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Article

Spatiotemporal Analysis of Traffic Accidents Hotspots Based on Geospatial Techniques

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Abstract: This paper aims to explore the spatiotemporal pattern of traffic accidents using five years of data between 2015 and 2019 for the Irbid Governorate, Jordan. The spatial pattern of traffic-accident hotspots and their temporal evolution were identified along the internal and arterial roads network in the study area using spatial autocorrelation (Global Moran I index) and local hotspot analysis (Getis–Ord Gi*) techniques within the GIS environment. The study showed a gradual increase in the reported traffic accidents of approximately 38% at the year level. The analysis of traffic accidents at the severity level showed a distinguished spatial distribution of hotspot locations. The less severe traffic accidents (~95%) occurred on the internal road network in the Irbid Governorate's towns where the highest traffic volume exist. The spatial autocorrelation analysis and the Getis–Ord Gi* statistics with 99% of significance level showed clustering patterns of traffic accidents along the internal and the arterial road network segments. Between 2015 and 2019, a notable evolution of the traffic-accident hotspots clusters was pronounced. The results can be used to guide traffic managers and decision makers to take appropriate actions for enhancing the hotspot locations and improving their traffic safety status.

Keywords: traffic accidents; spatial autocorrelation; Getis–Ord Gi* statistics; GIS; severity analysis

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1. Introduction

Traffic accidents are one of the most significant global challenges due to their serious threat to human life, economy, and social consequences [1]. According to the World Health Organization, the number of deaths on the world's roads is unacceptably high, and approximately 1.35 million people die each year [2,3]. It has been reported that most traffic accidents occur in low- and middle-income countries, accounting for more than 90% of traffic-accident fatalities. To understand the causes of traffic accidents, traffic safety analysis has emerged to support decision-makers in implementing suitable measures to eliminate or mitigate the occurrence of traffic accidents [4,5]. Therefore, addressing traffic accidents in the context of spatial and/or temporal dimensions is needed to determine the best and most consistent solutions to such issues.

The national statistics of traffic accidents provide an overall view of the road-traffic safety situation; therefore, the interaction between traffic accidents and their environment might not be presented. This is because each road-traffic accident has its own characteristics in terms of the environment, vehicle, road, driver, and traffic-management attributes. Thus, analyzing traffic accidents is necessary for national plans for traffic safety management. In this context, various researchers and international agencies have employed spatial and temporal mapping of traffic accidents and created their models for road safety measures. In this context, several approaches have been used to determine the temporal (yearly, monthly, daily, hourly) distributions as well as the spatial distribution of traffic accidents along the roads. Statistical-based mapping approaches such as Kernel Density Estimation (KDE), K-means, Moran I, and Getis–Ord are among the most-used ones in this domain as they show the statistical significance of traffic-accident hotspots [6,7]. These hotspots are of great value to decision-makers, traffic engineers, traffic researchers, and drivers.

In developing countries such as Jordan, traffic accidents are a significant public problem as they are the second leading cause of death [8]. They are a severe challenge in Jordan, where approximately two people die each day in car crashes, and the country loses 2–3% of its gross domestic product (GDP) due to this issue [9]. According to the Jordan Public Security Directorate's traffic accident department [10], the total number of traffic accidents in Jordan in 2019 was 161,511 with a total number of 643 fatalities, 792 severe injuries and 10,159 minor injuries. In the Irbid Governorate (the second-largest populated governorate in Jordan), traffic accidents increased from 12,293 in 2015 to 16,940 in 2019, representing an increase of around 38% during that period [10]. Therefore, it is necessary to study the spatiotemporal distribution/evolution of traffic accidents in the Irbid Governorate as to the best knowledge of the researchers no studies have been conducted yet to evaluate the traffic accidents in this region.

Here, we implemented the Getis–Ord Gi* analysis, and global Moran I index for evaluating the spatiotemporal distribution of traffic accidents in the Irbid Governorate in Jordan, including rural areas, using all traffic accidents between 2015 and 2019 at the street segments as a unit of scale. This provides fundamental analysis for planners and decision-makers for implementing safety measures at the governorate, which could be extended to the country level.

2. Related Work and Original Contribution

Several studies have evaluated traffic accidents in urban and rural areas. In general, these studies can be divided into two groups: the first group focused on analyzing the factors that cause traffic accidents [4,11–15]. The essence of these studies was to determine the interaction between the characters of environment, human, road, and vehicle in relation to traffic accidents. The second group employed various geospatial techniques to map traffic-accident hotspots. These geospatial techniques, such as KDE, are normally used to map the density of traffic crashes based on the number of crashes' points at each location [16–19]. Some research works employed distance-based approaches to determine the traffic-accident clusters [6,20–22].

Many research works have considered the temporal analysis of traffic accidents [23–27] in which they explored the evolution of traffic-accident clusters over a period using simple time-series analysis. Kingham et al. [28] investigated the temporal evolution and spatial clustering of traffic accidents in Christchurch city (New Zealand), and the temporal evolution of fatal crashes in Iowa (USA) has been studied by [29]. Similarly, Bíl et al. [6] investigated the crash-hotspots evolution in the Czech road network between 2010 and 2018 and found that only 50% of hotspots were stable (remained in approximately the same position) over the entire 9-year period.

In addition, spatiotemporal analysis techniques of traffic accidents have been conducted by different researchers. For example, Kaygisiz et al. [30] and Olsen et al. [31] determined traffic-accident hotspots within individual roads yearly. Harirforoush et al. [19] analyzed spatiotemporal patterns of traffic accidents in Sherbrooke for 3 years (2011–2013). KDE was employed to map the spatiotemporal patterns of traffic accidents for 4 different seasons. Wang et al. [32] used spatiotemporal analysis techniques to explore the relationship between traffic congestion and road accidents in England during 2003–2007. They used random-effects negative binomial and spatial models using a full Bayesian hierarchical approach to examine if congestion affects the frequency of accidents. Tola et al. [5] employed spatial autocorrelation analysis and Getis–Ord Gi* statistics to identify crash hotspots across Ethiopian regions for 4 years (2014–2017).

Several studies have been conducted to assess the traffic accidents in Jordan. For example, Obaidat and Ramadan [33] used different stepwise statistical regression models to investigate traffic accidents at hazardous locations on urban roads. Al-Masaied [8] assessed the safety impact of policy measures implemented from 1997 to 2008, including increased police enforcement and stricter enforcement of traffic laws. The study found that traffic enforcement and enforcing traffic laws with stiff penalties had a significant positive safety effect on accidents and fatalities. Al-Omari et al. [34] analyzed the trends and characteristics of traffic accidents in Jordan from 1998 to 2010. The study found that most traffic accidents occurred at or below the 50 km/h speed limit. Al-Rousan et al. [35] used descriptive analysis and independent sample t-tests to examine the characteristics of distracted driving crashes on rural and suburban roadways in Jordan. These studies, however, did not consider the spatial domain of traffic accidents from the geographic and road network element perspectives. In this context, very few studies put effort into understanding the spatial distribution of traffic accidents at the city level in Jordan. For example, Al-Omari and Obaidat [36] analyzed pedestrian accidents in Irbid, Jordan, and found that most of them occurred at road intersections. Al-Omari et al. [37] modeled traffic accidents in arterial roads in Irbid city using the Weighted Overlay Method (WOM) and the Fuzzy Overlay Method (FOM) using accident data from 2013 and 2015. The study found that both the WOM and FOM successfully identified hotspots in portions of the study area. Alkhadour et al. [38] investigated traffic accidents in Amman, Jordan, using nearest neighbor index analysis. The findings indicated that spatial clustering and recurrence of traffic accidents exist in the study area. The findings confirm that hotspots were concentrated primarily in commercial, residential, and industrial zones located in and around the study area's central regions. Although these studies highlighted the clusters of traffic accidents, they did not examine their spatiotemporal distribution based on the tests of statistical significance.

3. Revisiting the GIS-Based Traffic Accidents Evaluation Methods

Considering the spatial and temporal distribution, traffic accidents are not spread evenly across streets; they cluster in some areas and are absent in others. The analysis of traffic accidents through mapping technologies can transfer vital information to traffic officials and community members efficiently and effectively. In this context, many traffic-accident mapping techniques are dedicated to identifying high-density areas (hotspots). A common concept of a hotspot location is an area larger than the specific value of a specific event. This suggests the existence of either cold or hot spots/areas with less or greater than a specific value based on how far below or above the specific value they are. Several geographical information systems (GIS) techniques can perform such analysis and mapping. These GIS techniques would be grouped into three categories in this context, as shown in Table 1. Meanwhile, the visual representation and depiction of hotspot maps are also critical and should be consistent with the features of interest. For example, in the case of traffic accidents, a dot or an area map showing the spatial distribution or density of accidents would be too imprecise. However, a line map would be more appropriate. At this level of analysis, questions such as on which street segments accidents happen and on which they do not would be answered. In this context, the appropriate unit of analysis can be street segments, paths or sections of highways, which would be represented on maps as straight, bent or curved lines. In such a case, traffic management would be relatively precise in changing traffic and street patterns.

Table 1. Categories and techniques for mapping hotspot locations of traffic accidents within the GIS environment.

Category	Technique	Description
Preliminary global statistical tests	Tests for clustering (e.g., nearest neighbor index, Moran's I, and Geary's C statistic)	Relative measure to compare spatial distributions between different types of spatial events or against the same type for different periods of time. generate an understanding of the global patterns in the data and show evidence of clustering existence. This clustering does, however, vary at different scales.

Table 1. *Cont.*

Category	Technique	Description
Mapping techniques	Continuous surface smoothing methods (e.g., kernel density)	The quartic kernel estimation method requires identifying the grid cell size and search radius prior to running which remains a problem.
Local indicators of spatial association (LISA) statistics	Getis–Ord Gi* statistic	LISA statistics are a more advanced method to understand hotspot of traffic accidents. They assesse the local association between data by comparing local averages to global averages. LISA output indicates the level at which hotspot can be more clearly distinguished from other levels of concentration.

4. Materials and Methods

4.1. Study Area

The Irbid governorate is in the northern part of Jordan between 32°45′38″ and 35°33′21″ North and 32°14′11″ and 36°4′36″ East, with an area of 1571.7 km^2. It is bordered by the Syrian Arab Republic to the north, Palestine to the west, the Mafraq governorate to the east, and the Al-Balqa, Ajloun, and Jerash Governorates to the south. The region consists, geographically, of hills with medium heights that gradually descend to reach elevations below the mean sea level in the Jordan Valley. It has a strategic location as a transit station to the neighboring countries and historical and archeological importance. In terms of population, it is the second-largest governorate in Jordan after Amman, with approximately 1,957,000 inhabitants in 2019 (the highest population density in the country is at ~1178.7 inhabitants/km^2). It consists of 18 municipalities (Figure 1). The governorate witnessed progressive urban and economic growth after 1990 for various reasons, including natural population growth and external immigration from other cities and neighboring countries. It is considered the number one agricultural region in Jordan, especially in cultivating citrus, olives, and cereal crops. It is uniquely characterized by the availability of social and youth services, construction development, and a tri-cultural mix of Bedouin, rural, and urban. The governorate has five universities, several archeological and natural touristic sites, three industrial estates, and several vocational training centers and trade markets, with the existence of infrastructure including local and national road networks, electrical power, transportation means, postal and communication services, and a sewage network.

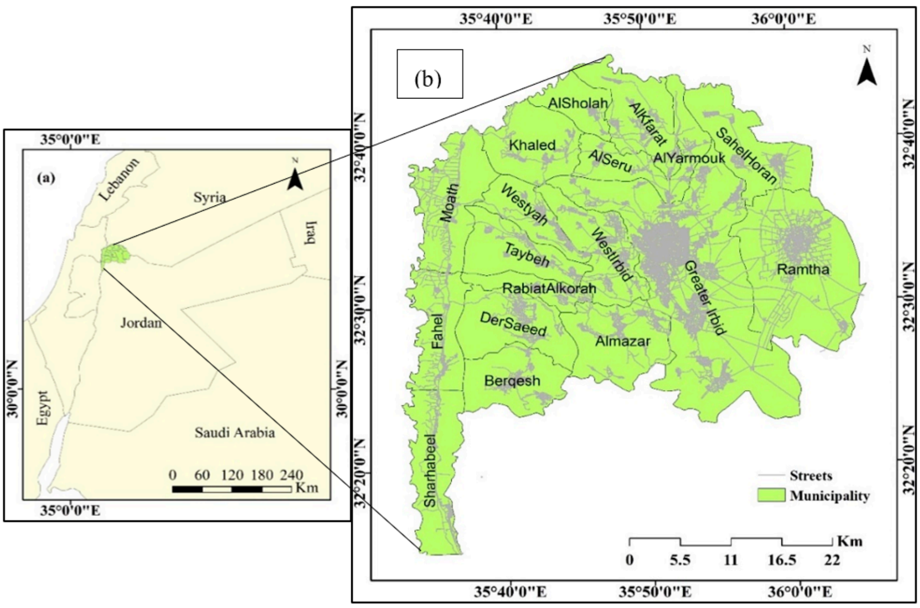

Figure 1. (**a**) location map of the Irbid Governorate in Jordan and (**b**) administrative boundaries of the 18 municipalities in the Governorate.

4.2. Methods

This study followed a specific protocol (Figure 2) to identify the hotspot road-accident locations as follows:

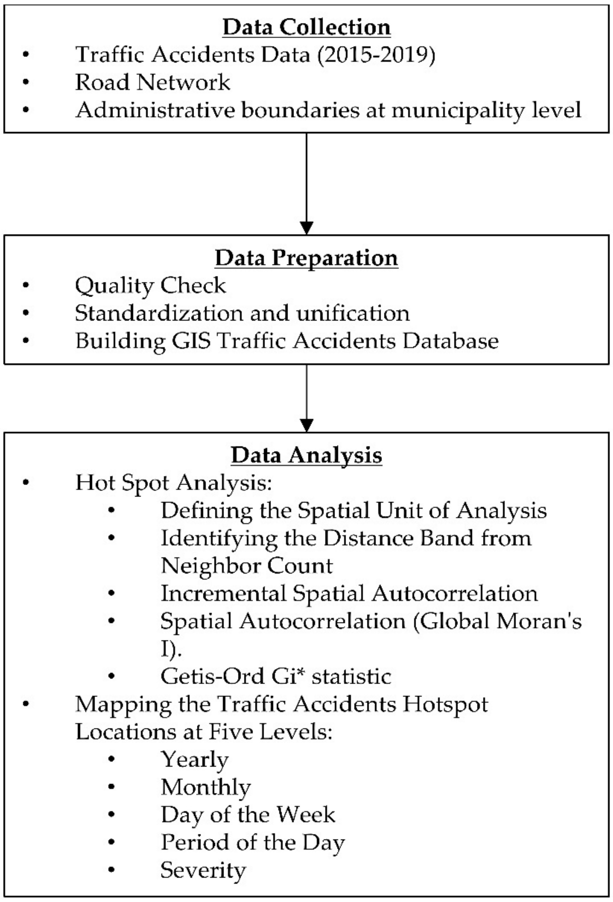

Figure 2. Schematic diagram of the implemented procedures for mapping traffic-accident hotspot locations.

4.2.1. Data and its Preprocessing

In this study, we used the entire recorded traffic-accident database archive from the Jordan General Security Bureau. The database contained all accidents that had been reported between 2015 and 2019. The database contained information about the accidents' coordinates, types, dates, times, severity levels, gender and age of the drivers, number of vehicles involved in the accident, road status, speed, and drivers' mistakes. The total number of reported accidents was 76,163 during the study period. In addition, the road network of the center line of all types of streets in the study area (i.e., residential streets, one-way and two-way streets, transit streets, and arterial highways), administrative boundaries at the municipality level, and Google Maps for the study area were used in the analysis.

We made an intensive revision for the traffic-accident database and made the needed sittings and data formatting to be compatible with the GIS analysis requirements. This included separating the information about the date and time of the accidents into separate fields and unifying the information about drivers' mistakes into common expressions (there were 52 different expressions that were unified into 11 expressions). We also combined and coded the information about accident severity into one field instead of five separate fields. This field contained the severity of the accidents as ranked from 1–5 (i.e., 1 = no injury; 2 = slight injury; 3 = moderate injury; 4 = severe injury; and 5 = fatal). Finally, we checked and deleted the repeated accidents, using their ID numbers as the primary key. We then converted the database into a point GIS feature class to be used for the spatiotemporal analysis. However, we noticed some confusing clusters on the generated maps (see Figure 3 as an example)—these accidents represented traffic accidents that were not reported in their actual location but by a police department and had identical coordinates. For the spatiotemporal analysis, these accidents were deleted from the database. Table 2 summarizes the total reported accidents, the filtered ones, and the percentage of the filtered accidents in each year. Meanwhile, we noticed various shifting distances of the accidents' locations from the center line of road network. This might be refer to different reasons such as the accuracy of the GPS units which have 5–10 m accuracy level, the surrounding environment such as high buildings and the street width, and other operational errors at the time of reporting the traffic accidents. Therefore, all filtered accidents were snapped to coincide exactly with the edge of its nearest road segment within 30 m (Figure 4) as this was approximately the maximum distance of the farthest point to a street segment (the center line). The road network was divided into segments of a maximum of 1000 m, which helps in identifying the specific road parts that have a higher probability of being hotspots (i.e., the spatial unit of analysis).

Figure 3. Examples of the confusing clusters of traffic accidents in the study area that represent the reported traffic accidents in a police department instead of its actual location.

Table 2. Summary of the number of the reported traffic accidents in the Irbid Governorate during 2015–2019.

Year	Total Num. of Accidents (Reported)	Num. of Accidents Used in the Spatiotemporal Analysis (after Filtering)	%
2015	12,293	5475	44.5
2016	14,759	10,068	68.2
2017	15,701	11,458	73.0
2018	16,470	10,149	61.6
2019	16,940	12,901	76.2
Total	76,163	50,051	65.7

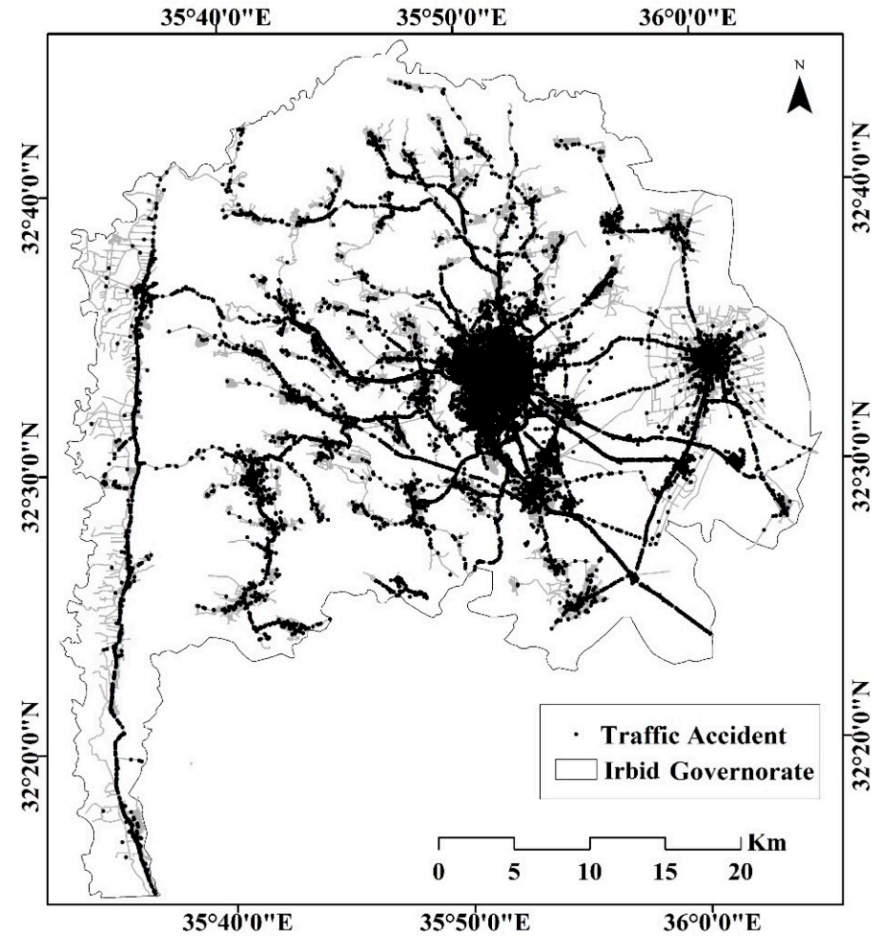

Figure 4. Spatial distribution map of traffic accidents in the Irbid Governorate during 2015–2019.

4.2.2. Hotspot Analysis of Traffic Accidents in Irbid Governorate

Defining the Spatial Unit of Analysis

To study the spatial distribution of traffic accidents, the spatial arrangement of their smallest constituent spatial units must be understood. These spatial units may vary depending on the objectives of a given analysis. For instance, when the emphasis is on understanding the spatial distribution of an individual traffic accident, accidents should not be aggregated; thus, they should correlate with each other rather than with road network elements (e.g., intersections, road segments) and treat each individual accident as a unit of analysis where located. On the other hand, considering the spatial dependency of road network elements, traffic accidents that occurred in proximity should be aggregated to form an integral representation of that network element. Consequently, the spatial statistics return the collective values that characterize the distribution of traffic accidents on that road element [39]. This type of spatial unit was applied in this study.

Spatial Autocorrelation (Global Moran's I)

Spatial Autocorrelation (Global Moran's I) was used to determine the spatial distribution patterns of traffic accidents in the Irbid Governorate. The values of Moran's I depict whether the features' location and values are spatially clustered, dispersed or randomly distributed. The Moran's I, z-score and p-value were computed using the Spatial Autocorrelation (Global Moran's I) using Equation (1). This was performed by (i) identifying the Fix Distance Band method as a cutoff distance as the method for Conceptualization of Spatial Relationships (CSR). This allowed analyzing each feature (i.e., traffic accident) within the context of neighboring features; thus, neighboring features within this specified distance receive a weight of one and exert influence on computations for the target feature. Other features receive a weight of zero and have no influence on a target feature's computations, (ii) using Euclidean Distance (Equation (2)) as the distance method for calculating the distances from each feature to neighboring features, (iii) identifying the Distance Band or Threshold Distance that identifies the scale of analysis using the Incremental Spatial Autocorrelation function in ArcGIS Pro after calculating the "Distance Band from Neighbor Count", which helped in identifying the beginning distance at which to start the analysis of spatial autocorrelation and the distance from which to increment.

$$I = \frac{N \sum_i \sum_j W_{i.j} \left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\left(\sum_i \sum_j W_{i.j}\right) \sum_i \left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)^2} \tag{1}$$

where N is the number of cases, X_i is the variable value at a particular location, X_j is the variable value at another location, $\overline{X}$ is the mean of the variable, and W is a weight applied to the comparison between location i and location j. $W_{i.j}$ is a distance-based weight matrix which is the inverse distance between locations i and j $(1/dij)$.

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \tag{2}$$

where $(X_2,\ Y_2)$ is the coordinate for point a, $(X_1,\ Y_1)$ is the coordinate for point b, and d is the straight-line distance between points a and b.

Getis–Ord Gi* Statistic

This study implemented a hotspot analysis based on Getis–Ord Gi* statistic (i.e., Gi*). Gi* is one of the most robust geostatistical methods for mapping clusters and identifying locations that are statistically significant hot or cold spots. Hotspot analysis is particularly useful for (i) setting the needed actions for locations that have one or more clustering patterns such as traffic accidents, (ii) understanding the potential causes of that clustering, and (iii) visualizing the cluster locations and their geographic extent. It calculates the Gi* for each feature in a dataset and identifies where features with either high or low z-scores and *p*-values spatially clustered. It considers each feature within the context of its neighboring features and identifies it as a statistically significant hotspot if it has a high value and is surrounded by other features with high values as well. A statistically significant z-score is calculated when the local sum for a feature and its neighbors is proportionally very different from the expected local sum, and when that difference is too large to be the result of a random chance [40–42]. The Gi* statistic is a *z*-score; the larger the *z*-score (positive z-score) the more intense is the clustering of high values, whereas the smaller the *z*-score (negative z-score) the more intense is the clustering of low values. The Getis–Ord Gi* statistic was performed by following these procedures:

1. Evaluating the null hypothesis of the spatial distribution of traffic accidents that hypothesize a complete spatial randomness of traffic accidents in the study area. Calculating the z-scores and *p*-values of the point features (i.e., traffic accidents) to determine whether to reject the null hypothesis or not.
2. Aggregating the number of accidents associated with each road segment using a spatial join function that produced a new attribute field for the road network layer that indicates the sum of all accidents that happened on a particular road segment (i.e., spatial unit). This attribute field was then used as the input for calculating the hotspot function (Getis–Ord Gi*).
3. Appling a cutoff fixed distance band or threshold distance for calculating the conceptualization of spatial relationships.
4. Performing the hotspot analysis (i.e., Getis–Ord Gi*) and identifying the hotspot road segments at the various levels of analysis (i.e., attribute of interest) such as (i) year, (ii) month, (iii) day of the week, (iv) time of a day, and (v) severity. The statistical equation for calculating Gi* can be written as in Equations (3)–(5):

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \overline{X} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}} \tag{3}$$

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n} \tag{4}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \overline{X}^2} \tag{5}$$

where x_j is the attribute value for feature j, $w_{i,j}$ is the weight between features i and j, n is equal to the total number of features. The Gi* statistic is a z-score.

5. Results and Discussion

5.1. Analysis of Road Accident Data

Figure 5 shows the distribution of traffic accidents in the Irbid Governorate from 2015–2019 in five categories of analysis (i.e., yearly, monthly, daily, period of the day, and severity). The analysis at the year level showed a gradual increase in the reported traffic accidents of approximately 38% between 2015 and 2019. At the monthly level, the analysis revealed that traffic accidents varied between the months; however, July and August witnessed the highest average percentage values (i.e., 9.76% and 8.96%, respectively) during the study period. This might be due to summer vacation and the school break in Jordan, which are associated with the progressive social, tourism, entertainment, and trade activities in the study area. On the other hand, January and February witnessed the lowest average percentage values of traffic accidents, at 7.38% and 7.08%, respectively, in all the years of study. At the daily level, Sundays and Thursdays witnessed the highest percentage values of traffic accidents in all the years, with average values of 15.42% and 17.20%, respectively. This could be attributed to the fact that these two days represent the start and end of work during the week in Jordan, which usually have higher traffic volume levels between and within the cities and villages in Jordan, including the Irbid governorate. Friday witnessed the lowest average percentage of traffic accidents at 10.82%. At the day level, the hours from 12–18 pm and from 18–24 pm witnessed the highest average percentage of traffic accidents, at 18.82% and 32.46%, respectively.

In terms of severity level, the category of accidents with no injuries had the highest average value of 80.35%, followed by slight injuries (16.36%), medium injuries (1.50%), and severe injuries (1.16%). The total fatal number was 407 cases during the study period, representing 0.62% of the total number of reported traffic accidents in the Irbid Governorate. It is worthwhile to mention that most of the less-severe traffic accidents (~95%) occurred at lower driving-speed levels (i.e., 40–60 km/h) within the internal road network in the cities, towns, and villages that have higher traffic volume in the Irbid Governorate. The remaining traffic accidents occurred on arterial roads that link these settlements and have higher speed limits and severity levels. It is also worth mentioning that the probability of severe traffic-accident occurrences increases with higher driving speeds. The World Health Organization [3] reported that an increase of 1 km/h in driving speed could increase the percentage of human injuries by 3% and fatal cases by 4–5%; this would reach 20% in the case of pedestrians. Although the number of fatal traffic accidents is low within the Irbid Governorate, it negatively impacts the social and economic sectors. Meanwhile, the other traffic accidents would increase the pressure on the national domestic product in the country and the levels of infrastructure utilities in the governorate.

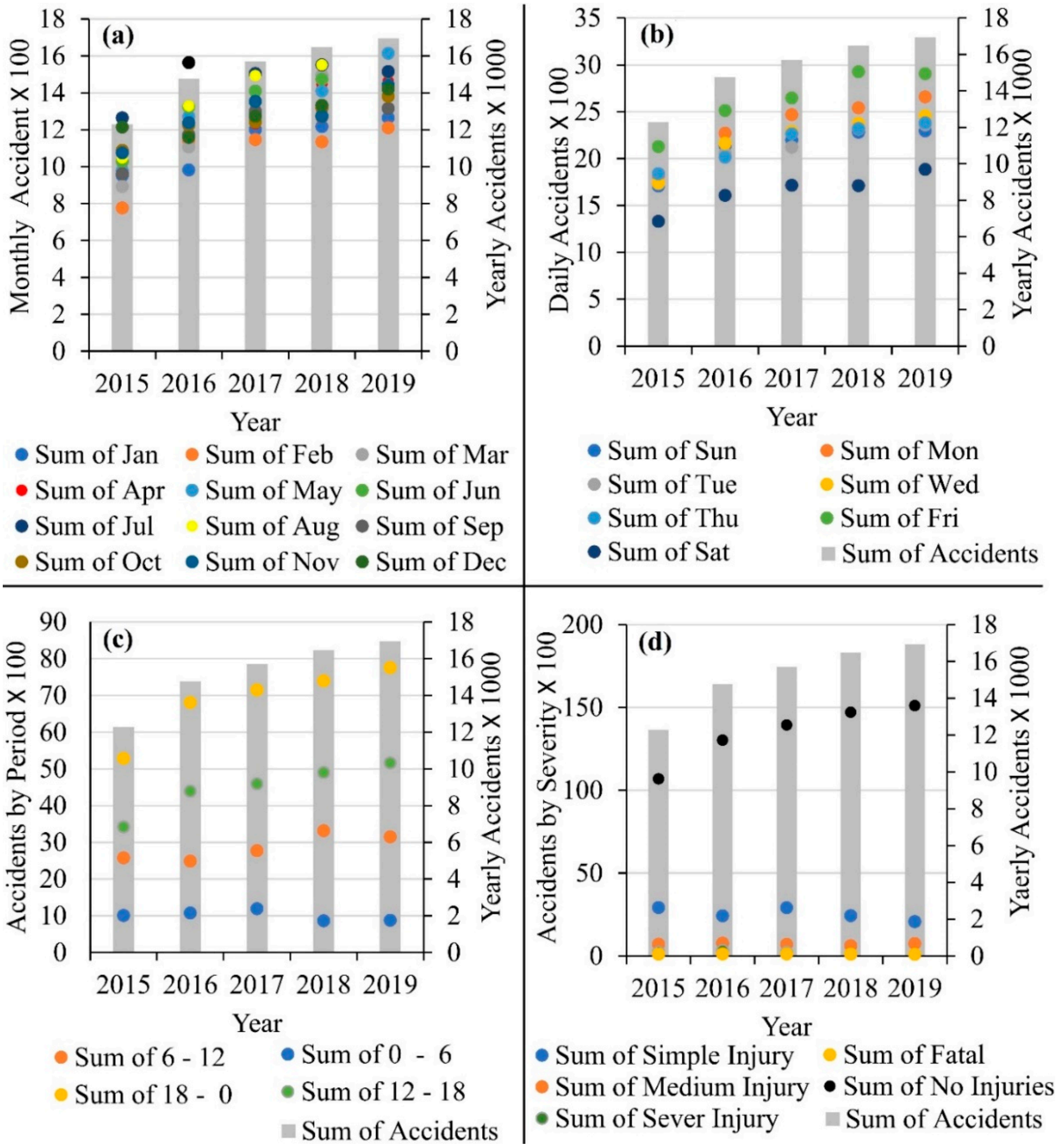

Figure 5. Distribution of traffic accidents in the Irbid Governorate at (**a**) monthly, (**b**) daily, (**c**) period of the day, and (**d**) severity level. The grey columns represent the total number of accidents at the year level.

5.2. Spatiotemporal Mapping of Hotspot Traffic Accidents in Irbid Governorate

5.2.1. Spatial Autocorrelation (Global Moran's I)

Implementing the geoprocessing function "*Distance Band from Neighbor Count*" revealed an average distance of 65 m, which was used as the beginning distance to analyze spatial autocorrelation and the distance from which to increment. By applying this value when calculating the incremental spatial autocorrelation function, one peak distance at 105 m was found with the highest z-score value (Figure 6). This distance was set in our case study at 100 m, ensuring that each accident had at least six neighbors, as suggested by [42]. This value reflects the inherent relationships in the point features of analysis in the input dataset. Table 3 shows the Global Moran's I Summary by Distance as calculated by the incremental spatial autocorrelation function for all traffic accidents in 2015–2019. Figure 7 shows the spatial autocorrelation graph of the z-score and *p*-value of all traffic accidents between 2015 and

2019 in the Irbid Governorate using Moran's I statistics. In Figure 7, the Moran's I was 0.018, the z-score for all accidents was 24.291, and the *p*-value was 0.000. This showed statistically significant status, namely densely clustered, as the positive Moran's I, the high z-scores, and the small *p*-values indicate that traffic accidents were spatially clustered, and there is less than 1% likelihood that this clustered pattern could be the result of random chance.

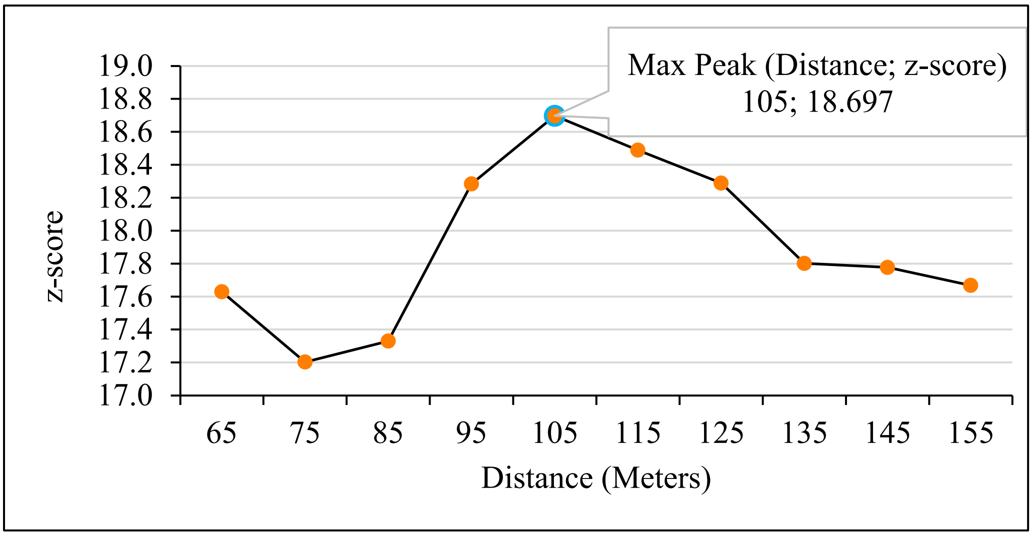

Figure 6. Graphical representation of the incremental spatial autocorrelation by distance and the peak value.

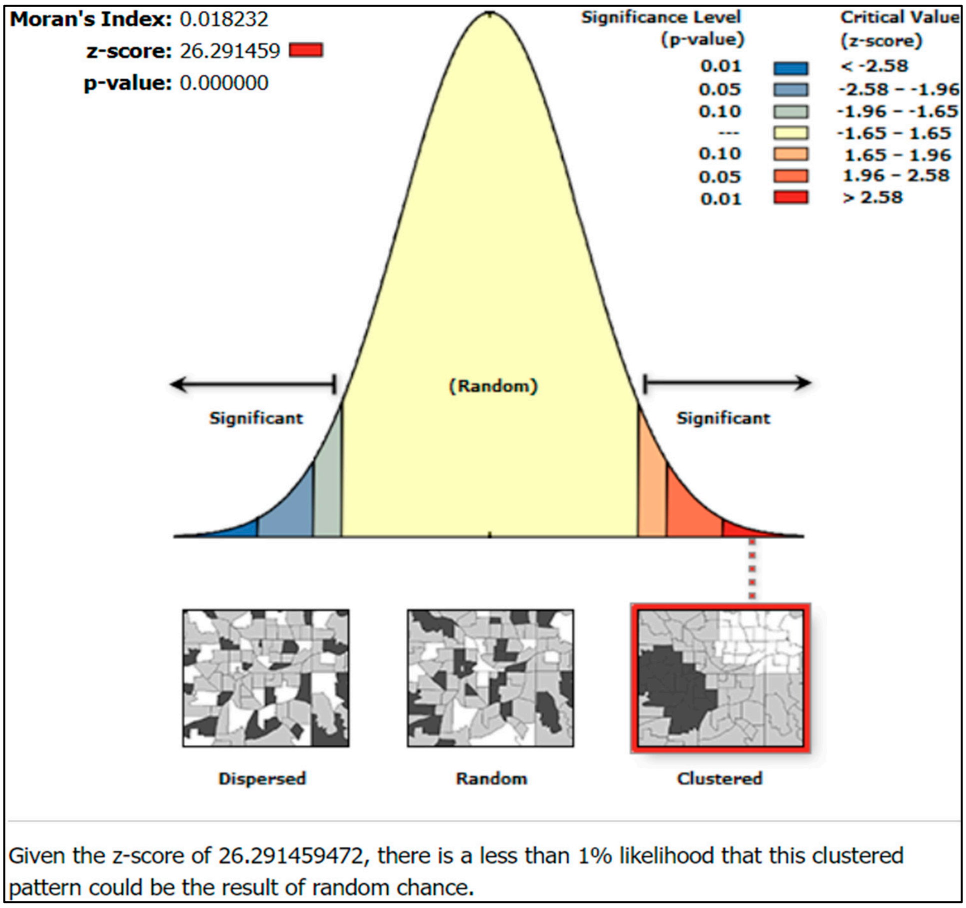

Figure 7. Spatial autocorrelation report with the significance graph of Moran's I, z-score, and *p*-value of traffic accidents in the Irbid Governorate using the data from 2015–2019.

Table 3. The global Moran's I summary by distance as calculated by the incremental spatial autocorrelation function.

Distance (m) *	Moran's Index	Expected Index	Variance	z-Score	*p*-Value
65.00	0.041913	−0.000021	0.000006	17.628812	0.0000
75.00	0.038452	−0.000021	0.000005	17.202281	0.0000
85.00	0.036705	−0.000021	0.000004	17.329749	0.0000
95.00	0.036883	−0.000021	0.000004	18.283657	0.0000
105.00	0.035879	−0.000021	0.000004	18.697440	0.0000
115.00	0.034091	−0.000021	0.000003	18.488937	0.0000
125.00	0.032416	−0.000020	0.000003	18.289320	0.0000
135.00	0.030373	−0.000020	0.000003	17.801679	0.0000
145.00	0.029340	−0.000020	0.000003	17.777098	0.0000
155.00	0.028194	−0.000020	0.000003	17.667624	0.0000

* First Peak and Max Peak (Distance; Value) are 105.00; 18.697440.

5.2.2. Hotspot Analysis Using Getis–Ord Gi*

Herein, we primarily analyzed the traffic accidents in the Irbid Governorate at both annual and severity levels between 2015 and 2019 using the Getis–Ord Gi* statistics. Figure 8 shows the spatiotemporal geographic distribution map of traffic-accident hotspots at the year level between 2015 and 2019. This map determines the road segments with hot or cold statistical traffic-accident hotspots. The popped-up map shows the temporal evolution of hotspot locations between the years of interest. From Figure 8, two types of hotspot locations can be identified. The first form of the hotspot is located along with the internal road networks of Irbid city, particularly where the residential and commercial activities are in the Irbid Governorate. The second hotspot can be identified along the arterial roads that link Irbid city with other cities and regions in Jordan. Examples of these roads are those that connect Irbid with towns in the Jordan Valley in the West, Mafraq and Ramtha cities in the East, and Jerash, Ajloun, Amman and Zarqa cities in the South.

Furthermore, one can notice a temporal evolution of traffic accident hotspots in the governorate between 2015 and 2019. Notably, the length of road segments associated with a 99% confidence level (i.e., GiBin = 3) decreased from 183.2 km to 129.1 km between 2015 and 2019 (Table 4). This reduction in hotspot distance is attributed to various traffic-management interventions such as static police stations, speed-control cameras, more traffic lights, and speed bumps enacted by traffic-management authorities in the governorate.

Because the maps that show locations of traffic-accident hotspots monthly, daily, and period of the day coincide with those at the yearly level, they are not shown herein. In Table 4, the length of road segments at 99% confidence level (i.e., GiBin = 3) for monthly, daily, and the period of day coincided with the number of traffic accidents recorded as such an increase of the number of accidents reflects an increase in the length of road segment hotspots and vice versa. For example, since the highest number of accidents was observed in June, July, and August (refer to Figure 3), the length of road segments in these three months was 154.6 km, 145.3 km, and 157.2 km, respectively. On the other hand, the lowest number of accidents was observed in January, February, and December with 117.1 km, 113.5 km, and 126.7 km of road segments respectively. A similar situation can be seen in the daily and the period of day levels.

The analysis of traffic accidents at the severity level showed a distinguished spatial distribution of hotspot locations (Figure 9). As can be seen, accidents with no injuries are clustered in the city center business district (CBD), where the vehicle speed does not exceed 40 km/h. However, as the speed limits increase, the severity of injuries also increases. For instance, fatal accidents occur on arterial roads due to the high-speed limit of approximately 100 km/h.

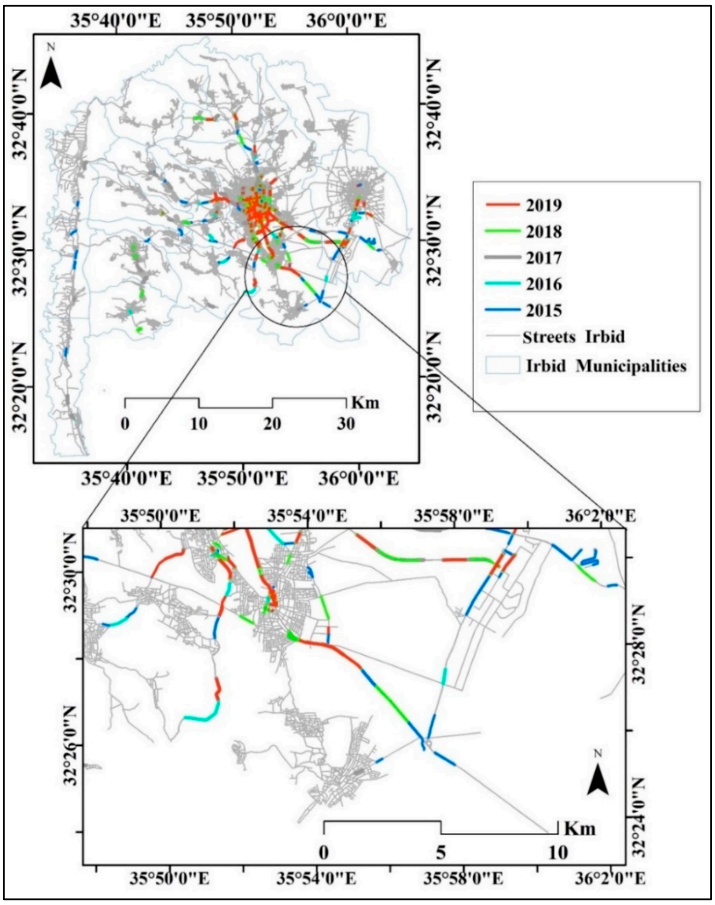

Figure 8. Composite spatiotemporal geographic distribution map of traffic-accident hotspots at the year level from 2015–2019.

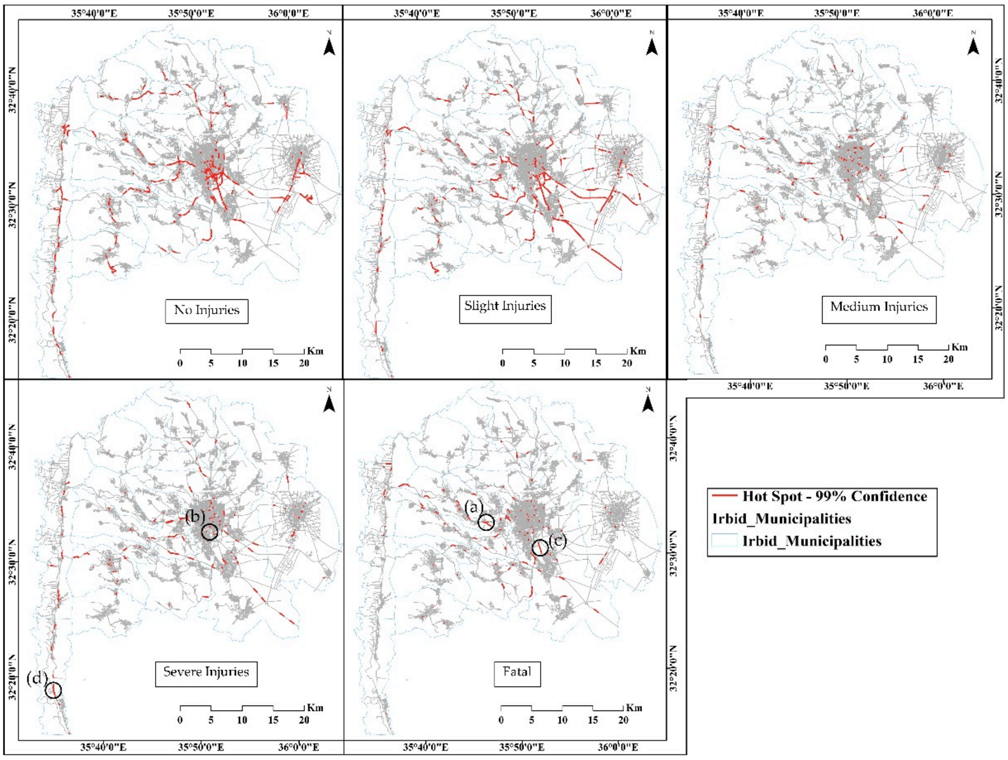

Figure 9. The spatiotemporal geographic distribution maps of traffic-accident hotspots at the severity level from 2015–2019. The lettered circles represent the location of the maps presented in Figure 10a–d.

Table 4. Summary of hotspot statistics for each year, month, daily, period of the day, and severity level, and their associated road segments length at 99% confidence level (i.e., GiBin = 3) for traffic accidents in the Irbid Governorate.

Category		Total Number of Traffic Accidents	Length at 99% Confidence Level (GiBin = 3) (km)
Year	2015	12,293	183.2
	2016	14,759	152.7
	2017	15,701	145.8
	2018	16,470	129.7
	2019	16,940	129.1
Month	Jan	5616	117.1
	Feb	5405	113.5
	Mar	6150	128.3
	Apr	6411	127.7
	May	6555	146.3
	Jun	6745	154.6
	Jul	7397	145.3
	Aug	6835	157.2
	Sep	6018	133.8
	Oct	6250	149.4
	Nov	6383	137.3
	Dec	6398	126.7
Day of the Week	Sunday	10,616	131.1
	Monday	11,757	153.1
	Tuesday	10,585	141.4
	Wednesday	11,021	154.5
	Thursday	10,818	148.2
	Friday	13,118	149.5
	Saturday	8248	139.8
Period of the day (Hours)	24–6	5008	133.5
	6–12	14,297	162.5
	12–18	22,464	154.6
	18–24	34,394	142.5
Severity	No Injuries	12,709	150.8
	Slight Injuries	3495	134.5
	Medium Injuries	960	80.1
	Sever Injuries	496	105.7
	Fatal	457	80.8

Figure 10 shows four examples of the fatal and severe-injury hotspot locations that have the highest confidence level. Figure 10a shows a section of the arterial road that links Irbid city with the capital, Amman. It witnesses high traffic and pedestrian volume as it is surrounded by various residential, educational, and commercial activities. The section is divided by a central traffic island with three lanes for each side. The speed limit is 90–100 km/hour depending on the vehicle type. The segment is not furnished with pedestrian access points and the required traffic signs. To improve traffic safety at this road segment, it is suggested to add pedestrian access points and guardrails to prevent random crossing of the road.

The second example (Figure 10b) represents one of the major sections in Irbid city. It has very high traffic and pedestrian volumes as it is surrounded by numerous commercial stores with different activities, residential households, governmental buildings, and Yarmouk University. All street segments in this area are separated by a central traffic island, but they lack pedestrian access and other traffic-safety needs. It is suggested to reconstruct all street segments in this area with the needed pedestrian access points at the main entrances of Yarmouk University and the traffic signs and guardrail at specific locations to prevent the random crossing of streets. In addition, it is recommended to allocate specific parking lots and bus stops to reduce random parking of cars and public transit.

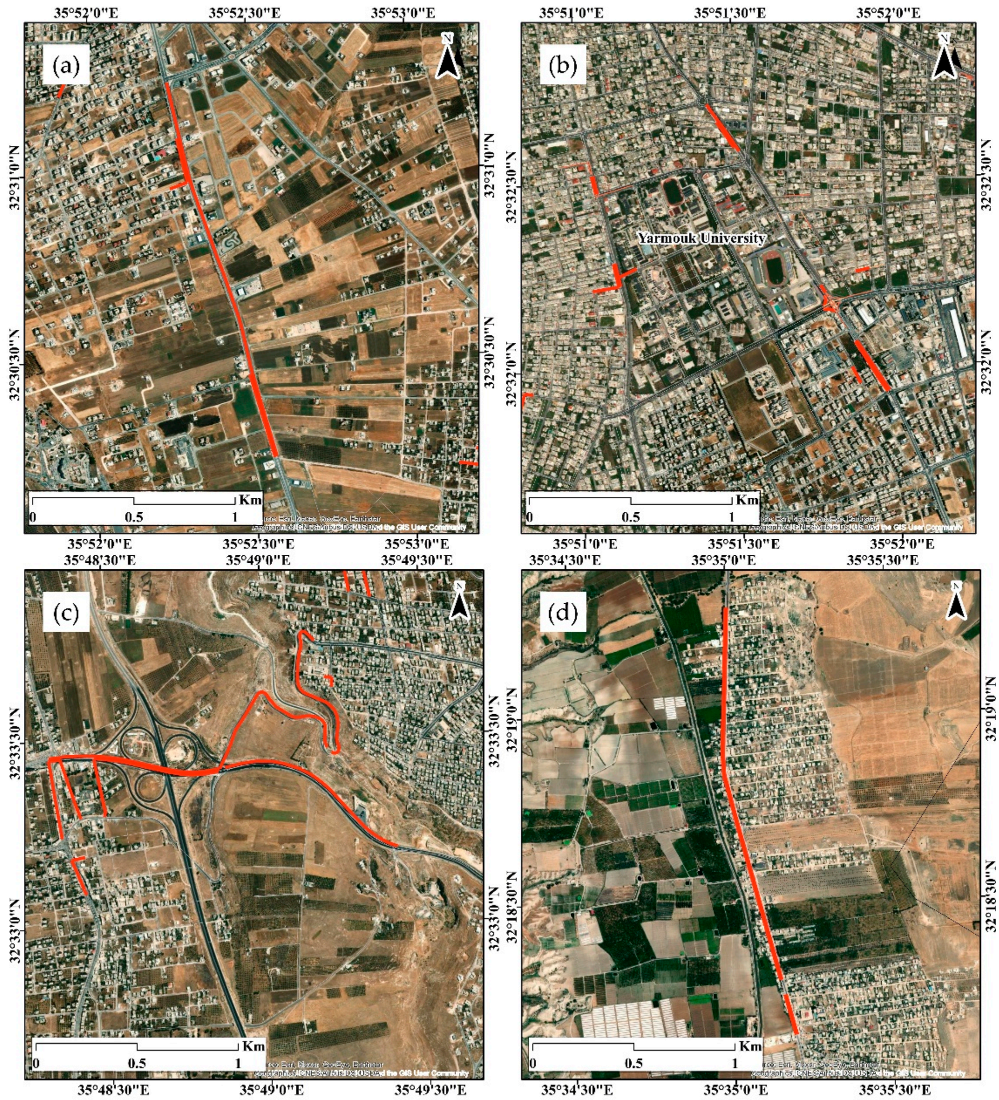

Figure 10. Examples the fatal and severe injury hotspot locations that have the highest confidence level. (**a**) a section of the arterial road that links Irbid city with the capital, Amman (**b**) the major sections in Irbid city, (**c**) the arterial road that links Irbid city with the towns in the Jordan Valley, (**d**) a section of the Jordan Valley Road. Refer to Figure 9 for reference location.

Figure 10c shows a section of the arterial road that links Irbid city with the towns in the Jordan Valley. This section has a high speed limit of 80km/hour with a gentle gradient and sharp and semi-sharp curves and road junctions and bridge loops. The main reason for the high number of traffic accidents in this section is related to drivers' mistakes such as exceeding the speed limits and zigzagging between lanes. These mistakes can be mitigated by setting traffic speed cameras.

Figure 10d shows a section of the Jordan Valley Road that receives high traffic and pedestrian volumes. The main reasons for traffic accidents refer to drivers' mistakes such as exceeding speed limits, driving in the opposite lane, and crossing the traffic light. It is recommended to increase traffic controls on this section by setting a static police station or speed-control cameras. It is also recommended to add pedestrian access at proper locations with guardian and speed bumps, and roundabouts.

Table 4 shows that the length of clusters in accordance with the severity of injuries varies from one place to another. At a 99% confidence level, one can notice that the hotspot locations of accidents with no injuries, slight injuries, medium injuries, and severe injuries were observed at approximately 150.8 km, 134.5 km, 105.7 km, 80.1 km, and 80.7 km within the internal road network of the cities and towns, and the arterial roads, respectively.

6. Conclusions

Over the past few decades, the emergence of the Geographic Information System (GIS) has provided indispensable tools for modeling the spatial and temporal distribution of geographic events such as traffic accidents. These GIS tools were used to simply manipulate, store, and visualize traffic accident locations and clusters, as well as to analyze the significance of traffic-accident distribution based on statistical approaches. Moreover, the GIS software allowed storing spatial and temporal geodatabases for future predictions and the evolution of traffic-accident clusters. In this study, the spatiotemporal analysis of traffic accidents in the Irbid Governorate was investigated using clustering approaches. The temporal distribution of traffic accidents that occurred in the study area was analyzed using descriptive statistics. Furthermore, traffic-accident hotspots were determined along the road segments using the Global Moran I index and Getis–Ord G* analysis. This allowed an understanding of the influence of site characteristics on the frequency, intensity, and severity of traffic accidents.

The spatial autocorrelation analysis of traffic accidents showed that traffic accidents are clustered on some roads in the Irbid Governorate. The Gi* statistics, which were used to identify hot and cold traffic-accident clusters, provide a clear image of traffic-accident clusters along with the internal as well as arterial road networks during 5 years (2015–2019). It has been shown that there was a temporal evolution of traffic accident clusters between 2015 and 2019 due to various traffic-management interventions. According to the statistics with a 99% significance level, the length of road segments was reduced between 2015 and 2019. Moreover, the increase in accident numbers reflected the length of road-segment clusters and vice versa. The analysis also showed that fatal accidents occur when the road speed limit increases and vice versa. This means that accidents with no injuries cluster on the internal roads of Irbid city, whereas accidents with severe injuries and fatal cases occur on the roads with high speed limits. Therefore, the traffic management authorities should give the roads with high speed limits the highest priority to reduce the severity and fatality of traffic accidents.

To reduce the number and the severity of traffic accidents in the study area, some traffic solutions such as setting up speed limit signs, pedestrian crosswalk signs, and specific parking lots and bus stops were suggested. These solutions are highly recommended in the fatal- and severe-injury hotspot locations that were identified based on the statistical and mapping analysis.

This study confirmed that spatial analysis and statistical techniques within the GIS environment effectively identified traffic accident hotspots and road segments with statistical significance. Mapping the spatiotemporal pattern of traffic-accident hotspots along with the causes and proposed solutions for the hotspot locations would support the decision-makers and traffic-management authorities in prioritizing road maintenance, especially for those with frequent accidents, to improve traffic safety. The study recommends developing a national database of traffic-accident hotspots in spatial and temporal dimensions to apply effective traffic-safety measures at a national level.

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