Environmental Factors Influencing the Distribution of Pedestrian Traffic Accidents in Iran

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Abstract

Background: This study aimed to determine the environmental factors affecting the frequency of accidents leading to injury and death related to pedestrians in 31 provinces of Iran. **Methods:** Data necessary for the study were extracted from databases of traffic police, statistics center, ministry of roads and urban development, and Iran meteorological organization. Hot spots analysis was used based on Getis-Ord G statistics in geographically weighted regression models. Goodness of fit of models was evaluated using the Bayesian information criterion, Akaike's information criterion and Deviance statistics. **Results:** In this study, 49,409 incidents were investigated. Of these, 48,382 (98%) cases were injuries and 1027 (2%) cases were fatal accidents. The incidence of fatal accidents does not follow a specific pattern; however, the incidence of accidents leading to injuries is higher in the central and the northeastern provinces of the country and lower in the southern and southeast provinces of the country. The final models showed that the relationship between different variables, including demographic characteristics, road network, and distance from the capital, traffic volume, and rainfall with dependent variables (number of accidents in geographic units), was statistically significant. **Conclusion:** In order to better design preventive plans for traffic accidents and promote the safety of passageways for pedestrians inside and outside the cities, these factors need to be considered more carefully, and practical solutions should be developed and implemented for their correction.

Keywords: Environmental factors, geographic information system, pedestrians, statistical models, traffic accidents

Introduction

Pedestrians are considered as the most vulnerable road users. In many high- and middle-income countries, the pedestrians have a significant proportion of the deaths from traffic accidents. According to statistics, 2024 pedestrians in 23 European countries in 2017 died of accidents, accounting for more than 8% of deaths from traffic accidents.[1] Between 2006 and 2015, 47,789 pedestrians lost their lives in the United States due to traffic accidents, and 674,414 individuals were injured.[2] In Canada, about 25% of traumatic injuries occur in young pedestrians.[3]

Pedestrians account for the highest proportion of deaths from traffic accidents in the world's most populated cities. For example, in the cities of Bombay and Delilah, 76% and 53% of pedestrian deaths are from traffic accidents, respectively.[4] According to Tehran traffic police statistics, road traffic deaths in pedestrians account for more than 40% of traffic-related deaths.[5]

Considering the importance of this issue in recent years in different parts of the world, using different methods of spatial

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analysis and various statistical models, the role of various environmental and demographic factors in the frequency of spatial distribution and severity of traffic accidents related to pedestrians in urban areas has been studied. Some of these studies are mentioned in the following.

Richmond *et al*., in Canada, using geographic information system (GIS) and zero-inflated Poisson regression models examined the effect of providing tram on the incidence and pattern of pedestrian traffic accidents in Toronto between 2000 and 2011.[6] Blazquez *et al*., in Chile using the GIS, Moran's I index, and kernel density estimation, investigated the traffic accidents related to pedestrians in Santiago between 2000 and 2008.[7] Statter *et al*. in Chicago, using spatial analysis and hot spots, investigated the injuries caused by traffic accidents involving pedestrians who were under 16 year olds at a 400-m radius of the University of Chicago's Health-Care Center.[8] Ukkusuri *et al*. using various regression models for count data regression, investigated the relationship between various environmental factors of land use, road design, and safety of pedestrians, as well as the effect of the accumulation of various factors on pedestrian-related incidents in New York City between 2002 and 2006. The analyses were performed by regression models of a negative binomial model and generalized negative binomial model.[9] Siddiqui *et al*. in five cities of region 7 of Florida investigated the effect of various variables, such as road characteristics and various demographic and socioeconomic variables on traffic accidents of pedestrians and cyclists using three negative binomial and Bayesian Poisson-lognormal regression models with regard to spatial correlation and also regardless of spatial correlation.[10] Wang *et al*. analyzed the pedestrian-related traffic accidents in the London M25 ring road and the surrounding streets using a two-stage mixed multivariate model combining models of frequency and severity of the incidents.[11] Cottrill and Thakuriah investigated various environmental and behavioral variables, especially the situation of urban areas in terms of the concentration of minority groups and low-income households on traffic accidents of pedestrians in the city of Chicago using Poisson regression models with regard to the heterogeneity marginal effect and exogenous underreporting marginal effect.[12] Lee and Abdel-Aty, using log-linear models, investigated the relationship between the incidence of pedestrian traffic accidents and various traffic and environmental factors in the state of Florida. Furthermore, to predict the effective factors in the severity of these events, they used the ordered probit model.[13] Abdel-Aty and Keller examined the relationship between the severity of pedestrian traffic accidents at intersections and various traffic and environmental factors in Florida using ordered probit modeling techniques and Tree-based regression methodology.[14]

Cloutier *et al*. using point pattern analysis to describe the spatial distribution of child pedestrian accidents in Montréal and a geographically weighted regression model to show spatial variations in the relation between the number of accidents and selected explanatory variables.[15]

In Iran, although in recent years, due to the increasing production of cars, the traffic volume of the passages inside and out of the cities has increased significantly, the passageways have not been developed quantitatively and qualitatively in line with the car production process. In Iran, a significant proportion of traffic accidents are caused due to environmental factors, and the capacity of the passageways in terms of bearing traffic load and mixing of various vehicle types exacerbates the role of other factors in road accidents, including environmental factors. Investigating and comparing geographic units at the national level, considering the environmental factors of pedestrian-related traffic accidents can be effective in better identifying these factors and their contribution to incidents. Using the results of such studies, better planning can be done to reduce these risk factors. Therefore, this study aimed to provide models for determining the factors affecting the distribution of accidents leading to injuries and death of pedestrians in Iran.

Objectives

This study aimed to determine the environmental factors affecting the frequency of accidents leading to injury and death related to pedestrians in 31 provinces of Iran.

Methods

The present study was an ecological survey that was conducted descriptively-analytically. In this study, the statistical population consisted of traffic accidents leading to injuries or deaths of pedestrians throughout 2015 across Iranian provinces. The main source of information of this study was traffic police data collected by the Traffic Information and Communications Technology Bureau. At traffic police, Com 114 forms in seven pages for each accident are completed by accident experts. The form contains information about the culprit or nonculprit drivers such as age, sex, education level, occupation, type of certificate, using seatbelt or helmet, pedestrians or cyclists injured, type of injuries, color of clothing, position, vehicles characteristics including; type, system, user, license, safety equipment, driving route, accident conditions and environment in which the accident occurred; time, road condition, accident Location, brightness, road defects, visual barriers, human factors and accident vehicle which are recorded in separate sections. The scene of the accident with full details and auxiliary points and a full description of how the accident happened is registered in the forms. The forms, after completion by accident experts in each city or region of the country, are added to the online information support system. Information extracted from the forms is stored in four separate tables, including pedestrian, passenger, driver, and accident information. Other data necessary for the study, in addition to the databases of traffic police, extracted from statistics center, ministry of roads and urban development, and Iran meteorological organization. After cleaning the data, identifying and deleting the duplicates, the traffic police and forensic data were integrated. In order to reduce the error in estimations, independent variables information including population, roads network, traffic volume, and weather status in 2015–2016, which were more consistent with the dependent variables information, were used. The information about the location of the pedestrian-related traffic accidents was extracted using the traffic police data bank of the country. Different layers of geographic information were matched together, and zoning maps were extracted. The spatial and statistical analyses were done in two descriptive and analytic sections, using Arc-GIS 10.2.2 (ESRI Redlands, USA), Stata 12 (College station, Texas 77845, USA), and Geographic-weighted regression 4 (Arizona State University, Tempe, USA) softwares. To determine the high-risk areas, hot spots analysis was used based on Getis-Ord G statistics. GWR models were used to analyze the relationship between environmental factors and the location of these incidents.

It should be explained that because ordinary regression models do not take into account the spatial autocorrelation in spatial data, and also the role of the nonstationary part of the data regarding the relationship between variables is not considered in the calculations, Fotheringham et al. presented a geographically weighted regression model to study traffic accidents.[16] This model is a generalization of the typical regression model. In this model, based on the relation 1, the parameters are considered in different locations based on their geographic coordinates (v_i, u_i) from the different point i.

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{p} \beta_j(u_i, v_i)\, x_{ij} + \varepsilon_i \qquad (1)$$

In fact, the regression model based on the geographic information weights generates a regression equation for any spatial observation or geographic unit, and provides for each point or location R^2, β_0, β_k, and the t statistic; therefore, this model is based on point equations and predicts the outcome based on the combination of the least squares method and the weight matrix (W [i]) by decreasing the sizes based on the distance between i and j using equation.[2] The longer the distance between i and j, the more weight the relevant factor has.[16]

$$\hat{\beta}_i = (X^T W(i) X)^{-1} X^T W(i) y$$

$$W(i) = \begin{pmatrix} W_{i1} & 0 & ..... & 0 \\ 0 & W_{i2} & ..... & 0 \\ . & . & ..... & . \\ . & . & ..... & . \\ 0 & 0 & 0 & W_{in} \end{pmatrix} \qquad (2)$$

Goodness-of-fit and performance of the models were studied using the Akaike's information criterion, Bayesian information criterion, and Percent Deviance Explained. Multicollinearity variables were checked using the variance inflation factor.

Results

In this study, 49,409 incidents were studied. Of these 48,382 (98%) cases were injuries and 1027 (2%) cases were fatal accidents. The distribution of incidents leading to injuries and fatal accidents is different in 31 provinces of Iran. The incidence of accidents leading to injuries is higher

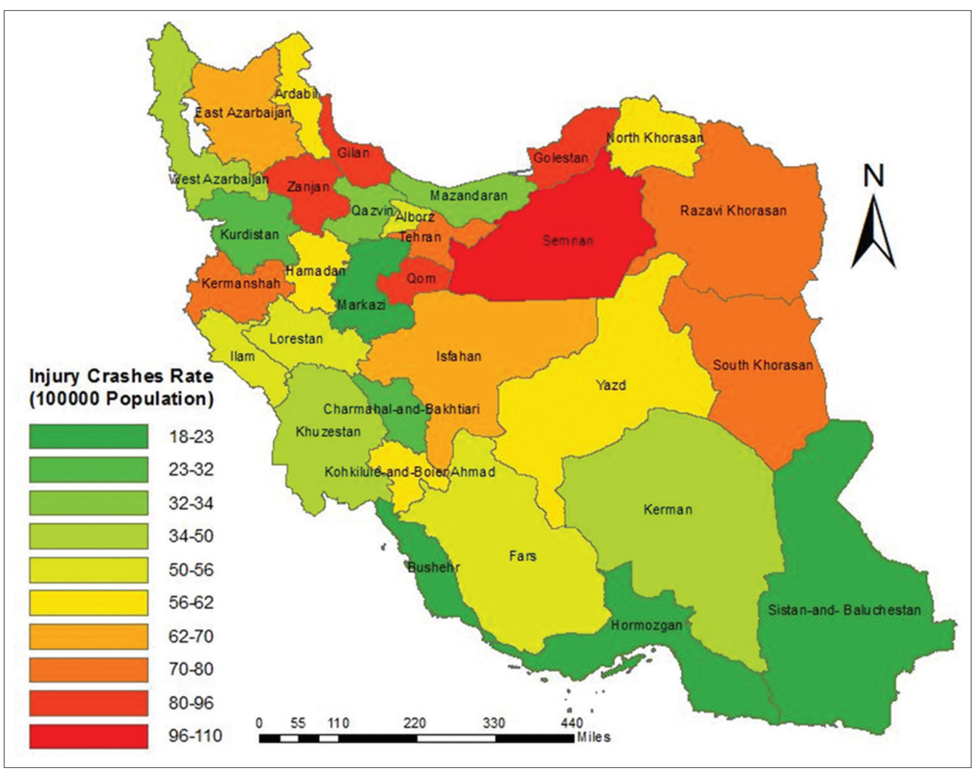

Figure 1: Incidence rate of injury pedestrian-related crashes in provinces of Iran, 2015–2016

in the central and northeastern provinces of the country and lower in the southern and southeast provinces of the country. The provinces of Semnan and Gilan with 110.34 and 96.30 in 100,000 of population had the highest, while Bushehr and Central provinces had the lowest levels, which were respectively 245 and 260 in 100,000 [Figure 1].

The occurrence of fatal accidents does not have a specific pattern. Golestan and South Khorasan provinces have the highest levels with 29.4 and 28.6 per 1,000,000 people, respectively, while the provinces of Ardabil and East Azerbaijan have the lowest levels with 5.5 and 5.8 per 1,000,000 people, respectively [Figure 2].

Figure 3 shows that the high-risk areas in terms of accidents leading to injuries are located in the north of Iran around the province of Tehran, and the low-risk areas are located in the south and southwest of the country. The Getis-Ord General G* statistics indicate that the distribution of high-risk and low-risk areas is not statistically significant ($P = 0.08$). Figure 4 shows that high-risk areas regarding fatal incidents are concentrated in the north of the country, and low-risk areas are mainly in the south of the country. The Getis-Ord General G* statistics indicate that the distribution of high risk and low-risk points regarding fatal accidents is not statistically significant ($P = 0.45$).

In this study, the relationship between different variables and frequency of pedestrian-related traffic accidents was investigated in the provinces of Iran. Independent variables include population, road network, traffic, and weather conditions. Table 1 lists the variables entered into the final models of factors affecting the frequency of traffic accidents leading to injuries and deaths of pedestrians in provinces of Iran with their descriptive characteristics including mean, standard deviation, minimum, and maximum.

The GWR model indicates that the relationship between the variables of area, population, length of highways, literacy rate, employment rate, and distance from the capital, developmental level, annual precipitation, and incidence of accidents in geographic units is statistically significant. In this regard, the direction of the relationship regarding the variables of area, developmental level, length of highways, and annual precipitation with dependent variable is positive, while the direction of the relationship between variables of population, literacy rate, employment rate, and distance from the capital with dependent variable is negative [Table 2].

The GWR model indicates that the relationship between variables of population, employment rate, distance from the capital, traffic volume, and the incidence of fatal accidents in geographic units is statistically significant. In this regard, the direction of the relationship of traffic volume with the dependent variable is positive, while the direction of the relationship between population, employment rate, and distance from the capital and dependent variable is negative [Table 3].

Discussion

The results indicate that most of the provinces in the northeast and some of the provinces in the central and northwest of Iran, especially the provinces of Semnan, Gilan, and Zanjan, are the

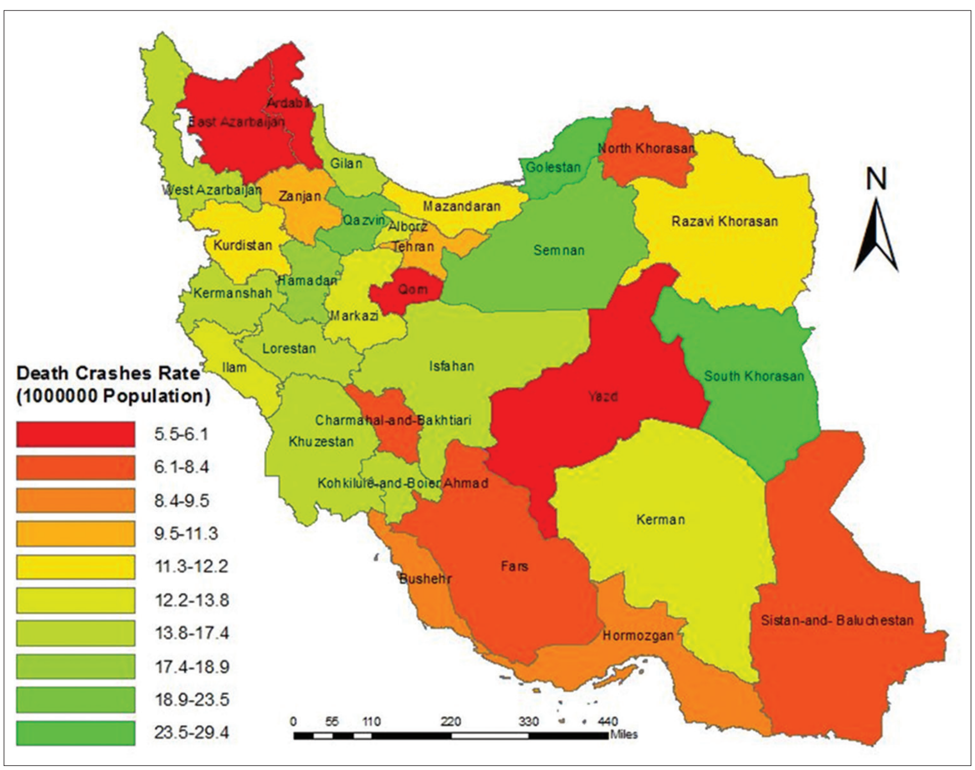

Figure 2: Incidence rate of fatal pedestrian-related crashes in provinces of Iran 2015–2016

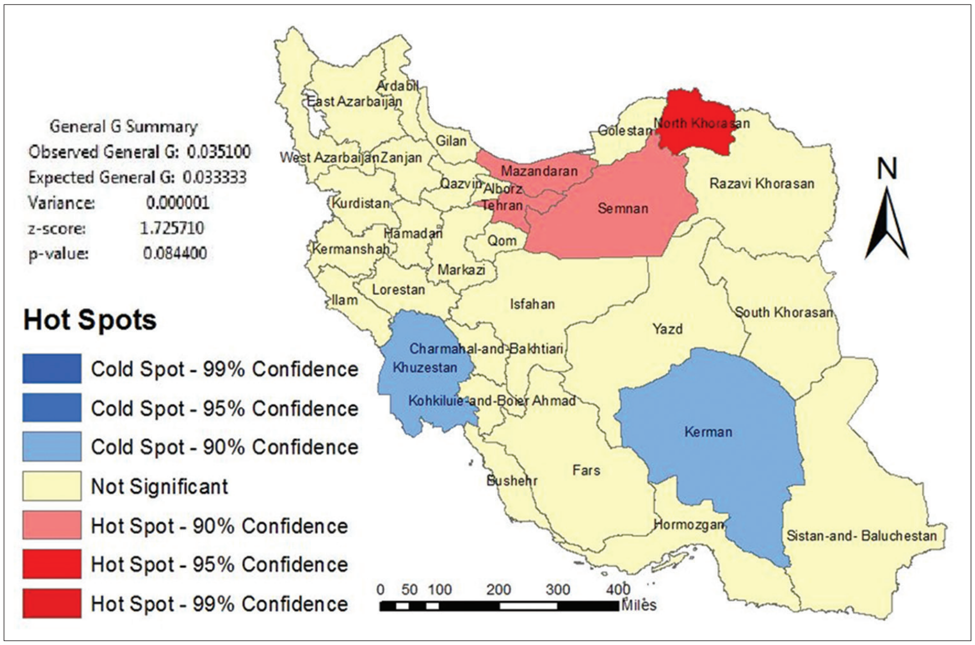

Figure 3: Hotspots of injury pedestrian-related crashes in provinces of Iran, 2015–2016

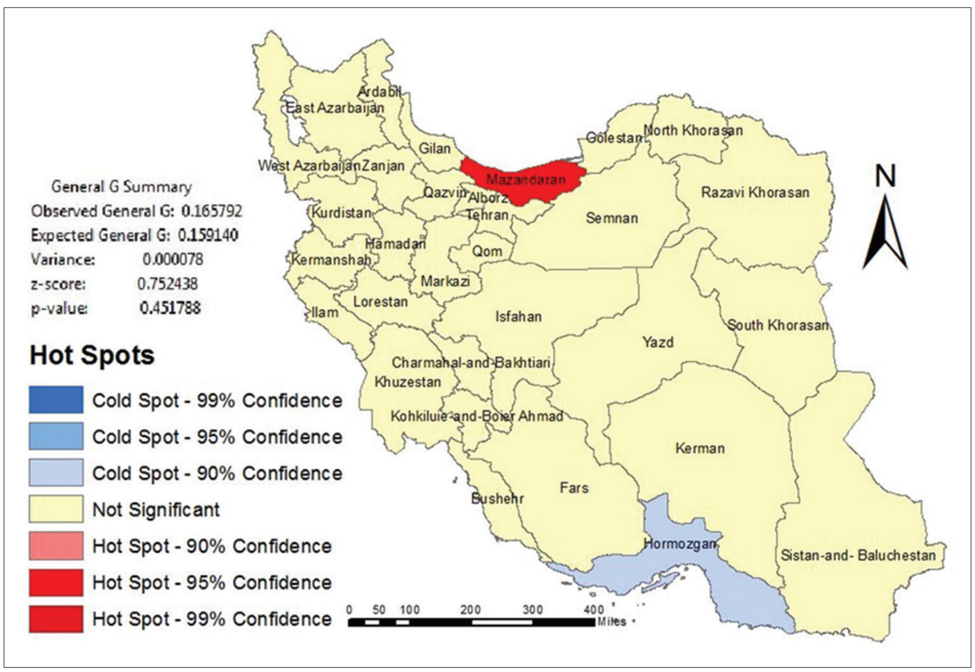

Figure 4: Hotspots of fatal pedestrian-related crashes in provinces of Iran, 2015–2016

most dangerous areas in terms of traffic accidents leading to injuries of pedestrians. On the other hand, Figure 2 shows that provinces of Golestan in the north, South Khorasan in the east and Qazvin in the center of Iran have the highest incidence of traffic accidents leading to injuries of pedestrians, but the distribution of the incidence of fatal accidents does not follow a clear pattern. In addition to provinces with high incidence rates, there are provinces with low incidence rates. In contrast to these results, Ouni and Belloumi from Tunisia showed that the distribution of fatal traffic accidents related to pedestrians in national and regional highways of the central provinces of Tunisia at different time intervals followed a cluster pattern.[17]

In total, the incidence of accidents leading to injuries and death and deaths of pedestrians in 31 provinces of Iran has been different in terms of various variables, including population, road network, traffic, and weather conditions during the year 2015.

This study showed that the frequency distribution of accidents leading to injuries had a significant relationship with population

Table 1: Descriptive statistics of independent variables in the models

Variable	Mean	SD	Minimum	Maximum
Population	2,578,267	2,482,988	580,158	13,267,637
Area (km^2)	52,541	50,642	5122	181,785
Population density (km^2)	104.5	185.2	7	969
Number of registered vehicles in 2016	69,239	102,773.4	9859	564,153
Length of roads (km)	6953.5	4125.8	1317	17,466
Literacy ratio	0.86	0.03	0.76	0.93
Employment ratio	0.87	0.03	0.75	0.90
Development level	0.41	0.05	0.30	0.60
Yearly rainfall	334.7	189.9	93	922
Distance from capital	614.1	387.3	10	1518
Traffic volume	6953.5	4125.8	1317	17,466

SD: Standard deviation

Table 2: Pedestrian injury crash final geographic-weighted regression model for provinces of Iran

Covariates	Minimum	Lower quartile	Median	Upper quartile	Maximum
Intercept	3.99	4.00	4.04	4.05	4.06
Area	0.15	0.19	0.28	0.39	0.46
Population	−0.26	−0.19	−0.09	−0.05	−0.01
Number of vehicle	−0.13	−0.10	−0.04	0.07	0.16
Length of highways (km)	0.21	0.24	0.25	0.28	0.32
Literacy ratio	−0.28	−0.22	−0.15	−0.09	−0.07
Employment ratio	−0.19	−0.16	−0.14	−0.14	−0.02
Distance from capital	−0.27	−0.23	−0.13	−0.07	−0.01
Development level	0.24	0.31	0.38	0.46	0.53
Yearly rainfall	0.00	0.04	0.07	0.11	0.14
Traffic volume	−0.06	0.03	0.10	0.19	0.22
Overall model results					
BIC			190.3		
AIC			201.9		
Percent deviance explained			0.68		

BIC: Bayesian information criterion, AIC: Akaike's information criterion

Table 3: Pedestrian death crash final geographic-weighted regression model for provinces of Iran

Covariates	Minimum	Lower quartile	Median	Upper quartile	Maximum
Intercept	2.581	2.586	2.590	2.593	2.597
Population	−0.14	−0.10	−0.07	−0.02	−0.01
Number of vehicle	−0.12	−0.08	0.03	0.11	0.20
Length of roads (km)	−0.11	−0.09	−0.03	−0.005	0.05
Literacy ratio	−0.02	0.01	0.06	0.10	0.15
Employment ratio	−0.16	−0.14	−0.09	−0.03	−0.01
Distance from capital	−0.31	−0.25	−0.22	−0.16	−0.12
Development level	−0.34	−0.22	−0.13	0.01	0.08
Yearly rainfall	−0.017	−0.009	0.008	0.03	0.04
Traffic volume	0.02	0.05	0.10	0.15	0.18
Overall model results					
BIC			89.74		
AIC			91.53		
Percent deviance explained			0.42		

BIC: Bayesian information criterion, AIC: Akaike's information criterion

variables, including population density, literacy rate, and employment rate. These connections are in a negative direction. In other words, the incidence of these events in provinces with lower population density, literacy rate, and employment is significantly higher than provinces with higher population density, literacy rates, and employment rates. Furthermore, the frequency distribution of fatal accidents has a significant relationship with population variables, including population density and employment rate. This connection is also in a negative direction. In other words, the occurrence of fatal accidents in provinces with lower population density and employment rates is significantly higher. Various studies in the United States, including Cottrill and Thakuriah in Chicago;[12] Sebert Kuhlmann *et al*., in Denver, Colorado;[18] Siddiqui *et al*., in Florida;[10] Ukkusuri *et al*., in New York;[9] and McArthur *et al*., in Michigan[19] also showed a significant correlation between population density and frequency of pedestrian traffic accidents, but the direction of the relationship in the studies mentioned was positive unlike the present. The review study of Moradi *et al*. also indicated that in most studies, population density and number of accidents among pedestrians were significantly and positively correlated.[20] Considering that lower population density and lower employment rates reduce traffic loads in the passages, one of the reasons for this may be the reduction in the exposure of pedestrians and vehicles in provinces with lower population density and lower employment rates.

The frequency of accidents leading to injuries is significantly correlated with the highway length, which is one of the most important transport variables. The direction of this relationship is positive. In other words, the incidence of these events is higher in areas with higher motorway densities. Considering that in these areas more cars are moving at a high speed, it can be said that the proportion of severe accidents involving pedestrians is increasing and thus the incidence of fatal accidents increases. Studies performed in other parts of the world have also shown such a relationship. Examples include Hashimoto in Florida;[21] Cloutier *et al*. in Canada;[15] Green *et al*. in the UK;[22] and Ouni and Belloumi from Tunisia[17] Therefore, it can be said that one of the factors that increase the incidence of traffic accidents leading to injuries is the low safety factor of Iranian highways for pedestrians.

The results show that with increasing level of development, the incidence of fatal accidents in provinces of Iran decreases. The high incidence of fatal events in less developed provinces can be due to the fact that in these areas, along with urban development, the criteria for improving the safety of pedestrians have also been taken into consideration. It should be noted that another study in Tehran, capital of Iran, showed that the incidence of traffic accidents in different classes of society was significantly different from the point of view of the socioeconomic status, and in the upper classes the incidence of such events associated with pedestrians was lower than the lower classes;[23] therefore, one of the causes of difference in the incidence of these events in developed geographic units can be the different social context.

This study had some strength. For the first time, the Iranian police information has been used systematically to determine the environmental factors associated with traffic accidents related to pedestrians at the national level, while the factors affecting the distribution of traffic accidents involving pedestrians have been compared and analyzed separately.

This study is one of the few studies conducted in the Eastern Mediterranean Region on pedestrian traffic accidents at the national level, so comparing its results with those of similar studies, which are mostly conducted in developed countries, may be useful for international comparisons.

Although some persons who had an injury in the traffic accidents die while being transported to the hospital or in a hospital, are categorized as injured persons in the police data. To determine the precise number of fatalities, we matched the police and forensic data.

This study also had some limitations. Due to the lack of geographical coordinates of traffic accident occurrences in police crooks and the large amount of national data, it was not possible to perform spatial analysis based on the exact location of the accident and individual extraction of point maps. Therefore, the accidents were analyzed in groups in spatial units (provinces).

Given that the present study is ecological, and the relationship of dependent and independent variables was investigated at the provincial level, as with many ecological studies, there is the possibility of ecological fallacies so that it is not possible to generalize the results to the individual level, and the results may be different from the results of a study at the individual level.

The environmental effects of accidents may change over time. To address this problem, as much as possible, the latest police data were used for the study, and geographical layers and information or estimates of the study time or close estimates were used for analysis.

Traffic police data, which were the main source of information used in this study, have several limitations for the following reasons:

1. In a small accident that does not result in death or serious injury, calling the emergency department is only action, and there is no police investigation
2. In the event that children are injured in an accident, all efforts of parents are to bring the child to the hospital/emergency department, and these accidents reported to the traffic police rarely
3. Drivers who used the alcohol and drugs are not usually reported to the police
4. In some accidents that caused a minor injury, the matter will be resolved through dialogue and the police may not report this accident
5. Those who go to the hospital after an accident and undergo medical treatment is not entered in the police database.

According to the limitations of the study, the following suggestions are provided for further research in this area:

- Due to underreporting and mismatch of the data of the responsible organizations in the field of traffic accidents, it is necessary to establish an efficient and effective

registration system for traffic accidents and their consequences in related organizations
- In addition to the ecological studies, it is necessary to conduct analytical studies on the individuals to determine the role of each environmental factors in pedestrian-related traffic accidents
- The causes of traffic accident data discrepancies and their consequences in forensic databases and traffic police need to be investigated
- It is necessary to study the coverage, validity, comparability, and timeliness of traffic accidents in the traffic police
- There is a need for comprehensive studies to standardize the forms of registration of traffic accidents at traffic police stations based on the experiences of developed countries
- To carry out detailed spatial analyzes in the future, an integrated plan for recording the geographic coordinates of the precise location of the accident using GPS should be developed.

Conclusion

Based on the results of this study, provinces in the northeast of Iran and some of the central provinces of the country are the most dangerous areas in terms of traffic accidents leading to injuries of pedestrians, the distribution of the incidence of fatal accidents does not follow a specific pattern, and in addition to provinces with high incidence, there are also provinces with low incidence rates. The frequency of pedestrian traffic accidents leading to injuries and deaths in Iranian provinces is related to some of the environmental variables, especially developmental level, length of highways, and annual precipitation and traffic volume. In order to better design preventive plans for traffic accidents and promote the safety of passageways for pedestrians inside and outside the cities, these factors need to be considered more carefully, and practical solutions should be developed and implemented for their correction.

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Conflicts of interest
There are no conflicts of interest.

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