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Research Article

Air Pollution and Mortality in the Elderly in Kerman, Iran

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Abstract

Background: Today, air pollution is a major issue in the world, particularly in metropolitan areas.
Objectives: Accordingly, this study aimed to investigate the relation between air pollution and mortality in the elderly in Kerman City.
Methods: This ecological study was conducted using 2006 - 2013 mortality data inquired from the Deputy of Health of Kerman University of Medical Sciences. The data on cardiovascular and respiratory mortality, as well as death due to trauma, diabetes, and other diseases that happened in men and women aged 60 and higher were extracted. Air pollution data (CO, SO_2, O_3, NO, NO_2, NO_x, and PM_{10}) for the same time frame were inquired from the Environmental Protection Agency of Kerman Province. Negative binomial regression was used to evaluate the relation between air pollutants and mortality using STATA13 software.
Results: During the study period, a total of 14,793 deaths occurred in elderly men and women in Kerman City. Cardiovascular diseases were the leading cause of death. The results of multivariate analysis of air pollutants indicated that NO was directly and significantly related to the total number of deaths in the elderly, and increase in sulfur dioxide, ozone and NO was significantly related to increased mortality among elderly women. Carbon monoxide was significantly related to cardiovascular death of the elderly. But air pollutants did not show any significant effect on respiratory-, trauma-, and diabetes-related deaths.
Conclusions: Our findings indicate that there is a significant relation between air pollution and mortality in the elderly. Accordingly, a warning system is suggested to reduce the elderly's commuting on highly air polluted days.

Keywords: Cardiovascular Death, Respiratory Death, Diabetes, Trauma, Elderly, Kerman

1. Background

Today, air pollution is one of the major environmental issues in the world's major cities and is jeopardizing the living conditions of human beings (1, 2). High population growth and increased energy consumption, rapid economic and urban development, expansion of urban traffic, inappropriate use of industrial systems and devices, and non-compliance with environmental regulations has resulted in air pollution in many countries (3).

According to the World Health Organization (WHO), approximately 3 million people lose their lives annually due to air pollution (4). WHO has estimated that exposure to particulate matter causes more than 500,000 premature deaths per year. The numerous adverse events that have occurred as a result of air pollution in the world can appropriately highlight the importance of this issue. In October 1948, sulfur dioxide (SO_2) and industrial dust caused the death of 20 people and sickened almost 6,000 people in Pennsylvania. In London in December 1952, burning coal in homes and SO_2 emissions along with inversion and air pollution entrapment caused the death of 4000 people. In December 1962, again air pollution in London took the lives of 300 people (3).

It seems air pollution has a very comprehensive impact on human health. The severe effects of carbon monoxide (CO) on human health include increased mortality due to heart and respiratory diseases, stroke, and acute heart attacks. Studies have shown a relation between respiratory diseases and environmental pollution in industrialized countries as well as countries with low or moderate income. Therefore, air pollution is nowadays a major global environmental health problem (5).

One of the groups that are likely to be more susceptible to air pollution is the elderly. A previous analysis of an elderly cohort in Hong Kong revealed that long-term exposure to PM2.5 and black carbon was associated with cardiovascular mortality, but not respiratory mortality, among an elderly population in Hong Kong, a high-density and high-rise city in Asia, and effect estimates remained similar for various time exposure windows (6). Yap et al. (7) conducted a time series study in Singapore and revealed that particulate air pollutants ($PM_{2.5}$, PM_{10}) were associated with non-accidental mortality and cardiovascular mortality, and the effects were greater on the elderly. Another study in Montreal showed positive associations between daily non-accidental mortality and all air pollutants, except ozone. They also noticed that people with cardiovascular disease, congestive heart failure, atrial fibrillation, diabetes, and cardiovascular disease are more likely to die from air pollution (8).

2. Objectives

This study aimed to investigate the relation between air pollution and elderly death in Kerman, Iran. This was the first study of this kind done in Kerman. Kerman City is one of the major cities of Iran located in the southeast, with a population of over 621,374 individuals according to the 2011 census (9).

3. Methods

This was an ecological study conducted in Kerman city. Initially, data on the number of deaths in the elderly per day, from 2006 until 2013 were inquired from the Deputy of Health of Kerman University of Medical Sciences. Elderly deaths were deaths that occurred due to any reason in people aged 60 and older. Then, these deaths were classified based on gender (male and female) and the cause of death (cardiovascular disease, respiratory diseases, trauma, diabetes, and other diseases).

Data on air pollution (including NO, CO, NO_2, NO_x, PM_{10}, SO_2, and O_3) were inquired from the Environmental Protection Agency of Kerman Province. These data are measured on a daily basis using a fixed station within the city. In this study, observations that were more than $\pm$ 3 SD away from the mean were recognized as outliers and were dealt with as missing data. Then missing air pollution data were estimated using the expectation-maximization (EM) algorithm in SPSS20 software. Details of these methods can be found in our previous publications (10). This study was approved by the Standing Committee on Ethics in Research of Kerman University of Medical Sciences (ethics code: IR.KMU.REC.1394.428). The relation between daily mortality and air pollution was analyzed using negative binomial regression in STATA13.

4. Results

During this time, 6465, 2958, 1017, 895, and 3458 deaths caused by cardiovascular diseases, respiratory diseases, trauma, diabetes, and other reasons, respectively, occurred among the elderly in Kerman. The numbers of deaths have been categorized on the basis of year and gender in Table 1. The average air pollutants during these seven years are shown in Table 2. The relation between daily levels of air pollutants and deaths in the elderly caused by cardiovascular diseases, respiratory diseases, trauma, diabetes, other diseases as well as the total number of diseases; categorized based on gender have been shown in Tables 3 to 8. The results of multivariate analysis of air pollutants indicated that nitrogen oxide (NO) was directly and significantly related to total numbers of deaths in the elderly; and an increase in SO_2, ozone, and NO was significantly related to increased mortality among elderly women (Table 3).

The results of multivariate analysis indicated that CO was directly related to cardiovascular death of the elderly, but this relation disappeared in the gender subgroups, probably because the population size decreased (Table 4). Air pollutants did not show any significant effect on respiratory- (Table 5), trauma- (Table 6), and diabetes- (Table 7) related deaths in the elderly of Kerman city. The results of multivariate analysis of air pollutants indicated that ozone played a significant role in increasing the death of the elderly who died from other diseases (Table 8).

5. Discussion

This study aimed to investigate the relation between air pollutants and the number of elderly deaths in one of the major Iranian cities. The results indicated that CO played a significant role in the cardiovascular deaths of the elderly. Indeed, CO triggers complex pro-inflammatory phenomena in the airways and combines with blood hemoglobin, and forms a stable hybrid, which is carboxyhemoglobin, thereby causing hypoxia and heart failure. Moreover, it affects the central nervous system and eventually, can lead to death (11). Studies conducted in Taiwan also showed a relation between CO and cardiac mortality,

Table 1. The Number of Total Deaths in the Elderly From 2006 to 2013 in Kerman City

Cause of Death	2006	2007	2008	2009	2010	2011	2012	All Years
Cardiovascular diseases								
Total	1184	946	619	986	1038	820	872	6465
Men	652	490	304	482	520	434	447	3329
Women	532	456	315	502	518	386	425	3134
Respiratory diseases								
Total	411	475	325	390	460	499	398	2958
Men	247	271	190	216	250	272	217	1663
Women	164	204	135	174	210	227	181	1295
Trauma								
Total	106	94	86	151	122	239	219	1017
Men	78	63	57	98	72	145	137	650
Women	28	31	29	53	50	94	82	367
Diabetes								
Total	79	169	122	101	129	189	106	895
Men	39	68	49	48	36	97	45	382
Women	40	101	73	53	93	92	61	513
Other reasons								
Total	399	435	389	425	606	655	549	3458
Men	227	255	205	235	346	365	318	1951
Women	172	180	184	190	260	290	231	1507
All deaths								
Total	2179	2119	1541	2053	2355	2402	2144	14793
Men	1243	1147	805	1081	1224	1313	1164	7977
Women	936	972	736	972	1131	1089	980	6817

Table 2. Status of Pollutants in Kerman During 2006 - 2013

Pollutants	Median	Mean	Minimum	Maximum	SD
CO, ppm	1.01	1.21	0.109	5.31	0.70
SO_2, ppb	7.45	8.26	0.10	70.30	4.66
O_3, ppb	20.10	24.17	1.91	82.30	16.03
NO, ppb	9.33	14.06	0.12	94	13.92
NO_2, ppb	20.25	19.65	0.16	43.31	7.35
NO_x, ppb	29.29	33.16	0.20	112.50	16.69
PM_{10}, $\mu g/m^3$	89.90	100.68	17	327	55.39

Table 3. The Results of Negative Binomial Regression of the Impact of air Pollutants on Overall Deaths Per Day (Ratio of Increased Daily Mortality for Every Unit Increase in Average Daily Emissions)

Pollutant	Crude IRR* and 95%CI	P-Value	Adjusted IRR and 95%CI	P-Value
Total				
CO, ppb	1.02342 (0.99874 - 1.04872)	0.063	0.98682 (0.94723 - 1.02808)	0.526
SO_2, ppb	1.00477 (1.00072 - 1.00884)	0.021[a]	1.00531 (0.99951 - 1.01115)	0.073
O_3, ppb	1.00030 (0.99922 - 1.00138)	0.580	1.00103 (0.99761 - 1.00446)	0.555
NO, ppb	1.00371 (1.00230 - 1.00513)	< 0.001[a]	1.00335 (1.00010 - 1.00661)	0.043[a]
NO_2, ppb	1.00162 (0.99827 - 1.00499)	0.342	0.99643 (0.99120 - 1.00169)	00.184
NO_x, ppb	1.00239 (1.00120 - 1.00359)	< 0.001[a]	1.00268 (0.99932 - 1.00604)	0.117
PM_{10}, $\mu g/m^3$	0.99933 (0.99897 - 0.99969)	< 0.001[a]	0.99940 (0.99901 - 0.99980)	0.004[a]
Men				
CO, ppb	1.04496 (1.01090 - 1.08017)	0.009[a]	1.00741 (0.95153 - 1.06656 -	0.800
SO_2, ppb	1.00339 (0.99853 - 1.00827)	0.171	1.0046 (0.99753 - 1.01187)	0.200
O_3, ppb	0.99925 (0.99777 - 1.00073)	0.324	1.00574 (0.99856 - 1.00258)	0.576
NO, ppb	1.00368 (1.00197 - 1.00539)	< 0.001[a]	1.00081 (0.99682 - 1.00482)	0.688
NO_2, ppb	0.99979 (0.99731 - 1.00227)	0.869	0.99441 (0.98799 - 1.00088)	0.090
NO_x, ppb	1.00301 (1.00157 - 1.00445)	< 0.001[a]	1.00371 (0.99957 - 1.00787)	0.078
PM_{10}, $\mu g/m^3$	0.99935 (0.99890 - 0.99981)	0.005[a]	0.99922 (0.99877 - 0.99971)	0.002[a]
Women				
CO, ppb	0.97830 (0.94308 - 1.01484)	0.241	0.93152 (0.87552 - 0.99110)	0.025[a]
SO_2, ppb	1.00709 (1.00184 (1.01235)	0.008[a]	1.00904 (1.00137 - 1.01678)	0.021[a]
O_3, ppb	1.00197 (1.00039 - 1.00355)	0.015[a]	1.00529 (1.00313 - 1.00980)	0.004[a]
NO, ppb	1.00275 (1.00088 - 1.00462)	0.004[a]	1.00536 (1.00109 - 1.00964)	0.014[a]
NO_2, ppb	0.99792 (0.99429 - 1.00156)	0.264	1.00156 (0.99467 - 1.00851)	0.657
NO_x, ppb	1.00115 (0.99955 - 1.00275)	0.157	1.000421 (0.99609 - 1.00476)	0.849
PM_{10}, $\mu g/m^3$	0.99950 (0.99902 - 0.99998)	0.044[a]	0.99983 (0.99983 - 1.00036)	0.542

Abbreviation: IRR, incidence rate ratio.
[a] Statistically significant.

especially in the elderly and in the winter (12). Another study conducted on British individuals aged over 45 years, also found a significant relation between CO and cardiovascular deaths (13). In Tehran, studies found that the most important effect of CO was on the cardiovascular system and increase in cardiovascular deaths (14), and there was a significant relation between CO and the daily number of deaths among people aged over 64 years in Tehran (15). The

Table 4. The Results of Negative Binomial Regression of the Impact of Air Pollutants on Overall Daily Deaths in the Elderly Caused by Cardiovascular Diseases (Ratio of Increased Daily Mortality for Every Unit Increase in Average Daily Emissions)

Pollutant	Crude IRR* and 95%CI	P-Value	Adjusted IRR and 95%CI	P-Value
Total				
CO, ppm	1.05253 (1.01536 - 1.09106)	0.005[a]	1.07095 (1.01484 - 1.13016)	0.013[a]
SO_2, ppb	0.99981 (0.99429 - 1.00536)	0.948	1.00079 (0.99277 - 1.00889)	0.846
O_3, ppb	0.99927 (0.99764 - 1.00091)	0.387	1.00061 (0.99838 - 1.00284)	0.592
NO, ppb	0.99918 (0.99718 - 1.00118)	0.424	0.99418 (0.98931 - 0.99907)	0.020[a]
NO_2, ppb	1.00450 (1.00076 - 1.00825)	0.018[a]	1.00041 (0.99306 - 1.00781)	0.913
NO_x, ppb	1.00072 (0.99909 - 1.00235)	0.382	1.00315 (0.99838 - 1.00794)	0.195
PM_{10}, $\mu g/m^3$	0.99961 (0.99912 - 1.00010)	0.127	0.99943 (0.99888 - 0.99998)	0.043[a]
Men				
CO, ppm	1.043605 (0.99352 - 1.09621)	0.089	1.04287 (0.96880 - 1.12259)	0.264
SO_2, ppb	0.99966 (0.99229 - 1.00709)	0.929	1.00177 (0.99079 - 1.01286)	0.753
O_3, ppb	0.99955 (0.99724 - 1.00186)	0.704	1.00016 (0.99704 - 1.00329)	0.917
NO, ppb	0.99949 (0.99677 - 1.00223)	0.719	0.99344 (0.98693 - 1.00000)	0.050
NO_2, ppb	1.00368 (0.99850 - 1.00888)	0.164	0.997842 (0.98784 - 1.00793	0.674
NO_x, ppb	1.00132 (0.99911 - 1.00354)	0.239	1.00521 (0.99884 - 1.0116)	0.109
PM_{10}, $\mu g/m^3$	0.99961 (0.99891 - 1.00032)	0.289	0.99947 (0.99869 - 1.00025)	0.190
Women				
CO, ppm	1.02697 (0.97320 - 1.08372)	0.332	1.05912 (0.97875 - 1.14609)	0.154
SO_2, ppb	1.00617 (0.99755 - 1.01486)	0.161	1.00583 (0.99402 - 1.01777)	0.335
O_3, ppb	1.00617 (0.99807 - 1.00274)	0.732	1.00205 (0.998868 - 1.005249)	0.207
NO, ppb	0.99991 (0.99702 - 1.00281)	0.955	0.99972 (0.99269 - 1.00679)	0.939
NO_2, ppb	1.00430 (0.99894 - 1.00969)	0.116	1.00847 (0.99784 - 1.01920)	0.119
NO_x, ppb	1.00044 (0.99804 - 1.00284)	0.718	0.99862 (0.99183 - 1.00546)	0.693
PM_{10}, $\mu g/m^3$	1.00002 (0.99932 - 1.00072)	0.947	1.00018 (0.99941 - 1.00095)	0.641

Abbreviation: IRR, incidence rate ratio.
[a] Statistically significant.

present study also showed that CO could probably affect deaths among the elderly. However, we found no significant relation between CO and deaths caused by respiratory diseases, trauma, or diabetes in the elderly.

In this study, there was a relation between NO and total deaths in the elderly, especially women. However, the results of this study did not show a significant impact of nitrogen oxides on deaths caused by cardiovascular dis-

Table 5. The Results of Negative Binomial Regression of the Impact of Air Pollutants on Overall Deaths in the Elderly Caused by Respiratory Diseases (Ratio of Increased Daily Mortality for Every Unit Increase in Average Daily Emissions)

Pollutant	Crude IRR* and 95%CI	P-Value	Adjusted IRR and 95%CI	P-Value
Total				
CO, ppm	1.05663 (1.00238 - 1.11382)	0.041[a]	0.99477 (0.91734 - 1.07874)	0.899
SO_2, ppb	1.00368 (0.99590 - 1.01152)	0.354	1.00865 (0.99667 - 1.02077)	0.158
O_3, ppb	0.99727 (0.99478 - 0.99976)	0.032[a]	0.99806 (0.99468 - 1.00145)	0.262
NO, ppb	1.00369 (1.00090 - 1.00644)	0.009[a]	1.00157 (0.99423 - 1.00897)	0.675
NO_2, ppb	1.00388 (0.99844 - 1.00935)	0.162	0.99992 (0.98939 - 1.01057)	0.989
NO_x, ppb	1.00277 (1.00044 - 1.00510)	0.020[a]	1.00028 (0.99316 - 1.00745)	0.938
PM_{10}, $\mu g/m^3$	0.99971 (0.99897 - 1.00045)	0.444	0.99949 (0.99867 - 1.00031)	0.227
Men				
CO, ppm	1.05413 (0.98111 - 1.13258)	0.150	0.98564 (0.88279 - 1.10047)	0.797
SO_2, ppb	0.99802 (0.98609 - 1.0101	0.747	0.99465 (0.97883 - 1.01071)	0.512
O_3, ppb	0.99793 (0.99457 - 1.00131)	0.230	0.99997 (0.99538 - 1.00458)	0.991
NO, ppb	1.00343 (0.99978 - 1.00710)	0.065	1.00021 (0.99070 - 1.00981)	0.965
NO_2, ppb	1.003117 (0.99570 - 1.01058)	0.411	0.99856 (0.98463 - 1.01268)	0.841
NO_x, ppb	1.00286 (0.99975 - 1.00598)	0.071	1.00373 (0.99431 - 1.01324)	0.438
PM_{10}, $\mu g/m^3$	1.00005 (0.99909 - 1.00102)	0.908	1.00016 (0.99910 - 1.00122)	0.767
Women				
CO, ppm	1.01560 (0.93666 - 1.10118)	0.071	0.98661 (0.87605 - 1.11113)	0.824
SO_2, ppb	1.00425 (0.99283 - 1.01580)	0.467	1.00884 (0.99117 - 1.02682)	0.329
O_3, ppb	0.99870 (0.99508 - 1.00249)	0.519	0.997976 (0.9930014 - 1.00297)	0.427
NO, ppb	1.00174 (0.99742 - 1.00608)	0.429	0.99933 (0.98899 - 1.9776)	0.900
NO_2, ppb	0.99979 (0.99163 - 1.00802)	0.961	0.9940573 (0.97899 - 1.00935)	0.444
NO_x, ppb	1.00089 (0.99727 - 1.00451)	0.630	1.00041 (0.99053 - 1.01038)	0.935
PM_{10}, $\mu g/m^3$	0.99928 (0.99813 - 1.00042)	0.219	0.99921 (0.99794 - 1.00049)	0.230

Abbreviation: IRR, incidence rate ratio.
[a] Statistically significant.

eases, respiratory diseases, trauma, diabetes, or other diseases in the elderly. The results of a study on people aged 50 - 64 years in Denmark showed no significant relation between nitrogen dioxide (NO_2) and deaths caused by cardiac diseases, including myocardial infarction, angina pectoris, high blood pressure, and stroke and diabetes (16). However, the results of a study from Canada on people with an average age of 60 indicated a relation between all causes of death and NO_2 (17). Wong in China also showed a relation between NO_2 and deaths caused by cardiac diseases among hospital-admitted patients (18). Given the aforementioned controversies and inconsistencies, it seems that NO_2 and its association with mortality require further investigation.

The results of this study showed that SO_2 did not have a significant impact on deaths caused by respiratory diseases, trauma, and diabetes, as well as other diseases in the elderly. However, there was a significant relation between SO_2 and all deaths among elderly women. Interestingly, the aforementioned issue was not seen in elderly men. In a study conducted in Kerman, Iran increased SO_2 was significantly related to respiratory deaths in men (19) and was also associated with increased respiratory hospital admissions among women (20). However, in a study conducted

Table 6. The Results of Negative Binomial Regression of the Impact of air Pollutants on Overall Deaths in the Elderly (Men and Women) Caused by Trauma (Ratio of Increased Daily Mortality for Every Unit Increase in Average Daily Emissions)

Pollutant	Crude IRR[a] and 95%CI	P-Value	Adjusted IRR and 95%CI	P-Value
Total				
CO, ppm	0.92804 (0.84031 - 1.02494)	0.141	0.87778 (0.75154 - 1.02524)	0.100
SO_2, ppb	0.99915 (0.98549 - 1.01300)	0.904	0.99995 (0.97762 - 1.02279)	0.997
O_3, ppb	0.99999 (0.99595 - 1.00405)	0.999	0.99622 (0.99043 - 1.00203)	0.203
NO, ppb	0.99997 (0.99498 - 1.00498)	0.991	0.99992 (0.98532 - 1.01475)	0.992
NO_2, ppb	0.99324 (0.98380 - 1.00277)	0.164	0.99223 (0.97231 - 1.01257)	0.452
NO_x, ppb	0.99908 (0.99475 - 1.00343)	0.681	1.00025 (0.98591 - 1.01479)	0.973
PM_{10}, $\mu g/m^3$	0.99979 (0.99858 - 1.00101)	0.745	0.99946 (0.99806 - 1.00086)	0.451
Men				
CO, ppm	0.92107 (0.81819 - 1.03690)	0.174	0.90335 (0.74883 - 1.08974)	0.288
SO_2, ppb	0.99778 (0.97893 - 1.01699)	0.820	0.99750 (0.96807 - 1.02782)	0.870
O_3, ppb	1.00114 (0.99600 - 1.00631)	0.663	0.99784 (0.99039 - 1.00534)	0.573
NO, ppb	0.99782 (0.99169 - 1.00398)	0.488	1.00121 (0.98111 - 1.02172)	0.907
NO_2, ppb	0.99632 (0.98475 - 1.00802)	0.536	1.00356 (0.97831 - 1.02945)	0.785
NO_x, ppb	0.99772 (0.99243 - 1.00304)	0.401	0.99774 (0.97792 - 1.01796)	0.826
PM_{10}, $\mu g/m^3$	0.99996 (0.99845 - 1.0011146)	0.989	0.99947 (0.99772 - 1.00121)	0.553
Women				
CO, ppm	0.96500 (0.799205 - 1.16651)	0.711	0.92309 (0.70315 - 1.21183)	0.564
SO_2, ppb	1.00078 (0.9794024 - 1.022638)	0.943	1.00220 (0.96635 - 1.03938)	0.906
O_3, ppb	1.00112 (0.99442 - 1.00787)	0.743	0.99979 (0.99046 - 1.00921)	0.966
NO, ppb	1.00128 (0.99280 - 1.00982)	0.768	0.99413 (0.97200 - 1.01676)	0.608
NO_2, ppb	0.99385 (0.97696 - 1.01103	0.481	0.98418 (0.94982 - 0.01979)	0.379
NO_x, ppb	1.00093 (0.99348 - 1.00843)	0.806	1.00776 (0.98597 - 1.03003)	0.488
PM_{10}, $\mu g/m^3$	0.9999715 (0.99801 - 1.00193)	0.977	1.00001 (0.99773 - 1.00230)	0.987

Abbreviation: IRR, incidence rate ratio.
[a] Statistically significant.

in Beijing long-term exposure to SO_2 was not related to respiratory deaths (21). Similarly, in another study from Taiwan, there was no relation between SO_2 and respiratory deaths (12), and in Spain, there was no relation between SO_2 concentration and patients admitted to hospitals due to asthma attacks (22) either. This lack of relation was also reported in another study conducted in New York (23).

In the present study, there was a significant relation between ozone and total deaths in elderly women as well as total deaths caused by other diseases. However, the results of multivariate analysis indicated that ozone did not significantly correlate with elderly deaths caused by cardiovascular and respiratory diseases as well as trauma and diabetes. Another study from China indicated that there was no significant relation between ozone and deaths caused by respiratory diseases (18) either. Also, ozone concentration was not related to asthma attacks in Spain (22). In contrast, ozone was related to respiratory deaths in men in Kerman (24).

Apparently, PM_{10} did not increase the death of elderly people in Kerman, Therefore, more research should be conducted in this regard. Several mechanisms have been proposed about how PM may impact death, including pneumonia, exacerbation of atherosclerosis, changes in heart

Table 7. The Results of Negative Binomial Regression of the Impact of Air Pollutants on Overall Deaths in the Elderly (Men and Women) Caused by Diabetes (Ratio of Increased Daily Mortality for Every Unit Increase in Average Daily Emissions)

Pollutant	Crude IRR[a] and 95%CI	P-Value	Adjusted IRR and 95%CI	P-Value
Total				
CO, ppm	1.03085 (0.93750 - 1.33492)	0.530	0.97666 (0.83972 - 1.13592)	0.759
SO_2, ppb	1.00602 (0.99180 - 1.02044)	0.408	1.00168 (0.98161 - 1.02215)	0.871
O_3, ppb	1.99943 (0.99515 - 1.00373)	0.797	1.00021 (0.99441 - 1.00604)	0.943
NO, ppb	1.00263 (0.99781 - 1.00748)	0.284	1.00155 (0.99082 - 1.01239)	0.778
NO_2, ppb	1.00168 (0.99198 - 1.01147)	0.735	1.00018 (0.9819871 - 1.01871)	0.985
NO_x, ppb	1.00225 (0.99815 - 1.00636)	0.282	1.00213 (0.99178 - 1.01259)	0.687
PM_{10}, $\mu g/m^3$	1.00015 (0.99891 - 1.00140)	0.807	1.00010 (0.99874 - 1.00146)	0.880
Men				
CO, ppm	1.02578 (0.88247 - 1.19237)	0.740	0.99749 (0.79443 - 1.25246)	0.983
SO_2, ppb	1.00263 (0.97543 - 1.03058)	0.851	0.99846 (0.96648 - 1.0315)	0.926
O_3, ppb	0.99956 (0.99298 - 1.00618)	0.896	1.00048 (0.99133 - 1.00971)	0.918
NO, ppb	1.00379 (0.99633 - 1.01132)	0.320	1.00701 (0.98453 - 1.03001)	0.544
NO_2, ppb	1.000005 (0.98478 - 1.01546)	1.000	1.00378 (0.96681 - 1.042165)	0.844
NO_x, ppb	1.00225 (0.99590 - 1.00864)	0.488	0.997102 (0.97589 - 1.01878)	0.792
PM_{10}, $\mu g/m^3$	0.99971 (0.99776 - 1.00166)	0.771	0.9996 (0.99752 - 1.00185)	0.779
Women				
CO, ppm	1.00903 (0.89220 - 1.14116)	0.886	0.94555 (0.76995 - 1.16119)	0.593
SO_2, ppb	1.00594 (0.98900 - 1.023182)	0.494	1.00001 (0.97416 - 1.02654)	0.999
O_3, ppb	1.00005 (0.99448 - 1.00566)	0.984	0.99960 (0.99208 - 1.00717)	0.918
NO, ppb	1.000452 (0.994045 - 1.0069)	0.890	1.001361 (0.98887 - 1.01400)	0.832
NO_2, ppb	1.00195 (0.98942 - 1.01463)	0.761	1.00222 (0.98053 - 1.02437)	0.842
NO_x, ppb	1.00069 (0.99525 - 1.00615)	0.804	1.00145 (0.98931 - 1.01374)	0.815
PM_{10}, $\mu g/m^3$	1.00004 (0.99842 - 1.00166)	0.958	1.00007 (0.99832 - 1.00182)	0.934

Abbreviation: IRR, incidence rate ratio.
[a] Statistically significant.

function, inflammation of the air sacs, aggravation of lung diseases, increased blood clotting, increased blood viscosity, increased plasma fibrinogen, and changes in heartbeat (25).

However, it seems that further studies are still needed to determine the mechanism of its action. Inhalation of PM can cause oxidative stress and inflammatory responses in the lungs (26). Also, PM can penetrate into the lungs in the form of dust. Besides, they may pass through the lungs and enter blood circulation and reach other organs (27). In studies conducted in Taiwan, increased systolic and diastolic blood pressure was associated with increased annual average levels of $PM_{2.5}$ and PM_{10} (28). In another study conducted in China, a relation was seen between PM_{10} and the number of overall deaths, and the impact was more severe on people aged 45 to 65 years than younger people (25). Conversely, another study conducted in Taiwan found no significant relation between PM_{10} and respiratory deaths (12). Furthermore, a significant relation was seen between short-term changes in deaths and PM_{10} and $PM_{2.5}$ in several US cities (29). In a previous study in Kerman, PM_{10} significantly increased respiratory mortality among men (24).

Epidemiological studies conducted over the past two decades around the world have shown that the effects of

Table 8. The Results of Negative Binomial Regression of the Impact of Air Pollutants on Overall Daily Deaths in the Elderly (Men and Women) Caused by Other Diseases (Ratio of Increased Daily Mortality for Every Unit Increase in Average Daily Emissions)

Pollutant	Crude IRR and 95%CI	P-Value	Adjusted IRR and 95%CI	P-Value
Total				
CO, ppm	0.92516 (0.87798 - 0.97488)	0.004[a]	0.90067 (0.83224 - 0.97473)	0.009[a]
SO_2, ppb	1.00602 (0.99180 - 1.02044)	0.499	1.00401 (0.99366 - 1.014469)	0.499
O_3, ppb	1.00373 (1.00156 - 1.00591)	0.001[a]	1.00361 (1.00064 - 1.00658)	0.017[a]
NO, ppb	1.00263 (1.00006 - 1.00521)	0.048[a]	1.00257 (0.99664 - 1.00852)	0.396
NO_2, ppb	0.99281 (0.98772 – 0.99793)	0.006[a]	0.99813 (0.98852 - 1.00783)	0.705
NO_x, ppb	1.00225 (0.99815 - 1.00636)	0.646	1.00232 (0.99646 - 1.00821)	0.438
PM_{10}, $\mu g/m^3$	1.00015 (0.99891 - 1.00140)	0.300	1.00011 (0.99935 - 1.00087)	0.769
Men				
CO, ppm	0.95237 (0.89012 - 1.01897)	0.157	0.96411 (0.86908 - 1.06953)	0.490
SO_2, ppb	1.00280 (0.99266 - 1.011224)	0.688	1.00592 (0.99229 - 1.01973)	0.396
O_3, ppb	1.00280 (0.99986 - 1.00575)	0.061	1.00243 (0.99840 - 1.00646)	0.237
NO, ppb	1.00147 (0.99805 - 1.00490)	0.399	1.00295 (0.99420 - 1.01178)	0.509
NO_2, ppb	0.99439 (0.98767 - 1.00116)	0.105	0.99895 (0.98548 - 1.01261)	0.880
NO_x, ppb	0.99969 (0.99673 - 1.00267)	0.842	0.99833 (0.98963 - 1.00711)	0.709
PM_{10}, $\mu g/m^3$	0.99954 (0.99861 - 1.00046	0.329	0.99969 (0.99868 - 1.00071)	0.558
Women				
CO, ppm	0.944729 (0.87199 - 1.02353)	0.164	0.95721 (0.84999 - 1.07796)	0.471
SO_2, ppb	0.99669 (0.98410 - 1.00944)	0.609	0.99577 (0.97993 - 1.01187)	0.605
O_3, ppb	1.00391 (1.00061 - 1.00722)	0.020[a]	1.00446 (0.99996 - 1.00898)	0.052
NO, ppb	1.00002 (0.99617 - 1.00387)	0.991	0.99952 (0.99094–1.00818)	0.914
NO_2, ppb	0.99469 (0.98700 - 1.00245)	0.180	0.99727 (0.98320 - 1.01154)	0.707
NO_x, ppb	0.99934 (0.99600 - 1.00270)	0.703	1.00331 (0.99492 - 1.01177)	0.440
PM_{10}, $\mu g/m^3$	0.99993 (0.99889 - 1.00096)	0.897	1.00061 (0.99949 - 1.00174)	0.281

Abbreviation: IRR, incidence rate ratio.
[a]Statistically significant.

air pollution on human health and deaths associated with air pollution are on the rise (30).

Kerman City encounters sand storms in the spring and autumn (31). Also, several stone, sand, and gravel crushing plants, as well as asphalt plants, operate around the city, which contribute to this city's air pollution. Therefore, it seems essential to pay particular attention to vulnerable groups, particularly the elderly on days with high air pollution. Suitable planning such as reducing elders' commuting time on high air pollution days can help prevent mortality. Table 9 presents the results of several studies conducted in various regions around the world about the effect of air pollution on mortality in the elderly. Similar to the findings of our study, some other studies also suggest that air pollution can contribute to increased cardiovascular and respiratory mortality in the elderly.

5.1. Conclusions

It seems among the elderly, cardiovascular diseases are more vulnerable to air pollution than others. Carbon monoxide, nitrogen oxide, and sulfur dioxide may play an important role in elderly deaths. A warning system to reduce elders' commuting on high air pollution days is suggested.

Table 9. A Summary of Studies Conducted in Various Regions Around the World on the Effect of Air Pollution on Mortality in the Elderly

ID	Year	Country/Region	Results
Fischer et al. (32)	2003	Netherlands	The study showed that the pollutants PM_{10}, BS, and SO_2, NO_2 and CO increase the risk of mortality, especially in the elderly (individuals with 65 - 74 and higher than or equal to75 years of age).
Daumas et al. (33)	2004	Brazil	The study showed that an increase in total suspended particles (TSP) levels from the 10th to the 90th percentile (104.7 $\mu g/m^3$) increase the risk for mortality in elderly people from cardiovascular and respiratory diseases.
Filleul et al. (34)	2004	Bordeaux	The study showed that an increase of 10 mug/m^3 of black smoke increased the risk of cardiorespiratory mortality among the elderly (odds ratio = 1.30, 95% CI: 1.01 - 1.68).
Enstrom (35)	2005	California	The study showed that for the initial period, 1973 - 1982, a 10-mu g/m^3 increase in $PM_{2.5}$ increased risk of mortality in the elderly RR (1.04, 1.01 - 1.07). However, this risk was no longer present for the subsequent period, 1983 - 2002. The findings presents no current relation between fine particulate pollution and total mortality in elderly Californians, but they do not rule out a small effect, particularly before 1983.
Cakmak et al. (36)	2007	Chile	The study shows that for elderly above the age of 85 years, the percentage increases in non - accidental mortality associated with an increase in PM_{10} equivalent to its mean was 14.03 (3.87), for O_3 8.56 (2.02), for SO_2 7.92 (3.23); and for CO 8.58 (4.45). Results suggested that the very elderly are particularly vulnerable to dying from air pollution.
Halonen et al. (37)	2009	Finland	The study indicated an association of hospital admissions for arrhythmia with Aitken mode particles and $PM_{2.5}$ from traffic. There were also positive associations between most particle fractions with admissions for pneumonia and asthma - chronic obstructive pulmonary disease (COPD). All particle fractions namely Aitken, accumulation, and coarse mode caused adverse respiratory health effects in the elderly. Generally, associations were stronger for respiratory compared to cardiovascular consequences.
Jimenez et al. (38)	2011	Madrid (Spain)	The study indicated that in the elderly coarser PM fractions (PM_{10} and $PM_{10-2.5}$) is associated with respiratory - specific mortality, and $PM_{2.5}$ is related to cardiovascular - specific mortality. In addition, compared to winter, the risk of mortality due to exposure to particulate matter was greater in summer.
Krstic (39)	2011	Vancouver	Findings showed a very weak negative association between air pollution and the elderly's mortality.
Goldberg et al. (8)	2013	Montreal, Quebec	The study found that daily non-accidental mortality among the elderly is positively associated with all air pollutants except ozone, especially amongst elderly persons having cardiovascular diseases, congestive heart failure, and diabetes. It was also suggested that individuals with certain health conditions, especially those with diabetes and cardiovascular diseases, hypertension, atrial fibrillation, and cancer, might be vulnerable to the short-term effects of air pollution.
Vanos et al. (40)	2013	Canada	The study revealed that weather type had the greatest modifying effect on the risk of dying due to ozone in the entire elderly population. This effect was the highest on average for the dry tropical (DT) weather type. All-weather type risk estimates increased with age due to exposure to carbon monoxide (CO), nitrogen dioxide (NO_2), and Sulphur dioxide (SO_2). For all weather types increased levels of air pollution were found to have adverse health effects for elderly individuals. Air pollution on the hot dry (DT) and hot humid (MT) days had negatively affected the entire population.
Yang et al. (6)	2018	Hong Kong	The study revealed that long - term exposure to ambient $PM_{2.5}$ and black carbon (BC) caused an elevated risk of cardiovascular mortality in elderly with the age of equal and greater than 65.
Yap et al. (7)	2019	Singapore	The study indicated that in single - day lag models, every 10 $\mu g/m^3$ rise in particulate matter increases non - accidental and cardiovascular mortality in the elderly. This was significant in the elderly $\geq$ 65 years and were seen in the acute phase of lag 0 - 5 days.
Dalecka et al. (41)	2021	Germany	The study revealed that after adjusting for reduced lung function and additional covariates, long - term exposures to NO_x and NO_2 were associated with increased risks of cardio - pulmonary mortality (CPM) among elderly women. The mediation analysis showed significant indirect effects of NO_2 and NO_x on CPM mediated through reduced FEV1 and FVC. The largest indirect effects were found for exposures to NO_2 and NO_x mediated through reduced FVC.

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Footnotes

Authors' Contribution: NK conceived the idea and supervised the research. ZA inquired the data and did the analysis. MM provided scientific support. NK and ZA wrote the final manuscript. All authors read and approved the final manuscript.

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