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Original Research Paper

GIS-based spatial analysis of urban traffic accidents: Case study in Mashhad, Iran

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HIGHLIGHTS

- GIS was used as a management system for accident analysis by applying combination of spatial-statistical methods.
- The operational approach of spatial patterns was developed in geographical information system (GIS) framework to analyze three types of urban accidents (fatal, injury and property damage only (PDO)).

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ABSTRACT

There is a growing concern in traffic accident rate in recent years. Using Mashhad city (Iran second populous city) traffic accident records as case study, this paper applied the combination of geo-information technology and spatial-statistical analysis to bring out the influence of spatial factors in their formation. The aim of the study is to examine 4 clustering analyses to have a better understanding of traffic accidents patterns in complex urban network. In order to deploy the clustering technique in urban roads, 9331 point features for inner city traffic accidents during 12 months have been registered according to their x and y location in geographic information system (GIS). The mentioned areas were analyzed by kernel density estimation (KDE) using ARCMAP and two other analyses using SANET 4th edition software so that the results of network analysis can be compared with traditional KDE method. In addition, this research introduces five classifications for determining the eventfulness of the under study area based on standard deviation and to make priority in creating security in the area. The nearest neighbor and K-function output analysis consist of four curves and regarding the fact that for all fatal, injury and property damage only crashes, the observed value curve is above the 5% confidence interval. Accidents in the study region are more clustered than expected by random chance. The importance of this study is to use GIS as a management system for accident analysis by combination of spatial-statistical methods.

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1. Introduction

Road accidents are worldwide and increasing, mainly because the development of transportation infrastructure fails to keep pace with other sectors like industry and real estate. Thus, the road traffic accidents are the leading cause of human deaths and/or illness worldwide (ICMR, 2009). These accidents often result in fatalities, injuries or damages to people around the world. Iran, having a population of 77 million and having 19 million registered automobiles and motorcycles, has a loss of 24,000 people each year because of traffic road accidents. The majority of these accidents result from human errors (inattention of drivers), therefore systematically analyzing the accidents, using appropriate solutions such as traffic control equipment, better design of roads and also effective activities of traffic police department could lead to a decrease in the number or the intensity of accidents. The human errors caused accidents are mainly the carelessness of drivers or pedestrians. Hence, the probability of accident occurrence, and its severity, can often be reduced by the systematic analysis of the incident scenarios and by resorting to appropriate solutions involving the application of proper traffic control devices, suitable roadway design practices and effective traffic police activities. However, the task of making effective solutions warrants analysis of spatial and temporal patterns in the zone of traffic accidents, which can be achieved through the application of geospatial technology (Cheng and Washington, 2008). The nonrandom distribution of accidents, both in time and space, often raises questions about the location and the reasons for that location (Schuurman et al., 2009). Unlike the conventional methods, spatial thinking helps to identify the patterns and suggest reasons for the pattern characteristics (Prasannakumar et al., 2011). GIS technology has been a popular tool for visualization of accident data and analysis of hot spots and hence it is used by many traffic agencies (DeepthiJayan and Ganeshkumar, 2010). Understanding of spatial and temporal crash patterns helps the safety specialists to detect the sections having a higher number of crashes, to compare with other similar locations. These sections are defined as hotspots (Elvik, 2008; Mohaymany et al., 2013).

Mashhad, one of the biggest tourist locations in Iran, has high importance in terms of health tourism development barriers in the country (Yazdi and Barazandeh, 2016). The city is a popular destination for religious tourists and pilgrims (Zainai et al., 2012). The aim of this research is to evaluate and show hotspots in Mashhad using information modeling for identifying the exact location of accidents via geographical information technology statistical locations. Spatial-temporal analysis is useful in identifying hotspots and can offer a way to improve the safety of these spots.

2. Literature review

Several studies have been conducted to establish spatial patterns in vehicle or pedestrian crashes to identify the critical locations (Flauhaut et al., 2003; Jones et al., 1996). Kim and Yamashita analyzed spatial patterns of pedestrian crashes in Honolulu, Hawaii using *K*-means clustering techniques (Kim and Yamashita, 2007). Baratian-Ghorghi et al. (2015) ranked the high-crash locations by developing a new methodology to predict the first and second possible entry points based on the crash locations and distance from upstream interchanges.

A study on traffic accidents using GIS and spatial-temporal methods was done in 1996 in Norfolk, UK. In the study *K*-function analysis method was used for identifying the presence or absence of hotspot clustered. The researchers, by finding centralized clustered accidents, were able to reduce the number of accidents in these spots (Jones et al., 1996).

A study on road accidents in Mechelen, Belgium was done in 2004 with the aim to find black zones. The researchers used linear and planar cluster analysis methods and by comparing them, researchers were able to find hotspots (Steenberghen et al., 2004). Moreover, the advantages and disadvantages of planar and linear cluster methods were mentioned in this study. This research facilitated road renovation around historical areas located in downtown.

Erdogan et al. (2008) performed a research in Turkey to evaluate accidents distribution in a highway, located in the entrance of Afyonkarashiasar city. This research used two different methods of kernel density analysis and after identification of hotspots, accidents' conditions were considered hourly, daily and seasonal basis. Moreover, introducing three important hotspots, the researchers offered a number of strategies to the traffic departments in order to solve the problem (Erdogan et al., 2008).

In the same year, a research was performed in London which presented a method to study wounding accidents' patterns, based on geographical information system (GIS) and assessment of kernel density. This paper tended to present a methodology to identify hotspots in terms of accidents, using GIS, with assessment of kernel density analysis, adding accidents' areas related data and identifying similar areas using average *K* algorithm. This methodology and clustering technique were obtained through studying data of accidents occurred in the studying area in London, through the past five years. Despite the past investigations, this research was performed based on the assumption that the traffic accidents occurred in the same area. In addition, this research tends to investigate hotspots, to cluster these points, and to perform semiotics based on spatial indices (Anderson, 2009).

Loo and Yao (2013) analyzed 603 simulated patterns of traffic crashes in three simplified hypothetical networks and the empirical crash pattern in Hong Kong in 2 years. They used the link-attribute approach and the network-constrained event-based approach to identify hot zones. The results suggested that the link-attribute approach and network-constrained event-based approach are usually consistent but there are major differences between these two approaches.

The objective of this research is to incorporate the use of advanced spatial statistical methods with GIS to evaluate an innovative approach of safety data analysis.

3. Study area

Mashhad (Fig. 1) is located in Khorasan Razavi Province, in northeast of Iran with an area over 233.3 square kilometers.

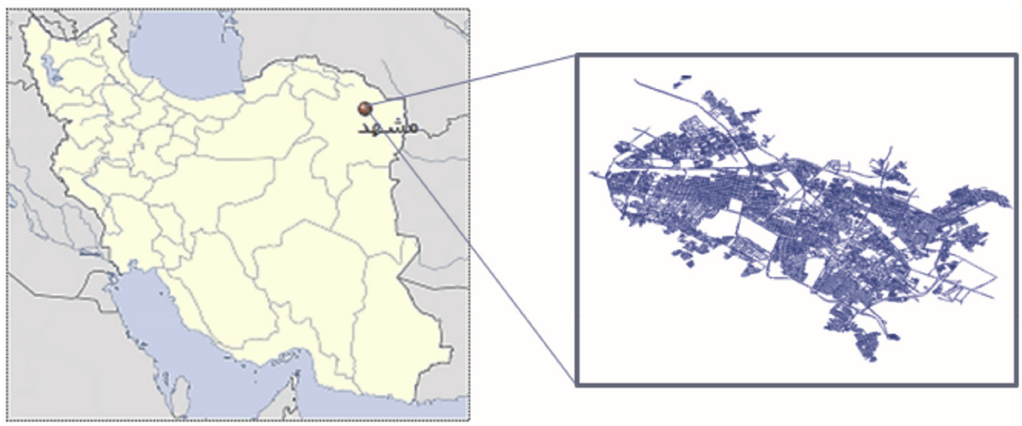

Fig. 1 – Map of the study area.

Considering that this city is main tourism pole of Iran, this city has witnessed a significant population growth in recent years that population of this metropolitan increased to 2,933,000 people from March 21, 2011 to March 19, 2012. Rapid growth and development and increase of vehicles, possibly leads to increase of traffic accidents. Therefore, predicting possible hotspots will assist decision makers to delineate the safe road segments which in turn can be effectively used as models in the development of safer roads.

9331 point features were registered for fatal, injury and property damage only (PDO) crashes in Mashhad, considering their location based on x and y location in the period between March 21, 2011 to March 19, 2012. Fig. 2 shows the above-mentioned points in street network of Mashhad. Based on visual observation of Fig. 2, it would not be easy to check the distribution of the data. It is necessary to apply appropriate analysis before conducting the hotspot analysis.

4. Methodology

The main purpose of this study is to examine the distribution of accidents through identification of hotspots using GIS and spatial statistics. Although the accidents have been thoroughly examined based on various attributes, a spatial framework will provide useful insight into road safety

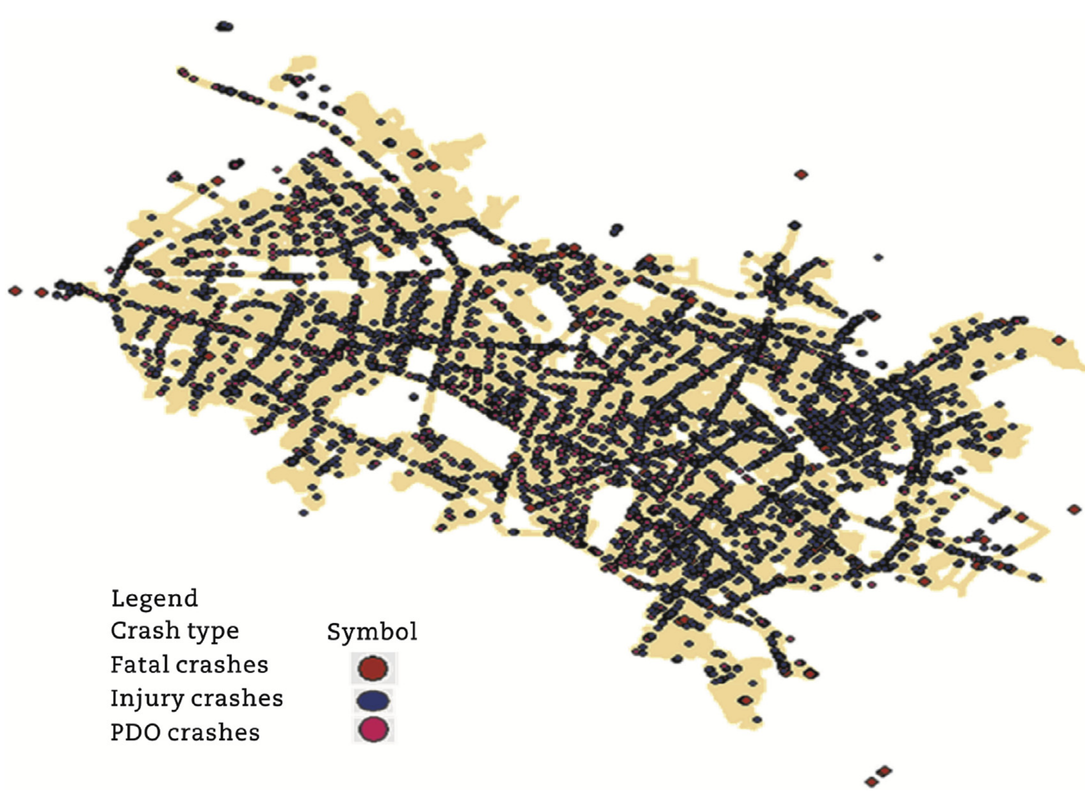

Fig. 2 – Traffic accidents leading to death, injury and damages in street network of Mashhad.

patterns. The analysis will utilize combinations of the methods and techniques including traditional KDE, nearest neighbor analysis and *K*-function. Nearest neighbor analysis and *K*-function will examine the presence or absence of clusters of accidents. If present, it indicates that there are locations in study area where accidents are more likely to occur. As a result, more funding and research must be dedicated for these locations.

Hotspots analysis will be used to identify and supply required information to help decision makers in making suitable decisions to prevent and reduce traffic accidents. In general, traffic accidents' statistics has been considered as assessment index to evaluate possible future traffic accidents in roads. Nowadays, using real data and GIS are of tools to predict spatial pattern of traffic accidents which have correlation with real conditions. Technical details of methodology used in the analysis are presented below.

4.1. Accident datasets

Accidents related data, used in this research, are presented in Fig. 3 in groups of traffic accidents leading to death, injury and damages. These data include locations of accidents for the period between March 21, 2011 and March 19, 2012, with total number of 9331, which are represented as geocoded *x* and *y* coordinates. In Fig. 3, "*" means the accidents with more than 31.5 million rials damages (1 USD is about 10,500 rials in 2011).

4.2. Accidents' data analysis method

Mapping spatial statistic is a key to understand occurrence of spatial-temporal accidents and spatial analysis includes a set of methods to describe and model spatial data. The most important issue is the presence of spatial effects among neighboring samples over space and time – an issue that can adequately be addressed using point pattern analysis (Yamada and Rogerson, 2003). This research used ARCGIS10 software to analyze kernel density and SANET software (Okabe et al., 2006) for spatial analysis on the network and nearest neighbor.

4.2.1. Kernel density analysis

There is a range of spatial software for understanding patterns of changing geographic locations. One of the most efficient

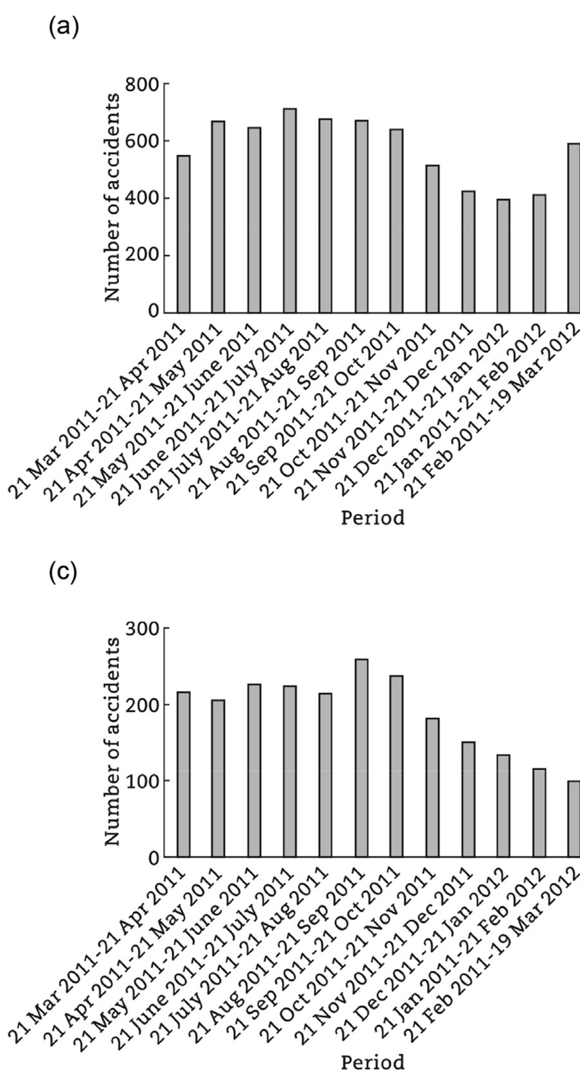

Fig. 3 – Intercity accidents of Mashhad metropolitan in the period from March 21, 2011 to March 19, 2012. (a) Accidents leading to injury. (b) Accidents leading to death. (c) Accidents leading to damages*.

tools for this purpose is kernel density analysis (Chainey and Ratcliffe, 2005). This research has various advantages including determination of static hotspots and clustering methods such as K-means. Main advantage of this method refers to the estimation of growth rate of accidents risk. Risk growth can be defined as an area around a special cluster with the highest accident risk, determined based on spatial analysis. Secondly, using density method, a contractual spatial analysis unit can be defined in consistent form in the whole study area in order to create criteria for clustering and comparison. Previous studies showed that conventional kernel density estimation (KDE) has been employed in several safety studies to detect the crash hazard regions (Anderson, 2009; Pulugurtha et al., 2007). The idea behind density estimation is that the point pattern has a density at any location in the study region not just at the location where the event occurs or is displayed (Lloyd, 2006; O'Sullivan and Unwin, 2002). Kernel density estimation includes placing a symmetric plane on each point and assessment of space from that point to the reference point based on mathematical function and total amounts for the whole levels for the reference point. This method is repeated for other consecutive points. So, this method provides possibilities to use kernel function for each observation and these kernel functions altogether provide density analysis for distribution of accidents points (Bailey and Gatrell, 1995).

Kernel density function presents a set of points as entrance and creates a density level. At first, density level of each independent and distinct point is defined with the highest amounts, which are recognized using their location from the zero point. Density level for a point out of specified radius equals to zero. Each of these separated density levels will be added to others in order to create density continuous level across the study area (Fotheringham et al., 2000).

$$f(x,y)=\frac{1}{nh^2}\sum_{i=1}^{n}K\left(\frac{d_i}{h}\right)$$

where h is the bandwidth, d_i is the distance from the center in the bandwidth, K is function of the kernel density, n is the number of observations.

Putting the kernel on line leads to creation of a continuous and smooth level. This method has been known as KDE, because around each point which the index is observed, a circular area (kernel) will be created across a specified band, in order to compute the amount of each index regarding its function. The sum of these amounts in all spaces introduces a level of density analysis. Density is measured in two ways, simple and kernel. Simple method divides the whole study area into numbers of predetermined cells and draws a circular neighborhood around each cell in order to compute the density amount of each independent cell. Radius of circular neighborhood affects density plan results. If the radius increases, there is a possibility that the circular neighborhood would include more feature points which results in a smoother density surface (Silverman, 1986). Rather than considering a circular neighborhood around each cell (the simple method), the kernel method draws a circular neighborhood around each feature point (the accident) and then a mathematical equation is applied that goes from 1 at the position of the feature point to 0 at the neighborhood boundary (Bailey and Gatrell, 1995).

4.2.2. *Nearest neighbor distance analysis*

The next method of traffic accident distribution analysis is the nearest neighbor distance analysis. Nearest neighbor distance analysis is used to determine whether the points (or accidents in this research) are clustered based on the nearest distance between two neighboring accident points. This analysis measures cumulative the number of points against the nearest neighbor distances. If average distance of the nearest neighbor is significantly smaller than the expected random point's pattern, null hypothesis is rejected in favor of clustering.

This process exists in SANET toolbox software and only requires input data of a network or a set of points. In this research, accidents have occurred in network streets, and intercity highways of Mashhad. Also, users must define the number of iterations and input class for the software. Number of simulations shows number of produced random points patterns. It is important that number of random samples should be big enough to distribute in normal and symmetric form. 50 iterations are performed for this research. The class interval is the range distance of each class of distances. 7.62 m is selected for this research.

4.2.3. *K-function analysis*

The last performed method of network points patterns analysis is K-function analysis. K-function analysis provides a more accurate analysis of points' distribution. In addition to the processes performed in nearest neighbor distance analysis, number of points with the shortest distances is assessed for each independent point in K-function analysis. When total points of each distance are counted for in data set, average of total points in each distance is shown on diagram. A method similar to the one used in analysis of nearest neighbor distance is used in this research. Similar to analysis of nearest neighbor distance, the input of a confidence interval for K-function analysis is commonly considered as 5%.

5. Results and discussions

5.1. *Kernel density*

Important criteria to estimate the most suitable density level is bandwidth (Bailey and Gatrell, 1995; Fotheringham et al., 2000; Silverman, 1986). Selecting bandwidth affects output of hotspots. For instance, larger bandwidth shows hotspots area in larger form. In this analysis, five categories were performed based on the standard deviation which considers that, one can prioritize investigations to solve safety problem of hotspots and this classification is shown in Table 1.

Figs. 4–6 show results of kernel density level for accidents leading to death, injury and damages in Mashhad from March 21, 2011 to March 19, 2012. Kernel density computations are computed through ArcMap. The default option and the only kernel density option in this software is quadratic density model. Each independent point of mound-shaped kernel density level is like quadratic functions. The results showed

Table 1 – Classification of intercity regions of Mashhad based on standard deviation in terms of distance between crashes.4

Type of region	Color based on standard deviation in terms of distance between crashes
Very low disaster-prone	
Low disaster-prone	
Average disaster-prone	
High disaster-prone	
Very high disaster-prone	

that the high crash-prone zones are concentrated in the vicinity of Mashhad city (Fajr Square in Hemmat highway). This is intuitive as the higher level of traffic interactions generates more safety problems. As the highways are extending outward from the core urban areas, the risk level is decreasing.

5.2. *Nearest neighbor distance analysis*

Output of this analysis is a diagram with four curves, which shows cumulative number of points against the nearest neighbor distances. The first curve is the observed traffic accident values, and the other three are the average values for the random point samples. 5% confidence interval is above

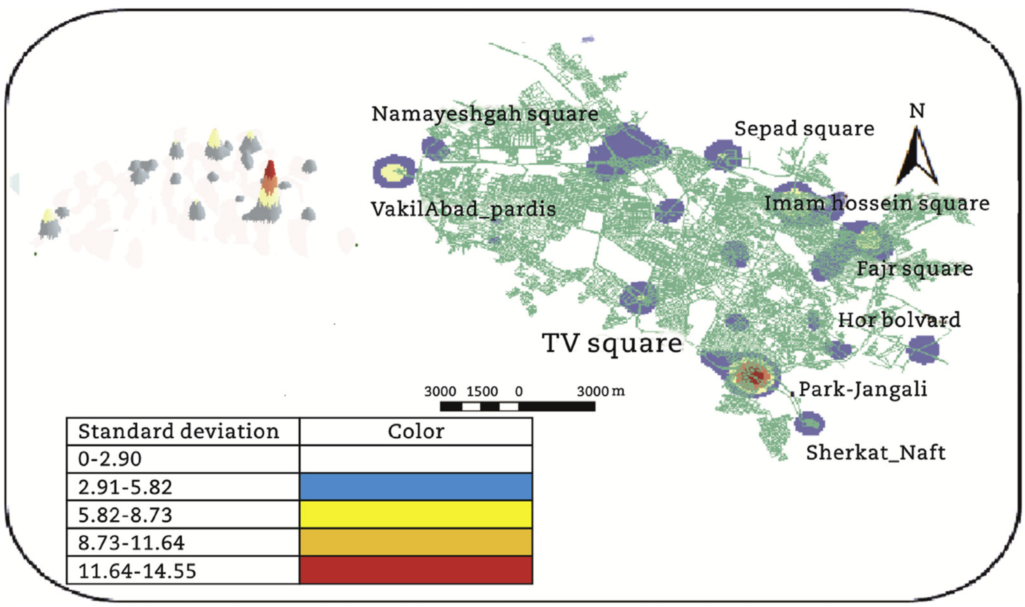

Fig. 4 – Results of kernel density level for accidents leading to death from March 21, 2011 to March 19, 2012.

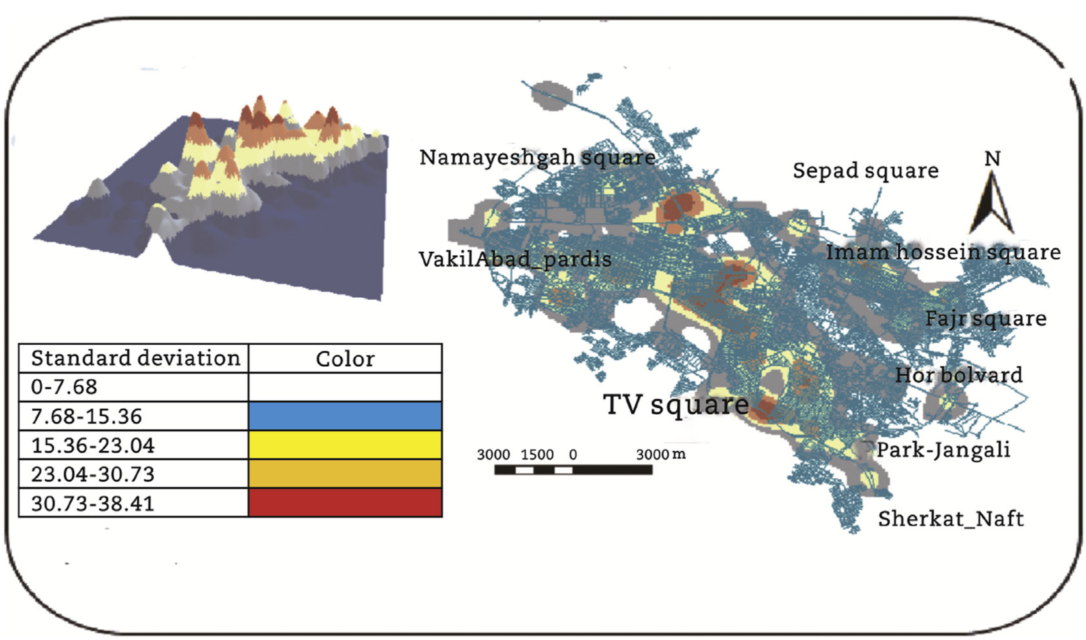

Fig. 5 – Results of kernel density level for accidents leading to injury from March 21, 2011 to March 19, 2012.

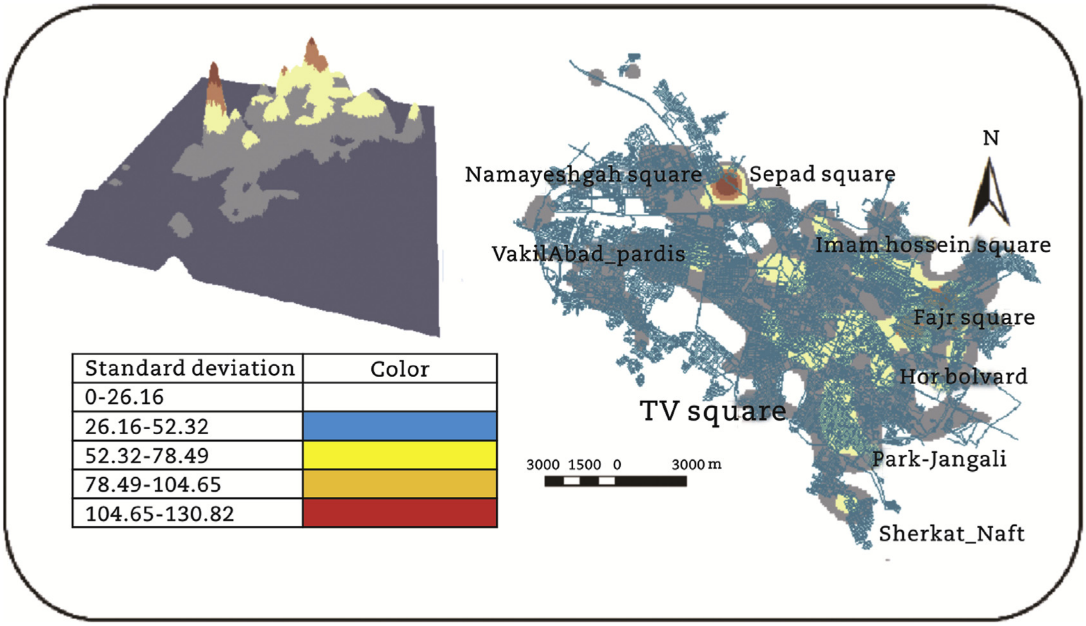

Fig. 6 – Results of kernel density level for accidents leading to damages from March 21, 2011 to March 19, 2012.

and below the average. Outputs of intercity accidents of Mashhad for accidents leading to death, injury and damages are shown in Figs. 7–9. Wherever the observed value curve is above the 5% of output confidence level, the observed data set is more clustered than expected by random chance. Diagrams of Figs. 7–9 show that points are clustered more than expected. This is estimated using number of observed cumulative points and number of random points in the classes between 0 and 152.4 m. Regarding that the amount is out of 5% of output confidence level, null hypothesis is rejected. Therefore, accidents analysis is assessed as clustered, more than those expected with random points.

In other words, the distribution of the fatal, injury and PDO accidents related to an expected random distribution appears to be more concentrated than those expected with random points. Since the standard error of the joint distributions is not known, there is not a simple significance test of this comparison. However, Figs. 7–9 suggest that three different types of crashes are more concentrated than those expected from random points and, hence, are more likely to have 'hotspots' or 'hot zones' where they are particularly concentrated. This nearest neighbor analysis, of course, does not prove that there are hotspots, but only points out the higher concentration of the accidents is related to expected random points.

5.3. *K*-function analysis

K-function is considered as a comprehensive esti???mator of point distribution. Unlike the nearest neighbor analysis, the *K*-function approach explores a spatial pattern across a range of spatial scales. The analysis is based on inter-event distances between observation-points. Output of *K*-function analysis is similar to analysis of nearest neighbor distance with four curves. *K*-function gives a more similar and accurate result. Since the observed values for diagrams of Figs. 10 and 12 are above expected 5% of output interval, it suggests that the injury and PDO crashes in the study area are more clustered than that expected by random chance. Therefore, rejecting null hypothesis provides enough evidence for budget allocation for hotspots related to injury and PDO crashes in Mashhad. However, based on Fig. 11, it can be noticed that the observed values are below the expected 5% of output

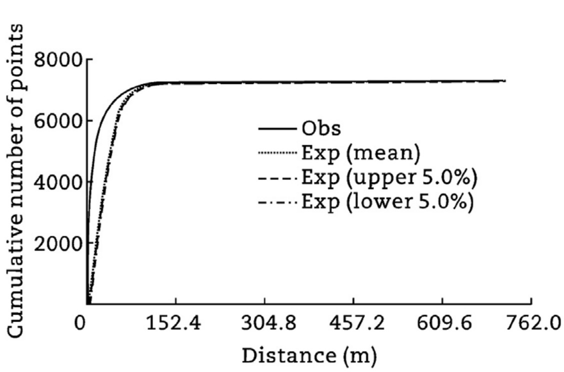

Fig. 7 – Observed and expected nearest neighbor curves for accidents leading to injury.

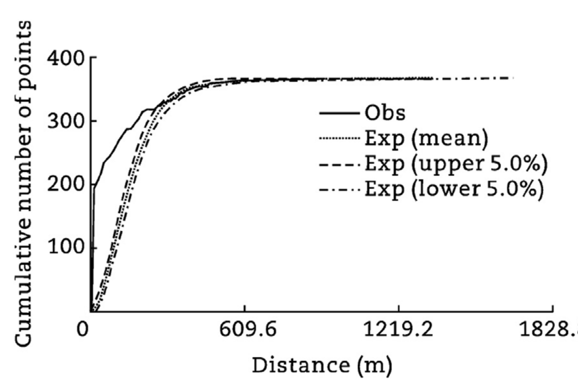

Fig. 8 – Observed and expected nearest neighbor curves for accidents leading to death.

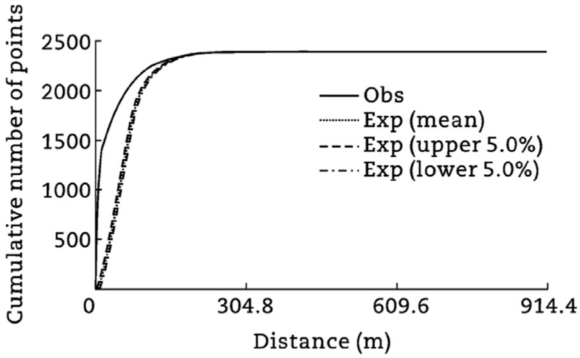

Fig. 9 – Observed and expected nearest neighbor curves for accidents leading to damages.

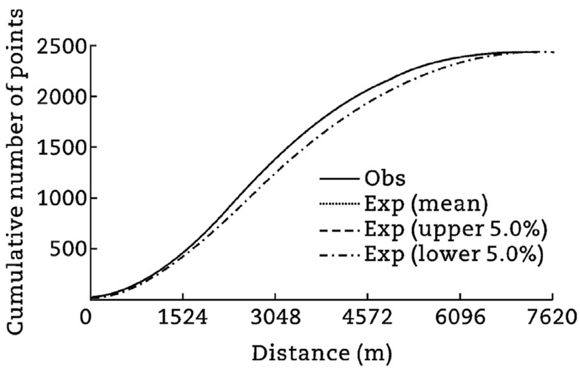

Fig. 10 – Observed and expected *K*-function curves for accidents leading to injury.

interval, which might suggest that based on one-year data, it is not reasonable to accept the results for KDE analysis. That is because, with 95% the data has been distributed randomly through the case study and allocating budget for the KDE analysis is not suggested.

For all three types of *K*-functions (fatal, injury and PDO crashes), observed values are above the corresponding upper envelope over the whole range of distances, so that we can conclude that accidents occurring in these regions are spatially clustered. However, it is necessary to mention that, since it is generally known that traffic accidents are spatially clustered, it is not a surprise that both the nearest neighbor and *K*-function methods detect clustering in the distribution of accidents.

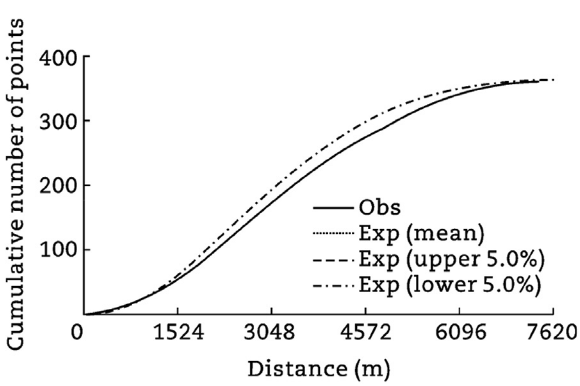

Fig. 11 – Observed and expected *K*-function curves for accidents leading to death.

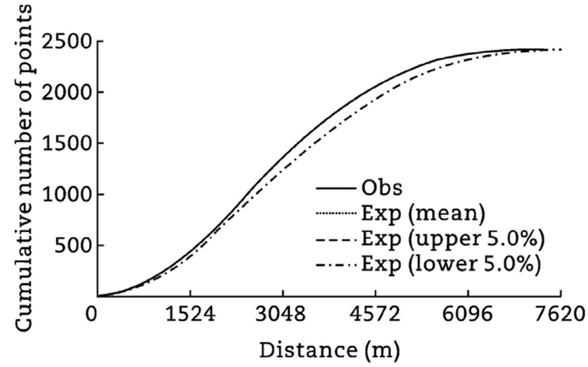

Fig. 12 – Observed and expected *K*-function curves for accidents leading to damages.

6. Conclusions

Although the number and speed of vehicles has been increased in recent years, the quality of roads have not been improved enough and safety standard of vehicles has not reached a desired level. In addition, people have not received required instructions and training to improve their attention in terms of safe driving. The present study aims to investigate and compare different types of traffic accidents in terms of spatial aspect, which is the first attempt in the Mashhad city corporation. Furthermore, the paper tends to develop the operational approach of spatial patterns in GIS framework in order to analyze three types of urban accidents (fatal, injury and PDO).

This paper used the combination of nearest neighbor analysis and *K*-function to investigate the distribution of urban crashes. In addition, kernel density estimation (KDE) were employed to identify hazardous segments of urban network. Moreover, nearest neighbor distance and *K*-function analysis have been conducted to ensure the existence of clustering. The results of kernel density estimation for fatal, injury and PDO crashes were used to estimate spatial risk pattern of accidents (hotspots). These locations were reported to traffic police department and urban department of transportation for treatment. This research used ARCMAP, which has specialized capacity to display and analyze spatial patterns of accidents in a way that authors are able to create basic spatial unit based on hotspots clustering method. Classification of hotspots of road accidents is an important issue for road safety. This research used five classifications based on standard deviation to prioritize investigations of hotspots' safety. This semiotics provides a snapshot of the process that occurs in the field of urban accidents. The results showed that the high crash-prone zones are concentrated in the vicinity of Mashhad city (Fajr square in Hemmat highway). This is intuitive as the higher level of traffic interactions generates more safety problems. As the highways are extending outward from the core urban areas, the risk level is decreasing. The implementation of the findings of this research will result in long term economic benefits, and improve traffic flow and safety. These findings help road safety specialists to have better understanding of such problems. Analysis of nearest neighbor distance and *K*-function were performed using SANET toolbox in the ARCGIS operational environment for fatal, injury and PDO crashes. Regarding that the resulted amounts of this research are out of 5% input confidence level, null hypothesis is rejected. Based on this analysis, these estimated accidents are more clustered than that expected by random chance. The results of nearest neighbor and *K*-function analysis emphasizes on the requirement for additional researches for spatial data analysis.

Examining the distribution of urban traffic accidents on a random basis will be a motivation for future researches to eliminate the budget allocation for unnecessary locations. According to the independency and randomness of traffic accidents, budget should only be allocated to the non-randomly distributed sections. However, it should be noted that in road safety research, it is necessary to extend the study period to a 3-year or 5-year period for a meaningful spatial analysis.

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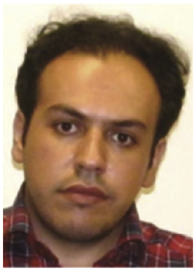

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