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Spatial Analysis of Traffic Accidents in the City of Medina Using GIS

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Abstract

The general objective of this research is to determine how to use the spatial analysis of traffic accidents in Medina Menorah City through geographic information systems. This research aimed to identify, locate and define the sites where traffic accidents are concentrated and determine the need to apply specific safety standards to reduce accidents and identify their causes thereof. This current research applied the analytical descriptive approach for its relevance with this specific research. This research collected traffic accidents data from the Ministry of the Interior, Department of General Traffic. That data captured the hotspots accidents in Medina Menorah City. Some of the most important results of the study are as follows: many roads were selected as High Accident Location HAL, such as Central Ring Roads, King Faisal bin Abdul-Aziz Road, Prince Abdul Majid bin Abdul-Aziz Road, and King Abdulla bin Abdel-Aziz Road. The high-speed roads are heavily linked to the massive increase of traffic accident rates, and the increase in the street section length led to the soaring number of total accidents. The study recommended performing more studies and different highway safety studies to identify and locate accident patterns on road networks. Due to the fact that the accidents concentration is intensely focused on Medina City center and Prophet's Mosque, it is a must to increase the number of public transportations to and from Prophet's Mosque, particularly during the Hajj period, because of the fact that the visitors of Prophet's Mosque is on the increase during the said period. This study can be applied in other cities because knowing the locations of traffic crash hotspots can provide us with valuable insights into the causes of accidents and this knowledge helps decision-makers to better assess the risk associated with accidents.

Keywords

Spatial Analysis, Traffic Accidents, Kernel Density, Hot Spot Analysis

1. Introduction

In fact, mapping spatial analysis statistics is fundamental to understand the occurrence of spatial-temporal accidents and spatial analysis comprises a set of different methods to describe and model spatial data. The issue that enjoys an optimal significance is the presence of spatial effects among neighboring samples along with both space and time that represent an issue that can adequately be addressed with the use of point pattern analysis.

Different studies use variant programs and tools for spatial analysis on the network and nearest neighborhoods of traffic accidents. Some of them used ARCGIS10 software to analyze kernel density and SANET software [1]. Some other studies used GIS for spatial analysis and for the identification and locating the hot spots of road accidents [2].

As a matter of fact, GIS spatial analysis and decision-making systems does not only enable the identification of high crash zones of roads, but it also helps in developing crisis management programs for providing adequate and fast pre-hospital services in the event of an accident and thus prevent the avoidable leading cause of deaths [3].

Recently there has been a tremendous increase in the numbers of studies investigating the tools for analyzing accidents and road design considerably. Among the commonly used tools, is the Geographical Information Systems (GIS) which enjoy a considerable capacity for performing whatsoever complex spatial analysis. GIS has also been used to represent the results of the statistical studies of accidents and perform spatial analysis of traffic accidents [4] [5].

It is habitual for researchers to combine GIS and other statistical models with the aim to evaluate the risk of road accidents. Some studies found that GIS and other related advanced statistical models can be used to evaluate the risks which result from traffic road accidents [6].

Traffic road accidents have been overwhelmingly on the increase in the past decades, thus, causing horrific fatalities and injuries worldwide. Therefore, in the recent years, the number of studies about the tools and instruments used for analyzing accidents and road design has considerably increased. Among these tools, Geographical Information Systems (GIS) which strongly stand out for their ability to perform complex spatial analyses [7].

According to the latest statistics, traffic road accidents cause approximately 50 million injuries per year, in average, across the globe and therefore, they represent a terrible problem for the public health. In addition, and according to the statistics of the World Health Organization (WHO), more than 1.35 million people died worldwide because of road traffic accidents in 2016 alone [8].

According to the 2011 statistics of the accidents of road traffic in Medina City during May of the same year, the number of the weekly accidents of road traffic, from 18 to 24 hours was approximately 671 accidents, and the number of injured persons was approximately 82 and 9 people died therefrom, indicating that such accidents of road traffic are due to their reckless driving and crazy over speed, especially on highways as well as due to their lack of alertness and attention when driving. With the aim to counter fight such dangerous phenomenon, the Region Traffic Department represented by the Traffic Safety Division, for the time being, is conducting various traffic studies to find out the causes of accidents of road traffic in the area and to manage to identify the accidents clusters and their hotspots and accordingly to set forward the proposed solutions which are expected to significantly contribute to reducing such catapulting accidents of road traffic [9].

Therefrom, the problem of the research arises and is represented in the increasing number of road traffic accidents in Medina City especially in certain hotspot zones which necessitates seeking the spatial analysis of traffic accidents in the city of Medina City by using GIS to help address this aggravating problem and thus to find solutions for decreasing such traffic road accidents and their losses and damages resulting therefrom.

2. Geographical Setting

The Kingdom of Saudi Arabia consists of thirteen administrative regions, each region is called Emirate, and each emirate consists of a score of governorates and centers. The Emirate of Medina Menorah is ranked third as per the area and fifth as per the toll of population. The Emirate of Medina consists of eight governorates, they are as follows: (Yanbu Al-Bahr, Al-Ula, Al-Mahd, Al-Hinakiyah, Wadi Al-Fare, Al-Ais, Khaybar, Badr) besides Medina. The eight governorates constitute 101 centers classified into 45 class “A” and 56 class “B”, respectively.

Medina Menorah is the capital city of the Medina Region. It is in the Eastern part of the Al Hijaz area, in the northwestern part of the kingdom, located about 250 kilometers to the East of the Red Sea (**Figure 1**). According to statistics of the Saudi Central Department of Statistics and Information, the total population in Medina Region in 2014 was 2.01 million, which is standing for 6.54% of the total population of the Kingdom.

Medina is a holy and ancient city, and it is considered the second holy city in Islam, after Makah. The presence of the Masjid al Nabawi, the Mosque of the Prophet Muhammad, which was built on the site of his home and where he was laid to rest, gives it its importance as a religious site. The Quba Mosque, the first mosque of Islam is also located in Medina. Medina City was traditionally compact, centering around the Prophet’s Mosque, and gradually grew throughout its history. However, most recently, the urban growth has occurred at a more substantial rate, due to the overall nation’s urbanization development which has been experienced significantly and has been translated in rapid increase in urban population too across the Kingdom of Saudi Arabia [10].

Medina’s structural organization is around a radial road network, which starts from the central area, where Prophet’s Mosque is located, the Grand Haram, and defined by the 1st Ring Road, which creates a central focus that attracts quite high pedestrian flows. In addition to the Ring Roads structure, there are other

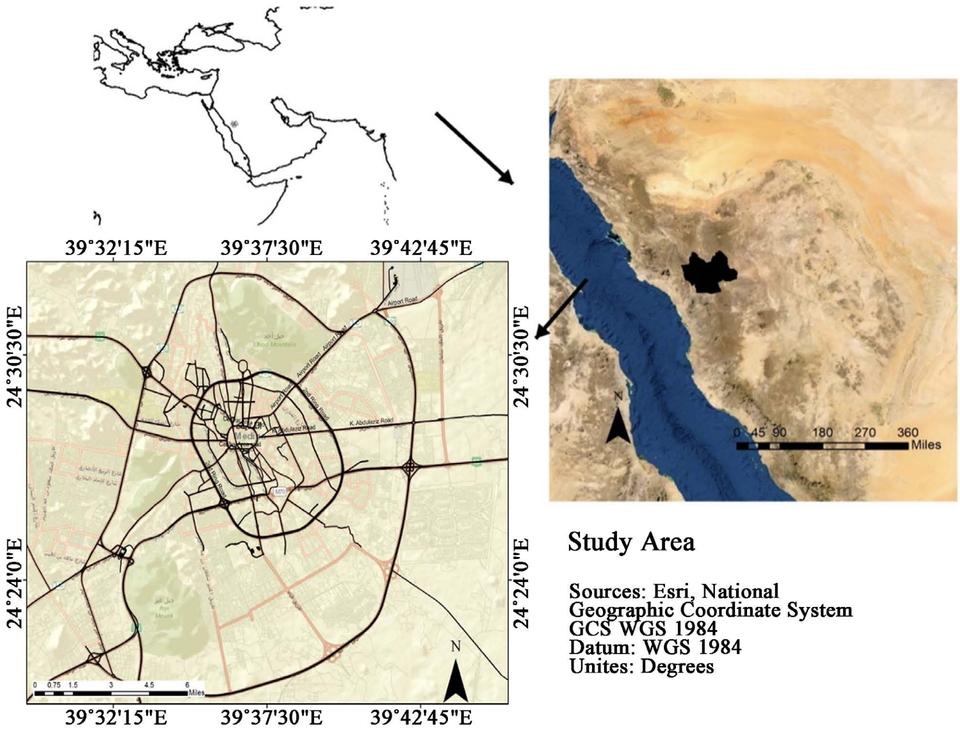

Figure 1. Study area.

numerous minor and major arterials, which function as the radial linkages across the city and the different Ring Roads therein, with the aim to minimize traffic disruption which is created by the high tourism rate. That is to say that the main roads which define the major street hierarchy and urban structure are as follows:

- The 1st Ring Road, King Faisal Bin Abdul-Aziz Road, which is circling around Haram area and the heart of the city, with a length of 5 kilometers.
- The 2nd Ring Road, Prince Abdulmajeed Road, which underpins an area characterized by its traditional urban pattern and dense population as well.
- The 3rd Ring Road, Amir Abdullah Road, with a length of 27 kilometers, which underpins an urban area characterized by its dense population, with a density that is overall higher than in any other areas of the city.
- The 4th Ring Road, King Khalid Road, which is situated at a further distance from the city Centre, of about 10:15 kilometers.
- Omar Ibn Al Khattab Road is a main radial road which extends to the Southwest and serves the traffic flows to/from Makah and Jeddah in a considerable manner.

The total amount of roads within the 1450 UGB is 5834 kilometers, and the amount of road surface per capita is 4.2 meters. This indicates the existence of a sufficient ratio of road infrastructure in reference to international standards. Generally, the citywide road network is functioning efficiently and has a hierarchy of highways that is well-defined, as well as major and minor arterial roads, and collector roads as well. However, due to the centralized road network structure and the huge numbers of religious visitors and the dynamics which are associated with them, Medina faces a challenge represented in the transportation issue; it is manifested in the on-going conflict between pedestrians and vehicular traffic in the central area, and within the 1st Ring Road, in particular. Moreover, there is another substantial aspect which affects Medina's overall movement structure which is represented in the limited accessibility to the historical sites that has become currently accessible by private cars and syndicate busses openly.

3. Methodology

The key purpose of this study is to examine the distribution of accidents through the identification of the hotspots using GIS and spatial statistics. The study analysis will use combinations of the methods and techniques including both the traditional Kernel density and Hot spot analysis. Both will significantly examine the presence or absence of clusters of accidents. Should they be present, it means that there are locations in the study area where accidents are more likely to occur. Accordingly, more funding and research must be allocated for solving the problems and addressing the problems of such locations.

Main steps show in **Figure 2**, the first step in the methodology was to recognize the accidents sites on roads either in Medina City or outside Medina region. After data collection, points of accidents were transformed from the Word file into the Excel sheet for transferring them to Geo-databases. Databases were created in order to arrange the attributes of accidents points, then, data were made ready for GIS transference. Improving quality of data collected was through extracting and deleting points with wrong coordination either outside study area or wrong place.

3.1. Data Analysis

The researcher used a Statistical Package for the Social Sciences (Version 24) Computerized Program with the aim to conduct the statistical analysis of this study. In addition, the researcher calculated the Means, standard deviations and Standard errors with the aim to identify and locate accident densities. Data were collected for three years (1439 H, 1440 H and 1441 H) from the General Department of Traffic for Medina city including road accidents points coordinates, time hour, day, month, year, type and shape of accidents. Accident data with individual differences and many other combinations can be worked out [11].

Total of 3015 accidents points in Medina City were arranged and tabulated for three years, in 1439, a total of 928 points were reported, in 1440, a total of 1271 points were reported, and in 1441, a total of 816 points were reported as shown in **Table 1**. The highest percentage of accidents in three years were 1440 that equal 42% of the total accidents, while the year 1441 is the lowest percentage by 27% of the total accidents in all the three years of the study.

By adding accidents points to Medina polygon layer, a total of 3334 points of accidents for three years were added and only 3015 points inside Median polygon.

total of 319 points equal to 9.5 % from the total points were outside Medina City. Wrong points as shown in Figure 3 are far from Medina City due to errors in recording late and long coordinates of accidents points. By comparing of density of accidents points through the three years, it appears that, the more concentrated area of accidents points was inside Medina City rather than out Medina City, as shown in Figure 4. Roads were classified in to two classes main roads with higher speed and more traffic density and secondary roads with slower

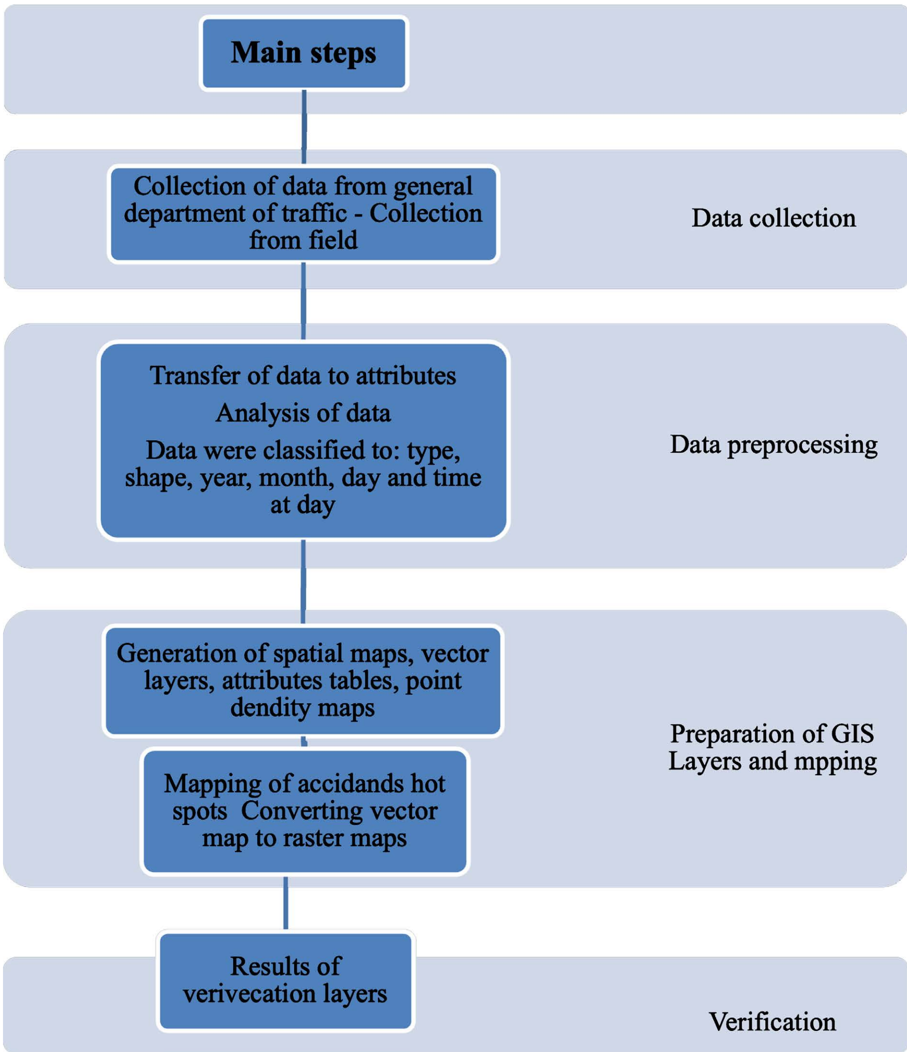

Figure 2. Method framework.

Table 1. Number of accidents points per year and percentage.

Year	Accidents points	percent
1439	928	31%
1440	1271	42%
1441	816	27%
Total	3015	100%

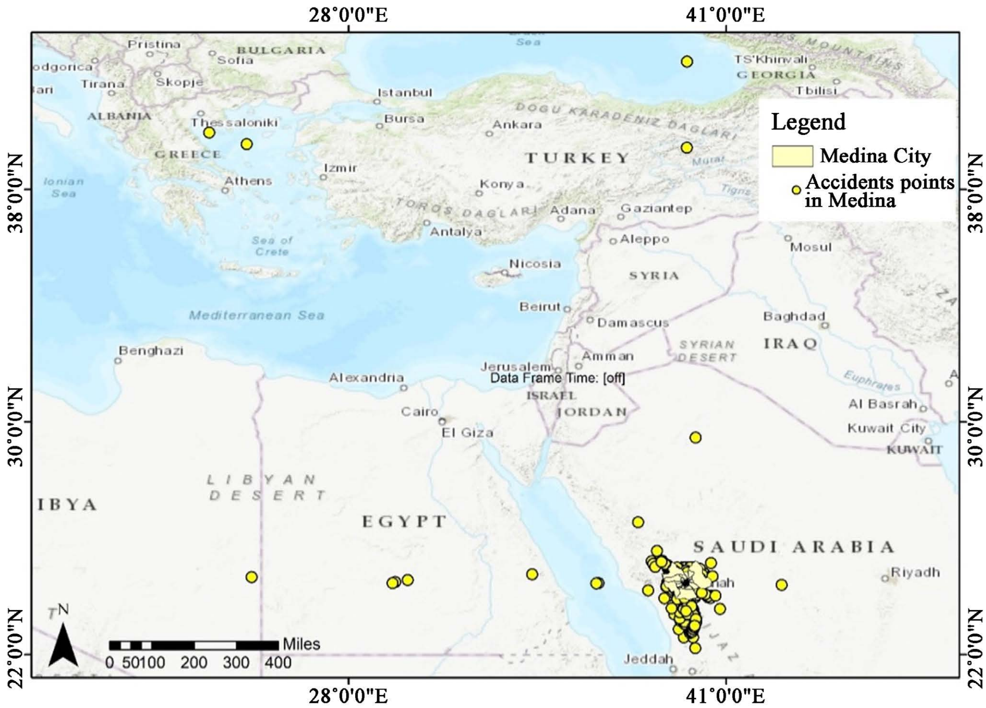

Figure 3. Accidents points collected in three years in Medina.

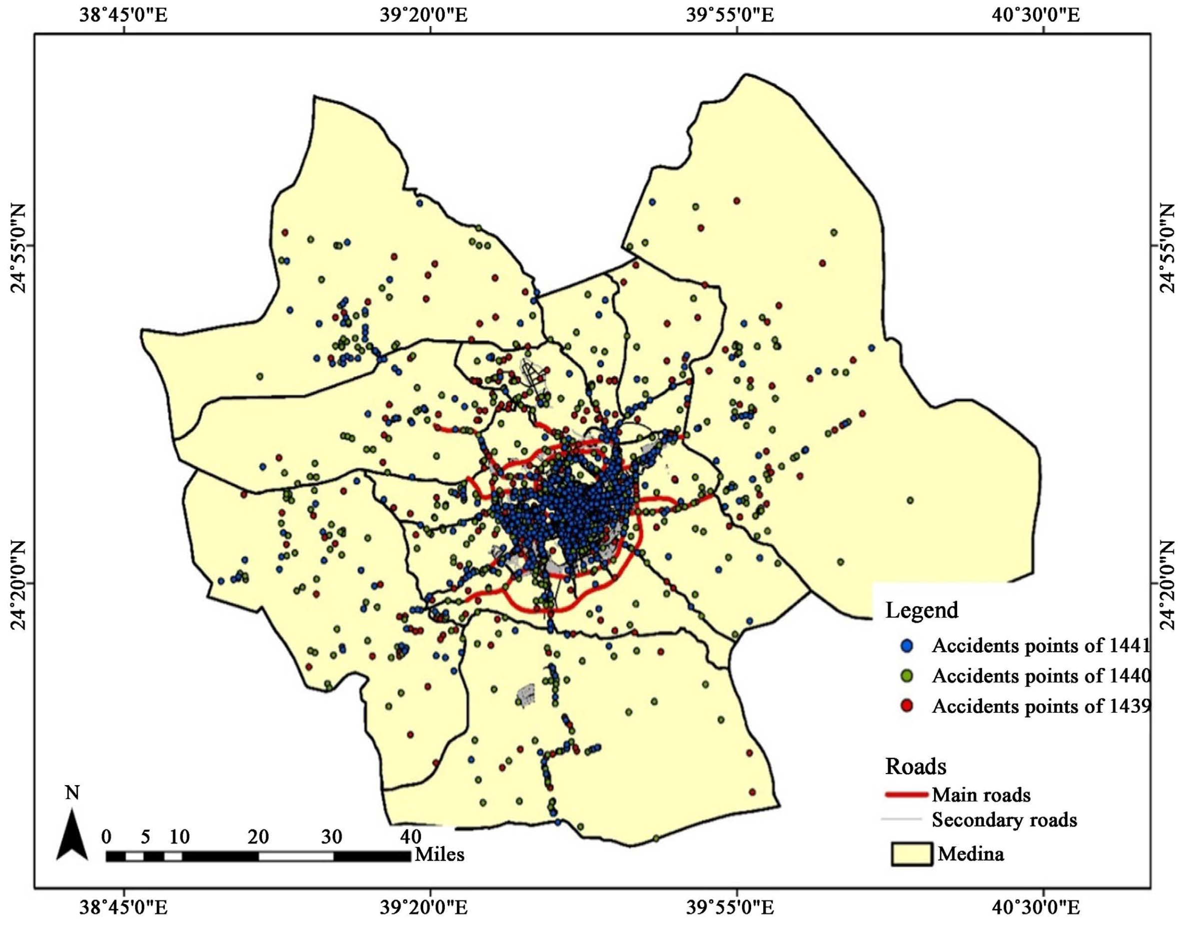

Figure 4. Accidents points collected in three years in Medina City.

speed and less traffic density, Figure 5 shows the roads with accidents points in three years (1439, 1440 and 1441) which appears more density of accidents on the main roads rather than on the secondary roads.

From observation of Figure 5 the most accidents points are concentrated on the main roads either ring roads or high-speed roads. These concentrations were developed by the spatial analysis of Kernel density of hot spot analysis.

3.2. Kernel Density to Determine Highly Concentrated Area

Kernel Density Estimation (KDE) is a spatial data analysis of Arcmap program. According to [12], Kernel Density was measured for determining the spread of risk of the accidents. The spread of risk can be defined as the area around the cluster where such risk may increase due to an accident. An analysis using KDE tool produces a raster output. Some studies used GIS as a management system for accidents analysis and determination of hot spots with statistical analysis [13].

Kernel density process is used to determine the density in each year and areas with high densities. Symbology of Kernel density is used for classifying the output data by method of Natural Breaks and classes 10 as shown in Figure 6, Figure 7 and Figure 8. Density of accidents was performed based on the standard deviation of number of accidents per year.

Kernel density collected for three years 1439, 1440 and 1441 shows that the most concentrated streets inside Medina city in the main roads, as shown in

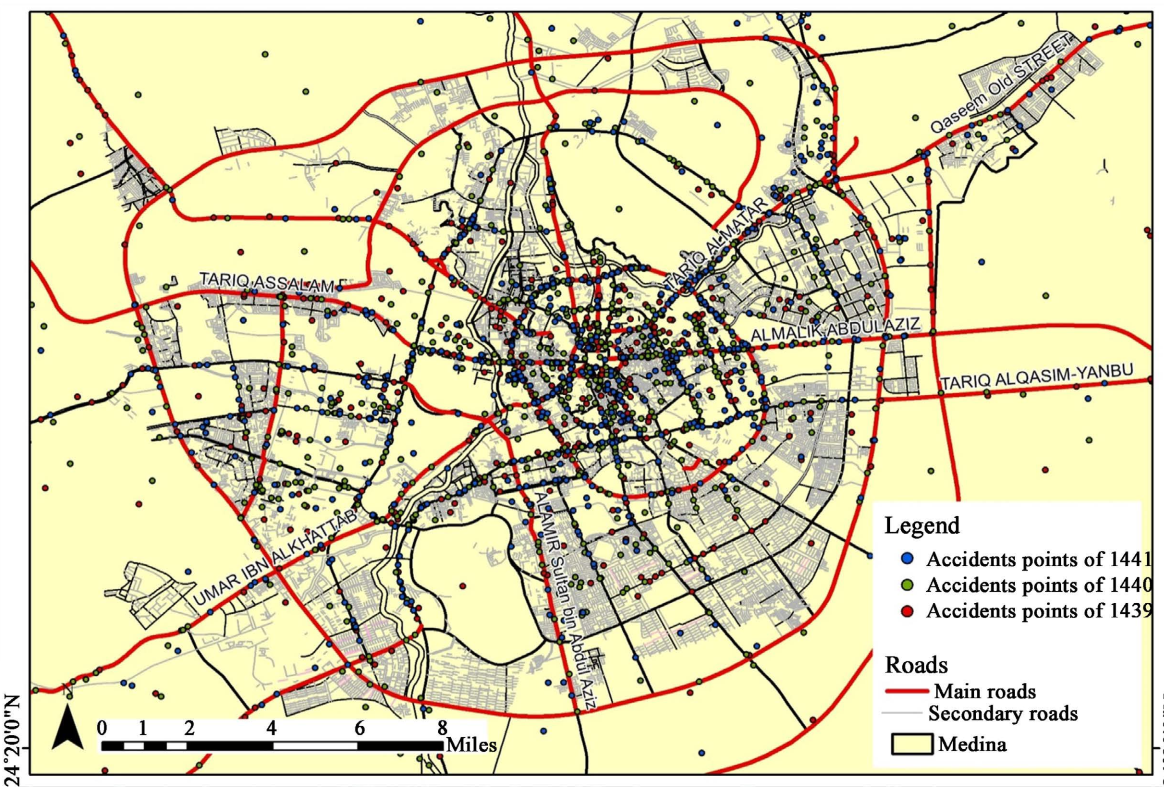

Figure 5. Accidents points collected in three years in Medina City.

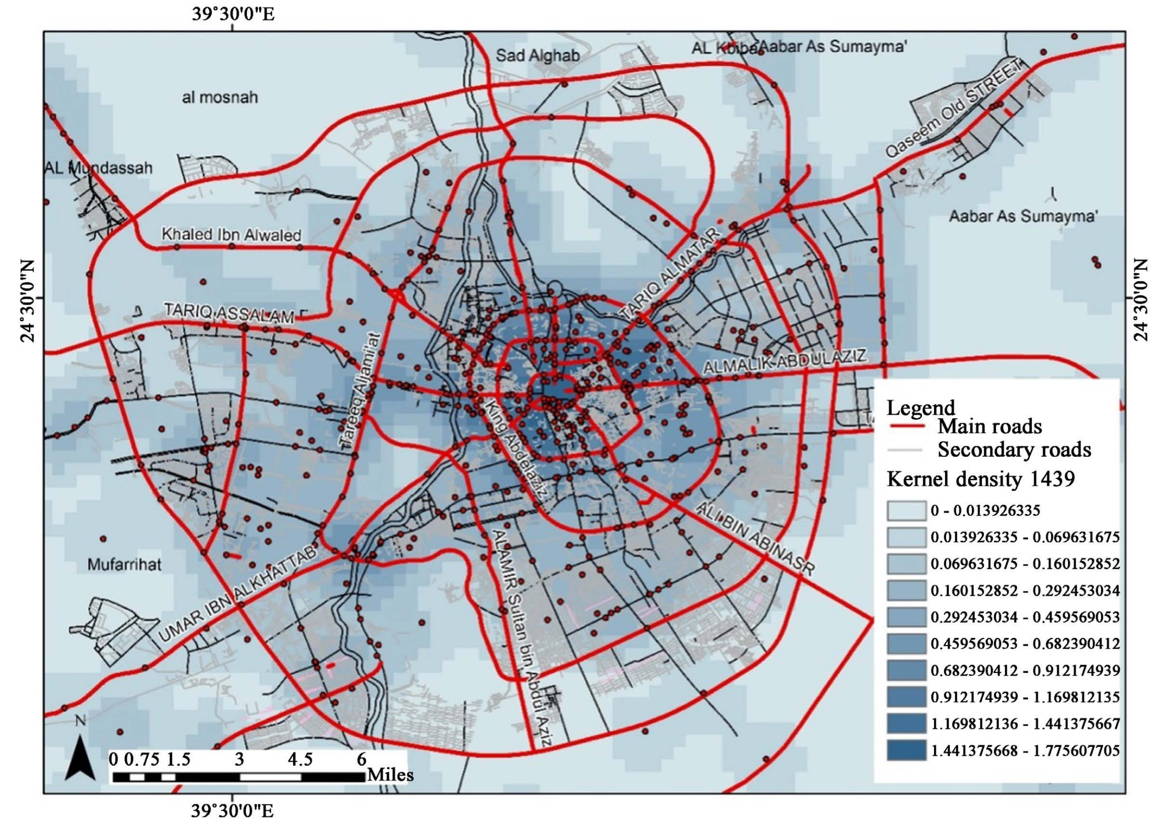

Figure 6. Kernel density for determination of hot spot accidents area in 1439.

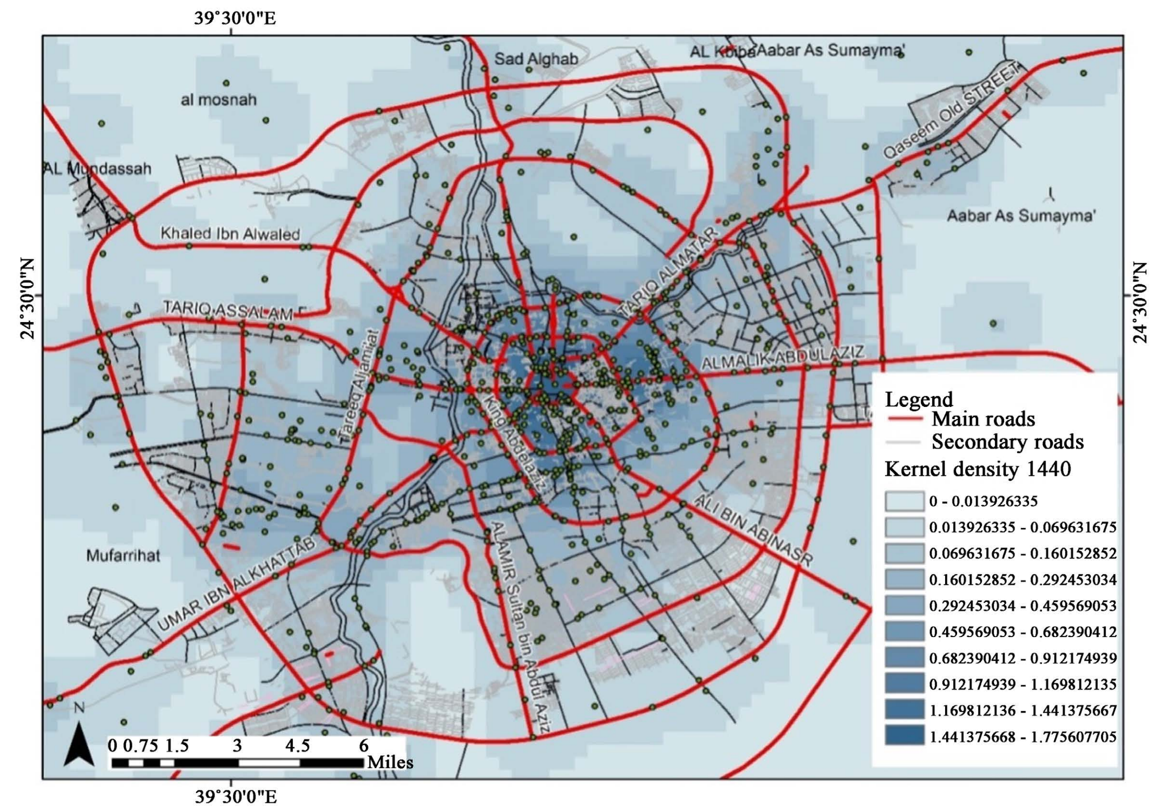

Figure 7. Kernel density for determination of hot spot accidents area in 1440.

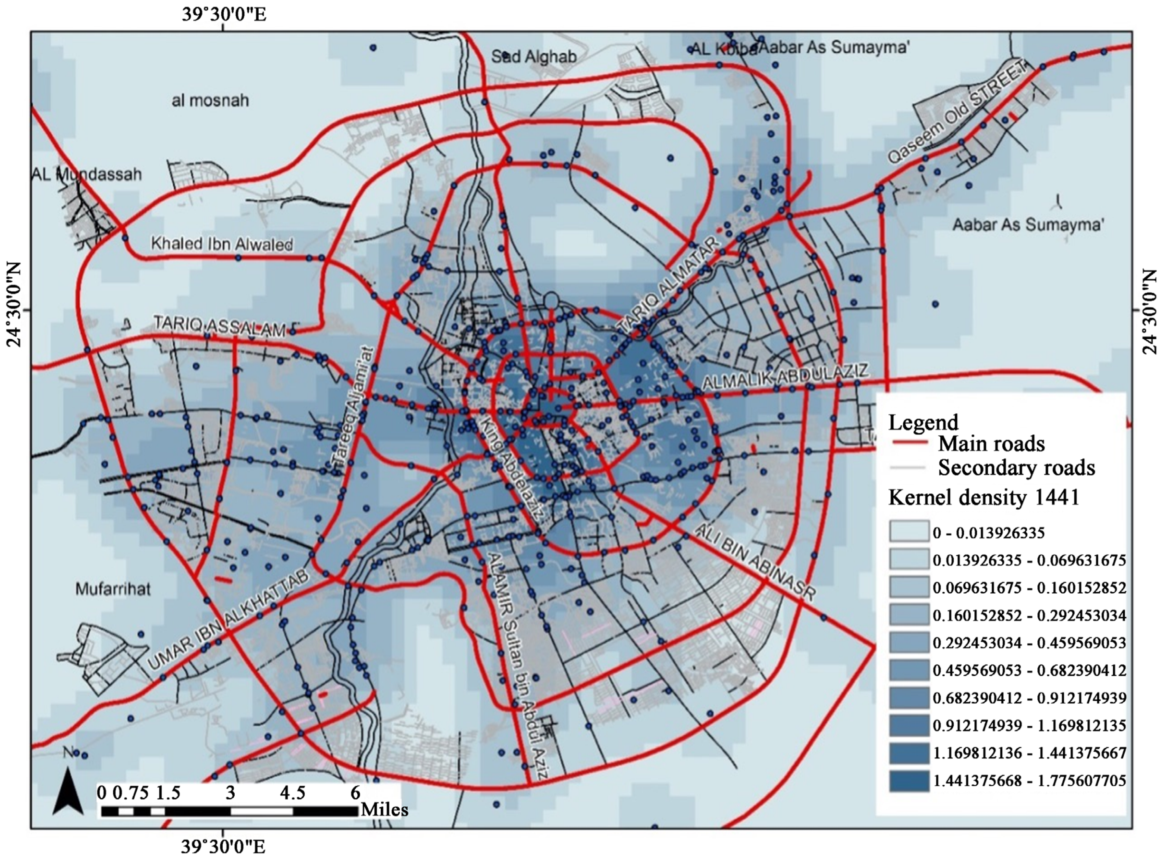

Figure 8. Kernel density for Medina city of hot spot accidents area in 1441.

Figure 9 they are: Central Area Road, North West part of the Second Ring Road, Prince Abdul Majeed Ibn Abdul-Aziz Road, Airport Road and Abu Bakr Al Sidiq Road.

3.3. Hot Spot Analysis

Hot pots analysis will be used with the aim to precisely identify, and supply required information to assist the decision makers in making appropriate decisions to prevent and reduce traffic accidents. In general, traffic accidents' statistics are used as assessment index with the aim to evaluate possible future traffic accidents on roads. In addition, Hot pots analysis identifies the statistically significant spatial clusters of both the high values (hot spots) and low values (cold spots). Thereafter, it creates an Output Feature Class with a z-score (Standard Deviations), p-value, and confidence level bin field (Gi_Bin) for each feature in the Input Feature Class. It is worth noting that the z-scores and p-values are optimal measures of statistical significance which indicate whether to reject the null hypothesis, feature by feature. They indicate whether the observed spatial clustering of high or low values is more pronounced than expected in a random distribution of the same values. The z-score and p-value fields do not reflect any kind of FDR (False Discovery Rate) correction. It is also worth mentioning that the Gi_Bin field precisely identifies statistically significant hot and cold spots

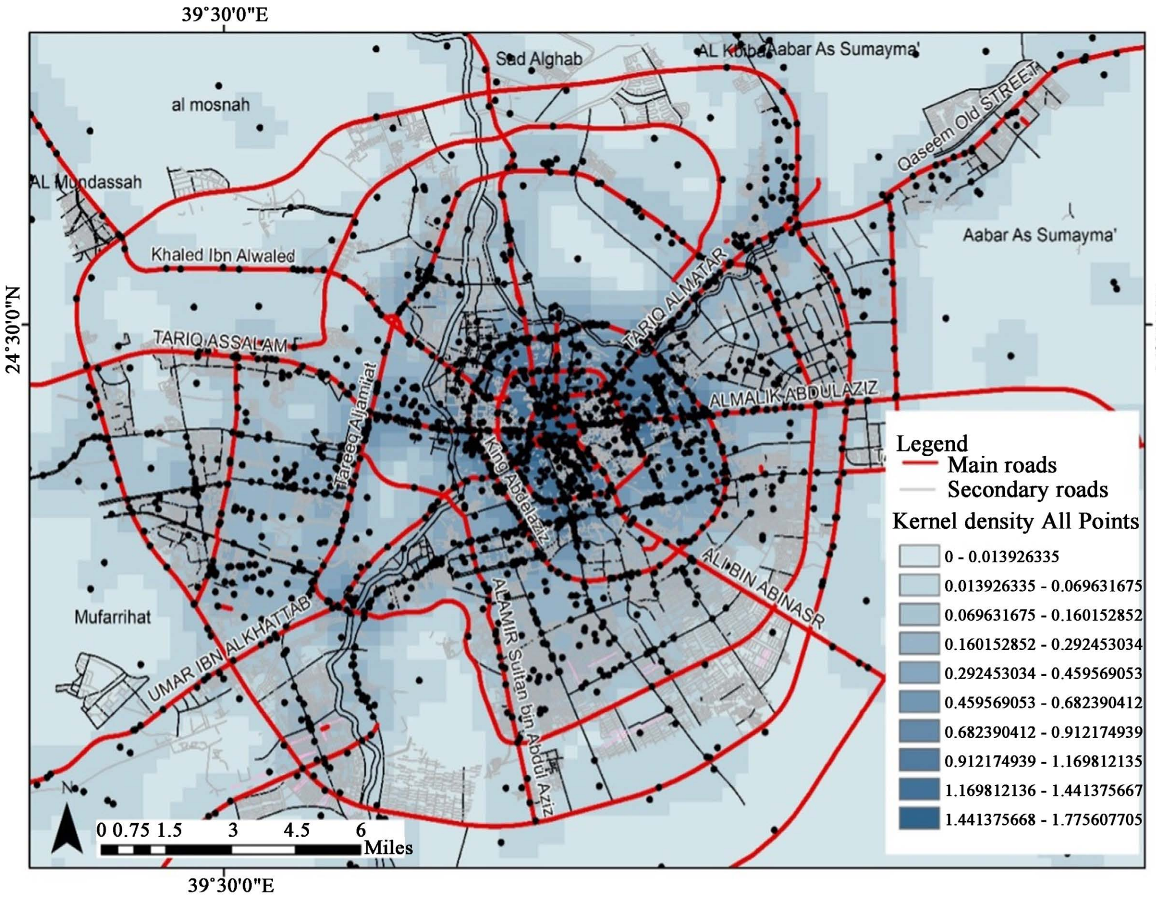

Figure 9. Kernel density for determination of hot spots area collected in three years.

regardless of the application or no application of the FDR correction. Thus, without the FDR correction, statistical significance is crucially based on the p-value and z-score fields.

Features in the ±3 bins are precisely reflecting statistical significance with a 99% confidence level; while features in the ±2 bins are reflecting a 95% confidence level; while features in the ±1 bins are reflecting a 90% confidence level. On the other hand, the clustering for features in bin 0 is not significant statistically (Table 2). A high z-score and small p-value for a feature are indicating a spatial clustering of high values. On the other hand, a low negative z-score and small p-value are indicative of a spatial clustering of low values. That is to say that the higher (or lower) the z-score, the more intense the clustering. However, a z-score near zero is indicative of no apparent spatial clustering.

Gi-Bin Hot Spot analysis was classified into7 categories show in Figure 10.

Figure 11 shows the hot spot areas with more accident's density are concentrated in the main roads of Medina City especially the following roads:

1-Central ring roads

Almalik Faisal bin Abdul Aziz Road

Alamir Abdul Majid bin Abdul Aziz Road

King Abdulla bin Abdelaziz Road

Table 2. Values level of standard deviations, probability and confidence level.

z-score (Standard Deviations)	p-value (Probability)	Confidence level
<−1.65 or >+1.65	<0.10	90%
<−1.96 or >+1.96	<0.05	95%
<−2.58 or >+2.58	<0.01	99%

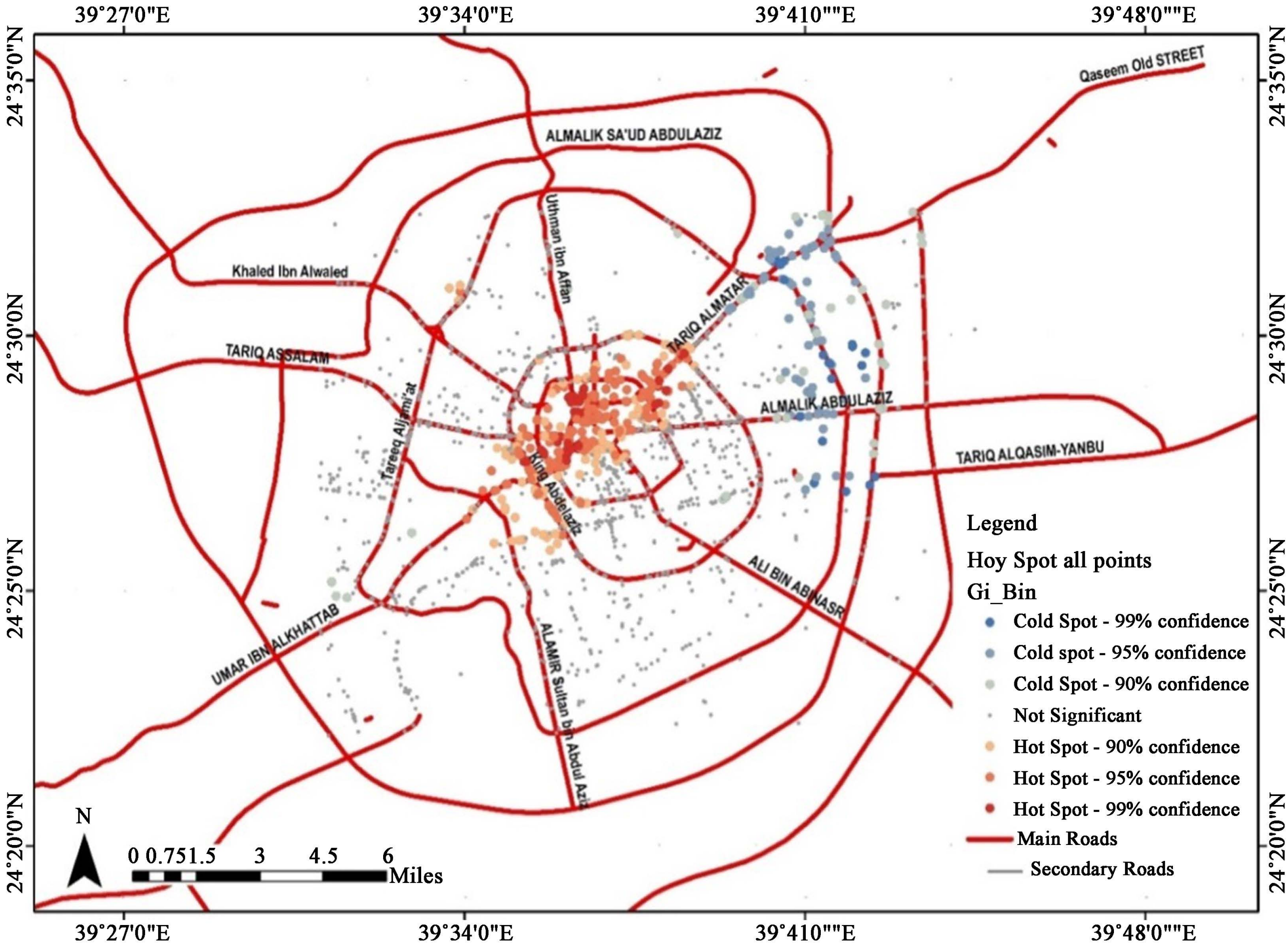

Figure 10. Hot Spot analysis for accidents points for the year 1439, 1440 and 1441.

2-High way roads of

Almatar

King Fahad

Alsalam

Omar bin Alkatab

Using Hot Spot Analysis Gi_Bin analysis form the total 3015 points only that have effects on hot spots, which provide the total of 1037 clusters arranged in cold spot with lower density accidents and hot spot with higher density accidents as shown in Figure 12. The Minimum z-score cluster was −3.834998 and Maximum z-score cluster was 7.47523, meanwhile the Standard Deviation of all clusters was 2.615039.

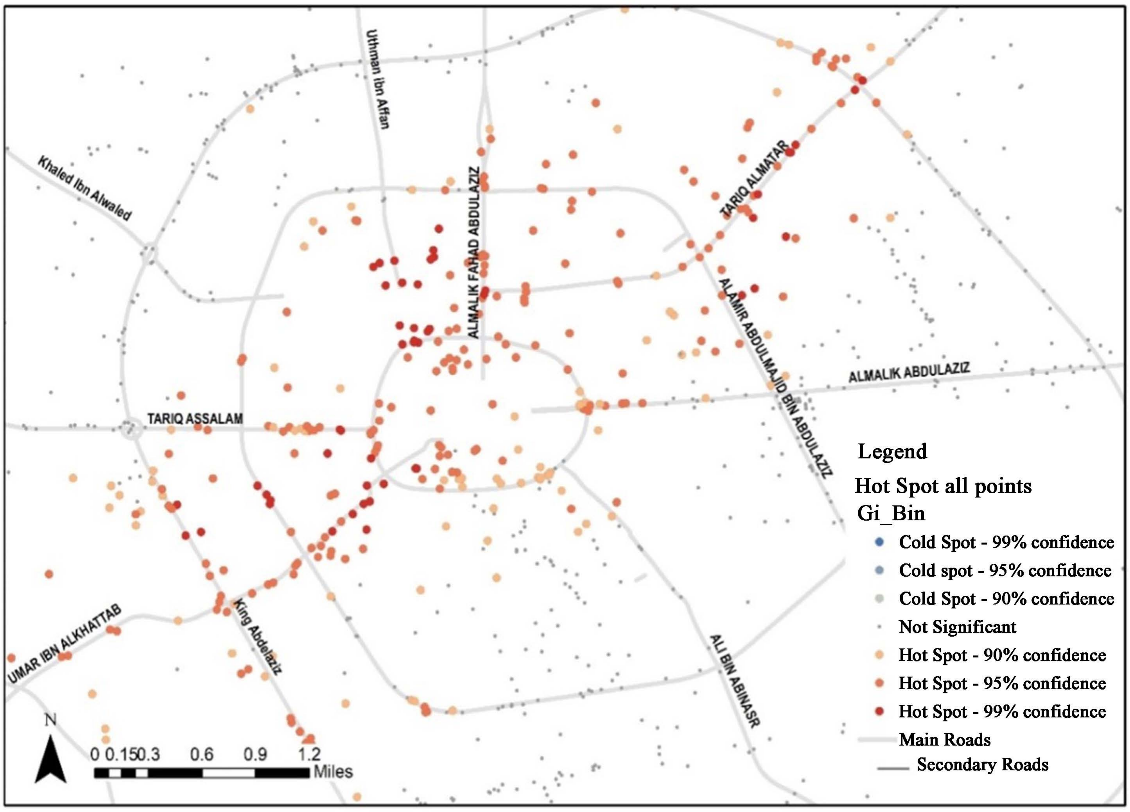

Figure 11. Hot Spot analysis for accidents points per years 1439, 1440 and 1441 zoomed in Medina ring roads..

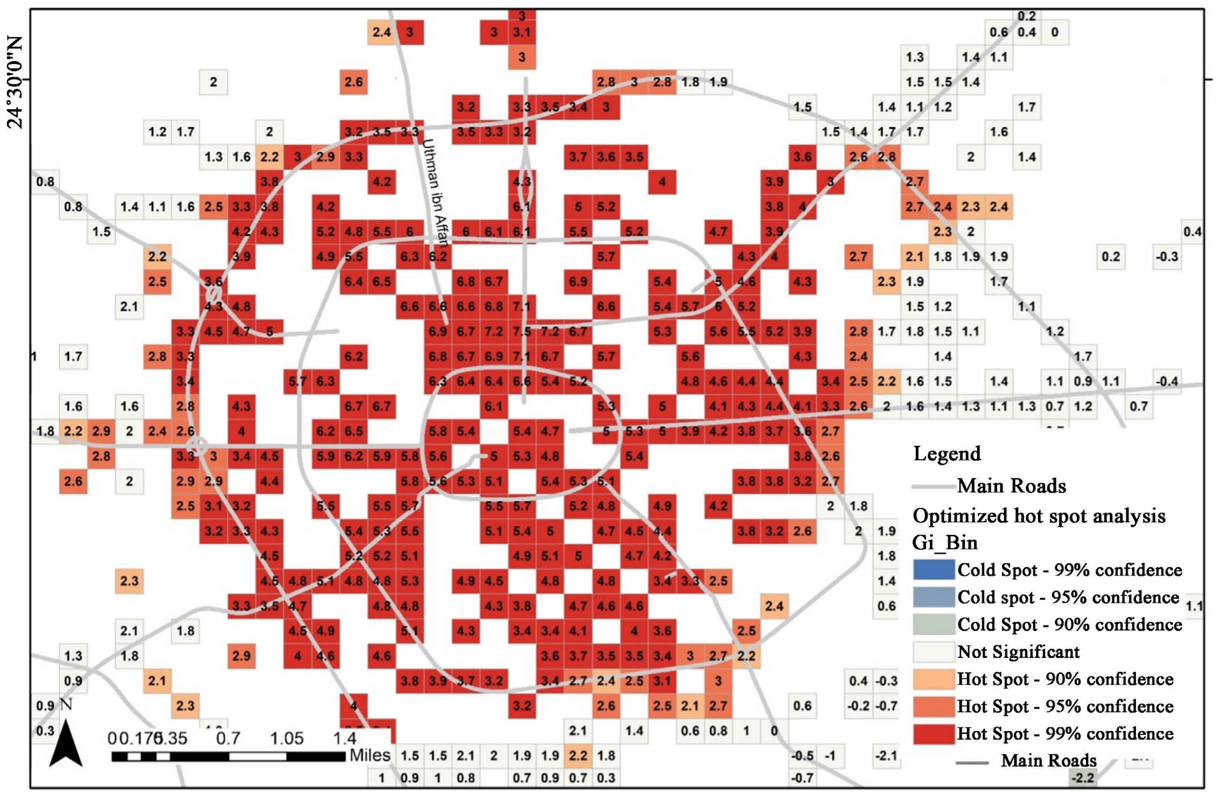

Figure 12. Hot spot and cold spot area z-score with roads layer of Medina.

4. Results and Discussion

Many studies used GIS tools with the aim to locate and identify the location of accidents on a digital map and thus to analyze the hot spots of traffic accidents thereof. On the other side, there is a huge diversity in the number of accident data records and of the factors used as well. The availability of data is determinant of the number of accident data and the analysis of the found factors.

Through reviewing various and several studies, it was found out that GIS spatial analysis and decision-making systems enable the identification of high crash zones of roads, and thus are helping in developing crisis management programs which are used for providing adequate and fast pre-hospital services in the event of an accident and thus preventing an avoidable leading cause of death [14].

After comparing the final map with the other existing maps of the practical factors, it was revealed that the ultimate map matched well with the maps of road traffic and high accidents zones. It seems that areas with a high density of fatal accidents have high speed long way. Therefore, there is a dire need for establishing speed calming (bumps) with the aim to reduce traffic accidents on black spot locations. Those results are consistent with the studies [15] [16].

Through the observations of streets with high density in the study area and the previous results of the analysis of traffic accident data over the period of the study (1439-1440-1441) for the traffic accidents in the principle urban streets in Medina City, high density of population around the center of Medina City increases the accidents density. Accordingly, significant results are concluded, they are as follows:

1) According to the accidents of the three years which represent the time span of the study (1439-1440-1441) which the government registered in Medina urban area, many roads were selected as High Accident Location HAL, they are as follows: Central ring roads (King Faisal bin Abdul-Aziz Road-Prince Abdul Majid bin Abdul-Aziz Road-King Abdulla bin Abdel-Aziz Road).

2) Other roads show less HAL, such as the following highway roads: Almatar Road-King Fahad Road-Alsalam Road-Omar bin Alkatab Road).

3) The selected HAL streets were considered based on Hot spot of z-score values.

4) Through the analysis results of the accident data, the results of the study show that the high-speed roads are heavily linked to the massive increase of traffic accident rates.

5) The results of the study also show that the increase in the street section length led to the increase of the number of total accidents.

6) The results of the study also show that the increase of the number of speed calming (bumps) is leading to the decrease of the number of property damages, and in turn decreases the traffic accident rates.

These findings help decisions maker to better assess the risk associated with road accidents and, as a result, help them to propose more effective countermeasures in order to reduce the annual crash rate.

5. Conclusions

Many studies as well as the present study used GIS tools with the aim to identify and show the location of accidents on a digital map and then to analyze the hot spots of traffic accidents. There is a huge diversity in the number of accident data records and of the factors used too. The number of accident data and the analysis of factors found are dependent extensively on the availability of data. The most commonly spatial methods tools used are Kernel Density and Hot Spot Analysis followed by Optimized Hot Spot and Statistical Analysis for the timely accidents data. Addressing spatial analysis is highly dependent on the accident's positions and clusters accident spots according to the optimized spatial patterns, which represent a powerful tool to study accident hotspot. The year 1440 had the highest number of accidents compared to those of 1439 and 1441. Many roads were selected as High Accident Location HAL, such as Central ring roads, King Faisal bin Abdul-Aziz Road, Prince Abdul Majid bin Abdul-Aziz Road, and King Abdulla bin Abdel-Aziz Road. The high-speed roads are heavily linked to the massive increase of traffic accident rates, and the increase in the street section length led to the increase of the number of total accidents.

Although this paper is limited to identification of hot spots in specific years, but it can also be utilized for identification of cold spots. This paper can be used as a base for further research for the effect of the road conditions, time of the day and driving behavior where re-searches can be extended. A case could be the analysis that can find which day of the week has higher rate of the accidents and where these are located.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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