Vital Surveillances

The Relationship Between the Atmospheric Environment and Road Traffic Fatalities — Shandong Province, China, 2012–2021

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ABSTRACT

Introduction: This study aims to analyze the potential impact of the meteorological environment and air pollutants on road traffic fatalities.

Methods: Road traffic fatality data in Shandong Province from 2012 to 2021 were obtained from the Population Death Information Registration Management System. Meteorological and air pollutant data for the same period were collected from the U.S. National Oceanic and Atmospheric Administration and the Ecological Environment Monitoring Center of Shandong Province, China. Pearson's correlation and ridge regression were used to analyze the impact of the meteorological environment and air pollutants on road traffic fatalities.

Results: From 2012 to 2021, there were 163,863 road traffic fatality cases. The results of the ridge regression analysis showed that the daily average temperature was negatively correlated with total fatalities and passengers and positively correlated with pedestrians, nonmotorized drivers, and motorized drivers. The daily minimum temperature was negatively correlated with total fatalities and positively correlated with motorized drivers. The daily maximum temperature was positively correlated with both pedestrian and nonmotorized drivers. The daily accumulated precipitation was negatively correlated with pedestrians. Sunshine duration was positively correlated with both nonmotorized and motorized drivers. Inhalable particulate matter (PM_{10}) and nitrogen dioxide (NO_2) were positively correlated with total fatalities, pedestrians, and nonmotorized drivers. Sulfur dioxide (SO_2) was positively correlated with total fatalities but negatively correlated with nonmotorized drivers, passengers, and motorized drivers.

Conclusions: Atmospheric factors associated with the occurrence of road traffic fatalities include air temperature, daily accumulated precipitation, sunshine duration, and air pollutants such as PM_{10}, NO_2, and SO_2.

Road traffic accidents are incidents that occur on a road or highway and involve at least one moving vehicle, resulting in injuries, property damage, or loss of life (*1*). The current global annual death toll from road traffic accidents is approximately 1.3 million people. Moreover, road traffic accidents have emerged as the primary cause of death for children and young adults globally (*2*). Road traffic accidents in China result in more than 250,000 deaths annually, accounting for approximately 19% of the total deaths worldwide(*3*). Investigating the potential factors influencing road traffic accidents is essential for reducing and preventing them.

Road traffic accidents involve three elements: humans, vehicles, and the environment. Meteorological conditions, including sunshine duration, precipitation, and high temperatures, contribute to road traffic accidents (*4*). Meteorological conditions directly impact the friction between vehicle tires and the road surface while also indirectly influencing drivers' emotions, perceptions, and behavior (*5*). Although it may seem that there is no relationship between air pollution and traffic accidents, haze caused by air pollution reduces visibility, which can lead to limited visibility. Moreover, air pollutants can cause both immediate injuries and long-term hazards to human health. Previous research (*6*) has suggested that air pollutants directly stimulate drivers' eyes, resulting in redness and pain, as well as headaches due to long-term effects. Therefore, exploring the impact of the meteorological environment and air pollutants on road traffic fatalities is critical for reducing road traffic accidents.

METHODS

Data on road traffic fatalities in Shandong Province were obtained from the Population Death Information Registration Management System of the Chinese Centers for Disease Control and Prevention during the period of death from January 2012 to December 2021. According to the cause of death classification and coding range of the International Classification of Diseases 10th Revision (ICD-10) in the Technical Guidance for Reporting Cause of Death, road traffic accident data that were included in the analysis were divided into four subgroups: pedestrian, nonmotorized driver, passenger, and motorized driver.

The atmospheric environmental data were divided into two parts: meteorological data and air pollution data.

The meteorological data of Shandong Province were obtained from the National Centers for Environmental Information (NCEI), which is part of the National Oceanic and Atmospheric Administration (NOAA) (http://www.ncei.noaa.gov) in the U.S from January 2012 to December 2021. The meteorological data consist of the following parameters: daily average temperature, daily maximum temperature, daily minimum temperature, maximum wind speed, relative humidity, daily accumulated precipitation, and sunshine duration.

The air pollution data were obtained from the Ecological Environment Monitoring Center of Shandong Province, China (http://www.sdem.org.cn/), from January 2012 to December 2021. The air pollutant data include the air quality index (AQI), fine particulate matter ($PM_{2.5}$), inhalable particulate matter (PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO).

R software (version 4.3.1; R Core Team, Vienna, Austria) was used for statistical analysis. We employed Pearson's correlation analysis to investigate the association between road traffic fatalities and the atmospheric environment. Ridge regression analysis was used to investigate the influence of the atmospheric environment on road traffic fatalities while accounting for multicollinearity. The minimum k value, which occurs when the standardized regression coefficients of each variable tend to stabilize, was chosen as the model's k value selection principle. The significance level of α was 0.05.

RESULTS

From 2012 to 2021, there were 163,863 road traffic fatality cases in Shandong Province. The mean age of individuals involved in road traffic fatalities was 51.97 years [standard deviation (SD): 18.10 years]. The findings indicated a positive correlation between daily average temperature and daily maximum temperature and total fatalities and each subgroup. The daily minimum temperature and sunshine duration were positively correlated with total fatalities and associated subgroups, except for pedestrians. The daily accumulated precipitation exhibited negative correlations with total fatalities and pedestrians. There was a positive correlation between relative humidity and pedestrians, but no association was found with total fatalities or other subgroups (Table 1).

There were associations between the AQI and total fatalities and the fatality subgroups. Specifically, the AQI was negatively associated with motorized drivers and positively associated with both total fatalities and the remaining subgroups. Further analysis revealed that PM_{10}, SO_2 and CO were positively correlated with pedestrians, nonmotorized drivers, and passengers and negatively correlated with motorized drivers. NO_2 was

TABLE 1. Correlations between meteorological conditions and road traffic fatalities in Shandong Province, China, 2012–2021.

Variable	Total (*N*=163,863)	Pedestrian (n_1=90,726)	Nonmotorized driver (n_2=23,730)	Passenger (n_3=14,339)	Motorized driver (n_4=35,068)
Maximum wind speed	−0.095*	−0.093*	−0.051*	−0.036*	−0.022*
Daily average temperature	0.048*	0.018*	0.038*	0.016*	0.047*
Daily minimum temperature	0.034*	0.002	0.032*	0.013*	0.047*
Daily maximum temperature	0.057*	0.026*	0.043*	0.019*	0.047*
Daily accumulated precipitation	−0.019*	−0.021*	−0.004	0.000	−0.004
Sunshine duration	0.016*	−0.005	0.014*	0.012*	0.031*
Relative humidity	0.007	0.012*	0.006	−0.005	−0.004

* P<0.05.

TABLE 2. Correlations between air pollutants and road traffic fatalities in Shandong Province, China, 2012–2021.

Variable	Total (N=163,863)	Pedestrian (n_1=90,726)	Nonmotorized driver (n_2=23,730)	Passenger (n_3=14,339)	Motorized driver (n_4=35,068)
AQI	0.097*	0.124*	0.016*	0.035*	−0.021*
$PM_{2.5}$ (μg/m^3)	0.077*	0.110*	0.006	0.033*	−0.034*
PM_{10} (μg/m^3)	0.112*	0.135*	0.024*	0.044*	−0.010*
SO_2 (μg/m^3)	0.063*	0.095*	−0.024*	0.046*	−0.026*
NO_2 (μg/m^3)	0.112*	0.116*	0.036*	0.049*	0.019*
O_3 (μg/m^3)	0.008	−0.014*	0.017*	−0.009	0.036*
CO (mg/m^3)	0.089*	0.125*	0.013*	0.046*	−0.042*

Abbrevitation: AQI=air quality index; $PM_{2.5}$=fine particulate matter; PM_{10}=inhalable particulate matter; SO_2=sulfur dioxide; NO_2=nitrogen dioxide; O_3=ozone; CO=carbon monoxide.

* P<0.05.

positively associated with both total fatalities and fatality subgroups. There was a positive correlation between O_3 and both nonmotorized and motorized drivers and a negative correlation between O_3 and pedestrians (Table 2).

The ridge regression analysis included variables in the atmosphere that were correlated with total road traffic fatalities and associated variables. For total fatalities, the ridge regression model yielded a k value of 0.198 and an F value of 9.638 (P<0.001), indicating the statistical significance of the model. The results showed that maximum wind speed (β=−0.030, P<0.001), daily average temperature (β=−0.009, P<0.001), daily minimum temperature (β=−0.007, P=0.021), and $PM_{2.5}$ (β=−0.021, P<0.001) were negatively correlated with total fatalities, whereas PM_{10} (β=0.019, P<0.001), SO_2 (β=0.009, P=0.046), and NO_2 (β=0.010, P=0.036) were positively correlated. For pedestrians, the ridge regression model yielded a k value of 0.195 and an F value of 64.389 (P<0.001), indicating the statistical significance of the model.

The maximum wind speed (β=−0.054, P<0.001), daily accumulated precipitation (β=-0.010, P=0.017), and O_3 (β=−0.030, P<0.001) were negatively correlated with pedestrians. Conversely, daily average temperature (β=0.014, P<0.001), daily maximum temperature (β=0.034, P<0.001), relative humidity (β=0.013, P=0.003), PM_{10} (β=0.069, P<0.001), NO_2 (β=0.021, P<0.001), and CO (β=0.015, P<0.001) were positively correlated with pedestrians. For nonmotorized drivers, the ridge regression model yielded a k value of 0.183 and an F value of 38.579 (P<0.001), indicating the statistical significance of the model. There were negative correlations with maximum wind speed (β=−0.035, P<0.001), SO_2 (β=−0.038, P<0.001), and O_3 (β=−0.028, P<0.001), while positive correlations were observed with daily average temperature (β=0.022, P<0.001), daily maximum temperature (β=0.035, P<0.001), sunshine duration (β=0.014, P=0.001), PM_{10} (β=0.013, P=0.005), and NO_2 (β=0.056, P<0.001). For passengers, the ridge regression model yielded a k value of 0.200 and an F value of 2.919 (P=0.001), indicating the statistical significance of the model. There were negative correlations between the daily average temperature (β=−0.006, P=0.002), SO_2 (β=−0.015, P=0.001), and NO_2 (β=−0.011, P=0.024) and passengers. The ridge regression model for motorized drivers had a k value of 0.195 and an F value of 15.868 (P<0.001), indicating the statistical significance of the model. There were positive correlations with daily average temperature (β=0.010, P<0.001), daily minimum temperature (β=0.024, P<0.001), sunshine duration (β=0.013, P=0.002), and NO_2 (β=0.045, P<0.001), while there was a negative correlation with SO_2 (β=−0.019, P<0.001) (Table 3).

DISCUSSION

From 2012 to 2021, there were a large number of road traffic fatalities in Shandong Province, China. Atmospheric conditions were correlated with road traffic fatalities, air temperature, daily accumulated precipitation, sunshine duration, PM_{10}, SO_2, and NO_2 were positively or negatively correlated with total road traffic fatalities and each subgroup.

Multiple atmospheric factors were found to be correlated with road traffic fatalities. The maximum wind speed was negatively correlated with pedestrian and nonmotorized driver speeds, similar findings to those of Gao et al. (7). Pedestrians and nonmotorized drivers often refrain from traveling or choose alternative modes of transport under high winds due to their light weight and inadequate wind resistance.

TABLE 3. Ridge regression analysis of the atmospheric environment and road traffic fatalities in Shandong Province, China, 2012–2021.

Variable	Total			Pedestrian			Nonmotorized driver			Passenger			Motorized driver		
	β	*t*	*P*	*β*	*t*	*P*	*β*	*t*	*P*	*β*	*t*	*P*	*β*	*t*	*P*
Intercept		84.706	<0.001		52.112	<0.001		92.243	<0.001		198.917	<0.001		143.573	<0.001
Maximum wind speed	−0.030	−7.252	<0.001	−0.054	−12.791	<0.001	−0.035	−8.321	<0.001	0.002	0.419	0.675	−0.006	−1.380	0.168
Daily average temperature	−0.009	−4.408	<0.001	0.014	4.497	<0.001	0.022	−9.549	<0.001	−0.006	−3.104	0.002	0.010	4.608	<0.001
Daily minimum temperature	−0.007	−2.309	0.021				0.006	1.708	0.088	−0.005	−1.787	0.074	0.024	7.725	<0.001
Daily maximum temperature	0.002	0.678	0.498	0.034	10.876	<0.001	0.035	10.976	<0.001	−0.002	−0.782	0.434	0.005	1.608	0.108
Daily accumulated precipitation	0.006	1.348	0.178	−0.010	−2.38	0.017									
Sunshine duration	−0.005	−1.086	0.278				0.014	3.310	0.001	0	−0.098	0.922	0.013	3.148	0.002
Relative humidity				0.013	2.942	0.003									
$PM_{2.5}$ (μg/m^3)	−0.021	−4.743	<0.001	−0.008	−1.820	0.069				0.008	1.788	0.074	−0.030	−6.732	<0.001
PM_{10} (μg/m^3)	0.019	4.175	<0.001	0.069	15.700	<0.001	0.013	2.784	0.005	0	−0.079	0.937	0.009	1.915	0.056
SO_2 (μg/m^3)	0.009	1.998	0.046	0.001	0.231	0.818	−0.038	−7.979	<0.001	−0.015	−3.256	0.001	−0.019	−4.017	<0.001
NO_2 (μg/m^3)	0.010	2.093	0.036	0.021	4.296	<0.001	0.056	11.400	<0.001	−0.011	−2.265	0.024	0.045	9.032	<0.001
O_3 (μg/m^3)				−0.030	−6.446	<0.001	−0.028	−5.741	<0.001				−0.006	−1.135	0.256
CO (mg/m^3)	0.001	0.267	0.790	0.015	3.499	<0.001	−0.003	−0.737	0.461	−0.006	−1.448	0.147	−0.008	−1.829	0.067

Abbreviation: AQI=air quality index; $PM_{2.5}$=fine particulate matter; PM_{10}=inhalable particulate matter; SO_2=sulfur dioxide; NO_2=nitrogen dioxide; O_3=ozone; CO=carbon monoxide.

Temperature was also associated with road traffic fatalities. There was a positive correlation between daily minimum temperature and road traffic fatalities, affecting motorized drivers. Low temperatures may cause icy road surfaces, leading to tire skidding and consequently increasing the risk of traffic accidents. High temperatures can also contribute to an increase in road traffic fatalities. High temperatures can alter the physical properties of vehicle tires (*8*), resulting in modified vehicle performance and posing risks to safe driving behavior. Li et al. (*9*) demonstrated that precipitation, particularly extreme precipitation, increases the risk of road traffic accidents. In this study, precipitation was found to be negatively correlated only with road traffic fatalities involving pedestrians. Precipitation can make travel inconvenient, particularly for pedestrians. Therefore, during precipitation events, pedestrians tend to venture outdoors less frequently, consequently reducing the risk of accidents in vulnerable traffic conditions.

In this study, several air pollutants that were significantly correlated with total road traffic fatalities and specific subgroups were identified. PM_{10} exhibited positive correlations with road traffic fatalities involving pedestrians and nonmotorized drivers. Particulate matter decreases atmospheric visibility (*10*), increasing the likelihood of traffic accidents due to limited driver visibility. Particulate matter, which frequently includes heavy metals, can impact a driver's visual and olfactory senses (*11*), ultimately affecting the driver's behavior behind the wheel.

This study revealed that there was a positive correlation between NO_2 concentration and road traffic fatalities. Nitrogen oxides (NO_x), which originate mainly from motor vehicle exhaust, are the primary pollutants responsible for the formation of photochemical smog. Photochemical smog is a potent irritant that causes acute effects on the human eye and respiratory tract, resulting in allergic reactions, including tearing, sneezing, and coughing. In addition, NO_x can have psychological and cognitive impacts on drivers (*12*). Both the acute and long-term effects of NO_x can significantly harm the human body, particularly drivers, and pose substantial risks to traffic safety.

The atmospheric data used in this study correspond to the day of the fatality rather than the atmospheric conditions during the traffic accident, and the atmospheric conditions may also have a lag effect on road traffic fatalities, which may result in misleading associations. A study demonstrated (*13*) that approximately 60% of individuals do not survive beyond the first hour of a road traffic accident, indicating a high rate of timely mortality. Additionally, the current study was an ecological study, and individual information on road traffic fatalities, particularly regarding unsafe driving behavior, was not collected. In the future, a survey will be conducted to collect individual information on road traffic fatalities in Shandong Province, aiming to analyze the contributing factors to road traffic fatalities comprehensively. This study is based on an analysis of the cause of death and atmospheric monitoring, which has positive implications for the prevention of road traffic fatalities and the development of related policies.

The occurrence of road traffic fatalities was found to be linked to meteorological factors, including air temperature; daily accumulated precipitation, and air pollutants such as particulate matter and NO_2. The implementation of atmospheric environmental management to reduce air pollution levels, as well as timely and accurate weather warnings and forecasts, has a positive impact on reducing the incidence of road traffic fatalities.

Conflicts of interest: No conflicts of interest.

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