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Effects of Urban Characteristics on Traffic Accidents

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Abstract

This study aimed to examine the effects of urban planning, road network, and other urban related characteristics on road traffic accidents. Amman, the capital of Jordan, which consists of 22 urban districts, was taken as a case study. A cross-sectional data on traffic accidents of different types, urban planning, road network, passenger- and vehicle-kilometers of travel, public transport accessibility, and topographic characteristics were collected. Multivariate regression analyses were performed to develop statistical relationships that may help city planners and traffic engineers to set safety policies and regulations for safe urban environment. The results of analyses indicated that the increase in vehicle-kilometers of travel, road and intersection densities, and percentage of mixed land-use were significantly increasing all types of accidents in each urban district. Also, the results indicated that population density, availability of public transit lines along primary and collector streets, accessibility to public transit services, and school density were significantly related to the pedestrian accident density.

INTRODUCTION

Jordan is a Mediterranean country with a middle-income level. The country faces a serious road accidents problem. For example, during the years 2009, 2010, and 2011, the total number of road accidents was 122793, 140014, and 142588 accidents, respectively. The total number of fatalities and injuries during these years were 2040 and 51187, respectively. Also, the economic costs of these accidents were estimated at US$ 1.25 billion. These socio-economic costs are very high for a country having a population of about 6.1 million and registered vehicles of approximately 1.1 million in 2010.

Amman, the capital of Jordan, is located in the middle part of the country. In 2010, the city has a population of 2.367 million, which constitutes about 40% of the country's' population. In the same year, the total number of traffic accidents in Amman was 90657 accidents of which 1574 pedestrian accidents and the remaining were vehicular accidents. It is worth mentioning that the city experienced about 65% of the total number of traffic accidents in Jordan. Thus, the city faces a serious road accident risk in terms of the proportion of population. Although previous studies conducted in Jordan have investigated traffic accidents in urban areas, most of these studies were performed at intersection, block, or arterial level rather than at urban district level [1-3]. These studies did not explore the influence of city planning, road network, public transport, or topographic characteristics on traffic accidents at district level. In fact, these characteristics may affect the level of travel within a district or among urban districts. Thus, exploring the effects of these characteristics on traffic accidents may help city planning and traffic engineers to establish regulations and policies concerning such characteristics.

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The objective of this study was to explore the effects of city planning, road network, public transport, and topographic characteristics on the total traffic accidents, pedestrian accidents, and vehicular accidents densities at the district level. To achieve this objective, data on the related characteristics and accidents in Amman city were obtained for three years (2009-2011). Multiple regression analyses were used to develop statistical equations that may have practical applications in city planning and traffic management. To achieve the stated objective, a comprehensive literature survey was performed in the following section, followed by methodology of data collection, analyses of the collected data, and discussion of the obtained results sections.

LITERATURE REVIEW

Literature has indicated that traffic accidents are related to urban planning characteristics. For example, Al-Masaeid and Suleiman [4] investigated relationships between urban planning variables and traffic crashes in Damascus, the capital of Syria. And they found that traffic accidents are related to urban planning variables at zonal level. Also, studies conducted in Nigeria and Australia reported that traffic accidents are associated with higher urban population density [5,6]. However, other studies conducted in England indicated that higher urban population densities experienced fewer accidents and higher road casualties [7,8].

Several studies pointed out that land-use has different effects on traffic and pedestrian accidents. Studies reported that business and commercial areas or frontages and mixed land-use had higher traffic accident occurrences, while higher percentage of open spaces and agricultural lands had lower traffic accidents [4,9,10]. Also, literature has explored the correlation between infrastructure characteristics and pedestrian accidents. For example, Dumbaugha and Li [11] indicated that bus stops and parking areas are associated with higher pedestrian accidents. Other studies revealed that the distribution of public buildings has a great effect on pedestrian accidents [12].

Further studies highlighted the impact of street network characteristics on traffic and pedestrian accidents. The studies found that the increase in street network length, intersection density, and vehicle-kilometers of travel (VKT) would increase traffic crashes [4,13]. Evidence from studies conducted in Australia and European countries showed that pedestrian accidents are associated with high percentage of arterial road and high number of intersections [6,14]. Also, the existence of public bus services would reduce traffic volume and eventually may reduce traffic and pedestrian accidents [13].

The literature review demonstrates that urban characteristics, such as population density, land-use, road type, and intersection design play significant roles in influencing the occurrence and severity of traffic accidents. Compact and mixed land-use urban development patterns tend to reduce accidents, emphasizing the importance of thoughtful urban planning and safety measures. Further research at finer geographic scales, such as the district level in Amman, may contribute to a better understanding of the relationships between traffic accidents and urban characteristics in specific regions.

METHODS

To achieve the objective of this study, Amman, the capital of Jordan, was selected as a case study. As shown in Figure 1, Amman consists of 22 districts that have different areas with a total urban area of 800.59 Sq. Km (Amman city, 2014; Greater Amman Municipality, 2014). The city is located in a mountainous area, which encompasses seven hills [15].

Data on traffic accidents were obtained from the Central Traffic Department, Public Security Headquarters [16]. The data included the total number of traffic accidents, pedestrian accidents, and vehicular accidents over a three-year period. The total number of accidents included both vehicular and pedestrian accidents. A vehicular accident means single- or multiple-vehicle accidents. Traffic accident density (TAD), pedestrian accident density (PAD) and vehicular accident density (VAD) were computed for each district as the average annual number of related accidents divided by the district area.

The data on urban characteristics were obtained from Greater Amman Municipality (GAM). These data included land-use, commercial malls density, school density, city center district, and population density. Different land-use categories in Amman are identified, such as residential land, mixed land-use (commercial, office, and residential uses), green land (recreation areas), and public building land (governmental facilities). The percentage of each land-use type is determined at the district level, such as percentage of mixed land-use (PML), percentage of commercial land-use (PCL), and percentage of residential land-use (PRL). The number of schools in each district is obtained, and schools' density (SD) is computed as the total number of schools divided by the area of the district. It is worth mentioning that districts are classified based on their location with respect to the central business district (CBD) or city downtown, with dummy variables representing whether a district is totally or partially within the city center or not. Finally, population density (PD) for each district is calculated as the average population in the period (2009-2011) divided by the area of the district.

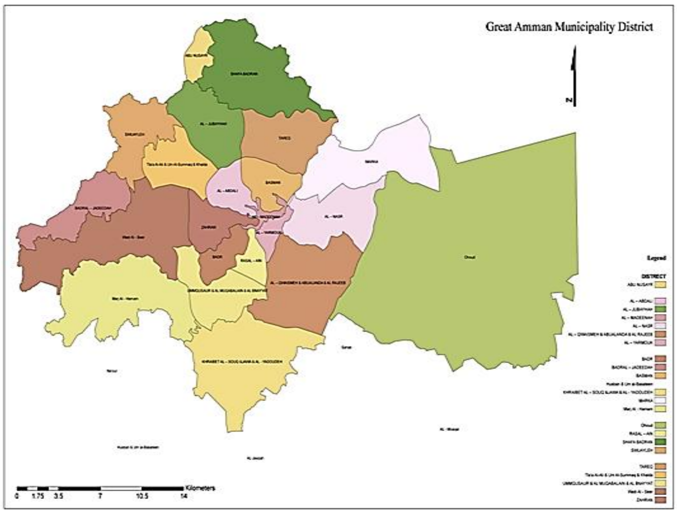

Figure 1. Amman Municipality Boundary and Its Districts

The road network in the city consists of three main types: primary, collector, and local streets. The total length of these roads is 4,658.6 km. Data on road network and traffic operation variables were obtained from GAM and through field survey. These variables included vehicle-kilometers of travel density (VKTD), passenger-kilometers of travel density, intersection density (ID), traffic signal density (TSD), road density (RD), percentage of primary and collector/distributor roads covered by public transport line length (PTL), and percentage of area served by public transport (PSPT). The VKTD was computed as the sum of peak hour vehicle volume multiplied by the length of the primary roads, divided by the area of the district. Similarly, passenger-kilometers of travel density (PKTD) was computed as the sum of peak hour passenger volume multiplied by the length of primary roads served by public transport, divided by the area of the district. The PSPT along roads was identified as the area served by public transport lines in each district by considering a 400-meter buffer distance on each side of the public transport lines and dividing it by the built-up area within each district. The Highway Capacity Manual [17] reported that the 400 m distance is the limit of the areas served by public transit [18]. The RD was computed as the total length of primary, collector and local roads, divided by the district' area. Similarly, ID was computed as the sum of all intersections along all types of roads, divided by the district' area. Also, the density of primary and collector roads (PCD) in each district was computed.

Finally, the study also examined the effect of topography on traffic accidents, considering the difference in elevation of each district, which ranges from the highest point to the lowest point. The span elevation (SE) is computed as the difference in elevation of each district divided by the longest distance passing through the district. This factor was used to explore the effect of topography on traffic accidents [15].

RESULTS AND DISCUSSION

In this study three types of accident density models were developed. These types include total traffic accident density, pedestrian accident density, and vehicular accident density models. In the first step of analysis, a correlation matrix was developed to explore possible relation between the included variables and the related accident density. In the second step, accident density models were developed based on the influential variable or a set of variables that are un-correlated. In this step, a model is discarded if the p-value is greater than 0.05 or the coefficient of determination is less than 0.70.

The following subsections present the statistical results of the total traffic accident, pedestrian accident, and vehicular accident densities. The soundness of the empirical results obtained and comparisons of findings with literature are highlighted in the discussion section.

Modeling of Traffic Accident Density (TAD)

The statistical analyses revealed that total traffic accident density is significantly influenced by VKTD, PCD, ID, PTL, PRL, CC, and SE. However, it was found that the coefficients of determination between the total traffic density and PRL, CC, or SE are less than 0.70. As such, these models were discarded. Table 1 shows the developed models for total traffic accident density. Model 1 in Table 1 indicates that the total traffic accident density increases with the increase in vehicle-kilometers of travel and road density. Model 2 reveals that the total traffic accident density increases with the increase percentage of primary and collector streets and intersection densities. Also, model 3 demonstrates that total traffic accidents density decreases with the increase in the percentage of primary and collector roads covered by public transport. Figure 2 shows a scatter plot of the total traffic accident density and the percentage of primary and collector roads that are covered by public transport (PTL). Clearly, roads covered by public transport may contribute in the reduction of private vehicle use and ultimately reduce the probability of traffic accidents. Finally, model 4 illustrates that total traffic accident density is strongly influenced by the vehicle-kilometers of travel density and the percentage of mixed land-use. The increase in the percentage of mixed land-use may generate traffic with different purposes, thus; increases speed differences and traffic interactions. Figure 3 illustrates a scatter plot of the total traffic accident density and the percentage of mixed land-use.

Table 1. Total Traffic Accidents Density Models

Model#	Prediction Models	Key Finding
Model 1	$TAD = 0.061\,VKTD + 0.466\,RD^2$	This model is statistically significant at 0.05, with a coefficient of multiple determination R^2 of 0.96.
Model 2	$TAD = 30.558\,PCD + 70.45\,ID$	This model is statistically significant at 0.05, with a coefficient of multiple determination R^2 of 0.95.
Model 3	$TAD = -209.84 + {}^{273.82}/_{\sqrt{PTL}}$	The model is statistically significant at 0.05, with a coefficient of determination R^2 of 0.70.
Model 4	$TAD = 8.8\,PML + 0.07\,VKTD$	The model is statistically significant at the 0.05 level, with R^2 of 0.96

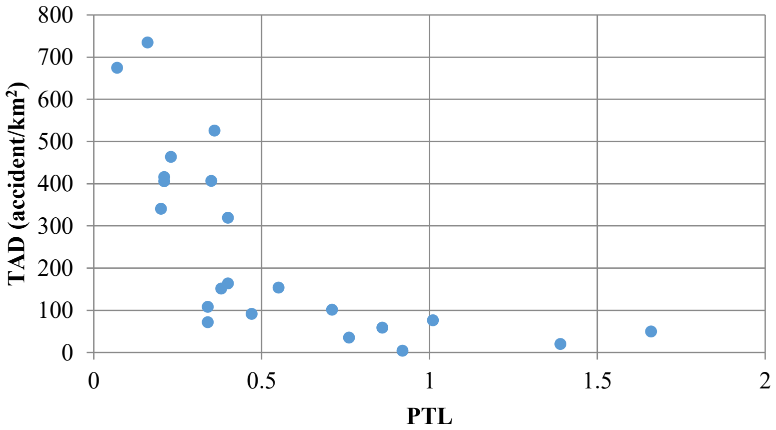

Figure 2. The Relation between the Traffic Accidents Density and the Percentage of Primary and Collector Streets that are Covered by Public Transport Lines

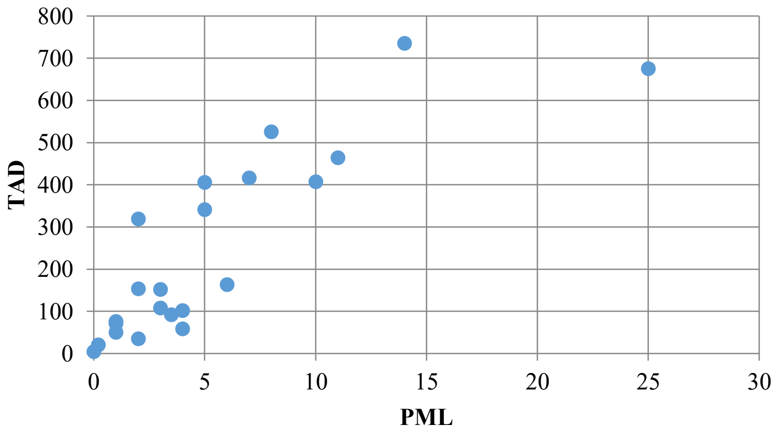

Figure 3. The Relation between the Traffic Accidents Density and the Percentage of Mixed Land-Use Area

Modeling of Pedestrian Accidents Density (PAD)

Modeling of PAD involves a set of regression equations to understand the impact of various urban characteristics on pedestrian accidents at the district level in Amman city. Regression equations presented in Table 2 illustrate that pedestrian accident density is strongly affected by vehicle-kilometers of travel density and road density (Model 5), passenger-kilometers of travel density and intersection density (Model 6), percentage of area served by public transport lines (Model 7), population density and percentage of commercial areas at the district level (Model 8), percentage of mixed land-use, school density, the location of the district with respect to the central business district (CBD) or down town, and school density (Model 9). Figure 4 shows a scatter plot of the pedestrian accident density and the percentage of mixed land-use. It is worth mentioning that the increase in all the above urban, traffic, and road characteristic variables would increase pedestrian accident density except the increase in the percentage of district's area served by public transport lines (Model 7). Probably, the availability of public transport service would reduce private vehicle volume and eventually will reduce pedestrian exposure to risk. Figure 5 shows a scatter plot of pedestrian accident density and the percentage of district's area served by public transport lines.

Table 2. Pedestrian Accidents Density Models

Model#	Prediction Models	Key Finding
Model 5	$PAD = 0.001\,VKTD + 0.035\,RD^{1.7}$	The model is statistically significant at 0.05 level with a coefficient of multiple determination (R^2) of 0.90.
Model 6	$PAD = 0.001\,PKTD + 1.498\,ID$	The model is statistically significant at 0.05 level with a coefficient of multiple determination (R^2) of 0.94.
Model 7	$PAD = -3.015 + {}^{3.991}/_{\sqrt{PSPT}}$	The model is statistically significant at 0.05 level with a coefficient of multiple determination (R^2) of 0.72.
Model 8	$PAD = 0.07\,PD + 0.84\,ID + 0.33PCL$	The model is statistically significant at 0.05 level with a coefficient of multiple determination (R^2) of 0.83.
Model 9	$PAD = 0.34\,PML + 2.56\,CC + 0.62\,SD$	The model is statistically significant at 0.05 level with a coefficient of multiple determination (R^2) of 0.96. (CC=1 if the district totally or partially within the CBD, 0 otherwise)

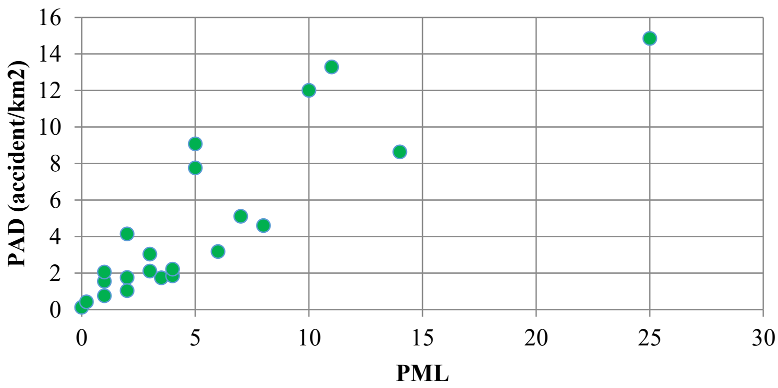

Figure 4. The Relation between the Pedestrians' Accidents Density and the Percentage of Mixed Land-Use

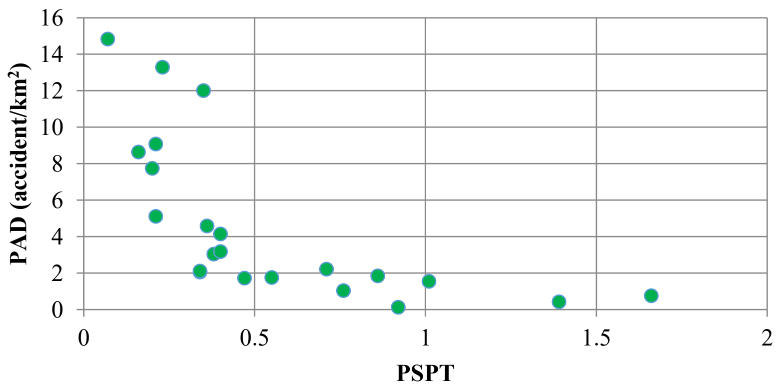

Figure 5. The Relation between the Pedestrians' Accidents Density and the Percentage of District's Area Served by Public Transport Lines

Modeling of Vehicles Accidents Density (VAD)

This part of analysis focuses on identifying the factors that affect vehicle accident density at the district level in Amman city. Results of regression analyses and modeling are shown in Table 3. The analyses indicated that vehicle accident density would increase with the increase in vehicle-kilometers of travel density and road density (Model 10), primary and collector street density (Model 11), and percentage of mixed land-use (Model 12). Figure 6 shows the scatter plot of the vehicle accident density and the percentage of mixed land-use. In contrast, the increase in the percentage of primary roads served by public transport lines may reduce vehicle accident density, as shown in Model 13. Figure 7 presents a scatter plot of vehicle accident density and the percentage of primary roads covered by public transport lines.

Table 3. Vehicles Accidents Density Models

Model#	Prediction Models	Key Finding
Model 10	$VAD = 0.06\,VKTD + 0.452\,RD^2$	The model is statistically significant at 0.05 level where R^2 is 0.96.
Model 11	$VAD = 30.16\,PCD + 68.83$ ID	The model is statistically significant at 0.05 level where R^2 is 0.95.
Model 12	$VAD = -204.907 + {}^{268.446}/_{\sqrt{PTL}}$	The model is statistically significant at 0.05 level where R^2 is 0.70.
Model 13	$VAD = 8.45\,PML + 0.07\,VKTD$	The model is statistically significant at 0.1 level where R^2 is 0.96.

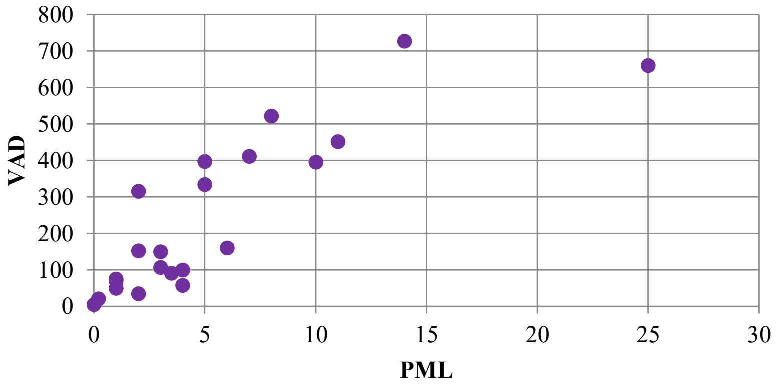

Figure 6. The Relation Between the Vehicle Accidents Density and the Percentage of Mixed Land-Use

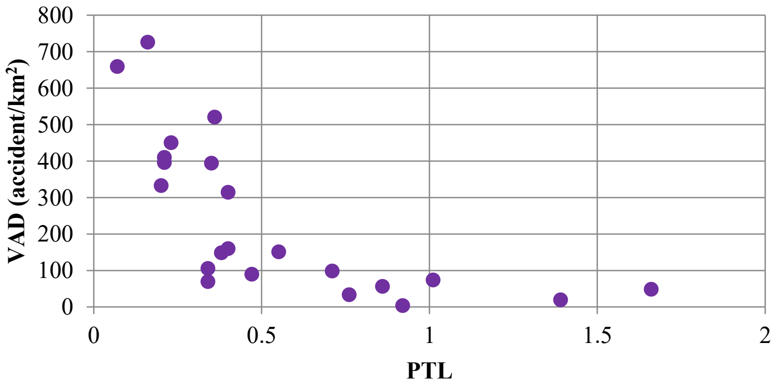

Figure 7. The Relation between the Vehicle Accidents Density and the Percentage of Primary Streets that are Covered by Public Transport Lines

Discussion

This study was conducted to explore the effect of urban planning, road network, and traffic characteristics, on total traffic, pedestrian, and vehicular accident densities at the district level. The road network characteristics were found to be the most significant factors that affect traffic, pedestrian and vehicular accident densities. Increases in road and intersection densities were found to increase all types of accident densities. This result is logical, since an increase in road and intersection densities would increase the opportunity of traffic conflict and speed variability. This finding is compatible with the results of several previous studies [4,5,7,8,13, 19-22]. Also, it was found that an increase in the percentage of primary and collector road density may increase the total traffic and vehicular accident density. Probably, accident hazards were particularly exacerbated along primary and collectors, where vehicles travel at relatively high operating speeds and at the intersection where traffic interacts with opposing streams. In contrast, results of the study did not confirm that pedestrian accident density increases with the increase in the primary and collector street density. Empirical observation revealed that most of primary roads which are subjected to high traffic or speed levels are provided with over-pass pedestrian bridges. This segregation strategy eliminates the conflict between traffic and pedestrians and ultimately prevents this type of accidents.

Results of this study also indicated that all types of accident densities are strongly and positively influenced by the vehicle-kilometers of travel density. This finding is compatible with findings in previous studies [4,19,22]. Furthermore, it was found that pedestrian accident density is associated with districts that have high passenger-kilometers of travel density. Probably, an increase in the PKTD would increase the level of pedestrian exposure to the risk of accidents.

This study investigates the impact of public transport services on accident density. The results of analyses indicated that an increase in the percentage of primary and collector streets served by public transport lines would reduce total traffic and vehicular accident densities as shown in Figures 2 and 7, respectively. This result is logical because availability of public transit encourages residents to use it rather than using their own private cars and ultimately reduce traffic congestion on roads. Also, the results showed that an increase in the percentage of area served by public transport within 400 m on each side of the public transport line would reduce pedestrian accident density, as illustrated in Figure 5. Again, this result seems to be sound because lower accessibility may force captive passengers to walk longer distances and exposed to higher risk of pedestrian accidents. Therefore, the increase in the public transport accessibility would contribute to pedestrian accident reduction. As such, it is recommended to provide public transport services along primary and collector streets and improve accessibility to reduce all types of accidents at district level. For comparable purposes, this issue received less attention in the previous safety studies.

This study also quantified the effect of land-use, in terms of percentage of mixed land-use (PML), on accident density. The results of analysis indicated that PML have a significant effect on all types of accident densities as illustrated in Figures 3, 4, and 6. These figures show that all types of accidents increase with the increase in the percentage of mixed land-use. In fact, mixed land-use will generate mixed traffic with different trip purposes and high-speed variability; therefore, higher traffic interaction or conflict between vehicles and pedestrians would be expected. This situation may increase all types of the investigated traffic accidents. This finding is similar to the findings obtained in several safety studies [8-10,21,23,24]. Investigating Figures 3, 4, and 6 it is recommended to limit the percentage of mixed land-use to about 3%.

Investigation of the impact of schools density on accidents was also explored in this study. The analysis indicated that schools density had a significant effect on pedestrian accident density. The results revealed that pedestrian accident density increases with the increase in school density at district level. In Jordan, approximately one-third of accident casualties are attributed to pedestrian accidents. Previous studies conducted in Jordan indicated that children and young have exposed to an elevated level of pedestrian accidents. Empirical observations show that a considerable number of schools are located in frontage of primary or collector roads without reasonable calming measures. This result is similar to those obtained from several studies [9,20,25-27]. Therefore, schools should be located away from primary and collector streets with reasonable calming measures.

The effect of population density on accidents was investigated in this study. The obtained results showed that population density increases the level of pedestrian accident density. This result is compatible with the results of previous studies [4-7,14,28,29]. In Jordan, the average household size is 5.2 members, and the average generated trips by a household on a workday is 7.7 trips [30]. As such, the total number of generated trips in Amman per day in 2010 is about 3.5 million. In Amman, walking trips represent 26% of the total generated trips [31]. Probably, the lack of sufficient well-planned sidewalks may contribute to this problem. Field observations indicated that sidewalks are narrow with un-even surface level. Therefore, pedestrians may force in some locations to use streets instead of sidewalks. As such, they are exposed to a high level of pedestrian accidents. Further analyses revealed that pedestrian accident density is affected by the location of the district with respect to the CBD or downtown. Equation model 9 in Table 2 indicates that pedestrian accident density is relatively high in districts located totally or partially in the CBD area. This result is expected, because these districts are exhibited large pedestrian volumes with insufficient sidewalk widths. For walkability and pedestrian safety purposes, studies reported the importance of providing sufficient sidewalk widths [32].

Finally, this study investigated other urban characteristics that may affect the accident density such as percentage of public builds density, percentage of built-up area, percentage of green area, percentage of industrial area, percentage of residential area, and span elevation. However, the analyses carried in this study did not confirm the impact of these planning and topographic variables on accident density at the predefined level of correlation. It is worth mentioning that peak hour traffic volume and peak hour passenger volume were used in computing VKTD and PKTD due to unavailability of daily volumes. Probably the use of daily volumes may provide more accurate results. Furthermore, the effects of driver behavior, level of enforcement, weather conditions, and site-specific geometric data are well acknowledged in traffic accident occurrences [33]. Speeding, traffic signal red runners, close-following, and failure to give priority to traffic or pedestrian are main causes of sever accidents in Jordan [26,34]. However, it was difficult to incorporate these variables in accident analysis at district level. While the specific results relate to Amman city, it is recommended to conduct further studies in other cities that have different characteristics in terms of socioeconomic, city size, or population level.

CONCLUSIONS

Based on the results of this study the following points were concluded:

- The results of the study indicated that the increase in vehicle-kilometers of travel density was significantly increasing all types of traffic accidents in each urban district. Also, the results revealed that pedestrian accident density is significantly related to the level of passengers served by public transport.
- Road network characteristics, such as road density and intersection density, were found to have a significant effect on all types of accidents at district level. This finding is compatible with the results of previous studies.
- The results of analysis indicated that increasing of the percentage of primary and collector streets covered by public transport lines and improving the accessibility to public transport services would reduce pedestrian accident density at the urban district level.
- The analysis performed in this study showed that the percentage of mixed land-use was significantly influenced by all types of accidents at the district level. Thus, city planner engineers should reduce mixed land-use in urban areas.
- The results obtained from this study consistently showed that pedestrian accident density was significantly related to school density at the district level. Therefore, it is important to locate schools far away from primary or collector streets and provide school zone with a suitable calming measure.
- The results of this study revealed that pedestrian accident density was strongly related to population density. This result is consistent with the results of previous studies. Thus, city planners should recommend moderate population density at district or city level.
- Finally, the results indicated that districts located totally or partially within the central business areas (CBD) exhibited high pedestrian accident density. Therefore, districts located in the CBD or close to it should provide with reasonable pedestrian walking and crossing facilities.

Future Work

This study was conducted at district level, therefore; it is recommended to conduct further studies at neighborhood level and incorporating more detailed data such as daily traffic and pedestrian volumes, level of enforcement, traffic calming measures, types of intersections, street-network, and land-use variables. Furthermore, it is recommended to conduct further accident studies to investigate accident severity contributing factors.

Declaration of Conflicting Interests

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Data Availability

The data are available upon request.

Author Contribution Statement

The authors confirm contribution to the paper as follows: study conception and design: H. Al-Masaeid, R. Al-Tal; data collection: M. Mahmoud; analysis and interpretation of results: H. Al-Masaeid, M. Mahmoud; draft manuscript preparation: H. Al-Masaeid. All authors reviewed the results and approved the final version of the manuscript.

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