

Original Article

Spatial analysis of driving accidents leading to deaths related to motorcyclists in Tehran

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ABSTRACT

Purpose: Traffic accidents are one of the main causes of death and disability, causing annual deaths of 1.23 million and tens of millions injured people worldwide. Meanwhile, a significant proportion of the deaths and injuries caused by traffic accidents occur among motorcyclists. According to the world health organization's 2015 report, about 25% of deaths from traffic accidents occur in motorists. In Iran, a significant proportion of deaths and injuries result from traffic accidents among motorcyclists, especially in passages within the cities. According to traffic police, about 25% of deaths and 50% of injuries in traffic accidents of Tehran are reported among motorcyclists. Therefore, due to the importance of this issue, the spatial factors influencing the incidence of motorcycle-related accidents in Tehran were investigated using the geographic information system.

Methods: The present work was a cross-sectional and descriptive analysis study. The data necessary for the study were extracted from Tehran traffic police as well as municipality databases. Zoning maps were used to display the distribution of events. In the analytical investigation, Moran index was used to determine the distribution pattern of the events, while Getis-Ord G^* statistics were applied to analyze hot spots. To investigate the role of regional and environmental factors in the frequency of traffic accidents related to motorcyclists in geographic units (Tehran 22 districts), Poisson regression and negative binomial models were used. The geographically weighted regression (GWR) model was used to analyze the relationship between environmental factors and the location of these events. Statistical analyses were performed using SPSS, STATA, ARC-GIS and GWR software.

Results: The southern and eastern margins of Tehran are the most vulnerable areas in terms of deaths related to traffic accidents of motorcyclists. Highways are considered the location of most traffic accidents which lead to death of motorcyclists. Getis-Ord General G^* ($p < 0.04$) indicates that the distribution of high-risk points is statistically significant. The final model showed that in Tehran, the association of different variables including demographic characteristics, pathways network and type of land use with the number of accidents in geographic units was statistically significant. The spatial distribution of traffic accidents leading to deaths of motorcyclists in the center of Tehran varies considerably with changes in population density, length of highways, volume of traffic, and land use in different parts. **Conclusion:** Most of the traffic accidents leading to deaths of motorcyclists occur in highways. Various environmental variables play a role in determining the distribution pattern of these types of events. Through proper traffic management, controlling environmental risk factors and training people the safety of motorcyclists in Tehran can be improved.

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Introduction

Traffic accidents are one of the main causes of death and disability, causing annual deaths of 1.24 million people and injuries

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over tens of millions in the world.¹ According to a study of the global burden of diseases, in terms of the number of years of life lost due to premature death or disability, road traffic accidents were ranked ninth in 1991 across the world and it is predicted to reach the third rank in 2020.²

Meanwhile, a significant proportion of the deaths and injuries caused by road traffic accidents occur among motorcyclists. According to the World Health Organization's 2015 report, about 25% of deaths from road traffic accidents occur in motorists. The incidence of motorcycle-related accidents in eastern Asia and the western Pacific countries is higher than in the rest of the world, as in these areas, 34% of the deaths from road traffic accidents occur in motorists. During the recent years in the United States, death rates for motorcyclists have increased sharply so that between 2010 and 2013, the proportion of motorcyclist deaths to total deaths from traffic accidents has risen from 15% to 20%.³

According to the global study on the burden of diseases and injuries, in recent years, road traffic accidents in the age group of 15–49 years have been ranked first in terms of the number of years of life lost due to premature death in our country.⁴ The World Health Organization's 2013 report on road safety indicates that mortality rates from road traffic accidents in Iran are much higher than the global average (34.1 per 100,000 versus 18 per 100,000).¹

In Iran, in recent years, many families and individuals, especially young people can easily afford a motorcycle due to its mass production and relative low price. Therefore, the use of motorcycles has increased dramatically for intra-city commute. Because of the unsafe nature of the vehicle due to the lack of protection for its users and the rapid loss of its balance, particularly in the event of traffic accidents, and also the increasing use of it by young people, traffic accidents in the country are rising rapidly and a significant proportion of deaths and injuries result from traffic accidents of motorcyclists, especially in the passages in cities, however, there is no accurate and exact statistics on the issue.

According to traffic police statistics, about 25% of deaths and more than 50% of injuries from driving accidents in Tehran occur among motorists.⁵

According to a survey of 1290 trauma patients who had been referred to Sina hospital in Tehran in two months, 385 (29.8%) suffered from motorcycle-related traffic accidents.⁶

Methods

The present study was a cross-sectional and descriptive analysis research. In this study, the statistical population consisted of traffic accidents leading to death of motorcyclists during the years 2011–2016 in Tehran, all of which were studied. The data were extracted from Tehran traffic police as well as municipality databases and Iran Statistics Center.

In this study, in addition to extraction of information from police documents, a large database of traffic accidents related to the forensic organization that included cyclists' deaths and other deaths or injuries, and also the Tehran municipality records were used. Police documents is an accident registration database collected by police using a specific form named "form 114 Com". This form has 7 pages and is completed by road traffic police for each accident. This form includes information about the driver characteristics, including age, sex, level of education, occupation, type of driving certification, seat belt or helmet wear, pedestrians or cyclists injured in accidents, clothing color and position of the pedestrians and cyclists, safety equipment, direction of pedestrians or cyclists' movement, accident conditions and the environment in which the incident occurred; including time, road status, location of the incident, luminance, roadside defects and obstacles that

recorded in separate sections. Forensic database and municipality records were also assessed to confirmation of cyclists' deaths.

All documents of traffic accidents related to motorcycle riders that registered in the traffic police department of Tehran were also reviewed. The exact addresses of the incidents were extracted using the Geographic coordinates and auxiliary points recorded in these documents. Then, using the addresses, geographic coordinates of the occurrence of recorded accidents and related maps were prepared. Other maps required to conduct spatial analysis were taken from the Tehran municipality. In the absence of a map/maps of some spatial complications, maps were prepared by the researchers.

Statistical analyses were done in two parts of descriptive and analytic, using SPSS, Stata, and Arc-GIS software. To describe the quantitative data, the absolute and relative frequency, mean, standard deviation, minimum, and maximum were used. Zoning maps were used to show the distribution of events based on geographic units.

Regression models were used to analyze the role of local and regional factors in the frequency of traffic accidents in geographic units (22 districts of Tehran). Given the fact that the dependent variable in these units is the number or density of traffic accidents in geographic units, the Poisson regression model was used. In the Poisson model, the probability y_i , which means observing the i^{th} dependent variable, is obtained from the following relation:

$$P(y_i) = \frac{e^{-\lambda_i} \lambda_i^{y_i}}{y_i!}$$

In which e indicates Napier constant ($e = 2.71$) and λ represents the number of events. An important feature of the Poisson regression model is the equation of mean and distribution variance, which in practice may not be held leading to over dispersion. Due to the large dispersion of traffic accident data, this model cannot be used in some cases. In the Poisson regression model, conditional variance is equal to the conditional mean.

$$V(y_i|x_i) = E(y_i|x_i) = \lambda_i = e^{x_i \beta}$$

In which y_i indicates dependent variable in the form of the number of events or accidents. Moreover, X_i represents the vector of independent variables in the model, β is the vector of regression coefficients, and λ_i is the mean of the number of events or accidents. To estimate the Poisson regression coefficients, the maximum likelihood method is used. In the Poisson regression model, the predicted value of \hat{y}_i is the conditional mean of the events on the condition of X_i .^{7,8}

Regarding the fact that ordinary regression models consider neither spatial autocorrelation in spatial data nor the role of the non-stationary part in these data in the relationship between variables, the geographically weighted regression model is used for the analysis of environmental factors influencing the distribution of the events under study.

Fotheringham et al.⁹ proposed this model for investigation of traffic accidents. This model is a generalization of the regular regression model. In this model, based on the following equation, the parameters in different locations vary according to their geographic coordinates (V_i, U_i) from the point i .

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

In fact, the regression model based on geographic information weights generates a regression equation for any spatial

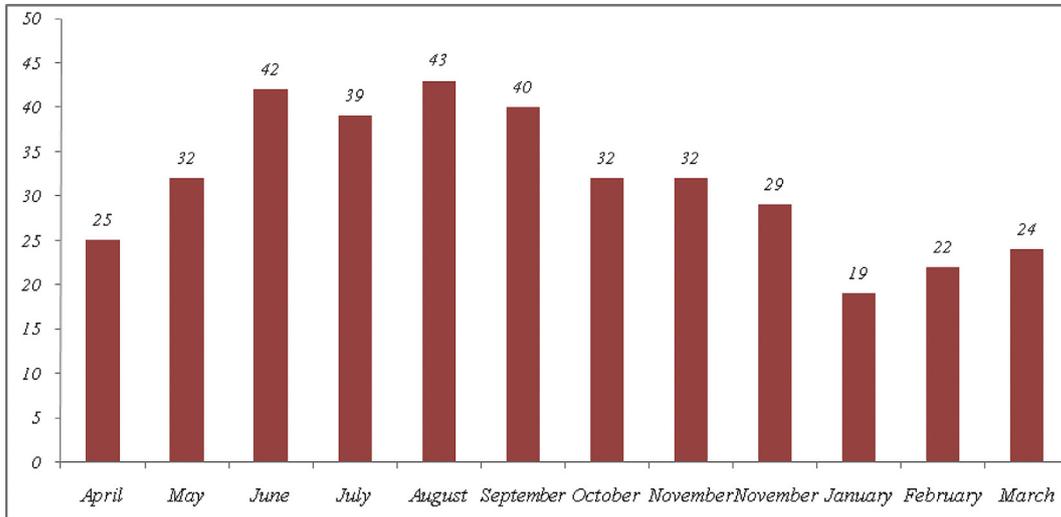


Fig. 1. Distribution of absolute frequency of traffic accidents leading to death of motorcyclists in 22 districts of Tehran, 2011–2016.

observation or geographic unit, and provides for each point or location R^2 , β_0 , β_k , and t statistic; therefore, this model, which is based on point equations, predicts the outcome by using the combination of minimum squares and weight matrices $W(i)$ with decreasing sizes based on the distance between i and j using the following equation. The longer the distance between i and j , the more weight the relevant factor will have.¹⁰

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

$$W(i) = \begin{pmatrix} W_{i1} & 0 & \dots & 0 \\ 0 & W_{i2} & \dots & 0 \\ \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \dots & \cdot \\ 0 & 0 & 0 & W_{in} \end{pmatrix}$$

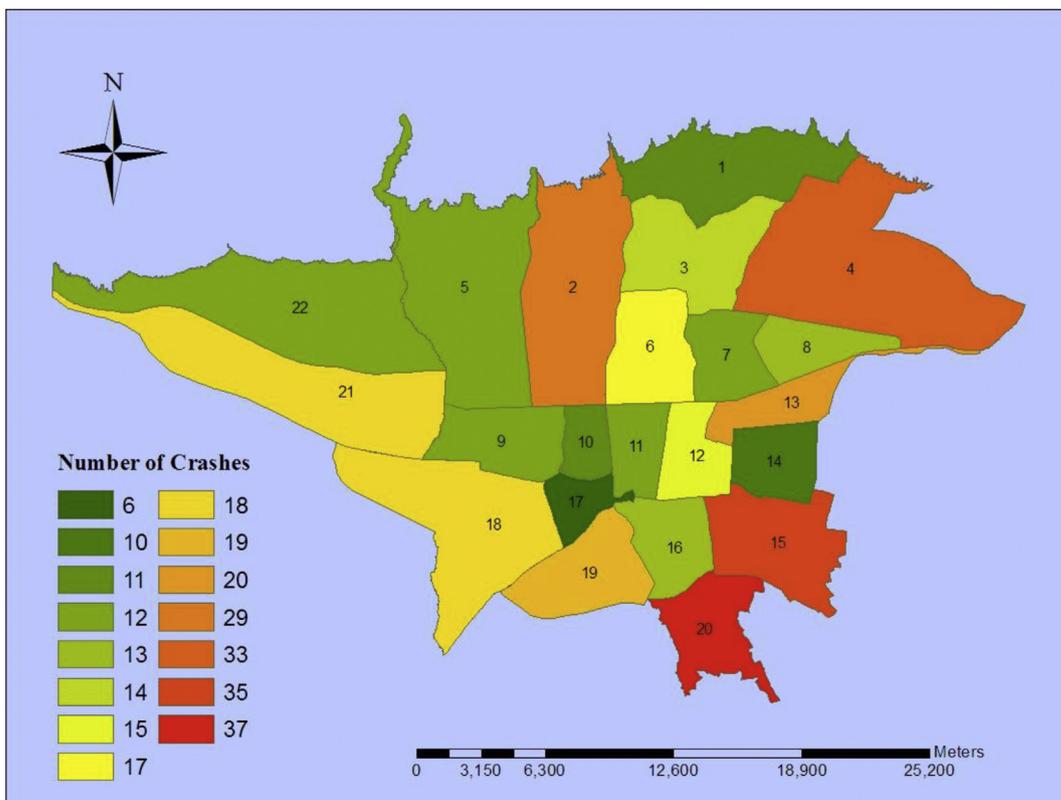


Fig. 2. Number of accidents leading to death of motorcyclists in 22 districts of Tehran, 2011–2016.

Goodness-of-fit and performance of models were controlled using Akaike's information criterion (AIC), Bayesian information criterion (BIC), adjusted R-squared (R^2), and percent deviance explained.

Results

In this study, a total number of 379 accidents were investigated. The number of incidents during 2011–2016 did not have a specific trend. The most frequent cases were in 2011 and the least frequent ones happened in 2016. Fig. 1 shows distribution of the absolute frequency of the incidents studied in terms of the month of their occurrence. This figure indicates that the number of accidents in different months of the year has not had a specific trend. However, the average number of accidents in hot months is more than in cold months of the year. Most cases (43 accidents) have occurred in August and the lowest number (19 accidents) has been reported in January.

The frequency distribution of the incidents studied varies in Tehran's 22 districts. Area 20 with 37 cases (9.8%) and 17 with 6 cases (1.6%) had the highest and lowest frequency of events leading to death, respectively. Fig. 2 shows the distribution of the incidents studied in Tehran in the years 2011–2016 based on 22 districts. Accordingly, 281 cases (72.3%) of the incidents have occurred on the highways of Tehran. The most frequent events have been reported on Azadegan highway (26 cases) and the least frequent incidents have been on the highways of Shahid Bakeri, Shahid Fahmidah and Artesh (each has been one) (Fig. 3).

In this study, the relationship between different variables and frequency of traffic accidents in 22 districts of Tehran was investigated. The variables are divided into 3 general categories including populations and exposure, road networks, and travel and land use. Table 1 lists the variables entered into the final models of the factors affecting the frequency of traffic accidents in 22 districts of Tehran with their descriptive characteristics including mean, standard deviation, minimum and maximum.

Where $EMPE_i$ and $SHOP_i$ are the number of employees and shops in the area zone i ; respectively, and DB_i is the co-variate of Tehran Bazaar (traffic zone 1).

In multivariate analysis, using the Poisson model the following variables were entered into the final model: population density, number of illiterate people, number of parks, traffic volume, student population in the residential place, ratio of length of highways to total passages, ratio of length of arterial streets to total length of roads, ramp and loop length ratios to total length of the passages, total land use, commercial use, educational use, and transportation and warehouse use. Meanwhile, the population density, the number of illiterate people, the number of parks, the traffic volume, the population of students in the place of residence, the ratio of the length of highways to the total passages, total land use, commercial use and transportation and warehouse showed a significant relationship with the incidence of accidents of motorcyclists in geographic units (Table 2).

The GWR model indicates that local variations in geographic units play a role in determining the number of accidents. With

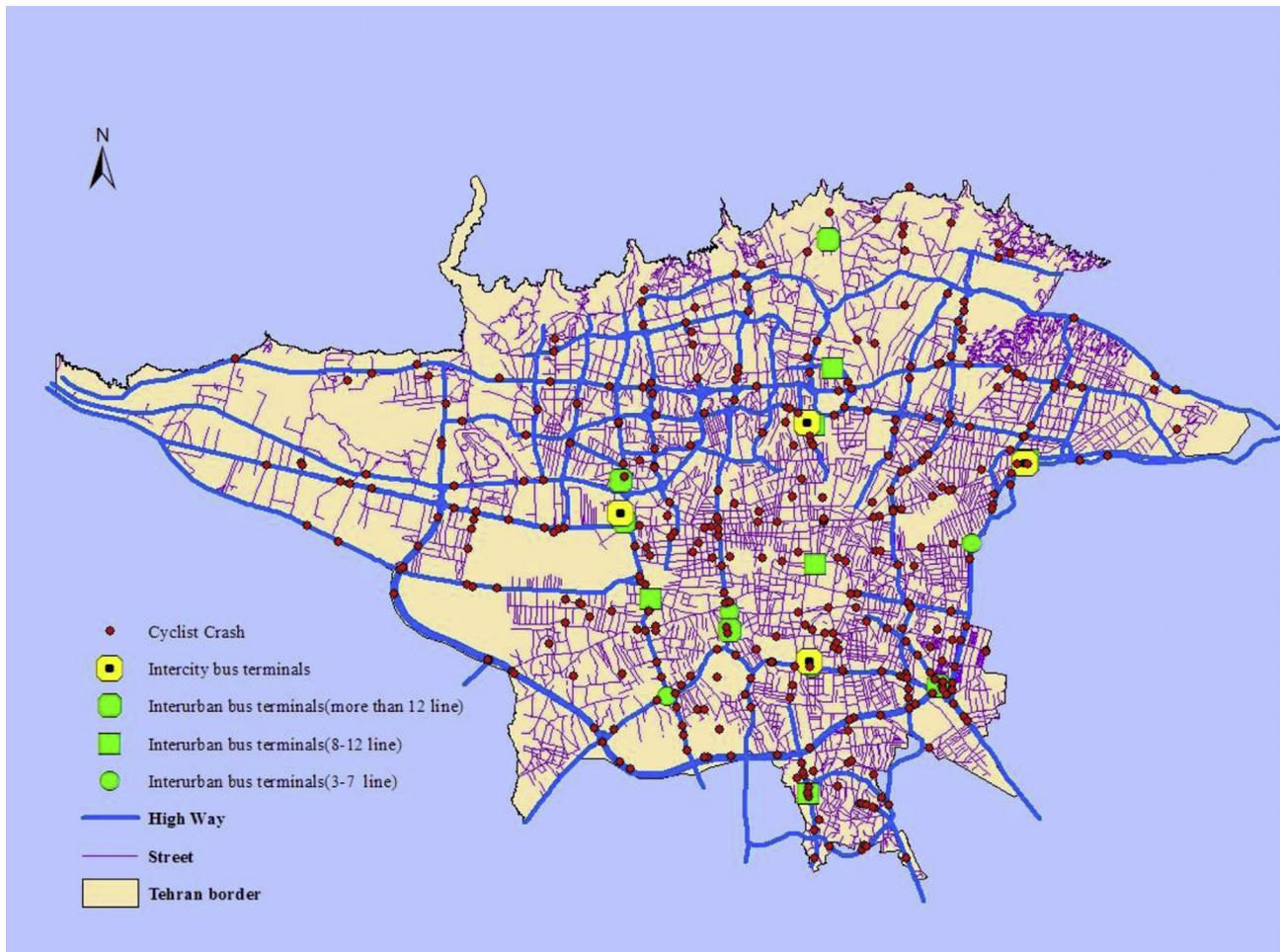


Fig. 3. Location of accidents leading to death of motorcyclists in Tehran relative to roads, 2011–2016.

Table 1
Variables used in the analysis of frequency factors of motorcyclists traffic accidents in Tehran, 2011–2016.

Variable	Mean	SD	Minimum	Maximum
Demographics and exposure				
Population density (n/km ²)	16,649.65	8582.95	1935.27	3,441,99
Population of illiterate people (n)	21,139	12,737	4478	58,107
Illiteracy rate (%)	0.06	0.03	0.03	0.13
Population of workforce at work parks (n)	41,534	42,283	3981	197,495
Occupation rate at work (%)	0.15	0.20	0.03	0.90
Student population at residential place (n)	16,938	12,694	4278	49,818
Student population ratio at residential place (%)	0.04	0.01	0.02	0.09
Daily travel production ^a	350,511	200,440	95,863	871,280
Travel production ratio	15,741	7004	1561	27,621
Number of parks (n)	35	23	6	91
Number of parks in square kilometer (mean)	1.58	1.03	0.10	5.07
Level of development (%)	60.56	15.16	0.49	100.00
Distance traveled (m)	15,736	9501	2906	39,675
Traffic volume	57.7	11.1	43.0	80.0
Roads and passages networks				
Length of highways (km)	9.31	10.31	0	44.10
The ratio of the length of the highways to the total length of the passages (%)	0.32	0.27	0	1.06
Arterial streets length (km)	20.91	16.51	0	66.90
The ratio of the length of arterial streets to the total length of the passages (%)	0.81	0.66	0	2.57
Ramp and loop length (km)	6.3	7.9	0	34.6
Ramp and loop ratio to the total length of the passages	0.20	0.21	0	0.73
Personal vehicle ownership per capita	0.35	0.12	0.22	0.68
Lack of parking (km ²)	14.23	606.23	17.91	2189.31
Land use				
Total land use (m ²)	18,110,266	10,711,801	6,105,032	40,071,922
Land use ration to total area (%)	0.70	0.15	0.41	1.22
Residential use (m ²)	8,092,634	4,682,181	2,064,359	20,349,977
The ratio of residential use to total land use (%)	0.34	0.14	0.10	0.59
Commercial use (m ²)	521,975.8	495,398.1	139,707.5	2,290,825.6
Commercial use ratio to total land use (%)	0.02	0.01	0.02	0.05
Educational use (m ²)	314,472.9	157,872.3	61,060.8	591,062.9
Educational use ratio to total land use (%)	0.02	0.01	0.01	0.04
Administrative use (m ²)	506,979.4	503,573.5	47,527.5	1,902,773.9
Administrative use ratio to total land use (%)	0.02	0.02	0.01	0.08
Industrial use (m ²)	702,163.8	1,489,559.4	31,036.4	6,940,509.1
Industrial use ratio to total land use (%)	0.02	0.03	0.01	0.13
Transportation and warehouse use (m ²)	497,527.3	827,650.5	41,485.6	3,243,042.4
The ratio of transportation and warehouse use to total land use (%)	0.08	0.01	0.03	0.02

^a Estimation is based on mathematical modeling with socio-economic variables. Number of travel attraction in each geographical unit, for instance, is calculated using: $TA_i = 1.620EMPE_i + 2.420SHOP_i + 62694DB_i$

increasing the illiteracy rate, the ratio of length of highways and arterial streets, travel attraction, mileage, developmental level, traffic volume, administrative and industrial use, the number of accidents increases in geographic units (Table 3).

Discussion

Incidence of traffic accidents leading to death of motorcyclists in Tehran in different months of the years 2011–2016 has not had a specific trend. However, the average number of accidents in hot months is more than cold months of the year. As some studies have shown, with increasing traffic volumes, the frequency of traffic accidents, such as accidents involving motorcyclists, is significantly increased.^{11,12} The reason for these seasonal differences can be the changes in the volume of traffic for motorcyclists.

More than 70% of the fatal accidents occurred on highways and freeways. Highways located at the main entrance and exit points in the south and east of Tehran, especially Azadegan, Imam Ali, Basij and Khavaran highways, account for most of the accidents. These findings are consistent with the results of some related studies, such as the study of Wier et al.¹³ in San Francisco and Mueller et al.¹⁴ in Washington, the study by Mannering et al.¹⁵ in Florida, according to which the number and severity of traffic accidents on highways and passages with heavy traffic was higher. Due to the fact that highway traffic in the south and east of Tehran is more than other

areas and in some of these highways there is a blend of various vehicles, one of the reasons for the high frequency of accidents in these areas can be high load of traffic, the mixture of different vehicles, as well as the poor safety facilities of motorcyclists; Therefore, it is necessary to determine the reasons for this issue by conducting further studies and to take necessary measures regarding the organization of the transport of vehicles and motorcyclists, including the separation of light and heavy vehicles in the highways of the south and east of Tehran.

The comparison of the 22 districts of Tehran in terms of the frequency of accidents leading to death in motorcyclists shows that the highest frequency of these incidents has occurred in district 20 (37 cases), which accounts for 9.7% of all cases, while this district only accounts for 3.3% of the total area of Tehran. Given the fact that most of the events in district 20 have occurred on the highways, one of the reasons for more traffic accidents related to motorcyclists in district 20 could be the relative high length of highways. The highways of this area are about 28 km long forming approximately 5% of the highways in Tehran.¹⁶

The final model of effective factors in the frequency of traffic accidents related to motorcyclists indicated that the frequency distribution of these types of events has been significantly associated with population variables including population density and number of illiterate people. The direction of these relationships is negative with population density and positive with the number of

Table 2
Final model of effective factors in the frequency of motorcycle accidents leading to death in Tehran, 2011–2016.

Variable	coefficient ^a	p value	Confidence interval coefficient of 95%	
			Maximum	Minimum
Population Density (km ²)	-155.962	<0.001	-76.927	-234.997
Population of illiterate people	6.97e-05	<0.001	10.04e-05	3.89e-05
Number of parks	-0.016	0.002	-0.006	-0.026
The ratio of the length of the highways to the total length of the passages	2.211	0.002	3.605	0.816
Land use	-2.95e-08	0.033	-2.33e-09	-5.67e-08
Industrial use	8.72e-07	0.003	1.44e-06	3.01e-07
Commercial use	-1.52e-06	0.019	-2.49e-07	-2.78e-06
Transportation and Warehouse use	-1.06e-06	<0.001	-5.85e-07	-1.53e-06
Educational use	1.39e-06	0.061	2.85e-06	-6.40e-08
The ratio of the length of arterial streets to the total length of the passages	0.245	0.162	0.590	-0.098
Traffic volume	0.041	0.001	0.066	0.015
Number of students at the residential place	0.001	0.028	0.002	0.0001
Ramp and loop ratio to the total length of the passages	-0.039	0.125	0.010	-0.090
Model evaluation criteria				
AIC	6.18			
BIC	84.32			

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

^a In the Poisson model and the negative binomial with a unit of change in the independent variable of the corresponding logarithm of the response variable varies based on the size of the corresponding variable coefficient, provided that other variables remain constant in the model. For example, if personal ownership per capita increases one unit in the spatial units under study, the number of incidents leading to injuries will drop by as much as 0.8, because its coefficient is less than one.

illiterate people. In other words, the occurrence of these types of accidents in areas with higher population density is lower and vice versa. Moreover, the higher number of illiterate people in the geographic units under study increases the number of fatal accidents in motorcyclists. Various studies conducted in the United States, including studies by Cottrill et al.¹⁷ in Chicago, Kuhlman et al.¹⁸ in Denver, Colorado, Siddiqui et al.¹⁹ in Florida, Ukkusuri et al.²⁰ in New York, and McArthur et al.²¹ in Michigan also showed a significant relationship between the population density and frequency of traffic accidents. Considering that more density of the permanent population leads to increased traffic load and slower movement of four-wheel vehicles and motorcyclists on the road, this can reduce traffic speed in the areas with higher population density.

In the final model, there is a significant relationship between the frequencies of deaths in motorcyclists with the ratio of length of highways to the total passages as one of the most important transport variables. The direction of this relationship is positive. In other words, the incidence of these types of events is higher in areas where the density of highways is higher. Considering that in these areas more cars and motorcycles move at high speed, it can be said that the proportion of high-risk accidents related to

motorcyclists is increased and thus the incidence of fatal accidents increases as well. Studies performed in other areas have also shown such a relationship. Examples include Hashimoto et al.²² in Florida, Cloutier et al.⁹ in Canada, Green et al.²³ in the UK.

The frequency distribution of deaths due to land use variables including general use, industrial, commercial, transportation and warehouse use has shown a significant relationship. It should be noted that studies carried out in other parts of the world have shown that one of the factors contributing to the distribution of traffic accidents is the use of land in different parts. These include Yao et al.²⁴ studies in Hong Kong, Ukkusuri et al.²⁰ in New York and Wier et al.¹³ in the United States of America; given the positive relationship between industrial use and the events involved, it is necessary to consider facilities required to enhance the safety of motorcyclists, particularly in areas with high industrial use, while developing different districts of Tehran, especially in the reconstruction of old textures.

Considering the environmental and structural differences of the high and low risk areas, it can be said that environmental factors play a major role in the distribution of traffic accidents involving motorcyclists in Tehran. Similar studies in other parts of the world, including the study of Slaughter et al.²⁵ in New York, the study of

Table 3
GWR model of influencing factors on distribution of accidents leading to deaths of motorcyclists in Tehran, 2011–2016.

Variable	Maximum	The third quartile	Mean	The first quartile	Minimum
Population density	-0.933	-0.934	-0.935	-0.936	-0.936
The ratio of illiteracy	0.258	0.257	0.256	0.255	0.255
The ratio of the length of the highways to the total length of the passages	0.369	0.369	0.368	0.367	0.366
The ratio of the length of arterial streets to the total length of the passages	0.181	0.181	0.180	0.179	0.179
Travel attraction	0.479	0.479	0.478	0.477	0.476
Distance traveled	0.099	0.099	0.098	0.097	0.097
Lacking of parking area	-0.383	-0.384	-0.385	-0.386	-0.387
Level of development	0.089	0.089	0.088	0.087	0.087
Traffic volume	0.073	0.071	0.069	0.067	0.066
Residential land use	-0.330	-0.331	-0.332	-0.332	-0.334
Commercial use	-0.094	-0.095	-0.095	-0.097	-0.098
Educational use	0.169	0.167	0.165	0.163	0.161
Administrative use	-0.028	-0.028	-0.029	-0.030	-0.030
Industrial use	0.060	0.057	0.054	0.051	0.049
Model indices					
BIC	67.5				
AIC	129.4				
Percent deviance explained	0.88				

GWR: geographically weighted regression, AIC: Akaike's information criterion, BIC: Bayesian information criterion.

Anderson et al.²⁶ in London, the study of Taquechel et al.²⁷ in Atlanta, the study of Wang et al.²⁸ in Texas, the study of Siddiqui et al.¹⁹ in Florida, and the study of Kuhlmann et al.¹⁸ in Colorado have also shown that environmental factors such as the radius of intersections, car warning signs, street width, street surface quality, street type, shopping area, street lighting, traffic volume, and population density play a significant role in distribution of traffic accidents. Therefore, by carrying out specific and extensive studies, the role of each of these factors in determining the traffic incidents associated with motorcyclists and their control strategies can be identified.

This study showed that if appropriate information is available about dependent variables and environmental factors, the influencing factors on the distribution of these events in urban roads can be identified using regression models, and then more targeted planning can be provided based on the results to reduce them.

The southern and eastern parts of Tehran are the most susceptible areas in terms of traffic accidents leading to deaths of motorcyclists. Most traffic accidents leading to deaths of motorcyclists in Tehran occur on highways, especially highways at the main entrance and exit points of Tehran; therefore, the highways of Tehran are the most dangerous passages for motorcyclists. The presence of high-risk points in terms of accidents in of south and east of Tehran indicates the significant role of environmental factors in traffic accidents leading to deaths of motorcyclists. Therefore, further studies are needed to identify these factors and to organize the commuting of motorcyclists in high risk areas.

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Ethical statement

This study was approved by the Ethics Committee of Tehran University of Medical Sciences in terms of ethics in research with IR.TUMS.REC.1395.03.38.32820 Code.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cjtee.2018.12.006>.

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