv package in R statistical software. In the first stage of the time series analysis, the relationship between health endpoints of cardiovascular mortality, respiratory mortality, hospital admissions due to respiratory diseases in patients aged ≥ 65 years, and hospital admissions due to cardiovascular diseases for each of the PM_{10}, NO_2, SO_2, and O_3 pollutants was determined by taking the effects of temperature, humidity, workdays, holidays, and days after holidays using Poisson regression in GAM. Then, the pollutants showing a significant relationship with any of the health endpoints in the first phase were analyzed in the second phase using multivariate regression in GAM.

Health Endpoint Assessment

In this part, AirQ 2.2.3 developed by WHO's Regional *Office*-European Center for Environment and Health was used. *WHO's default values* for BI and RR for health endpoints are presented in Table 1. It should be noted that this assessment is based on Attributable Proportion (AP) that expresses the health impacts of a particular population's exposure to air pollutants and shows the relationship between exposure and health outcomes without confounding effects on this relationship. AP is calculated using the following formula:[12]

$$AP = SUM\ \{[RR(C) - 1].P(C)\}/SUM\ [RR(C).P(C] \quad (2)$$

Where AP is the attributable proportion of health outcomes and RR(c) is the RR of health outcomes in the group (c) or the exposed group. The RR of

Table 1: WHO's default values for relative risk (per 10 mg m^{-3} increase in concentrations of PM_{10}, SO_2, NO_2, and O_3) and baseline incidence (per 100,000 people)

Health endpoint	Relative Risk (95% CI) per 10 mg/m³				Baseline Incidence [a]
	PM_{10}	NO_2	SO_2	O_3	
Cardiovascular mortality	1.008 (1.005-1.018)[b]	1.002 (1-1.004)[b]	1.008 (1.002-1.012)[b]	1.004 (1-1.006)[b]	497
Respiratory mortality	1.012 (1.008-1.037)[b]	-	1.01 (1.006-1.014)[b]	1.012 (1.0046-1.0208)[c]	66
HA Respiratory Disease	1.009 (1.006-1.013)[b]	-	-	-	1260
HA Respiratory Disease 15-64 years	-	1.002 (1-1.004)[b]	1.01 (1.006-1.01)[b]	1.006 (1.0026-1.009)[c]	66
HA Respiratory Disease >65 years	-	1.003 (1-1.012)[b]	1.004 (1.001-1.009)[b]	1.007 (1.003-1.011)[c]	-
HA [d] Cardiovascular Disease	1.008 (1.0048-1.0112)[b]	-	-	-	436

[a]Crude rate per 100,000 inhabitants; [b]Daily average; [c]8 h moving average; [d]Hospital Admission

a selected health outcome can be obtained using exposure-response functions. P(c) is the population ratio of the group (c) or the exposed group.

Knowing the BI of the selected health outcomes, the amount attributable to the population exposure can be calculated as follows:

IE = I.AP (3)

Where IE is the incidence of health outcome among the exposed and I is the BI of health outcome in the population under investigation.

Finally, knowing the population size, the number of excess cases can be calculated as follows:

NE = IE.N (4)

Where NE is the number of cases attributable to exposure and N is the size of the population under the study.

After all, the parameters required for the software (annual and seasonal maximum and annual 98th percentile) were obtained for all pollutants and their concentrations were reported on the basis of 10 mg m^{-3} of air pollutants.

The data of PM_{10}, SO_2, and NO_2 were reported based on a daily average and that of O_3 was expressed as 8 h moving average. The degree of exposure in Shiraz was estimated with a population of 1.5 million people.

Results and Discussion

Health Impact Assessment Using WHO's Default Values for BI and RR

The percentage of population's exposure to different concentrations of pollutants in Shiraz during 2012 and 2013 is presented in Figure 1. According to Figure 1A, the population was exposed to 80-89 and 60-69 mg m^{-3} PM_{10} concentrations on most days during 2012 and 2013, respectively, which are higher than the national standard of air quality (NAAQSs) published for the annual average of PM_{10} (NAAQS, 2010). Additionally, as shown in Figures. 1B, 1C, and 1D, the maximum population's exposure to NO_2, SO_2, and O_3 respectively ranged 30-39, 60-69, and 60-69 mg m^{-3} in 2012 and 20-29, 20-29, and 70-79 mg m^{-3} in 2013.

Short-term health impacts of exposure to PM_{10}, NO_2, SO_2, and O_3 on cardiovascular mortality, respiratory mortality, hospital admissions due to respiratory diseases, and hospital admissions due to cardiovascular diseases based on *WHO's default values* for BI and RR are presented in Table 2. As seen in this table, for a BI of 497 per 100,000 person for cardiovascular deaths, the number of deaths resulting from this endpoint attributable to PM_{10} was 542 cases in 2012 and 345 ones in 2013, which accounts for 7% and 4% of the total cardiovascular deaths attributed to air pollution, respectively. Respiratory deaths caused by exposure to PM_{10} were estimated to be 263 and 181 cases in 2012 and 2013, respectively. The results also showed that the number of hospital admissions for respiratory diseases at centerline of RR (RR=1.008) and BI of 1260 in 100,000 people were about 1375 and 874 in 2012 and 2013, respectively. Thus, the hospital admissions resulting from respiratory diseases attributable to PM_{10} accounted for 7% and 4.5% of the total hospital admissions for this health endpoint in 2012 and 2013, respectively. Moreover, the hospital admissions due to cardiovascular diseases were 530 in 2012 and 338 in 2013 at centerline RR for Shiraz with a BI of 436 in 100,000 people. In the most pessimistic state, this number reached 740 and 477 in 2012 and 2013, respectively.

As presented in Table 1, WHO's default value for RR of cardiovascular mortality is 1 within a confidence interval of 5%, implying that AP values are zero and the number of excess cases is attributed to NO_2 exposure. Besides, the number of cardiovascular and

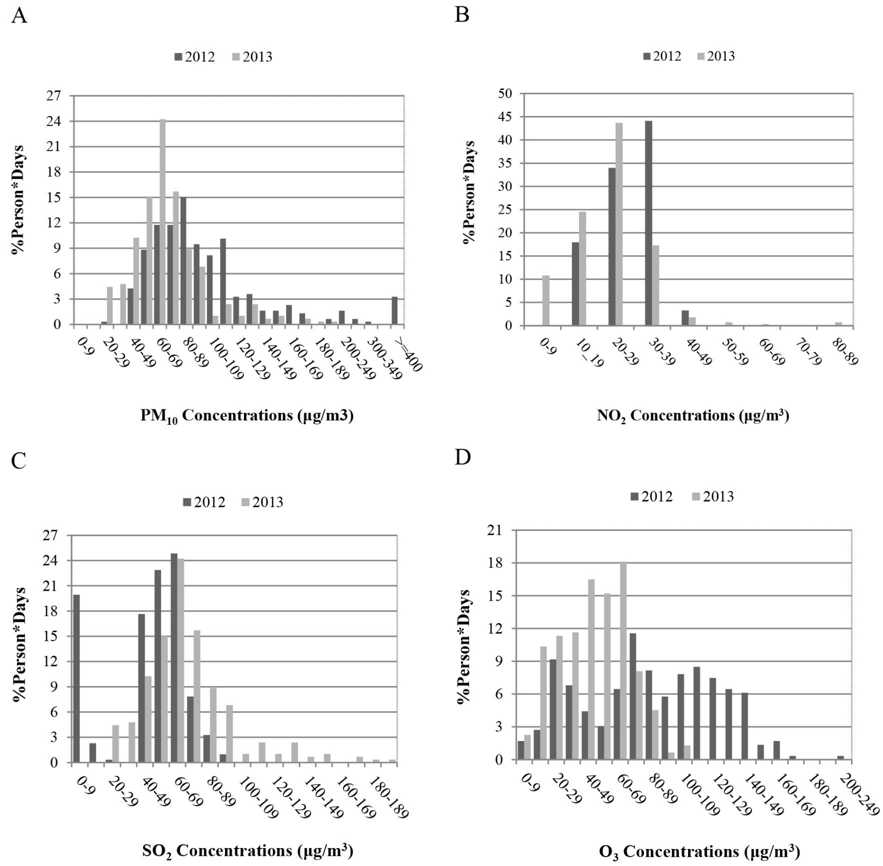

Figure 1: Percentage of Shiraz inhabitants' exposure to different concentrations of pollutants during 2012 and 2013

Table 2: Percentage of attributable proportion and number of excess cases attributable to short-term impacts using WHO's default values for relative risk (for 10 mg m^{-3} increase in concentrations of PM_{10}, NO_2, SO_2, and O_3) and baseline incidence.

	2012		2013	
	Attributable proportion	**No. of excess cases**	**Attributable proportion**	**No. of excess cases**
Cardiovascular mortality				
PM_{10}	7.27 (4.67-15.0)	542.50 (348.6-1118.2)	4.62 (2.94-9.83)	344.70 (219.2-733.2)
SO_2	0.36 (0.0-1.29)	3.60 (0.0-12.8)	0.27(0.0-0.98)	2.70 (0.0-9.7)
NO_2	3.0 (0.76-4.43)	223.70 (57.2-330.7)	4.07(1.05-5.99)	304.0 (78.4-446.9)
O_3	1.50 (0.0-2.23)	112.10 (0.0-166.8)	2.93 (0.0-4.33)	218.60 (0.0-323.2)
Respiratory mortality				
PM_{10}	10.53 (7.27-26-63)	104.30 (72.0-263.7)	6.77 (4.62-18.31)	67.10 (45.8-181.3)
SO_2	3.72 (2.26-5.13)	36.90 (22.5-50.9)	5.04 (3.08-6.92)	50 (30.6-68.6)
O_3	4.55 (1.72-7.35)	45.10 (17.1-72.8)	8.62 (3.35-13.5)	85.40 (33.2-134.4)
HA Respiratory Disease				
PM_{10}	7.27 (4.49-9.89)	1375.4 (850-1871)	4.62 (2.82-6.35)	873.9 (534.2-1201.2)
HA Cardiovascular Disease				
PM_{10}	8.11(5.55-11.31)	530.60 (363.6-793.7)	5.17(3.50-7.30)	338.2(229.4-477.6)

respiratory deaths attributable to SO_2 was estimated to be 224 and 37 in 2012 and about 304 and 50 in 2013. Moreover, the centerline RR for respiratory deaths attributable to SO_2 was 1.01, suggesting that the risk of respiratory mortality increased by about 1% per 10 mg m^3 increase in SO_2 concentration. However, given the fact that the RR of cardiovascular mortality is higher than that of respiratory mortality, a decrease in the number of deaths related to respiratory mortality was not unexpected due to the low BI index for this health endpoint.

As shown in Table 1, the risk of cardiovascular mortality per 10 mg m^{-3} increase in ozone concentrations increased by 0.4%. A 1.25% increase in the risk of respiratory deaths per 10 mg m^{-3} increase in ozone concentration can also be inferred from the Table. Based on Table 2, the number of cardiovascular and respiratory deaths was estimated to be about 112 and 45 in 2012 and 218 and 85 in 2013. In addition, hospital admissions due to respiratory diseases caused by PM_{10} had the maximum short-term health impacts on the population of 1.5 million people in Shiraz in

2012 and 2013. Similarly, other studies using WHO's default values demonstrated that the greatest health impacts were related to PM_{10}. For instance, Tominz et al. (2005) conducted a similar study on 200,000 people in Trieste (Italy) and indicated that 52 deaths in total, 28 cardiovascular deaths, and 6 respiratory deaths were attributed to PM_{10} concentrations of over 20 mg m^{-3}. Also, in Milan (Italy) with a population of 1,308,000 people, the number of excess cases attributable to PM_{10} was estimated to be 677 out of the total number of deaths.[13] In another study on about 9 million people in 13 cities in Italy, PM_{10} and O_3 impacts on human health were investigated during 2002-2004. Based on the results, about 1372 and 516 excess cases among the total of 8220 deaths were respectively estimated for PM_{10} and O_3 in concentrations higher than 20 mg m^{-3}.[18] It must be added that health impact assessment was carried out using WHO's default values for BI and RR in these studies.

Health Impact Assessment Using BI and RR Using Regional Values Via GAM

BI and RR estimates from regional values in 2012 and 2013 with 95% confidence interval per 10 mg m^{-3} concentration of pollutants in relation to health endpoints are presented in Table 3. As the Table shows, for each 10 mg m^{-3} increase in PM_{10} concentration, the risk of cardiovascular mortality and hospital admissions due to cardiovascular diseases increased by 0.07% and 0.06%, respectively. Indeed, there was a 2% increase in the risk of respiratory mortality for NO_2 and a 1.2% increase in cardiovascular deaths per 10 mg m^{-3} SO_2. Also, for each 10 mg m^{-3} increase in the concentration of O_3, the risk of cardiovascular mortality, hospital admissions due to respiratory diseases, and hospital admissions due to respiratory diseases increased by about 0.7, 1.6, and 1.4 respectively in patients aged ≥ 65 years.

The increased risk of mortality and diseases varies in different regions due to geographical, statistical, and climatic differences. For example, a large-scale study in Europe revealed a 0.45% increase in the risk of cardiovascular mortality for each 10 mg m^{-3} increase in one-hour O_3 concentration.[8] Another study in California showed that cardiovascular mortality risk increased by about 0.6% for each 10 mg m^{-3} increase in PM_{10} concentration.[19]

According to Table 1, WHO's default values for BI and RR do not exist for respiratory mortality caused by exposure to NO_2 and hospital admissions due to respiratory diseases resulting from exposure to O_3. Thus, the RR of these health endpoints was obtained using GAM. Based on Tables 1 and 2, the RR estimated from regional values is higher than WHO's default values for pollutants, excluding PM_{10}.

The short-term health impacts of exposure to PM_{10}, NO_2, SO_2, and O_3 based on the average RR is illustrated in Table 4. According to this Table, the number of cardiovascular deaths attributable to PM_{10} was estimated to be about 12.8 in 2012 and 7.9 in 2013. The number of hospital admissions due to cardiovascular diseases as the result of exposure to PM_{10} was 33 and 20 in 2012 and 2013, respectively. About 3.6% and 2.7% of the total number of respiratory deaths were caused by NO_2 exposure in 2012 and 2013, respectively. The number of respiratory deaths attributable to these pollutants in the BI of 32.3 per 100,000 people was also 17 and 13 in 2012 and 2013, respectively. As shown in Table 4, most of the health impacts for RR and BI estimated from regional values in 2012 and 2013 were related to respiratory diseases attributable to O_3, with about 134 and 252 of the total number of cases.

Since WHO's default values for BI and RR for hospital admissions due to respiratory diseases caused by exposure to SO_2, NO_2, and O_3 pollutants in patients aged ≥65 years do not exist in AirQ2.2.3, the attributable proportion and number of cases have not been estimated in most previous studies. In the present study, the values for BI and RR of hospital admissions for respiratory diseases attributable to O_3 in patients aged ≥65 years were estimated based on regional values (Table 2). Accordingly, the attributable proportion of this endpoint was about 5% and 9.5%

Table 3: Baseline incidence values (per 100,000 people) and relative risk (per 10 mg m^{-3} increase in concentrations of PM_{10}, NO_2, SO_2, and O_3) estimated from regional values using GAM in 2012-2013

Health endpoint	Relative Risk (95% CI) per 10 mg/m³				Baseline Incidence [a]
	PM_{10}	NO_2	SO_2	O_3	
Cardiovascular mortality	1.0007 (1.0005-1.0009)[b]	-	1.012 (1.0008-1.02)[b]	1.007 (1.003-1.01)[c]	125.3
Respiratory mortality		1.02 (1.009-1.03)[b]	-	-	32.3
HA Respiratory Disease	-	-	-	1.016 (1.002-1.028)[c]	156.0
HA Respiratory Disease ≥65 years	-	-	-	1.01 (1.002-1.02)[c]	52.8
HA [d] Cardiovascular Disease	1.0006 (1.0003-1.0009)[b]	-	-	-	373.6

[a]Crude rate per 100,000 inhabitants; [b]Daily average; [c]8 h moving average; [d]Hospital Admission

Table 4: Percentage of attributable proportion and attributable number to short-term impacts using centerline relative risk (per 10 mg m^{-3} increase in concentrations of PM_{10}, NO_2, SO_2, and O_3) via GAM

	2012		2013	
	Attributable proportion	**No. of excess cases**	**Attributable proportion**	**No. of excess cases**
Cardiovascular mortality				
PM_{10}	0.68 (0.48-0.87)	12.8 (9.2-16.4)	0.42 (0.3-0.54)	7.9 (5.7-10.2)
SO_2	4.43 (0.30-8.81)	83.4 (5.8-165.7)	6.77(0.48-13.15)	127.4 (9.1-247.3)
O_3	2.60 (1.13-4.02)	48.9 (21.3-75.7)	5.02 (2.21-7.67)	94.4 (41.6-144.2)
Respiratory mortality				
NO_2	3.64 (1.60-5.49)	17.60(7.8-26.6)	2.79 (1.22-4.23)	13.5 (5.6-20.5)
HA Respiratory Disease				
O_3	5.75 (0.75-9.65)	134.60 (17.7-225.9)	10.78 (1.48-17.45)	252.3 (34.8-408.5)
HA Respiratory Disease ≥65 years				
O_3	5.07 (0.75-8.38)	40.2 (6.0-66.5)	9.56 (1.48-15.34)	75.8 (11.8-121.7)
HA Cardiovascular Disease				
PM_{10}	0.58 (0.29-0.87)	32.80 (16.4-49.1)	0.36 (0.18-0.54)	20.3 (10.2-30.4)

Table 5: Correlation coefficient and degree of freedom resulting from time series analysis

Parameter	**PM_{10}**		**SO_2**		**NO_2**		**O_3**	
	P value	**df**	**P value**	**df**	**P value**	**df**	**P value**	**df**
Cardiovascular mortality	0.69	1	0.65	1	0.24	1	0.59	1
Respiratory mortality	0.02	1	0.04	3.73	-	-	0.32	3.5
HA Respiratory Disease	-	-	-	-	0.47	6.77	0.20	1.9
HA Respiratory Disease ≥65 years	-	-	-	-	0.31	1	0.02	2.2
HA Cardiovascular Disease	0.8	1	0.02	7.09	0.64	1	-	-

of the total cases in 2012 and 2013, respectively. In similar studies, the assessment was rarely carried out using the values of BI and RR obtained from the local data of the region. For instance, in a study conducted in Suwon, South Korea, the BI obtained from the local data and WHO's default values for RR was used to assess the health impacts of PM_{10}, SO_2, NO_2, and O_3 pollutants. Based on the results, the number of cardiovascular deaths caused by exposure to PM_{10} and O_3 was about 35 and 16 out of the total cases, respectively.[20] In another study, Rezzato and Mazzano reported 4 deaths attributable to PM_{10} and 3 deaths attributable to NO_2 and O_3 in an industrial area with 24,000 inhabitants in a small town in Italy.[12]

The correlation coefficient and degree of freedom resulting from the time series analysis using GAM (multivariate regression) are presented in Table 5. According to the results and PM_{10} concentration-response function, there was a linear relationship between PM_{10} and respiratory mortality (df=1, $P<0.05$). There was also a nonlinear relationship between NO_2 and respiratory mortality and hospital admissions due to cardiovascular diseases (df>2 and $p<0.05$). The linear trend of O_3 with hospital admissions due to respiratory diseases among patients aged ≥65 years old (df=1, $P<0.05$) was confirmed, as well. Overall, the study results showed that the interaction of the pollutants has a simultaneous effect on PM_{10} and NO_2 respiratory mortality. Similarly, some studies have indicated a linear relationship between exposure to O_3 and PM_{10} and death.[21, 22]

This study had some limitations including the assumption of a causal relationship between the pollutants under the study and the health endpoint resulting from exposure to them. Indeed, the effects of confounding variables on this relationship were not investigated in this research. However, such studies are very useful since they provide valuable information about the importance of air pollutants and their remarkable effects on humans.

Conclusion

The study results confirmed the effect of pollutants, especially ozone and particulate matter on the health of inhabitants in the region. Moreover, health impact assessment of the pollutants using WHO's default values for BI and RR was different from an assessment using regional values for BI and RR. This difference may be due to the values obtained based on geographical, statistical, and climatic features. Therefore, it is recommended that further studies should be conducted on health impact assessment of specific BI and RR to different regions due to their various characteristics.

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