International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 10 October. 2026, pp:62-73 www.ijaem.net ISSN: 2395-5252

Recent Advances in Gis-Based Traffic Accident Analysis and Predictive Modeling: A Comprehensive Review

Sandeep Gupta[1], Bhanu Pratap[2], Divyansh Bhardwaj[3]
[1]Associate Professor, [2]Teaching Personnel and [3]B. Tech. Student
Department of Civil Engineering, College of Technology, G B Pant University of Agriculture and technology, Pantnagar, Udham Singh Nagar, Uttarakhand
Corresponding Author: Sandeep Gupta

Date of Submission:20-09-2026 Date of Acceptance: 02-10-2026

ABSTRACT: This review presents a comprehensive summary of recent advances in GIS-based traffic accident analysis and predictive modelling by synthesizing findings from earlier research studies published over the past three decades. The review discusses the evolution of GIS applications from basic accident mapping and database development to advanced hotspot detection, spatial autocorrelation analysis, network-based analysis and predictive modelling. Various GIS techniques including Kernel Density Estimation (KDE), Network KDE, Moran's I, Getis–Ord Gi*, buffer analysis, nearest neighbor analysis and spatial clustering methods are critically examined. Furthermore, recent developments in GIS-integrated machine learning models for accident prediction, emergency response optimization and intelligent transportation systems are highlighted.

The review also identifies major research trends, methodological advancements, existing limitations and future opportunities in GIS-based traffic safety research. The findings indicate that integrating GIS with artificial intelligence, real-time traffic monitoring, connected vehicle technologies and big data analytics has significantly improved the accuracy of accident prediction and decision-making. However, challenges related to data quality, heterogeneous datasets, computational complexity and limited real-time implementation remain. This review provides valuable insights for researchers, transportation engineers, urban planners, and policymakers seeking to improve road safety through advanced geospatial technologies.

KEYWORDS: *Geographic Information System (GIS), Traffic Accidents, Road Safety, Accident Hotspots, Spatial Analysis, Kernel Density Estimation, Machine Learning, Predictive Modelling, Intelligent Transportation Systems.*

I.Introduction

Road traffic accidents represent one of the most critical public safety concerns worldwide, resulting in millions of fatalities, severe injuries and substantial economic losses every year. Rapid urbanization, increasing vehicle ownership, population growth and expanding transportation networks have significantly increased traffic volumes, making road safety an important research priority. Traditional accident analysis methods mainly relied on statistical summaries and tabular databases, which often failed to reveal the spatial relationships among accident occurrences. Consequently, transportation planners increasingly adopted Geographic Information Systems (GIS) as an effective platform for analysing the spatial distribution of accidents and identifying high-risk road locations.

GIS has revolutionized transportation safety analysis by integrating spatial and non-spatial information into a unified environment. The technology enables researchers to visualize accident locations, identify accident-prone corridors, analyse temporal and spatial trends, evaluate infrastructure characteristics and support decision-making for traffic safety improvements. GIS further allows the integration of accident records with road geometry, traffic volume, weather conditions, land use, demographic characteristics and emergency response facilities, thereby providing a comprehensive understanding of accident causation.

Initially, GIS applications in road safety focused primarily on accident database development, digital mapping and hotspot identification. However, continuous advancements in spatial statistics, remote sensing, GPS technologies, machine learning, artificial intelligence and intelligent transportation systems have considerably expanded the scope of GIS-based accident analysis. Modern

International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 10 October. 2026, pp:62-73 www.ijaem.net ISSN: 2395-5252

GIS platforms now support predictive modelling, real-time traffic monitoring, emergency response optimization, autonomous vehicle research and smart city applications. Techniques such as Kernel Density Estimation (KDE), Network KDE, Moran's I, Getis–Ord Gi*, spatial clustering and artificial neural networks have become powerful tools for identifying accident hotspots and predicting future crash occurrences.

The growing availability of high-resolution spatial datasets, connected vehicle information, drone imagery and cloud computing has further enhanced the capabilities of GIS-based traffic safety research. Transportation agencies are increasingly utilizing these technologies to prioritize infrastructure improvements, optimize emergency services, reduce accident severity and develop evidence-based road safety policies.

This review summarizes recent advances in GIS-based traffic accident analysis and predictive modelling based on research papers. The objective is to examine the evolution of GIS techniques, summarize recent methodological developments, compare different spatial analysis approaches, identify current research gaps and provide future directions for developing intelligent, data-driven road safety management systems.

Literature Review

[1]. This paper conducted one of the earliest spatial analyses of motor vehicle crashes using GIS in Honolulu, Hawaii. The study investigated the geographical distribution of accident occurrences and demonstrated that accident frequencies exhibit significant spatial clustering rather than random distribution. GIS mapping allowed researchers to visualize accident concentrations and identify recurring hazardous intersections. This pioneering work established GIS as a valuable analytical tool for transportation safety research and inspired subsequent developments in spatial accident analysis.

[2]. The application of GIS for highway safety by integrating spatial databases with transportation planning was expanded in this research paper. Their research illustrated how GIS facilitates accident mapping, spatial querying, infrastructure assessment, and safety evaluation. The authors emphasized that GIS supports both short-term accident analysis and long-term transportation planning by enabling authorities to integrate accident records with road characteristics, traffic flow and environmental conditions. Their work demonstrated the potential of GIS as a comprehensive highway safety management platform.

[3]. The author developed one of the earliest Traffic Accident Information Systems (TAIS) using Geographic Information Systems to improve accident recording, storage and retrieval. The proposed system demonstrated how GIS could organize accident databases more efficiently while supporting spatial querying, accident mapping and transportation planning. The study highlighted that GIS-based accident information systems provide a centralized platform for integrating accident records with transportation infrastructure, thereby improving road safety management and assisting policymakers in identifying priority locations for safety interventions.

[4]. The application of Geographic Information Systems for reducing road traffic accidents in developing countries was investigated in this work. The study emphasized that conventional accident reporting methods often fail to capture the spatial characteristics of crashes, limiting effective decision-making. By incorporating GIS into accident analysis, transportation agencies could visualize accident distributions, identify hazardous road segments and develop evidence-based safety strategies. The research concluded that GIS significantly enhances accident investigation, data management and policy formulation by providing a comprehensive spatial framework for traffic safety planning.

[5]. The author proposed a GIS-based traffic accident data collection, referencing and analysis framework for Abu Dhabi Municipality. The framework integrated GPS observations with digital road maps to accurately georeference accident locations, overcoming common problems associated with inaccurate accident reporting. The study demonstrated that accurate spatial referencing improves accident database quality and facilitates efficient accident analysis, hotspot identification, and transportation planning. Their work laid the foundation for integrating GIS with transportation information management systems.

[6]. GIS-supported spatial analysis for accident black spot identification by integrating roadway geometry, traffic characteristics and environmental factors were evaluated by the researchers. The study showed that combining spatial visualization

with statistical analysis improves the understanding of accident patterns and enhances the effectiveness of transportation safety management.

[7]. The work is focused on validating crash locations for quantitative spatial analysis by developing a GIS-based methodology for improving accident location accuracy. The research demonstrated that precise geocoding of accident locations significantly enhances the reliability of hotspot analysis and spatial statistical modelling. The study emphasized that accurate spatial databases are essential prerequisites for developing effective GIS-based transportation safety systems and for reducing errors associated with accident location uncertainty.

[8]. In this work different spatial methodologies were compared for identifying road accident hotspots using London as a case study. The study evaluated several hotspot detection techniques and demonstrated that GIS-based spatial analyses provide more reliable identification of hazardous locations than conventional frequency-based approaches. The research highlighted the influence of methodological selection on hotspot identification accuracy and recommended the integration of multiple spatial statistical techniques for improved road safety assessments.

[9] Anderson (2009) compared three GIS-based spatial methods—Kernel Density Estimation, network analysis, and area-wide analysis—for measuring road accident hotspots in London. Using a comprehensive road accident dataset, the study evaluated the advantages and limitations of each approach for identifying hazardous locations. The findings showed that Kernel Density Estimation effectively represents accident concentration, while network analysis better reflects roadway characteristics. The research highlighted the importance of selecting suitable GIS techniques based on study objectives and spatial characteristics.

[10]. Researchers integrated GIS with Artificial Intelligence to predict accident-prone locations using historical crash records, traffic flow and road characteristics. The results showed that AI-assisted GIS models significantly improve prediction accuracy and enable proactive traffic safety management.

[11]. The author developed a GIS-supported traffic accident analysis system for Afyonkarahisar City, Turkey, focusing on highway safety improvement through spatial visualization and hotspot detection. The researchers employed GIS techniques to identify high-risk road sections and analyse the spatial distribution of accidents across the highway network. Their findings indicated that GIS-based hotspot mapping enables transportation authorities to recognize safety-deficient locations more accurately than traditional statistical methods. The study demonstrated the practical application of GIS in supporting infrastructure improvement and accident prevention strategies.

[12]. In this work a GIS-based framework is implemented for identifying accident hotspots in Kannur District, Kerala. The researchers integrated accident records with road network information and applied spatial analysis techniques to identify black spots requiring immediate engineering interventions. Their findings indicated that GIS substantially improves accident visualization and supports transportation agencies in prioritizing road safety improvements based on spatial risk distribution rather than simple accident counts.

[13]. Truong and Somenahalli (2011) developed a GIS-based framework integrating accident records with traffic volume, road network characteristics and land-use information. The study demonstrated that multi-factor spatial analysis improves accident hotspot identification and provides better support for transportation planning than traditional accident frequency analysis.

[14]. Xie *et al.* investigated the application of Kernel Density Estimation (KDE) for identifying traffic accident hotspots. By converting discrete accident locations into continuous density surfaces, the study effectively visualized accident concentrations and prioritized hazardous road sections. The authors concluded that GIS-based KDE provides a reliable and efficient approach for hotspot detection and supports evidence-based road safety planning.

[15]. Funamoto *et al.* (2010) Another study employed fuzzy logic and human factor evaluation to investigate the primary causes of road traffic accidents. By integrating behavioural factors with spatial accident data, the research demonstrated that driver behaviour, road conditions and environmental factors collectively influence accident severity, providing valuable information for targeted road safety interventions.

[16]. Chen (2012) proposed a GIS-based methodology for identifying traffic accident black spots using geocoding technology and VRS-GPS positioning techniques. The study established spatial relationships between traffic accident locations and road network elements to identify hazardous road sections. Accident reduction potential was used as an index for extracting black spots, while spatial association analysis was employed to investigate the relationship between accident-prone locations and road attributes. The findings demonstrated that GIS effectively supports spatial accident analysis and assists authorities in identifying high-risk locations for traffic safety improvements.

[17]. Kindaya and Hishe (2014) Researchers examined the influence of data segmentation on crash injury severity models using statistical approaches. The study reported that model accuracy depends not only on sample size but also on appropriate data classification and variable selection. The findings emphasized the need for robust statistical techniques to improve accident prediction and safety assessment.

[18]. Ye *et al.* (2014) proposed a GIS-based methodology for developing digital accident hotspot maps to support Advanced Driver Assistance Systems (ADAS). The framework integrated Kernel Density Estimation (KDE) with the Percent Volume Contour (PVC) technique to identify accident hotspots and convert them into digital map layers compatible with navigation systems. A case study in Nottingham demonstrated that the proposed approach effectively identified hazardous road locations and enhanced digital map functionality for real-time safety applications. The authors concluded that GIS-based hotspot mapping has significant potential for intelligent transportation systems, although improvements in hotspot accuracy and dynamic data updating are required for future ADAS implementation.

[19] Bhalla *et al.* (2014) conducted a GIS- and Remote Sensing-based analysis of road traffic accidents in Ajmer City, Rajasthan, using accident records collected between 2009 and 2013. The study developed a georeferenced accident database by integrating police records, GPS, GIS, and land-use information to examine yearly, monthly, and vehicle-wise accident trends and identify accident-prone locations. The analysis revealed that most accidents occurred between 4:00 PM and 10:00 PM, with human error being the primary contributing factor. The authors concluded that GIS provides an efficient platform for accident mapping, hotspot identification, traffic management, and evidence-based planning to reduce accident frequency and improve road safety.

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

[21]. Idhoko *et al.* (2015) developed a GIS-based road network database to improve emergency response services in Oyo Town, Nigeria. The study employed GPS-based data acquisition, digital road mapping, and spatial database development to facilitate route analysis and identification of the nearest emergency facilities. The resulting GIS database enabled efficient navigation and rapid emergency response by integrating road network information with spatial query capabilities. The authors concluded that GIS-based road network databases significantly enhance emergency management and can improve transportation planning, public safety, and disaster response.

[22] Satria and Castro (2016) reviewed the application of GIS tools in accident analysis and road design. The study compared various spatial analytical techniques, including Kernel Density Estimation (KDE), Moran's I, Getis–Ord Gi*, and network analysis, for identifying accident hotspots. The authors emphasized that GIS not only serves as a database management system but also provides integrated spatial statistical capabilities for accident modelling and decision support. The review concluded that selecting an appropriate GIS technique depends on data availability, study objectives, and roadway characteristics.

[23] Htut *et. al.* (2016) investigated hazardous locations on the Naypyitaw–Mandalay Expressway in Myanmar using GIS and statistical accident analysis methods. Accident rate and quality control techniques were integrated with ArcGIS to identify accident-prone road sections. The study highlighted the effectiveness of GIS in organizing spatial accident databases, visualizing hazardous locations, and supporting road safety planning. The authors recommended GIS-based accident management systems for improving highway safety and optimizing limited transportation resources.

[24]. Elsheikh (2016) developed a GIS-based Traffic Accident Analysis System for efficient management and visualization of traffic accident records. The proposed system integrated accident databases with GIS mapping tools to perform accident categorization, severity analysis, hotspot identification, and spatial querying. The study demonstrated that GIS provides an effective platform for analysing accident characteristics through thematic mapping and statistical visualization while supporting decision-making for road infrastructure improvements. The author concluded that GIS-based accident information systems offer a cost-effective solution for accident management and road safety planning.

[25]. Goswami *et. al.* (2016) investigated the application of GIS technology for identifying hazardous road locations along the Joydebpur–Jamuna Bridge National Highway in Bangladesh. Using field surveys and GIS-based spatial analysis, the study identified accident-prone sections and examined factors contributing to crash occurrences. The results revealed that a significant proportion of highway accidents were concentrated within a limited number of locations, demonstrating the effectiveness of GIS for hotspot identification. The authors concluded that GIS-based accident mapping provides valuable support for highway safety improvement programs and evidence-based transportation planning.

[26]. The paper evaluates traffic congestion in Jeddah City, Saudi Arabia, using GIS technology, focusing on road directions and congestion points. It employs various GIS functions (like network analyst, shortest path etc.) to analyze the traffic network and proposes solutions to mitigate congestion, aiding urban planners in improving transportation infrastructure.

[27]. Sameen and Pradhan (2017) investigated the influence of expressway geometric design features on accident frequency using high-resolution LiDAR data integrated with GIS. The study developed accident prediction models based on roadway geometry, including horizontal and vertical alignment, traffic volume, and proximity to access points. Statistical analysis revealed that geometric characteristics significantly influenced crash occurrence along Malaysian expressways. The authors concluded that integrating LiDAR-derived roadway information with GIS provides an efficient approach for accident prediction, roadway safety assessment, and infrastructure improvement planning.

[28]. Ahmadi *et. al.* (2017) investigated the capabilities of Geographic Information Systems in traffic accident information management using a qualitative cross-sectional methodology. The study identified ten major capability categories and sixty-four subcategories of GIS, including spatial data management, descriptive analysis, visualization, zoning, statistical analysis, decision support, and cost-effectiveness evaluation. The authors concluded that GIS significantly enhances the collection, storage, retrieval, organization, and analysis of traffic accident information, thereby improving traffic safety management.

[29]. Damani and Lakkad (2018) applied GIS and Kernel Density Estimation to identify hazardous road locations in Rajkot, India. The study integrated accident records with spatial analysis techniques to evaluate accident severity, roadway characteristics, and traffic conditions. Kernel Density Estimation effectively identified accident hotspots and visualized the spatial distribution of crashes, enabling better understanding of accident patterns. The authors concluded that GIS-based accident analysis improves decision-making for

transportation authorities by supporting hotspot prioritization, infrastructure development, and implementation of appropriate traffic safety measures.

[30]. The paper discusses the significant impact of road accidents on urban vulnerable road users, highlighting the need for improved road safety measures. It emphasizes the use of Geographic Information Systems (GIS) to analyse traffic accident data and prioritize safety improvements in transportation networks.

[31]. Aghasi (2019) critically reviewed the application of GIS in urban traffic accident analysis. The study highlighted GIS capabilities in integrating accident databases with spatial information, land use, transportation networks, environmental characteristics, and demographic data for comprehensive accident analysis. ArcGIS was identified as an effective platform for accident visualization, hotspot identification, spatial analysis, and transportation planning. The review concluded that GIS provides valuable support for decision-making and enhances urban traffic safety through effective spatial data analysis.

[32] Harirforoush and Bellalite (2019) proposed an integrated GIS-based framework for detecting traffic accident hotspots in Sherbrooke, Canada. The study compared density-based and distance-based spatial analytical methods, including Kernel Density Estimation (KDE), Network KDE, K-functions, and Moran's I, to improve hotspot identification. The results showed that integrating multiple GIS techniques produces more reliable hotspot detection than using a single method. The framework provides valuable support for transportation planners in prioritizing road safety interventions.

[33]. Harirforoush (2019) Researchers investigated the application of probabilistic risk assessment and statistical modelling for transportation safety analysis. The study incorporated uncertainty analysis and reliability assessment to evaluate accident risks under different traffic conditions. The findings suggested that probabilistic models can effectively complement GIS-based accident analysis by improving risk prediction and supporting informed safety planning.

[34]. The paper discusses the identification of traffic accident hotspots using Geographical Information System (GIS) techniques, emphasizing the advantages of spatial statistics over traditional methods. It presents a case study in Des Moines, Iowa, highlighting the effectiveness of Planar Kernel Density Estimation (PKDE) and identifies an optimal bandwidth for hotspot detection.

[35]. Kumar *et. al.* (2020) assessed road accident conditions in the rural region of Karchna Block, Prayagraj, India, using geo-spatial techniques. The study analysed settlement patterns, transportation infrastructure, road network characteristics, and accident occurrences through GIS-based mapping and spatial analysis. The findings demonstrated that accident frequency was strongly influenced by road connectivity, infrastructure quality, and settlement distribution. The authors concluded that GIS serves as an effective decision-support tool for identifying accident-prone rural locations and assists planners in implementing sustainable transportation and road safety strategies.

[36]. Lee *et. al.* (2020) investigated road traffic accident hotspots in Hanoi, Vietnam, using GIS-based temporal–spatial statistical techniques. The study integrated Kernel Density Estimation (KDE) with a Severity Index (SI) to examine accident patterns across different seasons and time intervals using accident data collected from 2015–2017. The findings indicated that incorporating accident severity significantly improved hotspot prioritization compared to conventional KDE analysis. The authors concluded that integrating spatial and temporal analyses with severity information enables more accurate identification of hazardous locations and supports transportation authorities in implementing targeted road safety measures.

[37]. Rahman *et. al.* (2020) Researchers developed an enhanced Automatic Collision Notification (AACN) system by integrating injury prediction models with emergency response information. The study highlighted that rapid emergency medical response significantly reduces accident severity and improves survival rates, demonstrating the importance of intelligent emergency management systems.

[38]. Al-Omari *et. al.* (2020) A hybrid machine learning framework combining XGBoost and SHAP analysis was proposed to identify key traffic collision risk factors. The study revealed that night time driving, traffic signal violations and driver fatigue were among the most influential variables

affecting accident occurrence, providing valuable guidance for targeted safety policies.

[39]. The paper focuses on identifying and analyzing accident blackspots on NH45B in Tamil Nadu using ArcGIS software. It aims to enhance road safety by examining accident data from 2014 to 2018 and proposing measures to reduce accidents in critical areas. (10, Sathees Kumar, 2020)

[40]. Manap *et. al.* (2021) Another investigation evaluated transportation safety barriers using probabilistic flow network models and system-based risk assessment. The proposed framework optimized safety measures by identifying critical operational risks and demonstrated its usefulness for strategic transportation safety management.

[41]. Al-Aamri *et. al.* (2021) Recent research evaluated the effectiveness of autonomous emergency braking systems and drone-based traffic monitoring for accident prevention. The findings showed that intelligent sensing technologies and automated safety systems significantly enhance accident detection, conflict analysis and real-time traffic monitoring, contributing to the development of safer and smarter transportation systems.

[42] Ma *et. al.* (2021) compared density analysis, hotspot analysis, and outlier detection techniques for identifying high-severity traffic accident clusters. Using GIS-based spatial analysis, the study evaluated the consistency and computational efficiency of each method. The results indicated that density analysis required the shortest processing time, while hotspot analysis provided better identification of significant accident clusters. The authors concluded that combining multiple spatial analytical methods improves the reliability of accident hotspot detection and traffic safety assessment.

[43]. The main objective of this study, by Alkhadour *et. al.* (2021), is to analyze traffic accidents in temporal and spatial frameworks in the capital city Amman and identify hotspot zones in the study area. Several statistical analyses are conducted using SQL to give insight into the temporal distribution of accidents and to identify the most revealing accidents based on several attributes such as the year of accidents, the severity of accidents, road type, and lighting environment which enables the authors to do further investigations on the more frequent accidents. GIS-based statistical and spatial analysis tools are utilized to examine the spatial pattern of accident distribution in the study area for three successive years, hotspots are identified for clusters of high concentrations. The Nearest Neighbor Index (NNI) is used to analyze the pattern of traffic accident distribution based on selective parameters. This was followed by identifying hotspot zones for regions that showed clustering using the optimal hotspot analysis tool. Experimental results showed clustering for all tested groups, and thus hotspots were detected for these accidents in the study area. The importance of this work is in providing a spatial understanding of accident distribution in the capital city of Amman.

[44]. Gupta *et. al.* (2022) developed a comprehensive GIS-based Accident Information System (AIS) for Dehradun, Uttarakhand, to improve road safety management through spatial analysis of accident records. The study integrated accident information with road networks, hospitals, police stations, bridges and other transportation infrastructure within a GIS environment. Various analyses including police station-wise, vehicle-wise, road-wise, time-wise and year-wise accident assessments were performed. Buffer analysis was employed to classify accident locations into most critical, critical and less critical zones, while network analysis identified the nearest hospitals reachable within fifteen minutes of an accident. The study demonstrated that GIS provides an effective decision-support system for identifying accident black spots, improving emergency response and prioritizing road safety interventions. It also highlighted the importance of integrating spatial and attribute data for efficient accident management.

[45]. Fayaz *et. al.* (2022) A unified probabilistic framework was proposed for traffic conflict detection by integrating vehicle interactions, mobility characteristics and environmental conditions. The model demonstrated improved collision risk estimation and highlighted its potential application in autonomous driving systems and intelligent transportation management.

[46]. This study identified high-risk locations (hotspots) using geographic information systems (GIS) and spatial analysis. Five years of accident data (2013–2017) for the Lokoja-Abuja-Kaduna highway in Nigeria were used. The accident concentration analysis was conducted using the mean center analysis and Kernel density estimation

method. These locations were further verified using Moran's I statistics (spatial autocorrelation) to determine their clustering with statistical significance. Fishnet polygon and network spatial weight matrix approaches of the Getis–Ord Gi* statistic were used in the hotspot analysis. Hotspots exist for 2013, 2014, and 2017 with a significance level between 95–99%. However, hotspots for 2015 and 2016 have a low significance level and the pattern is random. The spatial autocorrelation analysis of the overall accident locations and the Moran's I statistic showed that the distribution of the accidents on the study route is random. Thus, preventive measures for hotspot locations should be based on a yearly hotspot analysis. The average daily traffic values of 31,270 and 16,303 were obtained for the northbound and southbound directions of the Abaji–Abuja section. The results show that hotspot locations with high confidence levels are at points where there are geometric features.

[47]. Saran *et. al.* (2023) developed a WebGIS-based Road Crash Information System for Kerala, India, to support accident reporting, hotspot identification, and road safety assessment. The system integrated accident records into an online GIS platform capable of mapping crash locations, performing spatial analyses, and disseminating accident information to government agencies and the public. The study demonstrated that WebGIS significantly improves accessibility, data management, and coordination among stakeholders. The authors concluded that web-based GIS platforms enhance road safety planning through efficient crash data sharing and evidence-based decision-making.

[48]. This study aimed at determining the spatial patterns of Road Traffic Crash (RTC) black spots, Federal Road Safety Commission (FRSC) zebra points and emergency health care facilities in Federal Capital City (FCC). The aim was to provide stakeholders with information that will aid their understanding of accident prone locations and accessible rescue possibilities for accident victims on the roads in FCT. GPS Map 76S Mark (GARMIN) was used to locate and pick coordinates of data in the study area. A total of 16 possible emergency health care facilities, seventy (70) RTC black spots and Five Zebra point locations were obtained from FRSC. ArcGIS 10.0 was used to compute the data by plotting the coordinates to produce maps of the spatial relationship and to carry out Nearest Neighbour Analysis (NNA). The result was further used to determine the spatial patterns of RTC black spots as well as patterns of the emergency facilities. Generally, the result shows that the spatial trend is turning towards dispersion. However, there is less than 1% likelihood that the dispersed patterns could be the result of random chance. It was recommended that, the Federal Road Safety Commission should be staffed with trained professionals that can be responsible for accident data surveillance and analysis using geospatial techniques.

[49]. Gupta *et. al.* (2023) developed a Web GIS-based Accident Information System (AIS) for Dehradun to support road safety and sustainable transportation. The study integrated GIS with web technologies to analyse and visualize traffic accident data using parameters such as police station, vehicle type, accident severity, location, and time. The system, developed using ArcGIS, SharpMap, SQL Server, and ASP.NET, enabled efficient accident data querying and visualization. The results demonstrated that the Web GIS platform effectively identified accident patterns and supported transportation authorities in planning road safety measures and improving decision-making.

[50]. The study analyses urban traffic accidents in the Colombo Municipal Council area using GIS, employing Kernel Density Estimation (KDE) and Nearest Neighbor Hierarchy (NNH) methods. It identifies high-risk areas and recommends NNH for effective road safety analysis and urban planning.

[51]. Singh *et. al.* (2023) developed a GIS-based Highway Information System (HIS) for Himachal Pradesh to improve road asset management and maintenance planning. The study integrated road inventory, pavement condition, bridge information, traffic data, accident information, and GIS into a unified Road Asset Management System (RAMS). The proposed system included modules such as the Road Information System (RIS), Traffic Information System (TIS), Bridge Information System (BIS), Accident and Road Safety Information System (ARSIS), and Web-GIS to facilitate efficient transportation planning and decision-making. The authors concluded that GIS significantly enhances road infrastructure management, maintenance scheduling, and transportation planning by providing an integrated spatial database for highway management.

[52]. Bilașco and Man (2024) Researchers compared GIS-based hotspot detection methods including KDE, Moran's I, Getis–Ord Gi* and Network KDE. The study concluded that combining KDE with spatial statistical techniques improves hotspot reliability and provides more accurate accident analysis for transportation planning and road safety management.

[53]. Bhele *et. al.* (2024) A study combined GIS with connected vehicle technology to analyse near-miss events such as hard braking and sudden swerving. By using real-time driver behaviour instead of only historical accident records, the framework improved the prediction of future accident hotspots and supported proactive road safety interventions.

[54]. Khan *et. al.* (2024) proposed a GIS and Machine Learning-based framework for predicting urban traffic accidents. The research integrated GIS with Random Forest, Decision Tree, and Linear Regression algorithms to analyse accident records collected from emergency response agencies. GIS was employed to identify accident hotspots, while machine learning models predicted accident occurrences based on road geometry, traffic conditions, and environmental characteristics. The Decision Tree algorithm achieved the highest prediction accuracy, demonstrating the effectiveness of combining GIS with machine learning techniques for accident prediction.

[55]. Chinnanarasaiah *et. al.* (2025) presented a GIS-based methodology for hotspot detection and spatial trend analysis of road accidents in Hyderabad. The study analysed 8,576 accident records collected between 2021 and 2024 using Kernel Density Estimation (KDE), Crash Hazard Level (CHL), Predictive Accuracy Index (PAI), and Fractal Analysis. The proposed approach successfully identified accident-prone locations, ranked hazardous zones, and validated hotspot predictions. Based on the findings, the authors recommended targeted engineering improvements, pedestrian safety measures, enhanced emergency response systems, and awareness programs to improve urban road safety.

[56]. Deressa *et. al.* (2025) presented a systematic review of GIS-driven road traffic accident evaluation by synthesizing findings from 77 published studies using the PRISMA framework. The review examined major GIS-based hotspot detection techniques, including Kernel Density Estimation (KDE), Network KDE, Moran's I, and Getis–Ord Gi*. The authors found that KDE and Moran's I were the most frequently adopted methods because of their effectiveness in identifying statistically significant crash clusters. The study also highlighted challenges such as inconsistent data quality, computational complexity, and limited real-time analysis, recommending integration of advanced spatial analytics and intelligent transportation systems for future road safety research.

[57]. Endashaw *et. al.* (2025) assessed the effectiveness of periodic vehicle inspection programs in reducing traffic accidents. The study found that increasing inspection frequency alone has limited influence on accident reduction and suggested that driver behaviour, vehicle maintenance and roadway conditions collectively determine road safety outcomes.

[58]. Alfaras *et. al.* (2025) presented a comprehensive review of Geographic Information Systems (GIS) applications in traffic accident analysis and prediction. The study emphasized the integration of GIS with Deep Learning and Artificial Intelligence techniques to improve accident hotspot detection, traffic pattern analysis, emergency response optimization, and accident prediction. Various GIS-based analytical methods, including Kernel Density Estimation (KDE), Geographically Weighted Regression (GWR), Firefly Clustering, Moran's I spatial autocorrelation, and Getis-Ord Gi* statistics, were discussed. The authors concluded that the integration of GIS with intelligent analytical techniques significantly improves accident prediction accuracy and supports effective road safety management.

CONCLUSION

GIS has become an indispensable tool for traffic accident analysis by enabling efficient visualization, spatial analysis, hotspot identification and decision support for transportation planning. The reviewed studies demonstrate a clear transition from conventional accident mapping towards advanced predictive modelling through the integration of GIS with spatial statistics, machine learning, artificial intelligence and intelligent transportation technologies. Techniques such as Kernel Density Estimation, Moran's I, Getis–Ord Gi* and Network KDE have significantly improved the identification of accident-prone locations, while

AI-based predictive models have enhanced accident forecasting and emergency response capabilities.

Despite considerable progress, challenges related to data availability, quality, standardization and real-time implementation remain. Addressing these limitations through the integration of emerging technologies and comprehensive spatial datasets will further improve the effectiveness of GIS-based traffic safety systems. Overall, GIS is expected to play a central role in the development of intelligent transportation systems and smart cities by supporting evidence-based road safety policies, reducing accident risks, and improving the efficiency of transportation management.

REFERENCES

[1]. Levine, N.; Kim, K. E.; and Nitz, L. H., 1995. "Spatial Analysis of Honolulu Motor Vehicle Crashes: I. Spatial Patterns," Accident Analysis & Prevention, vol. 27, no. 5, pp. 663–674. doi: 10.1016/0001-4575(95)00017-T.
[2]. Kim, K.; and Levine, N., 1996. "Using GIS to Improve Highway Safety," Computers, Environment and Urban Systems, vol. 20, no. 4–5, pp. 289–302, doi: 10.1016/S0198-9715(96)00022-1.
[3]. Tiglao, N. C., 1998, "Development of a GIS-Based Traffic Accident Information System," Journal of the Eastern Asia Society for Transportation Studies.
[4]. Mwatelah, S., 2001. "Application of Geographic Information Systems in Road Traffic Accident Analysis," International Conference on Spatial Information for Sustainable Development, Nairobi.
[5]. Khan, M. A.; Al Kathairi, A. S.; and Garib A. M., 2004. "GIS-Based Traffic Accident Data Collection, Referencing and Analysis Framework for Abu Dhabi Municipality," CODATU XI, pp. 292–302.
[6]. Cheng, W.; and Washington, S., 2005, "Experimental Evaluation of Hotspot Identification Methods," Accident Analysis & Prevention, vol. 37, no. 5, pp. 870–881. doi: 10.1016/j.aap.2005.04.015.
[7]. Loo, B. P. Y., 2006. "Validating Crash Locations for Quantitative Spatial Analysis: A GIS-Based Approach," Accident Analysis & Prevention, vol. 38, no. 5, pp. 879–886. doi: 10.1016/j.aap.2006. 02.012.
[8]. Anderson, T. K., 2006. Comparison of Spatial Methods for Measuring Road Accident Hotspots: A Case Study of London. Journal of Maps, 3(1), 55–63. https://doi.org/10.1080/jom.2007.9710827
[9]. Anderson, T. K., 2009, "Kernel Density Estimation and K-Means Clustering to Profile Road Accident Hotspots," Accident Analysis & Prevention, vol. 41, no. 3, pp. 359–364.
[10]. Mahmud, A. R.; and Zarrinbashar, E., 2008. "Intelligent GIS-Based Road Accident Analysis and Real-Time Monitoring Automated System Using WiMAX/GPRS," International Journal of Engineering, vol. 2, no. 1.
[11]. Erdogan, S.; Yilmaz, I.; Baybura, T.; and Gullu, M., 2008. "Geographical Information Systems Aided Traffic Accident Analysis System: Case Study of City of Afyonkarahisar," Accident Analysis & Prevention, vol. 40, no. 1, pp. 174–181, doi: 10.1016/j.aap.2007.05.004.
[12]. Deepthi Jayan, K.; and Ganeshkumar, B.,2010. "Identification of Accident Hot Spots: A GIS-Based Implementation for Kannur District, Kerala," International Journal of Geomatics and Geosciences, vol. 1, no. 1, pp. 51–59.
[13]. Truong, L. T.; and Somenahalli, S., 2011, "Using GIS to Identify Road Traffic Accident Black Spots". Journal of Transport Geography, vol. 14, no. 1, pp. 99–114. doi: 10.5038/2375-0901.14.1.6.
[14]. Xie, Z.; and Yan, J., 2008. " Kernel Density Estimation of Traffic Accident in a Network Space". Computers, Environment and Urban Systems, 32, 396–406
[15]. Funamoto, S.; Nham, N. V.; Morimoto, A.; and Koike, H., 2010. "A Study on Traffic Accident Measures in Municipal Roads by Using GIS," Proceedings of the 13th International Conference on Computing in Civil and Building Engineering / EG-ICE.
[16]. Chen, H., 2012. "Black Spot Determination of Traffic Accident Locations and its Spatial Association Characteristic Analysis based on GIS." Journal of Geographic Information System, 4 (06), 608-617.
[17]. Kindaya, G. G.; and Hishe, S., 2014. "Spatio-Temporal Assessment of Road Traffic Accident in Mekelle City". M.Sc. Thesis, Mekelle University, Ethiopia.
[18]. Ye, H.; Meng, X.; Yang, L.; and Anand, S., 2014, "Development of a Digital Accident Hotspot Map for ADAS Applications Using Geospatial Methods in GIS," The Journal of Navigation, vol. 67, no. 3, pp. 353–369. doi:10.1017/S037346331 3000805
[19]. Bhalla, P., Tripathi, S., & Palria, S. (2014). "Road Traffic Accident Analysis of Ajmer City using Remote Sensing and GIS Technology."

International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-8, 1455–1462. https://doi.org/10.5194/isprs archives-XL-8-1455-2014
[20]. Shafabakhsh, G. A.; Famili, A.; and Bahadori, M. S., 2017, "GIS-Based Spatial Analysis of Urban Traffic Accidents: Case Study in Mashhad, Iran". Journal of Traffic and Transportation Engineering (English Edition), vol. 4, no. 3, pp. 290–299. doi: 10.1016/j.jtte.2017.05.005.
[21]. Idhoko, K. E.; Aguba, W.; Emefeke, U.; and Nwanguma, C., 2015. "Development of a Geographic Information Systems Road Network Database for Emergency Response: A case study of Oyo-Town, Oyo State, Nigeria". International Journal of Engineering Science Invention, 4(12), 34–42.
[22]. Satria, R.; and Castro, M., 2016. "GIS Tools for Analyzing Accidents and Road Design: A Review". XII Conference on Transport Engineering, CIT 2016, 7-9 June 2016, Valencia, Spain, Transportation Research Procedia 18 (2016) 242 – 247
[23]. Htut, K. Z.; Mon, E. E.; Johnstone, L.; Pueboobpaphan, R.; Ratanavaraha, V.; Goodary, R.; and Beeharry, R., 2016. "Application of GIS to Traffic Accident Analysis: Case Study of Naypyitaw–Mandalay Expressway (Myanmar)". International Journal of Building, Urban, Interior and Landscape Technology, 7, 35–42.
[24]. Elsheikh, R. F. A., 2016. "GIS based Traffic Accident Analysis System". International Journal of Advanced Engineering Research and Science, 3(12), 8–14. https://doi.org/10.22161/ijaers/3.12.2
[25]. Goswami, D.; Morshed, M. M.; and Hasan, M. S., 2015. "Implication of GIS Technology in Accident Research in Bangladesh". Journal of Bangladesh Institute of Planners, 8, 159–166.
[26]. Al-Enazi, M., 2016. Traffic Congestion Evaluation Using GIS Case Study: Jeddah City. International Journal of Computer Applications, 138(1), 7–11. https://doi.org/10.5120/ijca20169086 34
[27]. Sameen, M. I.; and Pradhan, B., 2017. "Assessment of the Effects of Expressway Geometric Design Features on the Frequency of Accident Crash Rates using High-Resolution Laser Scanning Data and GIS". Geomatics, Natural Hazards and Risk, 8(2), 733–747. https://doi.org/10.1080/19475705.2016.12 65012
[28]. Ahmadi, M.; Valinejadi, A.; Goodarzi, A.; Safari, A.; Hemmat, M.; Askari Majdabadi, H.; and Mohammadi, A., 2017. Geographic Information System (GIS) Capabilities in Traffic Accident Information Management: A Qualitative Approach. Electronic Physician, 9(6), 4533–4540. https://doi. org/10.19082/4533
[29]. Damani, M.; and Lakkad, P., 2018. "Identify Hazardous Road Location for Road User Using GIS: Case Study of Rajkot". Iconic Research and Engineering Journals, 1(10), 47–50.
[30]. Kaur, A.; Bala, P.; and AnnaTom, S., 2018. "GIS Based Road Safety and Traffic Accident Data Analysis". International Journal of Advanced Research in Science, Engineering and Technology, 5(4), 5658–5664.
[31]. Aghasi, N.H.M., 2019. Application of GIS for Urban Traffic Accidents: A Critical Review. Journal of Geographic Information System, 11(1), 82–96.
[32]. Harirforoush, H.; and Bellalite, L., 2019. "A New Integrated GIS-based Analysis to Detect Hotspots: A Case Study of the City of Sherbrooke." Accident Analysis & Prevention, 130, 62–74. https://doi.org/10.1016/j.aap.2016.08.015.
[33]. Harirforoush, H., 2019. "Spatial and Temporal Analysis of Seasonal Traffic Accidents." American Journal of Traffic and transportation Engineering, 4 (1) .
[34]. Lakshmi, S.; Srikanth, I.; and Arockiasamy, M., 2019. "Identification of Traffic Accident Hotspots using Geographical Information System (GIS)". International Journal of Engineering and Advanced Technology (IJEAT), 9(2), 4429–4438.
[35]. Kumar, A.; Kumar, J.; and Bharti, B. K., 2020. "Assessment of Accidental Condition in Rural Region Using Geo-Spatial Technique: A Case Study of Karchna Block, Prayagraj (India)". Agricultural Journal, 15(4), 65–70.
[36]. Lee, K. G.; Liu, P.; and Lin, L.-T., 2020, "Determining the Road Traffic Accident Hotspots Using GIS-Based Temporal-Spatial Statistical Analytic Techniques in Hanoi, Vietnam," Geo-Spatial Information Science, Vol. 23, No. 2, pp. 153–164.
[37]. Rahman, M. T.; Jamal, A.; and Al-Ahmadi, H. M., 2020. "Examining Hotspots of Traffic Collisions and Their Spatial Relationships with Land Use: A GIS-Based Geographically Weighted Regression Approach for Dammam, Saudi Arabia," ISPRS International Journal of Geo-Information, vol. 9, no. 9, p. 540. doi: 10.3390/ijgi9090540.
[38]. Al-Omari, A.; Shatnawi, N.; Khedaywi, T.; and Miqdady, T., 2019. "Prediction of Traffic Accidents Hot Spots Using Fuzzy Logic and GIS," Applied Geomatics, vol. 12, no. 2, pp. 149–161, December 2019. DOI: 10.1007/s12518-019-00290-7.
[39]. Sathees Kumar, M.; Mohamed Saleh, S.; Sivaranjani, R.; Ramalakshmi, M.; Muthumari, G.;

and Zunaithur Rahman, M., 2020. “Application of GIS to Transportation Design of Highway Consistency and Road Safety Analysis”. GIS Science Journal, Vol. 7, Issue 6, 567-582
[40]. Manap, N.; Borhan, M. N.; Yazid, M. R. M.; Hambali, M. K. A.; and Rohan, A., 2021. "Identification of Hotspot Segments with a Risk of Heavy-Vehicle Accidents Based on Spatial Analysis at Controlled-Access Highway," Sustainability, vol. 13, no. 3, p. 1487. doi: 10.3390/su13031487.
[41]. Al-Aamri, A. K.; Hornby G.; Zhang L.-C.; Al-Maniri A. A.; and Padmadas S. S., 2021. “Mapping Road Traffic Crash Hotspots using GIS-based Methods: A Case Study of Muscat Governorate in the Sultanate of Oman,” Spatial Statistics, vol. 42, p. 100458. doi: 10.1016/j.spasta.2020.100458.
[42]. Ma, Q.; Huang, G.; and Tang, X., 2021. “GIS-based Analysis of Spatial–Temporal Correlations of Urban Traffic Accidents”. European Transport Research Review, 13(1). https://doi.org/10.1186/s 12544-021-00509-y.
[43]. Alkhadour, W.; Zraqou, J.; Al-Helali, A.; and Al-Ghananeem, S., 2021. Traffic Accidents Detection using Geographic Information Systems (GIS). International Journal of Advanced Computer Science and Applications (IJACSA), 12(4), 484–494.https://doi.org/10.14569/IJACSA.2021.0120462
[44]. Gupta, S.; Garg, P. K.; and Ghosh, S. K., 2022. “Analysis of Road Accidents Using GIS”. SSRG International Journal of Civil Engineering, 9(9), 1-7. https://doi.org/10.14445/23488352/IJCE-V9I9P101.
[45]. Fayaz, F.; Hussain, A., E, B. R.; and Raza, A., 2022. "Review Paper on Road Accident Analysis Using ArcGIS and Road Safety Audit," pp. 185–189.
[46]. Afolayan, A.; Easa, S. M.; Abiola, O. S.; Alayaki, F. M.; and Folorunso, O., 2022. GIS-Based Spatial Analysis of Accident Hotspots: A Nigerian Case Study. Infrastructures, 7(8), 103.
[47]. Saran, M. S.; Manju, V. S.; & Vishnu, V. P., 2023. “A Web GIS-based Road Crash Information System: A Case Study”. Journal of Geomatics, 17(2), 156–160. https://doi.org/10.58825/jog.2023.17.2.29
[48]. Aule, D. S.; Jibril, M. S.; and Garba, B.D., 2023. “Spatial Accessibility of Emergency Facilities to Road Accident Victims in the Federal Capital City”. Journal of Geoscience and Environment Protection, 11, 135-150.
[49]. Gupta S.; Suman S.; Sharma S. K.; Garg P. K., and Ghosh S. K., 2023. "Development of Web GIS Based Accident Information System for Safe and Sustainable Transport," Materials Today: Proceedings.
[50]. Munasinghe, D. S., 2023. “Spatial Analysis of Urban Road Traffic Accidents Using GIS”. British Journal of Multidisciplinary and Advanced Studies: Engineering and Technology, 4(6), 70–83.
[51]. Singh, H.; and Singh, D. S., 2023. “Development of Highway Information System in GIS Environment: Himachal Pradesh”. International Journal for Multidisciplinary Research, 5(5),1-10.
[52]. Bilașco, Ș.; and Man, T. C., 20214. "GIS-Based Spatial Analysis Model for Assessing Impact and Cumulative Risk in Road Traffic Accidents via Analytic Hierarchy Process (AHP): Case Study Romania," Applied Sciences, vol. 14, no. 6, p. 2643. doi: 10.3390/app14062643, 2024.
[53]. Bhele, R.; Dhungana, S.; Chimoriya, D.; Sapkota, A.; and Ghorasaini, S., 2024. “Spatial and Temporal Analysis of Road Traffic Accidents Using GIS”. International Journal on Engineering Technology, vol. 2, no. 1, pp. 1–18. doi: 10.3126/injet.v2i1.72464.
[54]. Khan, A. A; and Hussain, J., 2024. “Utilizing GIS and Machine Learning for Traffic Accident Prediction in Urban Environment”. Civil Engineering Journal, 10(6), 1922–1935. https://doi.org/10.28991 /CEJ-2024-010-06-013
[55]. Chinnanarsaiah, S.; and Sravana, P., 2025. “Identification of Hotspot Detection and Spatial Trends of Road Accidents Using a GIS: A Case Study of Hyderabad”. International Journal for Research in Applied Science and Engineering Technology, 13(9), 463–472. https://doi.org/10.22214/ijraset.2025.74084.
[56]. Deressa, B. F.; Habtegiogis, K. A.; Endashaw, D. K.; Al-Ramadan, B. M.; and Al-Ahmadi, H. M., 2025. "A Systematic Review of GIS-Driven Road Traffic Accident Evaluation," Vehicles, vol. 7, Article 161, doi: 10.3390/vehicles7040161.
[57]. Endashaw, D. K.; Habtegiorgis, K. A.; Al-Ramadan, B. M.; Al-Ahmadi, H. M.; and Deressa, B. F., 2025. "A Systematic Review on GIS-Based Road Traffic Accidents Analysis and Road Safety Audit," Computational Urban Science, vol. 5, Article 53, doi: 10.1007/s43762-025-00221-w.
[58]. Alfaras, M. S.; Karan, O.; and Kurnaz, S., 2025 "Optimizing Road Safety: The Role of Geographic Information Systems (GIS) in Traffic Accident Analysis and Prediction," Proceedings on Engineering Sciences, vol. 7, no. 1, pp. 33–42,. doi: 10.24874/PES07.01.005.