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Araştırma Makalesi | Research Article

Identification of Traffic Accident Hotspots Through Geographic Information Systems-Based Spatial Analysis: The Case of Bitlis, Türkiye

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Abstract

Traffic accidents persist as a critical transportation and public health challenge in Türkiye, echoing a global trend. In this framework, spatial analysis of accident data is of paramount importance for the precise identification of high-risk zones, the development of robust safety strategies, and the formulation of evidence-based policies aimed at mitigating accident rates. While numerous studies in the Turkish literature examine the spatiotemporal distribution of traffic accidents across various provinces, a comprehensive Geographic Information Systems (GIS)-based analysis specifically focusing on Bitlis has not yet been conducted. This gap underscores the necessity of scientifically investigating the region's accident patterns and generating data-driven insights to assist decision-makers. This study seeks to fill this significant academic void by analyzing the spatial distribution of traffic accidents in Bitlis through GIS-supported analytical methodologies. Utilizing a five-year accident point dataset (2020–2024), the research delineates density zones, conducts statistical hotspot analysis, and identifies high-risk road segments. The findings demonstrate that accident clusters are predominantly concentrated along corridors with heavy traffic volumes and road sections with challenging physical or structural constraints. Additionally, harsh climatic factors, road geometry, and driver behaviors emerge as primary determinants of accident occurrences. Consequently, this research represents the first comprehensive GIS-based accident analysis for Bitlis. The results provide a substantial reference for enhancing regional traffic safety, eliminating chronic blackspot, and planning strategic infrastructure investments while establishing a fundamental framework for future research.

Anahtar Kelimeler: Bitlis, traffic accidents, Geographic Information Systems (GIS), accident density, road safety, hotspots

Coğrafi Bilgi Sistemleri Tabanlı Mekânsal Analiz ile Trafik Kazası Sıcak Noktalarının Belirlenmesi: Bitlis, Türkiye Örneği

Öz

Trafik kazaları, küresel ölçekte olduğu gibi Türkiye'de de ulaşım güvenliği ve toplum sağlığı açısından kritik bir sorun olmaya devam etmektedir. Bu bağlamda, kaza verilerinin mekânsal analizi; yüksek riskli bölgelerin hassas tespiti, etkin güvenlik stratejilerinin geliştirilmesi ve kaza oranlarını azaltacak politikaların oluşturulması açısından hayati önem taşımaktadır. Türkiye literatüründe çeşitli illerin kaza dağılımlarını inceleyen çalışmalar bulunsa da Bitlis ili özelinde Coğrafi Bilgi Sistemleri (CBS) tabanlı kapsamlı bir analiz eksikliği dikkat çekmektedir. Bu çalışma, söz konusu boşluğu doldurmak amacıyla Bitlis'teki trafik kazalarının mekânsal dağılımını CBS destekli analitik yöntemlerle incelemeyi hedeflemektedir. Araştırma kapsamında, 2020–2024 yıllarını kapsayan kaza noktası verileri kullanılarak yoğunluk bölgeleri tanımlanmış ve istatistiksel sıcak nokta (hotspot) analizleri gerçekleştirilmiştir. Elde edilen bulgular, kaza kümelerinin temel olarak yoğun trafik akışına sahip güzergâhlarda ve fiziksel/yapısal koşulların zorlayıcı olduğu yol kesimlerinde yoğunlaştığını göstermektedir. Ayrıca sert iklim faktörleri, yol özellikleri ve sürücü davranışları kaza oluşumunda temel belirleyiciler olarak öne çıkmaktadır. Sonuç olarak bu araştırma, Bitlis ili için yürütülen ilk kapsamlı CBS tabanlı kaza analizi niteliğindedir. Elde edilen sonuçlar; bölgesel trafik güvenliğinin artırılması, kara noktaların belirlenmesi ve stratejik altyapı projelerinin planlanması için güçlü bir referans teşkil ederken gelecekteki çalışmalar için de temel bir veri çerçevesi sunmaktadır.

Keywords: Bitlis, trafik kazaları, Coğrafi Bilgi Sistemleri (CBS), kaza yoğunluğu, yol güvenliği, sıcak nokta

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Identification of Traffic Accident Hotspots Through Geographic Information Systems-Based Spatial Analysis: The Case of Bitlis, Türkiye

1. Introduction

Road traffic accidents represent a major global concern, resulting in substantial negative consequences for public security, economic sustainability, and societal prosperity (Heydari et al., 2019).

According to World Health Organization (WHO) data, traffic accidents claim approximately 1.19 million lives annually (World Health Organization, 2023). The expansion of urban areas and the intensification of commercial activities, coupled with the densification of transportation infrastructures, have led to a significant increase in traffic accidents. Geographical and statistical research reveals that such accidents can stem from factors such as adverse weather conditions creating slippery road surfaces (Azari et al., 2023), the failure of authorized institutions to implement appropriate planning and safety policies (Ouni & Belloumi, 2019; Prasannakumar et al., 2011), and insufficient investments in safety infrastructure (Hazaymeh et al., 2022). Furthermore, it has been stated that human-related factors, including reckless driving behaviors particularly prevalent among young drivers and the non-compliance of pedestrians with safety regulations, contribute significantly to these incidents (Bucsuházy et al., 2020).

Identifying the root causes of traffic accidents can guide preventive approaches, such as increasing behavioral awareness, developing appropriate safety strategies, and improving post-injury intervention processes (Lai & Chan, 2004). Furthermore, the detection of high-risk regions is a critical necessity for addressing security vulnerabilities and implementing strategic measures aimed at accident reduction (Durduran, 2010).

Road traffic accidents pose a significant challenge, particularly in developing countries, adversely affecting economic development processes and social well-being (Hossain & Faruque, 2019). These accidents, resulting from collisions of motor vehicles with other vehicles, pedestrians, stationary objects, or animals on or near the roadway, can lead to various losses such as fatalities, injuries, and property damage. When high accident density is observed in specific regions over an extended period (typically 1–3 years) in relation to traffic volume, road conditions, climate, and environmental factors, these areas are defined as 'black spots' and classified as high-risk zones (Cheng & Washington, 2005; Haghighi & Karimi, 2018). Identifying such locations is of critical importance for addressing security vulnerabilities and developing effective strategies aimed at accident reduction.

Despite the transformation in urban transportation dynamics and the increasing number of motor vehicles, the lack of road and infrastructure systems capable of adapting to these developments makes the rise in traffic accidents inevitable. For decision-makers, utilizing modern and innovative technologies in reducing traffic accidents, one of the most fundamental problems of cities, is of paramount importance for developing effective transportation plans and strategic road safety policies. In this regard, the collection of reliable accident data and the employment of advanced technological analysis methods emerge as an effective approach to lowering accident rates and resolving road safety issues (Alkan et al., 2024). Consequently, the use of such systems plays a pivotal role in identifying the root causes of accidents, leading to significant progress in road safety improvement efforts (Saplıoğlu & Karaşahin, 2006). Reducing the frequency of traffic accidents primarily requires the reliable identification of critical points or regions (black spots) where accidents are concentrated. By definition, areas where similar types of accidents repeatedly occur at the same geographical location or in its immediate vicinity within a specific timeframe are referred to as 'black spots' or 'accident-prone areas' in the literature (Siyavuş, 2022). In Türkiye, black spot studies have been systematically implemented since 1993. The General Directorate of Highways (KGM), responsible for the safety and inspection of the country's highways, effectively identifies high-risk regions through these studies and directs intervention programs accordingly.

Over the last few decades, Geographic Information Systems (GIS) have become a widely accepted tool for monitoring and analyzing road traffic accidents worldwide (Hazaymeh et al., 2022; Mesquitela et al., 2022). With the capacity to store, analyze, and manage large volumes of data, GIS is utilized to visually explore the relationships between accidents and contributing factors across both spatial and non-spatial dimensions (Yalcin, 2013). GIS offers various techniques that provide high efficiency in traffic data analysis. Among these techniques are hot spot analysis for identifying high-risk locations, space-time cube analysis for visualizing spatiotemporal trends in accident data, and Kernel Density Estimation (KDE) for spatial density estimation. Additionally, various statistical and network analyses are actively employed. Furthermore, geography-based methods such as heat maps, time-series analysis, buffer analysis, and seasonal mapping offer significant opportunities for identifying high-risk locations of road traffic accidents and formulating appropriate preventive measures.

Numerous studies have been conducted to examine traffic accidents at the provincial level in Türkiye. Previous research has investigated the temporal and spatial distributions of traffic accidents in provinces such as Ankara (Uyurca & Atılgan, 2018), İzmir (Haybat & Karakaş, 2020), Afyonkarahisar (Erdogan et al., 2008), Tekirdağ (Özşahin & Yılmaz, 2023), Rize (Colak et al., 2018), Kahramanmaraş (Özcan & Küçükönder, 2020), Konya (Diler et al., 2023), Siirt, Şanlıurfa (Güngör et al., 2021), Eskişehir (Yildirim et al., 2023), and Bursa (Haybat et al., 2022). However, to the best of our knowledge, no comprehensive study has yet been conducted in Bitlis that evaluates both the temporal and spatial distribution of accidents across the entire province.

In this context, revealing the spatial dimensions of traffic accidents in detail, identifying concentrated areas, and analyzing risk factors through objective data constitute a critical necessity for both scientific research and decision-making institutions. Especially in regions like Bitlis, characterized by complex topography, harsh climatic conditions, and a road network largely composed of undivided state highways, identifying the spatial distribution of accidents via traditional methods often proves insufficient. Due to this inadequacy, Geographic Information Systems (GIS) provide a powerful analytical platform that enables the assessment of accident data with positional accuracy, the reliable identification of black spots, and the examination of spatial relationships among factors contributing to accidents. By examining traffic accidents in Bitlis through GIS-based methods, this study aims to reveal the spatial distribution of accident densities, the locations of black spots, and the fundamental factors influencing these incidents. The findings are intended to fill a significant gap in the literature by contributing directly to the development of regional traffic safety strategies, the planning of risk-mitigating infrastructure applications, and national road safety policies.

2. Methodology

This study aims to systematically examine the traffic accidents occurring within the boundaries of the Bitlis provincial center and their spatio-temporal density distributions. The initial stage of the research involved official correspondence with General Directorate of Security of the Republic of Türkiye to ensure the reliability of the centralized data. As a result of this correspondence, detailed raw data regarding fatal and injury-involved traffic accidents within the borders of the Bitlis city center, covering the last five-year period (2020–2024), were obtained.

The obtained raw data were initially organized in MS Excel, and the spatial coordinate information of the accident points (georeferencing) was meticulously processed and integrated into a database compatible with Geographic Information Systems (GIS) format. Using the prepared database, spatial and temporal patterns of traffic accidents were analyzed in a GIS environment through the Getis-Ord Gi* hot spot analysis method. Getis-Ord Gi* hot spot analysis was applied using the Fixed Distance Band approach as the spatial relationship conceptualization, and neighborhood relationships were defined based on a 1000 m Euclidean distance band. The analysis results were presented visually by superimposing critical accident locations onto satellite imagery. Additionally, the study includes a classification of accidents based on their types (fatal/injury-involved) and provides a detailed examination of temporal trends in daily, weekly, and seasonal distributions, as well as the impact of road surface conditions on accident frequency. However, rainfall data were not integrated into the scope of this study, and correlation analysis was not performed to examine the relationships among variables as seen in Figure 1.

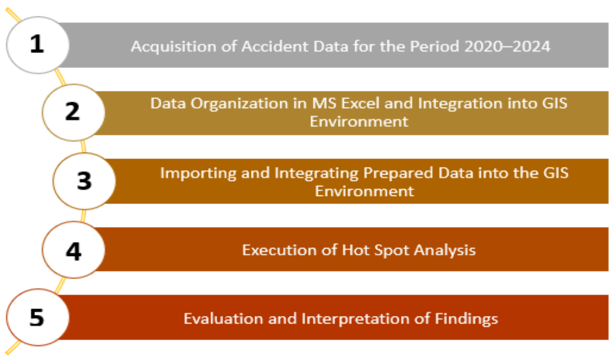

Figure 1. Methodological workflow of the study

2.1. Location and Characteristics of the Study Area

Bitlis province is located in the Upper Euphrates Section and Upper Murat-Van Section of the Eastern Anatolia Region, between the longitudes of 41°33' and 43°11' east and latitudes of 37°54' and 38°58' north (El, 2025). Situated at an average elevation of 1,637 meters above sea level, Bitlis covers a total surface area of 8,294 km². The province is bordered by Van to the east, Muş to the west, Siirt and Batman to the south, and Ağrı to the north. One of the most prominent geographical features of the region is Bitlis's location on the shores of Lake Van; this position plays a decisive role in the development of both settlement patterns and transportation networks (Figure 2). The continental climate prevailing in the city is characterized by heavy snowfall and low temperatures during the winter season, and hot and dry weather conditions in the summer months. These topographical and climatic characteristics are of a nature that can directly influence transportation safety and the spatial distribution of traffic accidents.

Figure 2. Topographical map of Bitlis (General Directorate of Mapping, HGM)

The average annual temperature in Bitlis is 9°C, and the annual precipitation is approximately 600 mm. Influenced by geographical and topographical conditions, urbanization in the city tends to expand toward the direction of Tatvan. The mountainous and rugged terrain extending toward Diyarbakır has limited residential growth in that direction; consequently, urban expansion has predominantly concentrated in the eastern part of the province. The vicinity of Selahattin Eyyubi Avenue at the eastern exit of the city center, along with the Hüsrevpaşa and Beş Minare neighborhoods, has become a significant residential focus. Furthermore, the E-99 international highway stretching along the Bitlis–Tatvan corridor remains a primary axis for intensive new construction and plays a decisive role in urban expansion. Conversely, urban development along the Bitlis–Muş (D300) route is more limited compared to the E-99 corridor, primarily because the E-99 axis, which provides international connectivity, carries a higher volume of traffic flow.

In recent years, divided road projects accelerated across the country have significantly improved Bitlis's transportation links with neighboring provinces and enhanced intra-city accessibility. Indeed, the divided road construction on the Bitlis–Tatvan E-99 highway has been completed, resulting in increased transportation capacity. Additionally, the Bitlis Ring Road, aimed at reducing urban traffic density and providing safer, faster, and more comfortable transportation, was opened to service on October 25, 2022. Constructed to a divided road standard with 2×2 lanes and bituminous hot mix pavement, this route also includes the 156-meter-long Sarik Bridge and the approximately 3-kilometer Bitlis Entrance Interchange, including its intersection branches. Images of the Bitlis Ring Road are presented in Figure 3.

Figure 3. Bitlis Ring Road

In the city of Bitlis, the road network consists of a total of 285.8 km of asphalt and 353.2 km of surface-treated roads. Additionally, within the provincial road boundaries, there are 52 km of cobblestone, stabilized, and unpaved (dirt) roads. The distribution of the road network in Bitlis according to pavement type (km) is provided in Table 1.

Table 1. Bitlis road network (General Directorate of Highways Bitlis Road Network, 2024)

Bitlis	Road Network by Surface Type (km)						
	Asphalt Roads						
	Asphalt Concrete (BSK)	Surface Treatment	Total	Interlocking Paving	Stabilized Road	Unpaved	Other Roads
State Highway	194.3	81.7	276	-	-	-	-
Provincial Road	91.5	271.5	363	16	5	31	11
Total	285.8	353.2	639	16	5	31	11

Figure 4 illustrates the road construction projects in and around City of Bitlis. The sections marked in red represent completed construction works, blue indicates ongoing projects, and green denotes sections planned for future bidding.

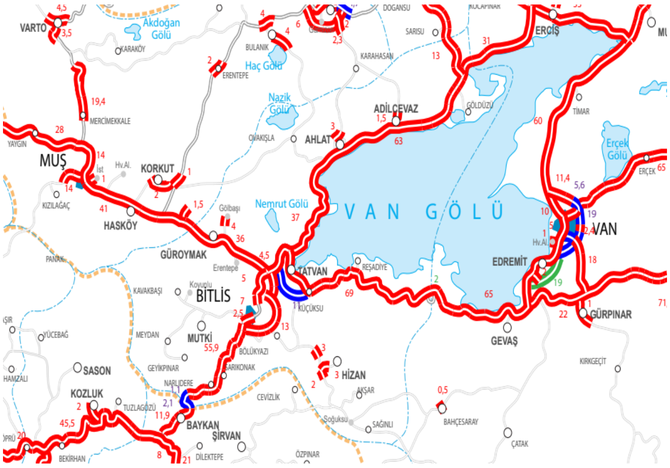

Figure 4. Divided road construction projects in the city of Bitlis (2024) (General Directorate of Highways Bitlis Road Network, 2024)

Regarding the population distribution across Bitlis, it has been determined that the male population is reported as 186,038, while the female population is 173,709. Parallel to the increasing population, the number of motorized vehicles in the city is also on the rise. While the total number of motorized land vehicles was 22,235 in 2019, this figure reached 24,780 by 2023. In the first month of 2024, the total number of motorized vehicles was 25,101, whereas this number was recorded as 26,924 by the eighth month. Concurrently with the increase in the number of motorized vehicles, the number of traffic accidents across the province has also increased. While 506 traffic accidents occurred in 2022, 618 accidents took place in 2023. According to the TÜİK July 2024 traffic statistics bulletin, 374 traffic accidents were identified in Bitlis within a seven-month period. As of the July 2024 results, these accidents resulted in 5 fatalities and 759 injuries in Bitlis (Turkish Statistical Institute (TÜİK), 2024).

Due to unplanned transportation systems and infrastructure development across City of Bitlis, numerous transportation-related issues are experienced. Roads remain insufficient relative to the growing population and vehicle count, leading to an increase in traffic accidents. The primary causes of these accidents include failing to adjust vehicle speed to road, weather, and traffic conditions; violating right-of-way rules at intersections and narrow passages; failing to follow lane-keeping and lane-changing rules; rear-end collisions; failing to stop at red lights or traffic officer signals; failing to slow down at pedestrian and school crossings; and high-speed driving, among others.

3. Results

According to data from the Turkish Statistical Institute (TÜİK), a notable increase in the number of registered motorized vehicles has been observed in Bitlis Province. As of 2024, the total number of vehicles was 27,747, which rose to 29,300 based on the available data for 2025. Since the official full-year statistics for 2025 were not yet released at the time of this study, this figure is presented as a projected value derived from the available TÜİK data. This approach allows for a more accurate representation of the observed upward trend throughout the research period. This statistical change indicates a significant growth rate of approximately 5.6% within a one-year period.

These findings clearly demonstrate that motorized vehicle ownership in Bitlis has exhibited a steady upward trend over the years, driving up urban transportation demand. This trend is strongly supported by traffic accident statistics covering the years 2020–2024 (Table 2). When the table is examined, the continuous growth in the number of motorized land vehicles (from 22,304 in 2020 to 27,747 in 2024) has brought about a substantial increase in the total number of accidents. Notably, while the total number of accidents was 1,506 in

2022, this figure reached a peak of 2,041 in 2024. Consequently, this dramatic rise in vehicle density constitutes a direct pressure factor on accident frequency

Table 2. The total number of road traffic accidents in the city of Bitlis from 2020 to 2024

Province	Year	Total Accidents	Total Motor Vehicles	Fatal/Injury Accidents	Number of Fatalities			Number of Injuries
					Total	At the accident scene	After the accident	
Bitlis	2024	2041	27747	732	19	9	10	1396
	2023	1615	24780	618	22	10	12	1193
	2022	1506	23141	506	21	8	13	939
	2021	1716	22720	658	22	16	6	1241
	2020	1385	22304	488	20	13	7	1003

The upward trend in the number of fatal and injury-involved accidents further supports this finding; this category rose from 506 in 2022 to 732 in 2024. Additionally, the number of injuries increased from 939 in 2022 to 1,396 in 2024, proving that traffic safety risks have increased in absolute terms. In contrast, despite the sharp rise in the total number of accidents, it is noteworthy that the total number of fatalities decreased to 19 in 2024 after remaining at levels of 21–22 between 2020 and 2023. While this suggests a declining trend in the fatality rate of accidents even as frequency increases, the simultaneous rise in the number of injuries may point toward the potential improvement of emergency response effectiveness rather than a reduction in accident severity.

Data from the 2020–2024 period indicate that the growth in the number of vehicles in the city of Bitlis has reached a critical threshold for traffic safety, necessitating the development of urgent and strategic intervention plans based on spatial analyses to prevent accident density. Figure 5 presents the percentage rates of total accidents occurring in the province between 2020 and 2024 according to road surface conditions.

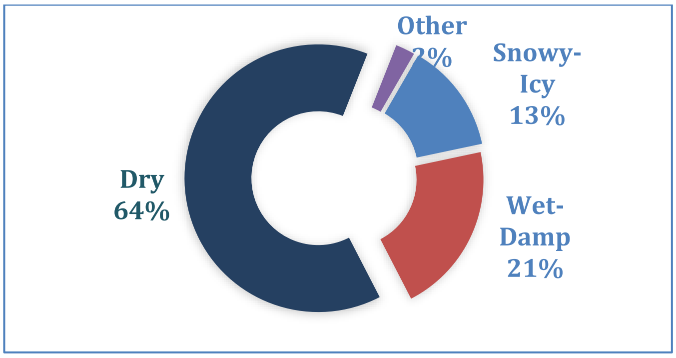

Figure 5. Number of accidents by road surface condition

Upon examining the data in the figure, it is observed that the majority of traffic accidents in the city of Bitlis occurred on dry road surfaces. According to the percentage distribution, 64% of the accidents took place on dry road surfaces. This situation indicates that most accidents may stem from driver-related factors (such as speed, distraction, insufficient following distance, etc.) or problems related to traffic infrastructure, rather than adverse weather or surface conditions. Furthermore, the rate of accidents occurring on wet or damp road surfaces is 21%, suggesting that roads becoming slippery after precipitation significantly increases the number of accidents. This rate points toward the necessity of increasing road maintenance activities during rainy periods and strengthening warnings for drivers regarding speed and following distance. The fact that 13% of accidents occurred on snowy or icy road surfaces clearly demonstrates the impact of Bitlis's harsh continental climate. Considering the climatic characteristics of the region, it is evident that practices such as salting, snow plowing, and mandatory chain use are critical for driving safety during winter months. Finally, 'other' surface conditions are represented by a low rate of 2%, suggesting they do not have a significant impact on the general distribution.

In regions dominated by harsh winter conditions like Bitlis, data indicates that traffic accidents predominantly occur on slippery, wet, and snowy road surfaces (Figure 6). Front and rear impact marks observed on vehicles point to collisions resulting from the loss of driver control, suggesting that accidents may develop as either single-vehicle skidding incidents or multi-vehicle collisions. Key factors paving the way for such accidents include increased braking distances, reduced visibility, and diminished road grip caused by winter conditions. Overall, it can be stated that road surface conditions have a decisive impact on traffic safety, with accident risks rising significantly during periods of precipitation and icing. The types of accidents occurring throughout the province and their total numbers between 2020 and 2024 are presented in Figure 7.

Figure 6. Traffic accidents occurring during rainy weather in the city of Bitlis (Bitlis Postası, n.d.)

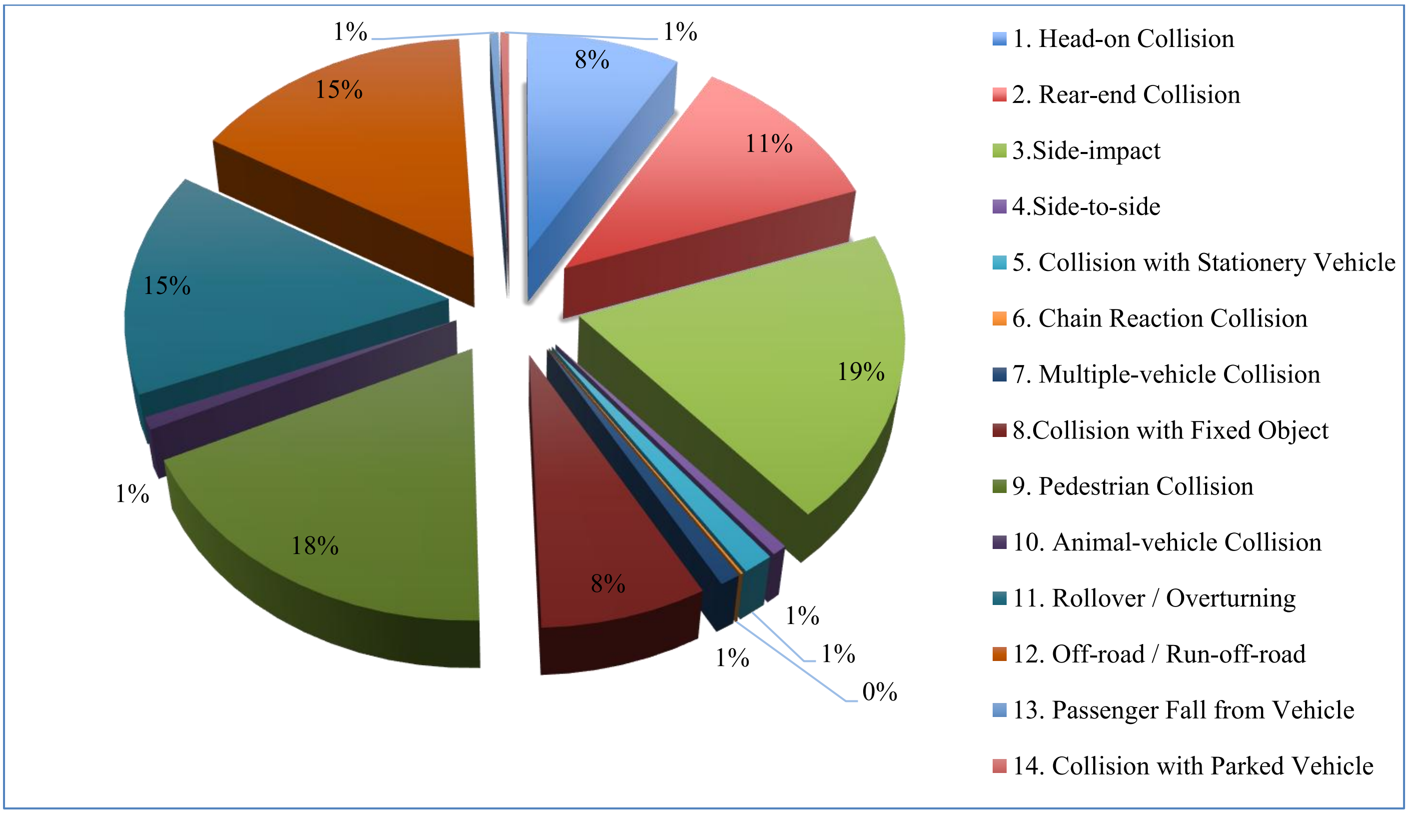

Figure 7. Types of accidents and their total numbers

The analyzed chart data clearly demonstrate significant variations in the distribution of traffic accidents occurring within the provincial borders of Bitlis based on their type, reflecting the region's specific traffic characteristics. The accident type with the highest share is side-impact collisions (164 incidents), a finding that suggests urban and intercity road intersections, junctions, and uncontrolled crossings play a major role in accident formation. Side-impact collisions are followed closely by pedestrian collisions (157 incidents). This high rate reveals that pedestrian safety in city centers or on routes near settlements is a critical issue, necessitating urgent improvements in pedestrian crossings, signaling, and driver awareness. The ranking of off-road incidents (132 incidents) in third place and rollover/overturning/skidding (127 incidents) in fourth highlights that loss of driver control, high speed, and road geometry defects are primary risks to be addressed in Bitlis traffic. These are followed by rear-end collisions (95 incidents) and head-on collisions (72 incidents), pointing to issues with following distance and lane discipline. Other accident types occur with lower frequency: collision with a fixed object (65 incidents), side-to-side collision (6 incidents), collision with a stationary vehicle (12 incidents), chain reaction collision (1 incident), multiple-vehicle collision (8 incidents), passenger fall from vehicle (4 incidents), collision with a parked vehicle (4 incidents), and animal-vehicle collision (7 incidents). Contrary to previous estimations, the low share of animal-vehicle collisions (7 incidents) in the total frequency indicates that the accident profile is predominantly focused on urban factors and driver behaviour.

Traffic accidents in the city of Bitlis are largely collision-based, with side-impact and pedestrian collisions being most prominent. This distribution underscores the need to prioritize pedestrian safety, implement speed control measures, and improve intersection and route designs in regional traffic. The time intervals and numbers of accidents occurring between 2020 and 2024 are presented in Figure 8.

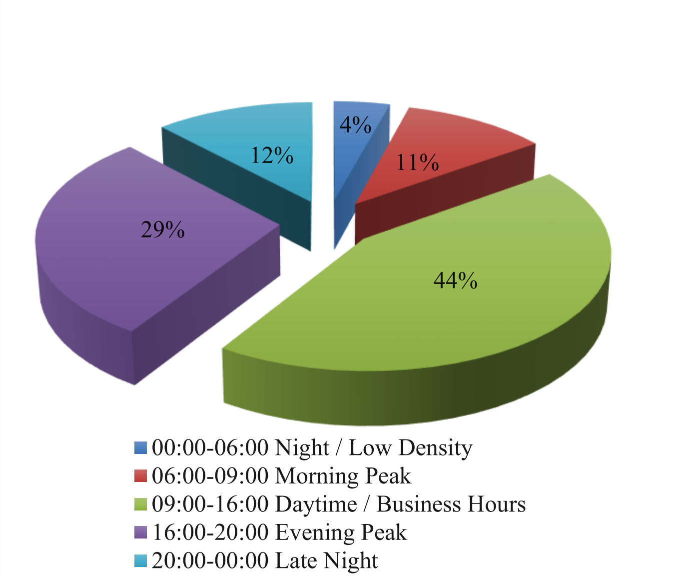

Figure 8. Time intervals of occurred accidents

It is clearly observed that the vast majority of traffic accidents in the city of Bitlis are concentrated during working hours, and the distribution is asymmetrical. A total of 73% of accidents occur during the “Daytime/Business Hours” (09:00–16:00) and the subsequent 'Evening Peak' (16:00–20:00) intervals, when urban mobility and economic activities reach their peak. In this distribution, the “Daytime/Business Hours” segment stands out as the highest risk interval with a 44% share. This situation points to the hours when commercial and logistical mobility are at their highest, the number of vehicles reaches its maximum, and the potential for driver distraction increases due to prolonged driving or workload. The high rate observed in the following 'Evening Peak' (29%) reflects risk factors caused by return-from-work traffic, increased urgency, and end-of-day fatigue.

Upon examining other time intervals, it is noteworthy that the “Late Night” (20:00–00:00) segment carries a marginally higher risk with a 12% share compared to the “Morning Peak” (06:00–09:00, 11%). This indicates that despite the decrease in density, night driving conditions (limited visibility, increased violations of speed limits) enhance the risk factor during these hours. Finally, the “Night/Low Density” (00:00–06:00) interval, when traffic is at its minimum, constitutes only 4% of the accidents. Accordingly, traffic safety strategies in the city of Bitlis should optimize preventive measures by focusing on the density and speed/distraction violations between 09:00 and 20:00 to reduce the absolute number of accidents. The distribution of accidents by day and their total numbers between 2020 and 2024 are presented in Figure 9.

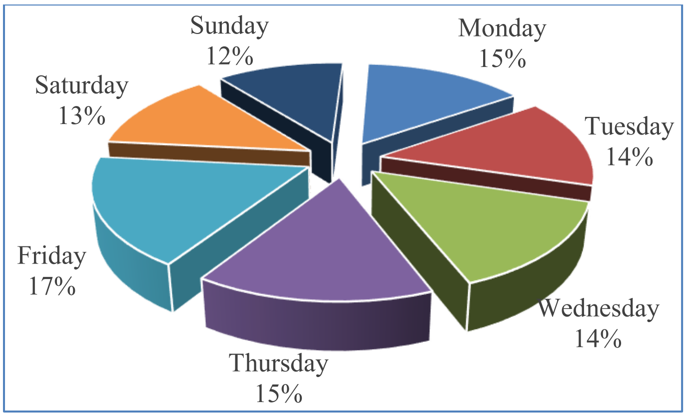

Figure 9. Distribution of accidents by day of the week between 2020 and 2024

In the weekly distribution of accidents, the highest risk was observed on Friday (17%), coinciding with the last working day of the week. This rate indicates that Friday is the most critical day due to a combination of pre-weekend fatigue, increased urban mobility, and a sense of urgency. This high-risk day is followed by Monday (15%), the start of the week, and Thursday (15%), as the end of the workweek approaches. These three days (Monday, Thursday, and Friday) account for nearly half of the total accidents, revealing that traffic safety interventions should primarily focus on these periods. Tuesday (14%) and Wednesday (14%), situated in the middle of the week, exhibit a relatively stable distribution close to the weekly average accident frequency. The days with the lowest recorded accidents are over the weekend; Sunday (12%) has the lowest accident frequency, while Saturday (13%) is slightly above this rate. While the lower weekend rates stem from the reduction in commercial and business traffic, it should be noted that weekend accidents often carry different risk profiles, such as leisure travel and long-distance journeys. Traffic safety strategies in the city of Bitlis should aim to reduce weekly accident frequency by intensifying traffic enforcement, driver awareness training, and risk-mitigation measures, particularly for Friday, Monday, and Thursday.

Traffic accidents that occurred in the city of Bitlis between 2020 and 2024 were mapped using Geographic Information Systems (GIS) through density analysis, and the spatial distribution of accidents was visualized. The analysis revealed that traffic accidents across the province do not exhibit a random spatial pattern; instead, accident locations are aligned along the main highway corridors forming the primary transportation backbone, resulting in chronic accident hotspots in specific areas (Figure 10).

Traffic accidents that occurred in the city of Bitlis between 2020 and 2024 were examined using modern Geographic Information Systems (GIS)-based analysis methods, and the spatial distribution of accidents was mapped by weighting the data according to the number of fatalities and injuries. The results of the Getis-Ord Gi* hotspot analysis indicated that traffic accidents do not exhibit a random spatial distribution across the study area; instead, statistically significant clusters were identified at specific intersections, streets, and road segments. In particular, hotspots at the 99% confidence level were observed in areas with intense pedestrian–vehicle interaction, such as the urban transit corridors of Bitlis city center, the intersections of the D300 and D965 highways, and the junction near the Bitlis–Tatvan State Hospital where the Muş–Tatvan road diverges (Figure 11).

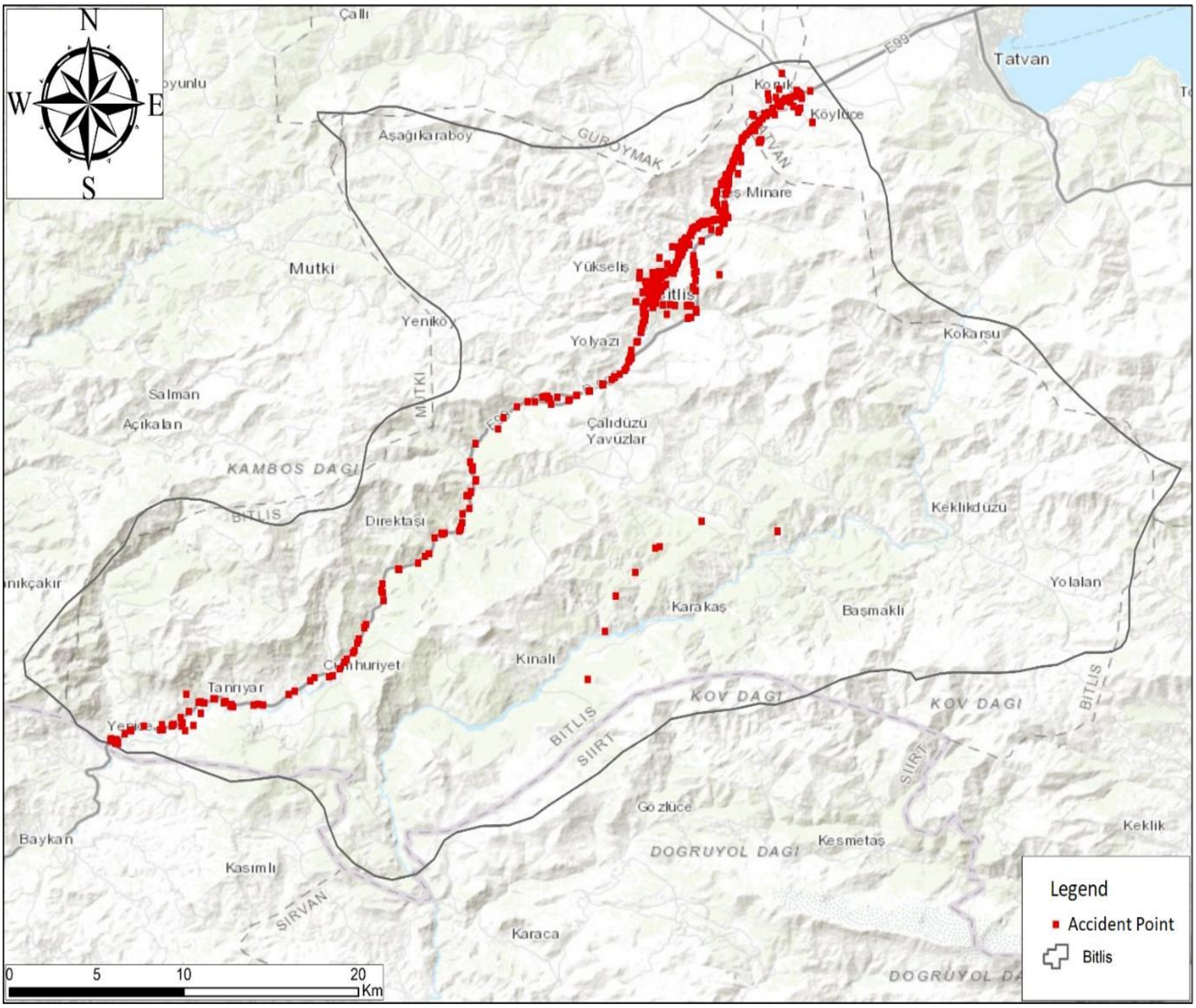

Figure 10. Density map of traffic accidents that occurred in the city of Bitlis between 2020 and 2024

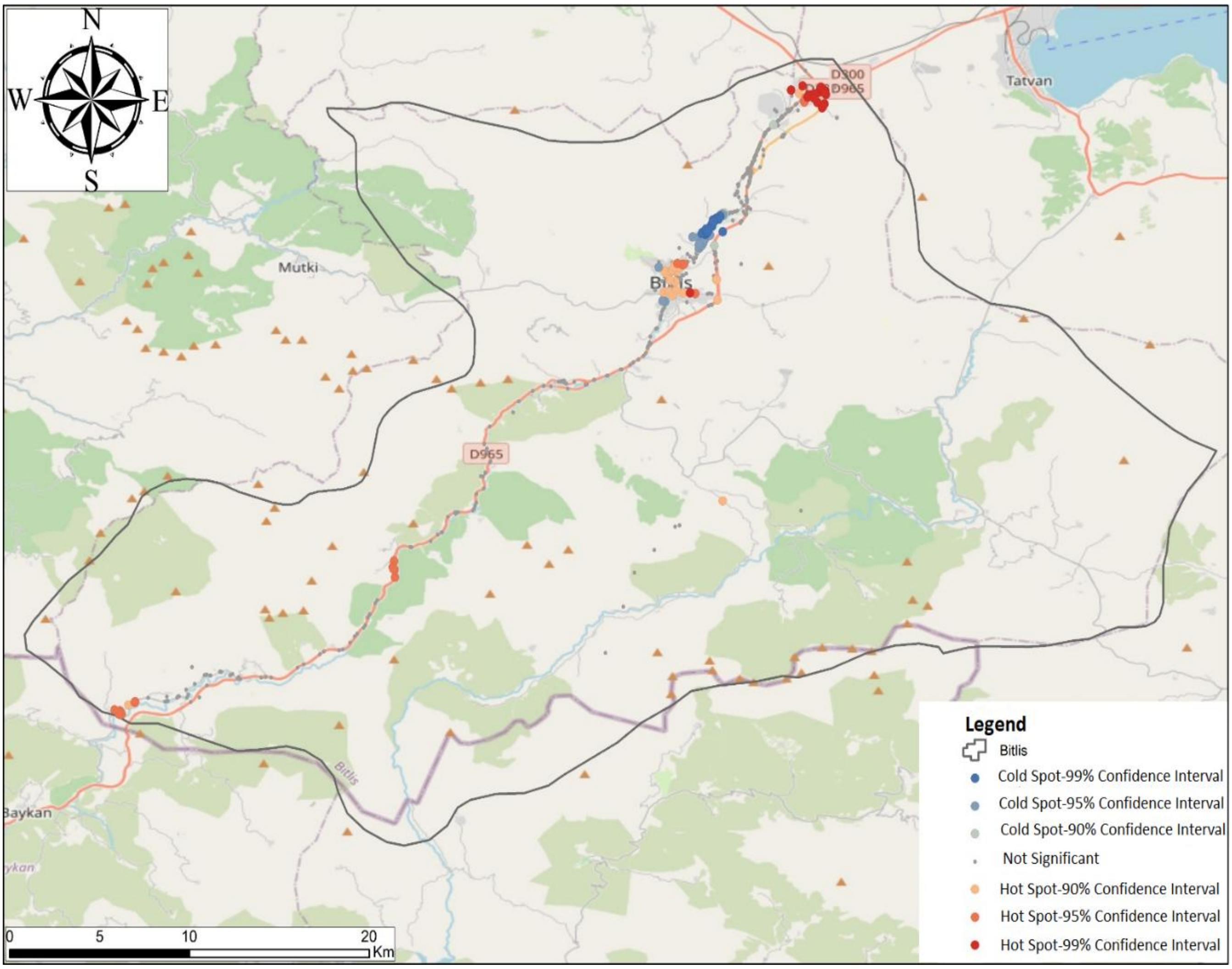

Figure 11. Hot spot analysis of traffic accidents occurring between 2020 and 2024

This map, generated through spatial analysis using Geographic Information Systems (GIS), provides a detailed representation of the spatial distribution of traffic accidents and the areas where fatalities and injuries are concentrated. The core component of the map is the hot spot analysis, which demonstrates that fatal and injury-related accidents are statistically significantly clustered in specific locations. Hotspots represented by red and dark red colors indicate areas with high accident density at the 95% and 99% confidence levels, clearly revealing that these concentrations are not random and highlighting these zones as critical traffic accident risk areas. Orange and light red tones represent hotspots at the 90% confidence level, indicating areas with relatively lower accident intensity but still posing potential risk. In contrast, cold spots shown in blue and its shades represent relatively safer areas where the number of accidents and associated fatalities and injuries are statistically significantly lower compared to surrounding regions. Gray or neutral-colored areas denote regions without statistically significant clustering, where accidents are spatially distributed in a random pattern. The concentration of hotspot areas along major highways, within and around the city center, and across transition zones between urban settlements and rural areas suggests that factors such as traffic volume, road geometry, speed variations, and pedestrian–vehicle interactions play a decisive role in accident severity (Figure 12).

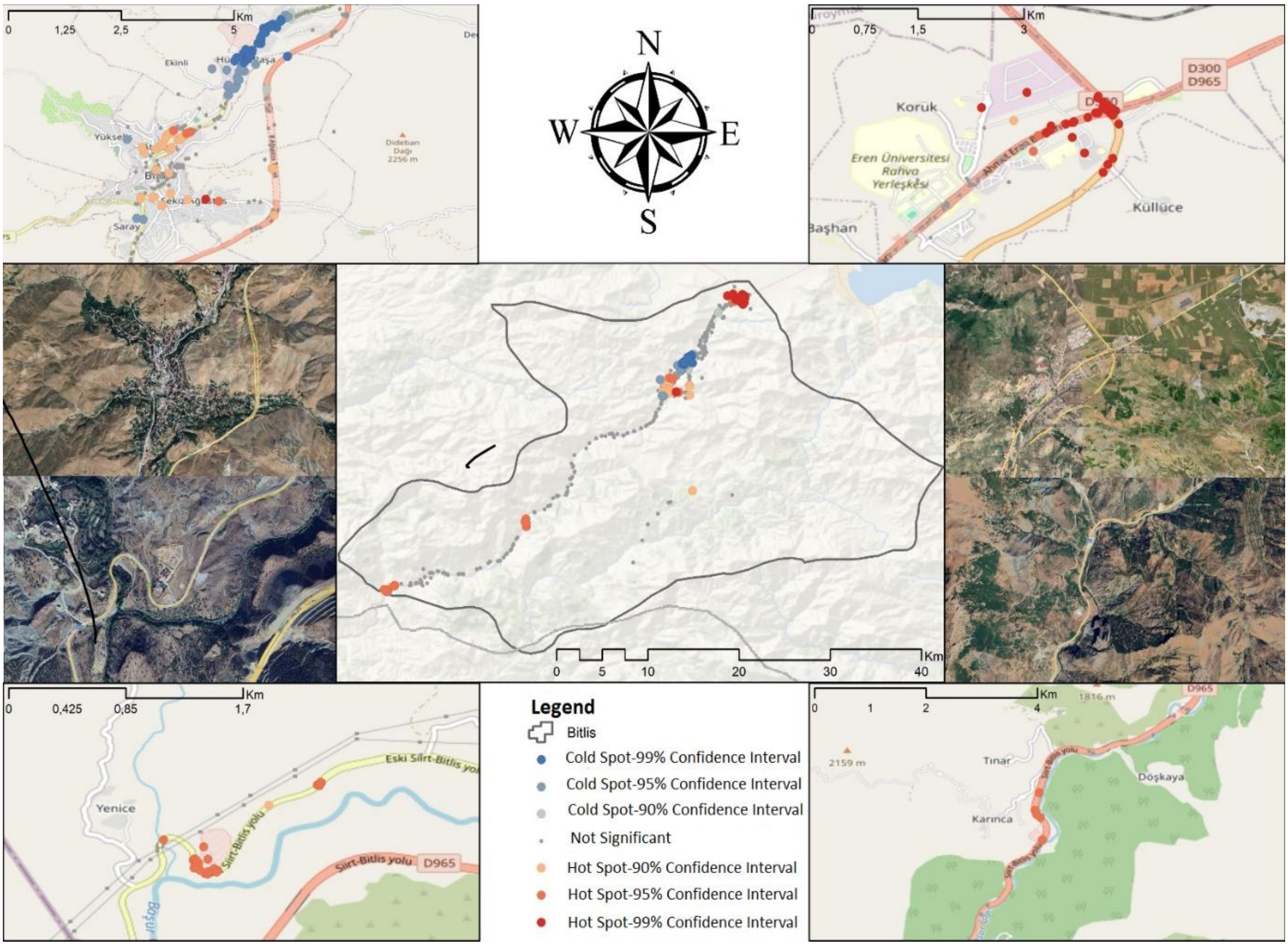

Figure 12. High-density traffic accident areas in the city of Bitlis between 2020 and 2024

These findings derived from the five-year dataset scientifically identify locations where accident risk has become chronic, demonstrating that engineering improvements and enforcement activities aimed at enhancing traffic safety should be prioritized and directed toward these critical points. Moreover, the hotspots concentrated along the curved sections of the Siirt–Bitlis road clearly reflect the direct impact of the region's topographic challenges and discontinuities in road geometry on accident severity (Figure 13).

Among the areas where traffic accidents are most concentrated in the city of Bitlis, the Bitlis–Siirt road (Dere Road) and the Üçyol area (including the Hospital Junction and the Muş–Tatvan road intersection) stand out as critical locations requiring targeted interventions due to their traffic and environmental characteristics. The high accident concentration along the Bitlis–Siirt road (Dere Road) is primarily associated with narrow roadway sections, sharp curves, variations in longitudinal grade, and limited sight distance. Therefore, priority measures along this corridor should include improvements to road geometry, widening of shoulders at curves, reinforcement of protective barriers, and enhancement of roadway lighting particularly to improve nighttime driving safety. In addition, reducing speed limits, installing speed warning signs, implementing dynamic speed enforcement systems, and deploying advance driver warning systems in high-risk segments are expected to reduce both accident frequency and severity. The Hospital Junction and the Muş–Tatvan road intersection located in the Üçyol area pose a high accident risk due to the convergence of heavy traffic flows from multiple directions, sudden lane changes, and frequent ambulance entry and exit movements. Accordingly, redesigning the intersection geometry, upgrading signalization systems, clearly separating intersection approaches, and installing advance and more perceptible directional signage are necessary. Furthermore, the implementation of traffic calming measures in the hospital vicinity, the improvement of pedestrian crossing safety, and the establishment of dedicated and priority access arrangements for ambulances would contribute to smoother traffic operations and a reduction in fatalities and injuries. Site-specific and spatially informed interventions developed for these two hotspot locations would provide an effective and sustainable approach to reducing traffic accidents in the city of Bitlis.

Figure 13. Bitlis–Siirt Highway

When the visual representation of Bitlis city center is evaluated together with GIS-based accident data, the direct relationship between physical constraints within the urban transportation network and traffic safety becomes clearly evident (Figure 14). The narrow street pattern imposed by the historical urban fabric and the sharp geometric discontinuities along the Dere Road corridor restrict vehicle maneuverability, thereby increasing accident risk. The intense pedestrian activity and irregular roadside parking behavior highlighted in the visual confirm, in physical terms, why the city center functions as a traffic accident hotspot, as these factors disrupt lane discipline and create complex vehicle–pedestrian interactions. Based on data from 2020 to 2024, accident density is observed to increase particularly at these bottleneck sections along the main arterial, where variations in speed limits and uncontrolled access points further exacerbate accident severity. In this context, integrating smart intersection designs and speed enforcement systems while preserving the urban fabric and prioritizing pedestrian safety into these mapped critical locations constitutes a strategic necessity for reducing urban traffic-related fatalities.

GIS-based analyses conducted on a five-year dataset (2020–2024), limited to law enforcement jurisdiction boundaries across City of Bitlis, clearly demonstrate that traffic accidents do not follow a random spatial distribution; rather, they cluster with high frequency at specific hotspots. The results obtained using the Getis-Ord Gi* method confirm that areas such as the Üçyol area (Hospital Junction), the Bitlis Eren University Road corridor, the Bitlis city center transit route, Hüsrev Paşa Neighborhood, and the Bitlis–Siirt road (Dere Road) represent statistically significant accident hotspots at the 99% confidence level.

Figure 14. Bitlis city center road corridor

Notably, Bitlis's harsh winter climate amplifies these spatial risks through a compounding effect. When accident density is correlated with meteorological data, factors such as snowfall, black ice, and fog are found to intensify accident severity (in terms of fatalities and injuries) by interacting with existing road geometry deficiencies and intersection complexity. For instance, in densely populated corridors such as Hüsrev Paşa Neighborhood, reduced pavement friction during winter months increases stopping distances, leading to a chronic prevalence of rear-end collisions. Similarly, the sharp curves and steep grade variations along the Dere Road corridor, when combined with reduced visibility in winter conditions, generate the highest risk profile for run-off-road accidents.

4. Discussion

According to TÜİK data, the number of motor vehicles, which was 22,304 in 2020, reached 27,747 by 2024 with a growth rate of 5.6%. This upward momentum, which drove the total number of accidents from 1,506 in 2022 to 2,041 in 2024, clearly demonstrates that the continuous increase in vehicle density in Bitlis constitutes a direct and powerful pressure factor on accident frequency. This situation directly aligns with the findings of studies conducted in other provinces of Türkiye (Haybat & Karakaş, 2020), which indicate that the increase in urban transportation demand exacerbates risks. Upon examining the data, despite the rapid increase in the number of injury accidents from 506 to 732 and the total number of injuries from 939 to 1,396, the relative downward trend observed in the total number of fatalities, which hovered between 21 and 22 during 2020–2023 and decreased to 19 in 2024 indicates improvements in the effectiveness of post-accident emergency response processes and medical facilities, rather than a decrease in accident severity. When evaluating the environmental context of the incidents, the fact that a vast majority of 64% of accidents occurred on dry road surfaces indicates that the root causes of these accidents lie in urban traffic infrastructure issues or direct human and driver factors such as excessive speed, violation of following distance rules, and inattention rather than adverse weather conditions. This trend regarding accident occurrence mechanisms is also supported by a similar study conducted in Afyonkarahisar (Erdogan et al., 2008). On the other hand, the accident rates of 21% on wet surfaces and 13% on snowy and icy roads consistent with research conducted in regions like Rize (Colak et al., 2018), which indicates that slippery surfaces in mountainous geographies increase accidents reveal the distinct and direct impact of the region's harsh continental climate and challenging winter conditions on driving safety. Particularly, the harsh winter climate of the region significantly exacerbates accident severity when combined with existing road geometry deficiencies in sections such as Hüsrev Paşa and Dere Road. Adverse conditions, including increased braking distances on slippery surfaces and reduced visibility from fog or snowfall, further compound these risks by triggering critical incidents like rear-end collisions and run-off-road accidents.

The concentration of 73% of total accidents during daytime business hours (44%, 09:00–16:00) and the subsequent evening peak hours (29%, 16:00–20:00), along with the prominence of Friday (17%), Monday (15%), and Thursday (15%) on a weekly basis, is consistent with the temporal data identified in urban accident analyses in Eskisehir (Yıldırım et al., 2023) and Bursa (Haybat et al., 2022) that emphasize how commercial mobility increases accident rates. Particularly, the significant increase during evening hours clearly reflects psychological and operational risk factors such as the density created by return-from-work traffic, end-of-day physical fatigue, and the sense of urgency among drivers.

The high risk in the Hospital Junction and Üçyol region, which was statistically identified at a 99% confidence interval through Getis-Ord Gi* hot spot analyses, is rooted in the intersection of heavy multi-directional traffic flows, sudden lane changes made by drivers due to deficiencies in directional signage, and intensive ambulance movements associated with the hospital route. The fact that these regional infrastructure bottlenecks, created by traffic volume and intersection branches, directly cause accidents is in perfect alignment with the results of black spot analyses identified through intersection geometry errors in Siirt (Alkan et al., 2024) and Şanlıurfa (Güngör et al., 2021). Furthermore, the physical constraints imposed by the unique historical fabric of the Bitlis city center, such as narrow streets, irregular and uncontrolled roadside parking, sharp curves along the Bitlis–Siirt highway (Dere Road) corridor, narrow shoulders, and high pedestrian density disrupt drivers' lane discipline and manoeuvrability, complicating vehicle–pedestrian interactions and significantly increasing the risk of accidents.

In light of all these spatial and statistical findings, in order to minimize the risks of fatality and injury, the following emerge as urgent and strategic necessities: the immediate integration of smart intersection and modernized signaling designs at multi-branch and high-density points such as the Hospital Junction; the improvement of road geometry at curves along the Bitlis–Siirt road (Dere Road) by widening shoulders and increasing lighting for nighttime driving safety; the intensification of winter maintenance activities, such as snow plowing and salting, through technological systems; and the installation of dynamic speed control and early warning systems, particularly at high-risk passages. When examining the types of accidents, the fact that side-impact collisions at intersections (164 incidents) and pedestrian collisions in areas near the city center (157 incidents) rank as the top two across all accident types with the highest frequencies undeniably proves that pedestrian safety, pedestrian crossings, and traffic calming projects must be urgently prioritized in urban traffic management and future infrastructure planning.

5. Conclusion

This study presents the first comprehensive spatial and temporal assessment of traffic accidents in the city of Bitlis using Geographic Information Systems (GIS)–based analytical techniques. The analysis of a five-year dataset covering the period from 2020 to 2024 clearly demonstrates that traffic accidents are not randomly distributed across the study area; instead, they exhibit significant spatial clustering along critical transportation corridors and urban transition zones.

The results indicate that the Üçyol area (Hospital Junction) and the Bitlis–Siirt (Dere Road) corridor constitute statistically significant accident hotspots at the 99% confidence level. These locations are characterized by a combination of unfavorable factors, including complex road geometry, steep longitudinal gradients, and intense vehicle–pedestrian interactions, all of which substantially increase accident risk. Temporal analyses further reveal that Fridays and the time interval between 09:00 and 16:00 represent peak periods for accident occurrence, likely associated with increased economic activity and heightened urban mobility during standard working hours.

One of the most notable findings of this study concerns the compounded impact of Bitlis's harsh continental climate on existing infrastructural vulnerabilities. Although the majority of accidents are attributed to driver-related factors and occur under dry pavement conditions, accident severity increases considerably during the winter months due to reduced pavement friction, limited visibility along mountainous road sections, and adverse weather conditions. The predominance of side-impact collisions and pedestrian-related accidents underscores the urgent need for a comprehensive revision in urban traffic management practices.

Based on the identified risk patterns, several strategic interventions are recommended to enhance traffic safety in the study area. From an engineering perspective, redesigning the geometric standards of the Bitlis–Siirt roadway, widening shoulders, and upgrading signalization at the Üçyol hospital junction stand out as critical measures. In addition, given the physical and historical constraints that limit roadway expansion in the city center, the integration of intelligent transportation systems, including dynamic speed enforcement and smart intersection designs, is proposed as an effective alternative. To mitigate seasonal risks, intensified winter road maintenance and de-icing operations, along with the implementation of advanced driver warning systems for icy conditions, are strongly recommended.

In conclusion, this study provides a robust and comprehensive data framework to support evidence-based decision-making and infrastructure investment prioritization for traffic safety in City of Bitlis. By addressing a geographically underrepresented area in the literature, the research contributes to filling an important spatial knowledge gap. Future studies may further enhance prediction accuracy by integrating high-resolution meteorological data, traffic volume information, and Multi-Criteria Decision-Making (MCDM) approaches to identify potential accident blackspots with greater precision. In this context, incorporating specific criteria suitable for the challenging topography of the study area, such as road slope and curve radius, into the MCDM framework is recommended to make the decision-making process more concrete and effective.

Ethics Committee Approval

This study was conducted using publicly available statistical data from the Turkish Statistical Institute (TÜİK) and anonymous traffic accident data obtained from official authorities (Republic of Türkiye Ministry of Interior, General Directorate of Security, Traffic Presidency). Since no primary data collection involving human participants, such as surveys or interviews, was conducted, ethics committee approval was not required.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper during the research, writing, and publication processes.

Author Contributions

A.A.E.: Conceptualization, Methodology, GIS Analysis, Writing – Original Draft, S.U.: Data Curation, Literature Review, Interpretation of Results, M.K.N.: Validation of Statistical Analyses, Technical Support, Visualization

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