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Research Article

Relationship Between Air Pollution, Weather, Traffic, and Traffic-Related Mortality

Maryam Dastoorpoor,[1] Esmaeil Idani,[2] Narges Khanjani,[3,*] Gholamreza Goudarzi,[4] and Abbas Bahrampour[5]

[1]Neurology Research Center, Department of Biostatistics and Epidemiology, School of Public Health, Kerman University of Medical Sciences, Kerman, IR Iran
[2]Department of Internal Medicine, Faculty of Medicine, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, IR Iran
[3]Environmental Health Engineering Research Center, Kerman University of Medical Sciences, Kerman, IR Iran
[4]Air Pollution and Respiratory Diseases Research Center, Environmental Technologies Research Center (ETRC), Ahvaz Jundishapur University of Medical Sciences, Ahvaz, IR Iran
[5]Modeling in Health Research Center, Institute for Futures Studies in Health, Department of Biostatistics and Epidemiology, Faculty of Health Kerman Univesity of Medical Sciences Kerman, IR Iran

[*]*Corresponding author*: Narges Khanjani, Department of Epidemiology and Biostatistics, Faculty of Public Health, Kerman University of Medical Sciences, Kerman, IR Iran. Tel: +98-03431325102, E-mail: n_khanjani@kmu.ac.ir

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Abstract

Background: Air pollution and weather are just two of many environmental factors contributing to traffic accidents (RTA).
Objectives: This study assessed the effects of these factors on traffic accidents and related mortalities in Ahvaz, Iran.
Methods: In this ecological study, data about RTA, traffic-related mortalities, air pollution (including NO, CO, NO_2, NO_x PM_{10}, SO_2, and O_3 rates) and climate data from March 2008 until March 2015 was acquired from the Khuzestan State Police Force, the Environmental Protection Agency and the State Meteorological Department. Statistical analysis was performed with STATA 12 through both crude and adjusted negative binomial regression methods.
Results: There was a significant positive correlation between increase in the monthly average temperature, the number of rainy days, and the number of frost days with the number of RTA ($P < 0.05$). Increased monthly average relative humidity, evaporation, and number of sunny days were negatively correlated with the frequency of RTA ($P < 0.05$). We also observed an inverse significant correlation between monthly average relative humidity, evaporation, and wind speed with traffic accident mortality ($P < 0.05$). Some air pollutants were negatively associated with the incidence rate of RTA.
Conclusions: It appears that some weather variables were significantly associated with increased RTA. However, increased levels of air pollutants were not associated with increased rates of RTA and/or related mortalities. Additional studies are recommended to explore this topic in more detail.

Keywords: Air Pollution, Weather, Traffic Accidents, Mortality

1. Background

Traffic accidents (RTA) impose serious medical, economical, and human costs on society (1). Injuries and deaths caused by car accidents are a major public health issue (2). As reported by the world health organization (WHO) in 2013, about 1.24 million deaths occur on the world's roads each year (3). In addition, it is predicted that RTA are going to be the second or third leading cause of death in high- and middle-income countries, and by 2020, car accident mortality could reach up to two million people in the world, and developing countries will suffer a considerable share of these mortalities (2, 4, 5). Iran is reported as one of the countries with the highest number of deaths caused by RTA (5). Annually, an average of about 30 per 100,000 people die because of RTA, which is much higher than the world average (22.6 per 100,000), and also higher than the rate of the Eastern Mediterranean Region (13.9 per 100,000) (5, 6). Traffic-related death is considered to be the second-leading cause of death in Iran, and comprises 10.3% of all reported deaths, which is almost five times the global average (2.1%) (6).

Therefore, it is necessary to understand the various factors that may cause RTA. Although a considerable number of studies have been published on this topic, more information is still needed about the various factors causing traffic crashes in order to provide a better method of managing them (1). Fortunately, over the past few decades, several studies about the various factors influencing RTA have been conducted in other parts of the world (7).

The various factors that can affect the incidence rate of traffic accidents may be inevitable, but many are preventable. For instance, Older and Spicer believe that a traffic accident is the result of three combined influences: human, environmental, and road (8). Some of the environmental factors influencing safe and sustainable urban transport include air pollution and weather variables such as storms, frost, snow, rain, fog, and general temperature fluctuations. A literature review showd that only a few studies have considered the effects of weather variables on RTA mortality (9-11). Weather parameters have a well-established relationship to RTA, involving such conditions as rain, snow, temperature, and wind speed (1). However, it seems as though the impact of some other factors, such as ambient air pollutants, on RTA and mortality has not been adequately studied. Furthermore, most of the previous studies are limited to accidents on rural expressways and highways, whereas urban and suburban accidents have yet not been studied (12). The reason may be that considering the effects of weather variables and air pollution on RTA is a relatively new concern. This is illustrated by the fact that for the first time in 1960, when planning a transit road between Liverpool and Hall, local weather was considered as a relevant factor, and later, this led to the more general study of weather variables before planning new roads in England (13). In recent years, determining the effects of various weather factors on the risk, severity, and frequency of RTA has attracted a lot of attention (14). There is no doubt that weather variables (e.g., frost, fog, rain, and dust), either directly or indirectly along with other environmental components, play an important role in RTA (1).

One study conducted about the relationship between climate factors and RTA was developed by Edwards, who studied the relationship between weather variables and car accidents in Wales, England. The results showed a significant increase in the severity and frequency of RTA in rain and fog conditions as compared to those with clear weather variables (14). Along similar lines, Usman et al. studied some of the other relevant factors, including rainfall intensity, visibility, temperature, and wind speed. They reported that low visibility, wet roads, high-speed winds, and low temperatures could substantially increase RTA frequency (10). Another study by Mahmoudi in Iran (on Sanandaj-Hamedan intercity roads) found that high-speed winds, frost, and snowfall play major roles in the incidence rates of RTA (15). However, a study in Ardebil showed that most accidents occurred on clear and sunny days, and that crashes increased with rising temperature, and that foggy days had the lowest number of RTA (16).

The oil and gas, and the industrial effects of the petrochemical and steel industry have caused Ahvaz to become more vulnerable to natural and artificial air pollution (17). The most common and the most toxic pollutants in Ahvaz are CO and PM_{10}; even though CO levels have dropped by about 25% compared to 2008, PM_{10} levels are still a concern due to micro-dust from western borders.

2. Objectives

Since pollution and weather variables can affect RTA incidence and mortality rates, we aimed to study the effects of these factors on traffic crashes and related mortalities in Ahvaz, Iran. Interestingly, despite being one of the most polluted cities in the world (18), there have not been any studies addressing the effects of air pollutants and weather variables on traffic crashes in Ahvaz.

3. Methods

This ecological study was based on recorded data from March 2008 until March 2015 in Ahvaz, Iran. Monthly data about urban RTA were obtained from the applied research office of the police force of Khuzestan province, categorized in terms of age, gender (of the guilty driver), and time of the accident. Data was obtained from the Khuzestan province's forensic medicine office.

Ambient air pollution data was acquired from the Khuzestan province environmental protection agency for seven major pollutants: (1) particulate matter less than 10 μm (PM_{10}), (2) nitrogen monoxide (NO), (3) nitrogen dioxide (NO_2), (4) nitrogen oxides (NO_x), (5) carbon monoxide (CO), (6) sulfur dioxide (SO_2), and (7) ozone (O_3). PM_{10} was the only type of particulate matter which has been recorded at the air quality monitoring stations over the years.

Data on means; max and min temperatures; average relative humidity; number of sunny, rainy and frost days; total evaporation; wind speed; and wind direction were collected from the meteorological organization of the Khuzestan province. Monthly traffic crash incidents and traffic-related mortalities were matched with monthly averages of air pollution and weather data.

Quantitative descriptive analysis was used to describe the damage, injury, and death rates caused by urban traffic crashes, while accounting for the pollutant levels and weather data. Initially, the Poisson regression assumptions were checked. According to a goodness-of-fit test, the distributions did not follow the Poisson distribution ($P < 0.001$). The relation between traffic crash incidents, traffic-related mortality, and monthly average air pollution and weather factors was analyzed using a negative binomial regression. All statistical analysis was performed using STATA 12, and a value of $P < 0.05$ was considered significant.

4. Results

A total of 76,006 traffic crashes were recorded by the police force of Khuzestan province between March 2008 to March 2015, which can be divided into three groups of property damage (71.6%), injury (27.7%), and death (0.7%). Most guilty drivers were men (96.6%) in the age range of 25 - 35 years (39.5%). Most traffic crashes had occurred between 6 - 12 a.m. (40.7%) and in the spring (27.8%). Moreover, as reported by forensic medicine, a total of 1,013 deaths were caused by urban traffic crashes in the previous seven years, with an average of 12.05 $\pm$ 4.2, and a minimum of three and maximum of 24 deaths per month (see Table 1).

A summary of air pollution data has been provided in Table 2. Clearly, PM_{10} is the major air pollutant with varying values for each season. The average value of this pollutant has been over 200 $\mu g/m^3$. During the study interval, PM_{10} rates were in the good range (0 - 50 $\mu g/m^3$) for 2.1%, in the moderate range (51 - 100 $\mu g/m^3$) for 15.7%, in the unhealthy range for sensitive groups (50 - 101 $\mu g/m^3$) at 26.5%, unhealthy for everyone (151 - 200 $\mu g/m^3$) at 20.8%, very unhealthy (201 - 300 $\mu g/m^3$) for 17.1%, and in the hazardous range (301 - 500 $\mu g/m^3$) for 10.7% of the days. Also, in 7.2% of the days, it has been in the 501 - 4498 $\mu g/m^3$ range.

The results of the negative binomial regression showed that O_3, PM_{10}, NO, NO_2, and NO_X concentrations were inversely associated with the incidence rate of traffic crashes. After adjustments for the effects of confounding factors, O_3, NO_2, and NO_X levels were still significantly associated with the frequency of RTA (Table 3).

Our results also showed that traffic crashes were positively correlated with monthly average temperature and the number of frost days, while negatively correlated with average relative humidity. When adjusted for the effects of confounding factors, average relative humidity, evaporation, and the number of sunny days were inversely correlated with the results, whereas monthly average temperature and number of rainy and frost days were positively correlated with the frequency of RTA (Table 3).

We observed a significant inverse relation between fatal accidents and NO and NO_2 concentrations. Adjusting for the effects of the confounding factors, O_3, PM_{10}, NO_2, and CO concentrations were inversely correlated with the rates of fatal accidents (Table 4).

Ultimately, our analysis showed that there was no significant association between climate factors and mortality. However, after adjusting for the effects of confounding factors, average relative humidity, monthly evaporation, and wind speed appeared to be inversely associated with mortality (Table 4).

Table 1. Characteristics of Traffic Crashes in Ahvaz from March 2008 to March 2015

Variable	No. (%)
Type of traffic crash	
Damage	54438 (71.6)
Injury	21047 (27.7)
Death	521 (0.7)
Total	76006 (100)
Age groups (year)	
Under 18 years	380 (0.5)
18 - 25	7601 (10)
26 - 30	15581 (20.5)
31 - 35	14441 (19)
36 - 40	11781 (15.5)
41 - 45	8361 (11)
46 - 50	7221 (9.5)
51 - 60	8361 (11)
61 - 70	1900 (2.5)
71 - 80	380 (0.5)
Total	76006 (100)
Sex	
Male	73464 (96.6)
Female	2542 (3.4)
Total	76006 (100)
Time of day	
24 - 6 (Morning)	3530 (4.6)
6 - 12 (Morning)	30959 (40.7)
12 - 18 (Afternoon)	20844 (27.4)
18 - 24 (Night)	20673 (27.2)
Total	76006 (100)
Season	
Spring	21141 (27.8)
Summer	19906 (26.2)
Fall	18246 (24)
Winter	16713 (22)
Total	76006 (100)

5. Discussion

RTA are one of the most important problems of modern societies, and include many social, economic, and health-related issues. The present study addressed the effects of weather and air pollution on urban RTA and traffic-related mortality rates in Ahvaz, Iran.

Table 2. Descriptive Indices of Air Pollutants and Climate Factors in Ahvaz from March 2008 to March 2015

Variable (Mean per month)	Mean	Median	Minimum	Maximum	SD
O_3 (ppm)	0.062	0.021	0.007	2.064	0.280
PM_{10} ($\mu g/m^3$)	237.15	162.50	25	4498	289.81
NO (ppm)	0.019	0.017	0.003	0.066	0.012
NO_2 (ppm)	0.021	0.017	0.002	0.081	0.016
NO_x (ppm)	0.037	0.035	0.006	0.134	0.022
CO (ppm)	1.319	1.000	0.100	9.100	1.499
SO_2 (ppm)	0.021	0.016	0.001	0.096	0.019
Temperature (°C)	26.7	27.1	11.6	39.5	9.1
Minimum temperature (°C)	19.7	20	18.8	20.4	0.6
Maximum temperature (°C)	33.6	33.9	32.6	34.3	0.6
Relative humidity (%)	43.1	41.0	19	77	15.8
Total rainfall (mm)	14.0	2.4	0	113	23.4
Total sunshine (hours)	256.4	253.2	144	374	62.6
Total evaporation (mm)	264.7	255.2	41	541	161.3
Wind speed (m/s)	11.5	10.0	7	44	5.3
Wind direction (°)	227.2	270.0	42	350	82.6

Table 3. Results of crude and adjusted negative binomial regression, and the effects of pollutants and weather variables on traffic crashes (ratio of increase in traffic crashes per month to unit of increase in pollutants and weather variables per month on average)

Variables	Crude IRR* and 95% CI	P	Adjusted IRR* and 95% CI	P
O_3 (ppm)	0.99825 (0.99746 - 0.99903)	< 0.001[a]	0.99884 (0.99806 - 0.99961)	0.004[a]
PM_{10} ($\mu g/m^3$)	1.00124 (1.00032 - 1.00217)	0.008[a]	0.99974 (0.99895 - 1.00052)	0.519
NO (ppm)	0.97420 (0.967008 - 0.98145)	< 0.001[a]	0.99452 (0.98308 - 1.0060)	0.352
NO_2 (ppm)	0.98062 (0.97444 - 0.98683)	< 0.001[a]	0.98929 (0.9803171 - 0.9983392)	0.020[a]
NO_x (ppm)	0.98698 (0.98270 - 0.99128)	< 0.001[a]	0.99264 (0.98807 - 0.99722)	0.002[a]
CO (ppm)	1.00003 (0.99994 - 1.00011)	0.483	0.99996 (0.99990 - 1.00002)	0.267
SO_2 (ppm)	0.99746 (0.9910563 - 1.003902)	0.439	0.99725 (0.99229 - 1.00223)	0.280
Temperature (°C)	1.01213 (0.99967 - 1.02475)	0.040[a]	1.02910 (1.01010 - 1.06745)	0.044[a]
Relative humidity (%)	0.98939 (0.98283 - 0.99598)	0.002[a]	0.97280(0.95550 - 0.99041)	0.003[a]
Total evaporation(mm)	1.00047 (0.99976 - 1.00118)	0.192	0.99759 (0.99545 - 0.99973)	0.027[a]
Sunny days (number in month)	0.99961 (0.99765 - 1.00156)	0.696	0.99646 (0.99295 - 0.99998)	0.040[a]
Rainy days (number in month)	0.99696 (0.99239 - 1.00155)	0.195	1.00312 (1. 00112 - 1.00799)	0.043[a]
Frost days (number in month)	1.17526 (1.12526 - 2.46156)	0.004[a]	1.09876 (1.05877 - 1.92172)	0.021[a]
Wind speed (m/s)	1.01331 (0.99186 - 1.03523)	0.226	1.00088 (0.98520 - 1.01680)	0.913

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

There are four air quality monitoring stations in Ahvaz, including the environmental protection agency station, the Naderi Square station, the university square station, and meteorological organization station. According to the environmental protection agency experts, the air quality monitoring stations' locations were representative of the

Table 4. Results of crude and adjusted negative binomial regression analyses, and the effects of pollutants and weather variables on traffic-related mortality (ratio of increase in traffic-related mortality per month and per unit of increase for pollutants and weather variables based on monthly averages)

Variables	Crude IRR* and 95% CI	P	Adjusted IRR* and 95% CI	P
O_3 (ppm)	0.99967 (0.99906-1.00028)	0.296	0.99933 (0.99868-0.99997)	0.043[a]
PM_{10} (μ g/m^3)	0.99973 (0.99914-1.00033)	0.392	0.99910 (0.99846-0.99974)	0.006[a]
NO (ppm)	0.99238 (0.98574-0.99907)	0.026[a]	1.00813 (0.99838-1.01797)	0.102
NO_2 (ppm)	0.99026 (0.98473-0.99583)	0.001[a]	0.98702 (0.97931-0.99480)	0.001[a]
NO_x (ppm)	0.99821 (0.99432-1.00211)	0.370	0.99852 (0.99438-1.00267)	0.485
CO (ppm)	0.99996 (0.99990-1.00001)	0.193	0.99993 (0.99988-0.99998)	0.011[a]
SO_2 (ppm)	1.00084 (0.99636-1.00533)	0.713	1.00039 (0.99659-1.00420)	0.840
Temperature (°C)	0.99786 (0.98975-1.00605)	0.609	1.01064 (0.98371-1.03831)	0.442
Relative humidity (%)	0.99891 (0.99418-1.00366)	0.653	0.97761 (0.96319-0.99225)	0.003[a]
Total evaporation(mm)	0.99979 (0.99933-1.00026)	0.391	0.99789 (0.99620-0.99958)	0.015[a]
Sunny days (number in month)	0.99949 (0.99829-1.00069)	0.408	0.99982 (0.99724-1.00240)	0.893
Rainy days (number in month)	0.99936 (0.99617-1.00256)	0.695	1.00139 (0.99707-1.00572)	0.528
Frost days (number in month)	1.20466 (0.76509-1.89675)	0.421	1.00750 (0.67360-1.50691)	0.971
Wind speed (m/s)	0.98857 (0.97385-1.00351)	0.133	0.98446 (0.97068-0.99844)	0.030[a]

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

ambient air quality of the whole city. Ahvaz, with an area of 8,152 square kilometers and the capital city of Khuzestan province, is located between the 48th degree to the 49th degree east of the Greenwich meridian, and between 31 degrees and 45 minutes north of the equator (19). According to the 2011 census, Ahvaz has 286,032 households and 1,056,589 residents (20).

Our results indicated that most urban traffic crashes among drivers were within the age range of 25 - 35 years, which is roughly consistent with previous studies. It seems like people involved in traffic crashes are mostly young adults. This group is the most active group in society, and therefore their loss imposes high economical costs on the society.

In this study, men were more involved in urban traffic crashes than women. Previous studies have also pointed out that more men are involved in RTA than women (21-25). The reason may be that male drivers are more often engaged in dangerous driving in comparison to females (2, 4, 26).

Our findings showed an inverse and significant association between concentrations of O_3, NO_2 and NO_X with urban traffic crashes. Likewise, we observed an inverse and significant association between concentrations of O_3, PM_{10}, NO_2 and CO with traffic crash mortality. Furthermore, weather variables such as relative humidity and evaporation were inversely associated with mortality, whereas numbers of sunny and clear days were inversely associated with traffic crashes.

In line with these results, other studies have also observed an inverse association between weather variables and the incidence rate, risk, and severity of traffic crashes (13, 27-32). For instance, in a study in Riyadh, Saudi Arabia, monthly RTA records for seven years were evaluated. It was ultimately determined that RTA were inversely correlated with relative humidity, evaporation, snowfall, and hail (32). It is also worth noting that in a study, by Fridstrøm et al. in 1995 in Denmark, RTA decreased by 1.2% per one day increase in the number of frost and snow days (30).

In Greece, Karlaftis and Yannis showed that increases in rainfall reduced the incidence rates of RTA, traffic-related mortality, pedestrian-involved crashes, and pedestrian mortality. These results are in conflict with many previous studies where rainfall increased RTA. Researchers think that the reason may be based on the safety-offset hypothesis, which suggests that drivers practice more caution and less speedy-driver behavior in conditions which they believe may dangerous, as southern European drivers are not used to driving in rain (13).

Bergel-Hayat et al. showed that on interurban roads (unlike highways outside the city), RTA were inversely related to weather variables such as rain. These researchers argued that reduced traffic volume and hence reduced exposure are the reasons for the lower number of RTA during rainfalls (27). In addition, Aguero-Valverde and Jovanis in Pennsylvania, USA, concluded that although there is a linear relationship between rainfall and an increased number of RTA using negative binomial models, no statistically significant relationship was observed using Bayesian hierarchical models (28). It therefore seems as though the relation between weather variables and RTA is highly dependent upon both the geographical features of the region and the local perceptions of extreme weather and dangerous conditions. Presumably, this is the reason for conflicting reports in the literature (1).

Other studies, such as those by Andrey and Yagar (1993) and Khattak et al. (1998), have also mentioned driver compensation in extreme weather conditions (33, 34).

In this study, we found a positive correlation between average temperature rates and the frequency of RTA. This result is consistent with the results of a study by Bergel-Hayat et al., where average temperature was correlated with the incidence rates of traffic crashes in France, the Netherlands, and Athens (27). These researchers observed that per one degree centigrade increase in average temperature, the incidence rate of monthly traffic crashes increased by 1 - 2% (27). Along similar lines, Karlaftis and Yannis reported that daily temperature increases could result in increased numbers of total RTA, traffic injuries, and pedestrian accidents (13). Nofal and Saeed stated that in Saudi Arabia, RTA are more frequent in the summer between noon and 3 p.m. when there is fierce sunlight, heavy traffic, and an average temperature of 42° C. In a study by Ranandeh Kalankesh et al. conducted in Kerman, Iran, it was reported that traumatic death happens more often in hot seasons, and the strongest association between temperature and traumatic death was seen in those aged 60 and over (35).

In this study, rainy and frosty days were associated with more accidents. Several studies have shown that rain and snowfall increase the incidence of RTA (30, 33, 36-40). For example, Andreescu and Frost showed that snow and frost days are the most important weather factors contributing to traffic problems, and snow can greatly increase the incidence of traffic crashes (40). In accordance with our findings, Eisenberg and Warner showed that snow leads to more non-fatal traffic crashes than fatal RTA (36). In the same vein, Andrey and Yagar maintain that the increased risk created by rain, snow, and frost is due to a combination of the slippery road conditions, low friction, low visibility, and light reflection from the road surface during nighttime conditions. Even if the driver adjusts his or her perception and vehicle conditions to the wet road, the risk of crash is still high because of low visibility (33).

Our results also suggested an inverse correlation between wind speed and traffic crash-related mortalities. Our results were in contrary with those of Hermans et al., which indicated that hurricanes and prolonged rainfall are directly related to an increased risk of traffic crashes in the Netherlands (41). Similarly, Baker and Reynolds reported that hurricanes in the UK increased traffic crash rates from 50% to 66% (42). Overall, the effects of wind speed have not been well studied in the literature, and only a few studies have addressed it in relation to traffic crashes (41-44). Furthermore, most studies do not agree that wind speed can increase the incidence and/or mortality rates of traffic crashes (1). Further studies are therefore required to assess the possible effects of wind speed.

5.1. Conclusions

Overall, the findings here suggest that some weather variables such as temperature and rainy and frosty days can substantially increase the risk of traffic crashes.

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Footnotes

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