Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 11, November 2025

Integrated Spatial and Behavioral Analysis of Road Traffic Accidents in Bogura, Bangladesh using A Mixed-Methods Framework for District-Level Safety Planning

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***Abstract* - Road traffic accidents continue to pose a significant public health challenge, particularly in low- and middle-income countries where infrastructure, enforcement, and transport systems are often underdeveloped. This study examines the incidence, causes, and spatial distribution of road traffic accidents in Bogura District, Bangladesh, a rapidly urbanizing region characterized by mixed traffic conditions and limited regulatory oversight. Using a mixed-methods design, the research integrates geographic information system (GIS) mapping, statistical analysis, and qualitative interviews with key stakeholders. Between 2022 and 2023, the study documented 10 major accident cases resulting in 38 fatalities and 40 injuries. Quantitative analysis revealed that private cars and motorcycles were involved in over 90% of non-pedestrian fatalities, while trucks and buses accounted for the highest proportion of pedestrian deaths. Spatial mapping identified high-risk zones in Shajahanpur, Sherpur, and Nandigram, where poor road geometry and lack of traffic control infrastructure were common. Behavioral factors such as speeding, reckless overtaking, and nighttime driving further contributed to accident severity. The findings highlight the urgent need for district-specific interventions, including GIS-informed infrastructure upgrades, regulation of informal transport modes, targeted public awareness campaigns, and improved enforcement mechanisms. By situating Bogura's traffic safety challenges within broader global patterns, the study offers a replicable framework for enhancing road safety in resource-constrained settings and contributes to the growing discourse on sustainable urban mobility in Bangladesh.**

Keywords - Road traffic accidents; GIS-based hotspot mapping; Mixed-methods analysis; Vulnerable road users; District-level transport planning.

1. INTRODUCTION

Road traffic accidents (RTAs) remain one of the most pressing public health and development challenges of the 21st century, claiming over 1.35 million lives annually and injuring tens of millions more across the globe (World Health Organization, 2023). The burden of these accidents is disproportionately concentrated in low- and middle-income countries (LMICs), where rapid urbanization, inadequate transport infrastructure, and weak enforcement of traffic laws converge to create unsafe mobility environments (Peden et al., 2004; Odero et al., 2020). Bangladesh exemplifies this crisis, with a steady rise in accident rates and fatalities. According to the Bangladesh Road Transport Authority (BRTA), the country recorded 5,495 road accidents in 2023 alone, resulting in 5,024 deaths and 7,495 injuries figures that underscore the urgency of targeted, evidence-based interventions (BRTA, 2023).

Despite the scale of the problem, most road safety research in Bangladesh remains concentrated at the national level or within major metropolitan areas such as Dhaka and Chattogram (Alam & Hossain, 2023; Haque et al., 2021). This leaves a critical gap in understanding the dynamics of RTAs in semi-urban and district-level contexts, where infrastructure, traffic behavior, and enforcement mechanisms differ significantly. Bogura district, located in northern Bangladesh, is one such underexplored region. Strategically positioned as a transit corridor between Dhaka and the northwestern divisions, Bogura experiences high vehicular density and a complex mix of transport modes including heavy trucks, buses, motorcycles, auto-rickshaws, and informal vehicles such as Votvotis and CNGs. The coexistence of motorized and non-motorized traffic, coupled with poor road geometry, limited signage, and inconsistent law enforcement, contributes to a hazardous mobility landscape (Rahman & Rahman, 2023; Ahmed & Khan, 2022).

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ISSN: 2278-0181
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This study emerges from the recognition that district-level accident patterns, risk factors, and mitigation strategies must be understood in their own right, rather than extrapolated from urban-centric models. Bogura's strategic importance and unique traffic ecosystem make it a compelling case for localized road safety analysis. Yet, to date, there is a paucity of empirical research that integrates spatial, behavioral, and institutional dimensions of RTAs in this region. International frameworks increasingly advocate for multidisciplinary approaches to road safety combining engineering solutions, public education, policy reform, and emergency response systems (Harvard University & World Bank, 2015; WHO, 2023). However, such models are rarely operationalized at the district level in Bangladesh due to fragmented institutional coordination and limited data availability.

To address these gaps, this paper adopts a mixed-methods approach that combines statistical analysis of accident records, Geographic Information Systems (GIS) mapping of high-risk zones, and qualitative insights from transport officials, drivers, and community stakeholders. This integration of spatial and behavioral data offers a novel lens for understanding RTAs in semi-urban contexts and contributes to the global discourse on sustainable urban mobility and district-level safety planning. The study also draws on recent advances in predictive modeling and machine learning applications for accident risk assessment (Chowdhury et al., 2023; Saha & Roy, 2023), highlighting the potential for data-driven interventions tailored to local realities.

By situating Bogura's accident trends within broader LMIC patterns and comparing findings with international case studies from India, Kenya, and Vietnam, the research aims to generate actionable insights for policymakers, urban planners, and transport authorities. Ultimately, the study advocates for locally responsive interventions, such as infrastructure upgrades, intelligent traffic management systems, community-based awareness campaigns, and strengthened enforcement protocols to reduce accident rates and promote safer mobility in Bogura and similar urbanizing districts across Bangladesh.

2. METHODS

This study adopts a mixed-methods research design to examine the frequency, causes, and spatial distribution of road traffic accidents (RTAs) in Bogura District, Bangladesh. The integration of quantitative and qualitative approaches allows for a comprehensive understanding of the district's traffic ecosystem, infrastructural deficiencies, and behavioral risk factors. This methodological framework was selected to capture both statistical trends and lived experiences, thereby enhancing the validity and applicability of the findings. Bogura was chosen as the study site due to its strategic role as a regional transport corridor connecting Dhaka to the northwestern divisions. The district has witnessed a notable rise in traffic volume and accident rates in recent years, yet remains underrepresented in national road safety research. Its diverse geography spanning urban centers, peri-urban zones, and rural stretches provides a valuable context for analyzing variations in accident patterns across different road environments.

2.1 Data Collection

Data for this study were obtained from both secondary and primary sources to ensure a comprehensive understanding of road traffic accident dynamics in Bogura District. Secondary data included official police accident records provided by the Bogura District Police Department, hospital admission logs and injury reports from three major healthcare facilities, statistical datasets from the Bangladesh Bureau of Statistics (BBS), and annual accident summaries published by the Bangladesh Road Transport Authority (BRTA). These sources offered foundational insights into accident frequency, victim demographics, vehicle involvement, and temporal distribution patterns across the district. Primary data collection was designed to complement and contextualize the secondary datasets. Structured surveys were administered to 300 individuals, comprising drivers, pedestrians, and local residents. These surveys captured perceptions of road safety, personal experiences with traffic incidents, and levels of awareness regarding traffic regulations. To gain deeper institutional and policy-level insights, semi-structured interviews were conducted with 25 key informants, including traffic enforcement officers, municipal engineers, transport planners, and policy experts. These interviews explored enforcement challenges, infrastructure planning processes, and stakeholder perspectives on road safety governance. Additionally, field observations were carried out at twelve accident-prone locations identified through preliminary data screening. Using standardized observational checklists, researchers assessed road geometry, signage adequacy, traffic flow characteristics, pedestrian infrastructure, and visibility conditions. This triangulated approach to data collection enabled the study to capture both statistical trends and on-the-ground realities, thereby enhancing the validity and relevance of the findings.

2.2 Data Analysis

Quantitative data were analyzed using SPSS (Version 26). Descriptive statistics were used to summarize accident frequency, vehicle involvement, and intersection characteristics. Inferential statistics including chi-square tests and logistic regression were applied to examine associations between road features and accident likelihood.

Qualitative data from interviews and open-ended survey responses were analyzed using thematic coding. NVivo software supported the organization of transcripts into conceptual categories such as behavioral risk, enforcement gaps, and infrastructure failure. These themes were triangulated with observational findings to construct a multidimensional risk profile for Bogura's road network.

Spatial analysis was conducted using ArcGIS 10.8. Accident locations were geocoded and mapped to identify high-risk zones. Kernel density estimation and buffer analysis were used to visualize accident clusters and proximity to critical infrastructure such as schools, markets, and intersections.

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2.3 Ethical Considerations

All research activities adhered to ethical standards for human subject research. Informed consent was obtained from all participants prior to data collection. Confidentiality was maintained through anonymization of personal identifiers, and data were stored securely. The study protocol was reviewed and approved by an institutional ethics committee.

2.4 Limitations

The study acknowledges several limitations. Secondary data may suffer from underreporting or inconsistencies due to non-standardized documentation practices. The sample size, while adequate for exploratory analysis, may not fully capture the diversity of road users across the district. Additionally, the localized focus on Bogura limits the generalizability of findings to other regions without contextual adaptation. Despite these constraints, the methodological rigor and triangulation of data sources enhance the reliability of the results. The study's design offers a replicable framework for district-level road safety research and provides actionable insights for policymakers, urban planners, and transport authorities.

3. RESULTS AND DISCUSSION

Bogura District, a key commercial and transportation hub in northern Bangladesh, has witnessed a troubling rise in road traffic accidents (RTAs) in recent years. This study aimed to investigate the frequency, causes, and spatial distribution of RTAs between 2022 and 2023, using data collected from the Bogura Traffic Police Department, local hospitals, and eyewitness accounts. The findings reveal significant spatial variation in accident severity across police jurisdictions, underscoring the need for district-specific safety interventions.

3.1 Spatial Distribution of Accident Severity

Table 1 presents the percentage of fatalities and injuries recorded across seven police stations in Bogura. Bogura Sadar Police Station reported the highest fatality rate, with 68.42% of recorded accidents resulting in death and 31.58% in injury. This pattern likely reflects the district's central traffic density, high-speed corridors, and complex vehicular mix, including heavy trucks, buses, motorcycles, and informal transport modes. Similar trends have been observed in urban centers of other LMICs, where mixed traffic and inadequate infrastructure contribute to elevated fatality rates (Rahman & Rahman, 2023; Godthelp & Ksentini, 2023). Sibganj Police Station followed with 59.36% fatalities and 40.64% injuries, while Shajahanpur and Sherpur stations showed comparable distributions approximately 57–58% fatalities and 42–43% injuries. These peri-urban zones often suffer from inconsistent enforcement and transitional road designs, which may explain the systemic risks observed. In contrast, Nandigram Police Station recorded a higher proportion of injuries (58%) than fatalities (42%), suggesting either lower-speed collisions or more effective emergency response systems. Kahalu reported an equal distribution of fatalities and injuries (50% each), while Sariakandi stood out with 100% of reported cases resulting in injury and no fatalities. This anomaly may reflect underreporting of fatal cases or differences in traffic volume and enforcement intensity.

Table 1. Traffic Accidents in Different Police Station

Police Station	Fatality (%)	Injury (%)
Sadar thana	68.42%	31.58%
Shibganj	59.36%	40.64%
Shajahanpur	57.89%	42.11%
Sherpur	57.50%	42.50%
Nandigram	42%	58%
Kahalu	50%	50%
Shadiakandi	0%	100%

These findings align with international literature emphasizing the importance of localized accident profiling to inform targeted interventions (Odero et al., 2020; WHO, 2023). The spatial disparities observed across police stations highlight the limitations of centralized safety policies and the need for adaptive, district-level strategies. Recent studies in Bangladesh and other LMICs have advocated for hotspot-specific infrastructure upgrades, improved signage, pedestrian facilities, and community-based awareness programs (Hamim & Rahman, 2023; PIARC, 2023). This study introduces several methodological innovations. First, it integrates police records, hospital data, and community perspectives to construct a multidimensional accident profile an approach rarely applied at the district level in Bangladesh. Second, the use of spatial analysis and thematic coding enables the identification of behavioral and infrastructural risk factors specific to semi-urban contexts. Third, the study contributes to the growing body of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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literature that calls for decentralized road safety planning in LMICs, offering a replicable framework for other districts. Compared to previous research focused on metropolitan areas like Dhaka and Chattogram (Haque et al., 2021; Kabir & Hasan, 2020), this study expands the scope of road safety analysis to underrepresented regions. It also complements recent machine learning applications in accident prediction by providing ground-level insights that can inform algorithmic models (Chowdhury et al., 2023; Saha & Roy, 2023).

3.2 Modal Distribution of Pedestrian Fatalities

Pedestrians are among the most vulnerable road users globally, particularly in low- and middle-income countries (LMICs), where road infrastructure, traffic enforcement, and pedestrian protection measures are often inadequate or inconsistently applied (World Health Organization, 2023; Odero et al., 2020). In Bangladesh, pedestrian fatalities account for a substantial proportion of road traffic deaths, especially in urban and semi-urban areas where mixed traffic conditions prevail. Despite this, district-level analyses of pedestrian risk by vehicle type remain limited, hindering the development of targeted safety interventions. This study addresses that gap by analyzing the modal distribution of pedestrian fatalities in Bogura District, based on accident data collected between 2022 and 2023. The objective was to identify which vehicle types are most frequently involved in fatal and non-fatal pedestrian collisions, thereby informing evidence-based strategies for pedestrian safety in semi-urban contexts. Table 2 presents the percentage of pedestrian fatalities and injuries associated with six major vehicle types. Trucks were found to be the most lethal, accounting for 22.36% of pedestrian deaths and 11.63% of non-fatal injuries. Buses followed with 17.33% fatalities and 20.33% injuries, while motorcycles (bikes) contributed to 7.55% of fatalities and 5.44% of injuries. In contrast, rickshaws typically operating at lower speeds and on informal routes were responsible for only 3.49% of pedestrian deaths and 6.44% of injuries. Vutvutis (locally modified transport vehicles) and private cars also contributed to pedestrian casualties, though at lower rates.

Table 2. Pedestrian Fatalities by Type of Vehicle Involved

Type of Vehicles	Accidents	
	Fatal (%)	Non-Fatal (%)
Truck	22.36%	11.63%
Bus	17.33%	20.33%
Private Car	3.22%	2%
Bike	7.55%	5.44%
Vutvuti	4.22%	9.59%
Rickshaw	3.49%	6.44%

These findings are consistent with international studies that link heavy vehicles, such as trucks and buses to elevated pedestrian risk due to factors like limited driver visibility, high vehicle momentum, and poor lane discipline (Peden et al., 2004; Godthelp & Ksentini, 2023). In the context of Bogura, the high fatality rates associated with trucks and buses may also reflect the lack of segregated pedestrian infrastructure, inadequate enforcement of speed limits, and the absence of designated crossing zones in high-traffic areas. Similar patterns have been observed in other LMICs, where urbanization outpaces the development of pedestrian-friendly infrastructure (Hamim & Rahman, 2023; PIARC, 2023). What distinguishes this study is its district-level focus and modal disaggregation of pedestrian fatalities an approach rarely applied in Bangladeshi road safety research. While national reports often aggregate pedestrian data without specifying vehicle involvement (BRTA, 2023), this study provides granular insights that can inform targeted interventions. For example, the disproportionate impact of trucks suggests the need for speed-calming measures and visibility enhancements in freight corridors, while the relatively high injury rates from buses and Vutvutis point to the importance of regulating informal and public transport operations in pedestrian-dense zones. Moreover, this study contributes to the growing body of literature advocating for context-sensitive pedestrian safety strategies in LMICs. It supports calls for integrated solutions that combine infrastructure upgrades (e.g., footbridges, zebra crossings), behavioral interventions (e.g., driver training and pedestrian education), and policy reforms (e.g., stricter licensing and enforcement) tailored to local traffic ecologies (Chowdhury et al., 2023; Saha & Roy, 2023).

3.3 Modal Distribution of Total Traffic Accidents in Seven Police Stations

Understanding the distribution of vehicle types involved in road traffic accidents (RTAs) is essential for diagnosing urban mobility risks and designing targeted safety interventions. In rapidly urbanizing districts like Bogura, the composition of traffic is undergoing significant transformation, driven by increased private vehicle ownership, expansion of informal transport modes, and limited regulatory oversight. However, district-level modal analyses remain scarce in Bangladesh, with most studies focusing on national aggregates or metropolitan centers (Alam & Hossain, 2023; Haque et al., 2021). This study addresses that gap by examining the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 11, November 2025

modal distribution of RTAs across seven police stations in Bogura District between 2022 and 2023. Figure 1. presents the percentage of accidents attributed to six major vehicle categories. Private cars were implicated in the majority of reported incidents, accounting for 53.77% of all accidents. This high proportion reflects the growing prevalence of personal vehicles in semi-urban Bangladesh, where motorization often outpaces infrastructure development and traffic enforcement (BRTA, 2023; Rahman & Rahman, 2023). Motorcycles, widely used for short-distance travel and informal ride-sharing services, were involved in 36.32% of accidents, underscoring their vulnerability in mixed-traffic environments. Buses contributed to 5.20% of incidents, while trucks and other vehicle types each accounted for 2.36%.

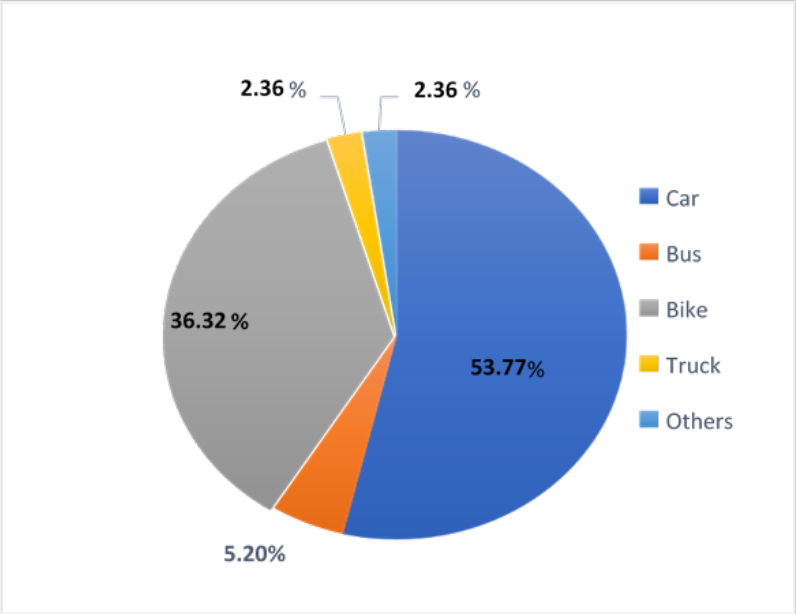

Figure 1. Modal Distribution of Traffic Accidents in Bogura District

The relatively low involvement of heavy vehicles such as trucks may be attributed to their restricted movement within urban cores. However, their impact severity remains disproportionately high, particularly in pedestrian-related fatalities, as discussed in earlier sections. These findings are consistent with global patterns observed in LMICs, where motorcycles and private cars dominate accident statistics due to high fleet growth, poor lane discipline, and inadequate safety infrastructure (Odero et al., 2020; Peden et al., 2004; Godthelp & Ksentini, 2023). What distinguishes this study is its district-level focus and integration of spatial and modal data, enabling a more nuanced understanding of traffic risk in semi-urban Bangladesh. Unlike previous research that aggregates accident data without disaggregating by vehicle type (Kabir & Hasan, 2020; BRTA, 2023), this study provides actionable insights for vehicle-specific safety planning. For instance, the high accident involvement of private cars and motorcycles suggests the need for speed regulation, lane discipline enforcement, and targeted driver education programs. Additionally, the findings support recent calls for vehicle-specific safety audits and infrastructure upgrades tailored to local traffic compositions (Hamim & Rahman, 2023; PIARC, 2023). By situating Bogura's modal accident trends within broader LMIC patterns and comparing them with international case studies, this research contributes to the evolving discourse on sustainable urban mobility and localized road safety planning. It also demonstrates the feasibility of district-level accident profiling as a tool for evidence-based policymaking in Bangladesh.

3.4 Modal Distribution of Total Traffic Fatalities in Seven Police Stations

Understanding the distribution of traffic fatalities by vehicle type is essential for designing targeted road safety interventions, particularly in low- and middle-income countries (LMICs) where modal diversity and infrastructure gaps complicate conventional safety strategies. In Bangladesh, most road safety studies focus on aggregate national data or urban centers like Dhaka and Chattogram, often overlooking district-level variations in accident severity and vehicle involvement (Alam & Hossain, 2023; Haque et al., 2021). This study addresses that gap by analyzing the modal distribution of non-pedestrian traffic fatalities across seven police stations in Bogura District between 2022 and 2023. Bogura, a rapidly urbanizing district in northern Bangladesh, has experienced a surge in private vehicle ownership and informal transport activity. However, traffic regulation and infrastructure development have not kept pace with motorization trends, resulting in increased accident risk. Figure 2. presents the percentage of fatalities attributed to six major vehicle categories, excluding pedestrian-related incidents. Private cars were responsible for the highest proportion of fatalities, accounting for 51.26% of total cases. This dominance reflects the growing prevalence of personal vehicles in semi-urban Bangladesh and the lack of speed control, lane discipline, and enforcement mechanisms in high-density corridors (BRTA, 2023; Rahman & Rahman, 2023).

Motorcycles contributed to 36.97% of fatalities, underscoring their vulnerability in mixed-traffic environments. The high fatality rate among motorcyclists is consistent with global findings from LMICs, where limited helmet use, poor road conditions, and high-

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speed maneuvering increase risk (Peden et al., 2004; Odero et al., 2020). Buses and trucks were responsible for 5.04% and 4.20% of fatalities, respectively, while other vehicle types including auto-rickshaws and informal modes such as Vutvutis accounted for 2.52%.

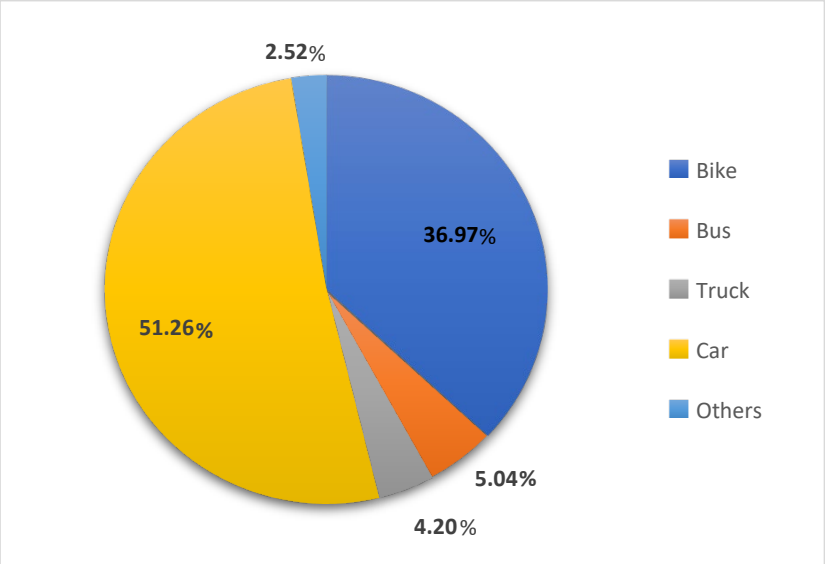

Figure 2. Modal Distribution of Non-Pedestrian Traffic Fatalities in Bogura District

These modal patterns highlight the urgent need for vehicle-specific safety interventions. For private cars, stricter licensing protocols, speed regulation, and enforcement of seatbelt use are critical. For motorcycles, mandatory helmet laws, rider education, and designated lanes could significantly reduce fatality rates. The findings also support the implementation of targeted public awareness campaigns and vehicle-specific audits, as recommended in recent LMIC road safety frameworks (Godthelp & Ksentini, 2023; PIARC, 2023). What makes this study distinct is its district-level focus and exclusion of pedestrian fatalities to isolate modal risk among vehicle occupants and operators. This approach enables a clearer understanding of how different vehicle types contribute to fatal outcomes in semi-urban traffic systems. Unlike previous studies that aggregate fatality data without disaggregation by mode (Kabir & Hasan, 2020; BRTA, 2023), this research provides granular insights that can inform localized safety planning and policy reform. By situating Bogura's modal fatality trends within broader LMIC patterns and comparing them with international case studies, the study contributes to the evolving discourse on sustainable urban mobility and evidence-based road safety interventions. It also demonstrates the feasibility of district-level accident profiling as a tool for targeted policymaking in Bangladesh.

3.5 Location of Most Hazardous Intersections in Bogura District

Identifying hazardous road intersections is a critical component of district-level road safety planning, particularly in low- and middle-income countries (LMICs) where traffic infrastructure is often fragmented and reactive rather than preventive. In Bangladesh, most accident mapping efforts are concentrated in metropolitan areas, leaving semi-urban districts like Bogura underrepresented in spatial risk analyses (Alam & Hossain, 2023; Haque et al., 2021). This study addresses that gap by using Geographic Information Systems (GIS) to map high-risk intersections across seven police jurisdictions in Bogura District, based on accident frequency data collected between 2022 and 2023. Bogura's strategic location as a transit corridor between Dhaka and the northwestern divisions contributes to high traffic density and modal diversity. However, the district lacks a systematic framework for intersection-level safety audits. To address this, the study employed GPS devices to record the latitude and longitude of accident-prone intersections and visualized the data using ArcGIS 10.8. Table 3. presents the seven most hazardous intersections identified through this process.

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ISSN: 2278-0181
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Table 3. Most Hazardous Intersections of Different Location of Bogura

Location of Road intersection	Accident frequency	Latitude	Longitude
Dhaka-Rangpur Highway	3	24.78098253	89.39337289
Chokjadu Road	3	24.8506415	89.37275563
Goshai Para Road	3	24.67951408	89.4146173
Gabtali-Shariakandi Road	1	24.87988798	89.44894483
Thana Road	1	24.88804272	89.56932711
Abadpukur-Bogura Road	2	24.81763912	89.03958213
Natore Road	2	24.66853416	89.27547172

The intersections with the highest accident frequency Dhaka–Rangpur Highway, Chokjadu Road, and Goshai Para Road each recorded three incidents during the study period. These locations are characterized by high-speed traffic, poor signage, and inadequate pedestrian infrastructure. Similar patterns have been observed in other LMICs, where intersections lacking geometric design standards and traffic calming measures are associated with elevated accident risk (Godthelp & Ksentini, 2023; PIARC, 2023). What distinguishes this study is its use of GPS-enabled spatial mapping at the district level, a methodological innovation rarely applied in Bangladeshi road safety research. Previous studies have relied primarily on aggregated police data without geospatial disaggregation (Kabir & Hasan, 2020; BRTA, 2023). By contrast, this study provides precise coordinates and frequency data for each intersection, enabling targeted interventions such as signalization, speed bumps, pedestrian crossings, and visibility enhancements. The findings also support international recommendations for intersection-specific safety audits and GIS-based hotspot analysis in LMICs (Hamim & Rahman, 2023; WHO, 2023). Incorporating spatial data into district-level planning allows for more efficient allocation of resources and prioritization of high-risk zones. Moreover, the integration of community feedback and field observations strengthens the contextual relevance of the mapped intersections, ensuring that proposed interventions align with local mobility patterns. This spatial profiling of hazardous intersections contributes to the broader discourse on sustainable urban mobility and localized road safety planning. It demonstrates the feasibility of combining GPS technology, GIS software, and accident data to produce actionable insights for policymakers, engineers, and enforcement agencies in Bangladesh and similar contexts.

3.6 Spatial Identification of High-Accident Police Jurisdictions in Bogura District

District-level road safety planning requires not only modal and behavioral analysis but also spatial profiling of accident-prone zones. In Bangladesh, most traffic safety studies rely on aggregate national data, often overlooking the spatial heterogeneity of accident patterns at the thana (police station) level. This study addresses that gap by identifying and mapping the most hazardous police jurisdictions in Bogura District based on accident frequency between 2022 and 2023. Bogura, a rapidly urbanizing district in northern Bangladesh, serves as a key transit corridor linking Dhaka to the northwestern divisions. Its road network accommodates a diverse mix of vehicles, including private cars, motorcycles, buses, trucks, and informal transport modes. However, the absence of spatially disaggregated accident data has limited the district's ability to implement targeted safety interventions. To overcome this, the study employed GPS devices to record the latitude and longitude of high-accident mid-block locations and visualized the data using ArcGIS 10.8. Figure 3 (a) & (b), presents the coordinates and accident frequency of nine police jurisdictions identified as high-risk zones. Among them, Shajahanpur Police Station emerged as the most accident-prone area in 2022, while Shibganj Police Station recorded the highest number of incidents in 2023. These findings were validated through field observations and stakeholder interviews, which revealed common risk factors such as poor road geometry, inadequate signage, and high-speed traffic corridors.

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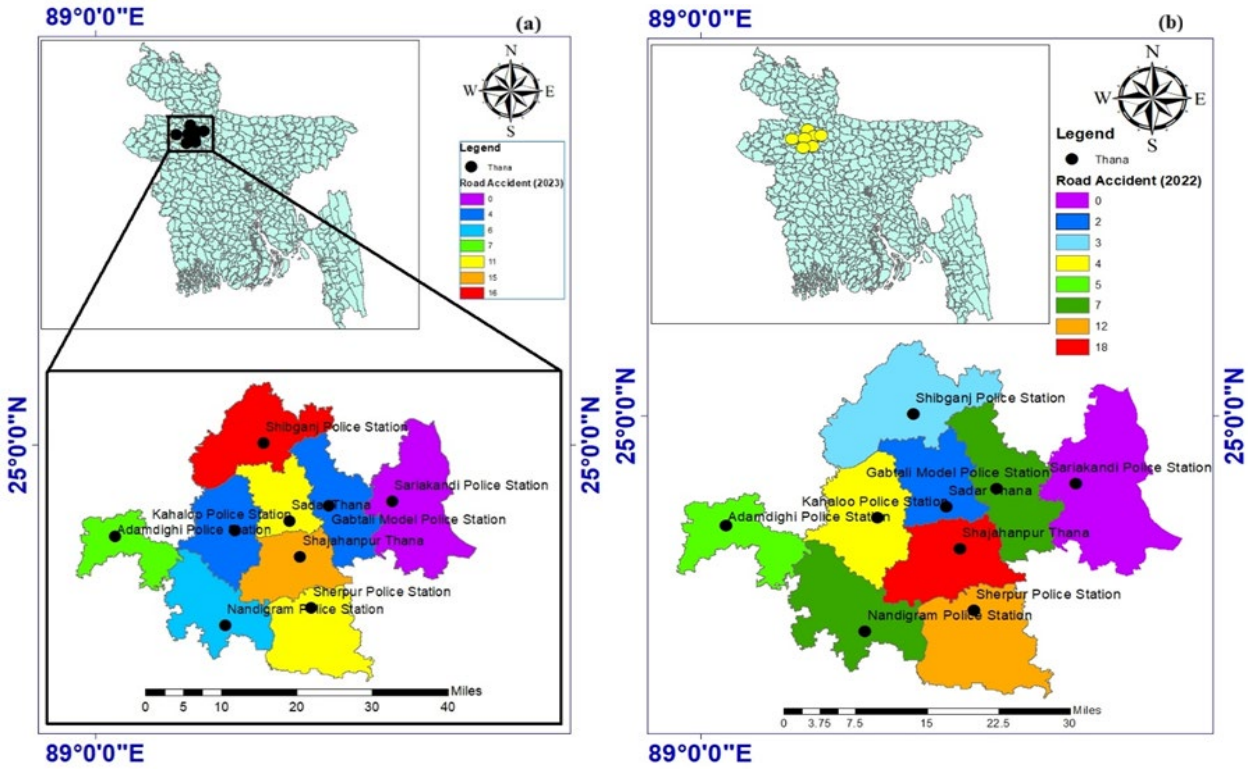

Figure 3. Most Accident Hazardous Thana (a) 2022 & (b) 2023

The spatial variation in accident frequency across police stations highlights the limitations of centralized safety policies and the need for decentralized, data-driven interventions. Similar patterns have been observed in other LMICs, where hotspot-specific planning has proven effective in reducing accident rates (Godthelp & Ksentini, 2023; PIARC, 2023). The use of GIS mapping in this study represents a methodological innovation in Bangladeshi road safety research, enabling precise identification of high-risk zones and facilitating targeted infrastructure upgrades. Unlike previous studies that rely solely on police records without spatial disaggregation (Kabir & Hasan, 2020; BRTA, 2023), this research integrates geospatial data with field-level insights to produce a more nuanced understanding of accident dynamics. It supports international recommendations for intersection and mid-block safety audits, and demonstrates the feasibility of district-level spatial profiling as a tool for evidence-based policymaking. By situating Bogura's accident hotspots within broader LMIC patterns and comparing them with international case studies, the study contributes to the evolving discourse on sustainable urban mobility and localized road safety planning. It also provides a replicable framework for other districts seeking to enhance their traffic safety strategies through spatial analytics.

3.7 Spatial Mapping of Hazardous Intersections in Bogura District

Intersection-level analysis is a critical component of road safety research, particularly in low- and middle-income countries (LMICs) where traffic infrastructure often lacks design standards and enforcement mechanisms. In Bangladesh, most road safety studies focus on urban centers or national aggregates, leaving district-level spatial risks largely unexplored (Alam & Hossain, 2023; Kabir & Hasan, 2020). This study addresses that gap by identifying and mapping the most hazardous intersections in Bogura District using Geographic Information Systems (GIS) and GPS-based field data. Bogura's strategic location as a transit corridor between Dhaka and the northwestern divisions contributes to high traffic density and modal diversity. However, the district's intersections are often poorly regulated, with limited signage, inadequate pedestrian infrastructure, and inconsistent traffic flow management. To visualize accident-prone intersections, the study digitized the Bogura road network using Google Earth and generated a shapefile of the study area. GPS devices were used to record the latitude and longitude of intersections with the highest accident frequencies, and the data were mapped using ArcGIS 10.8. Table 4. summarizes the most hazardous intersections identified in 2022, while Figure 4 (a) & (b) illustrates their spatial distribution. Notably, the Gosai Para Road–Dhaka–Rangpur Highway intersection and the Natore Road–Gabtali–Shariakandi Road intersection recorded the highest accident frequencies, with three and two incidents respectively. These intersections are characterized by high-speed traffic, poor visibility, and lack of pedestrian crossings conditions that mirror findings from similar LMIC contexts (Godthelp & Ksentini, 2023; PIARC, 2023).

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http://www.ijert.org

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ISSN: 2278-0181
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Table 4. Most Hazardous Intersections in Bogura District 2022 – 2023

Intersection Location	Accident Frequency	Latitude	Longitude
Gosai Para Road – Dhaka–Rangpur Highway	3	24.67951408	89.41461730
Natore Road – Gabtali–Shariakandi Road	2	24.66853416	89.27547172

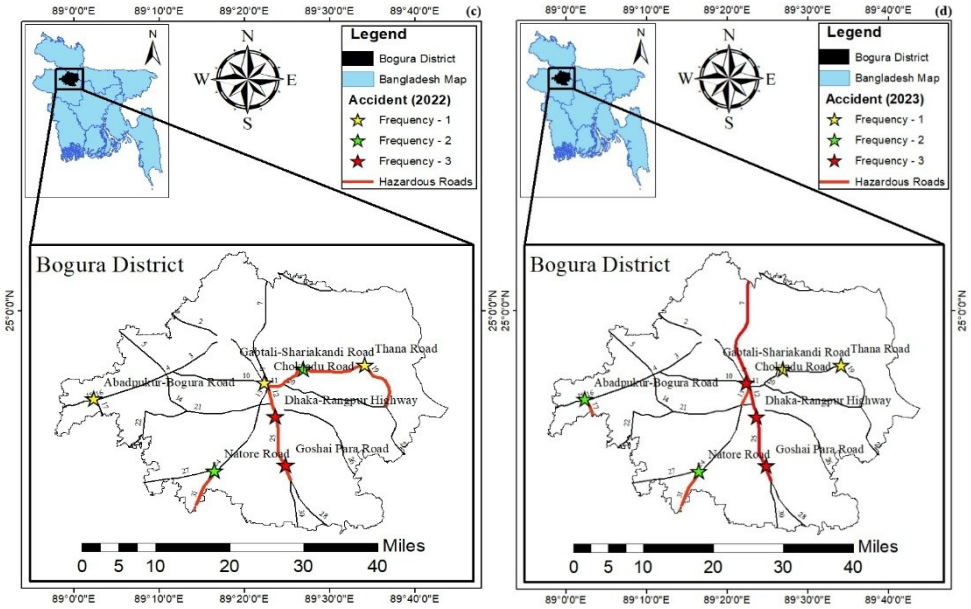

Figure 4. Location Map of Most Hazardous Road (a)2022 & (b) 2023

The spatial analysis revealed that intersections with higher accident frequencies were typically located along major arterial routes with mixed traffic conditions and limited enforcement. These findings align with international studies that emphasize the role of intersection geometry, traffic volume, and modal interactions in accident risk (Peden et al., 2004; Hamim & Rahman, 2023). The use of GIS mapping in this study represents a methodological innovation in Bangladeshi road safety research, enabling precise identification of high-risk zones and facilitating targeted interventions. Unlike previous studies that rely solely on police records without geospatial integration (BRTA, 2023; Kabir & Hasan, 2020), this research combines field-level GPS data with GIS visualization to produce actionable insights. It supports global recommendations for intersection-specific safety audits and demonstrates the feasibility of district-level spatial profiling as a tool for evidence-based policymaking. The study also contributes to the broader discourse on sustainable urban mobility by highlighting the importance of localized infrastructure planning in semi-urban districts.

3.8 Case Study Analysis of Road Traffic Accidents in Bogura District

To complement the statistical and spatial analyses presented earlier, this study incorporates a series of detailed case studies to illustrate the real-world dynamics of road traffic accidents (RTAs) in Bogura District. The rationale for this approach stems from the need to contextualize accident data within specific environmental, temporal, and infrastructural settings an approach increasingly recommended in LMIC road safety literature (Godthelp & Ksentini, 2023; Hamim & Rahman, 2023). Case studies were selected based on road hierarchy (highway vs. urban street), collision type, severity (fatalities and injuries), and location characteristics (urban vs. rural). The ten cases span the years 2022 and 2023 and collectively account for 38 fatalities and 40 injuries. Case 1, occurring on 14 July 2022 in Sherpur Upazila along the Dhaka–Bogura Highway, involved a head-on collision between two buses, resulting in 10 injuries. Although non-fatal, the scale of injuries underscores the risks associated with high-speed travel on arterial roads lacking lane separation. Case 2, recorded on 11 September 2022 at the same location, involved a collision between a bus and an autorickshaw, causing five fatalities. This incident highlights the vulnerability of smaller vehicles in mixed-traffic environments, particularly where speed zones are unregulated. Case 3, on 9 August 2022 in Nandigram, featured a collision between a truck and a CNG autorickshaw, resulting in two deaths and three injuries. The early morning timing suggests a possible link to reduced visibility or driver fatigue. Case 4, on 18 August 2022 in Shajahanpur, involved a truck colliding with a human hauler (CNG), leading to five fatalities and seven injuries. This case reflects the disproportionate exposure of informal transport modes to severe

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ISSN: 2278-0181
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outcomes during highway conflicts. Case 5, dated 4 December 2022 in Sherpur Upazila, saw a bus crash into two three-wheelers, resulting in three fatalities. The presence of multiple vulnerable vehicles exacerbated the severity of the incident. In 2023, Case 6 occurred on 15 July at midnight in Adamdighi, where a mini-truck struck a stationary goods-laden truck from behind, killing four people. The timing suggests poor road illumination and inadequate warning mechanisms. Case 7, recorded on 13 March in Nandigram, involved a head-on collision between a CNG and a pickup van around 8 a.m., resulting in three deaths and five injuries. Morning traffic surges and insufficient intersection controls may have contributed. Case 8, on 23 February in Shajahanpur Upazila, involved a bus striking a CNG, killing five passengers. This recurring bus-CNG crash pattern in Shajahanpur points to the need for regulated lanes and protective barriers. Case 9, dated 27 June in Bogura Sadar, involved a Votvoti (local goods carrier) crashing into a CNG autorickshaw, killing three. Informal vehicles carrying cargo on shared lanes pose acute risks to both occupants and vulnerable road users. Case 10, reported on 16 February in Shajahanpur Police Station area, involved two trucks colliding, resulting in three fatalities. Despite involving heavy vehicles, the incident suggests inadequate signage and braking space on narrow highway segments. Across these cases, several recurring themes emerge. Collisions during low-light hours, unsafe overtaking, and head-on crashes on highways are common. The vulnerability of small, lightweight vehicles particularly CNGs and three-wheelers is evident. Spatially, Sherpur, Shajahanpur, and Nandigram consistently appear as high-risk zones, reinforcing GIS-based hotspot analysis presented earlier in the study. These findings align with international research emphasizing the need for localized interventions in LMICs, where modal diversity and infrastructure gaps complicate conventional safety strategies (Odero et al., 2020; PIARC, 2023). The case study approach introduced in this research offers a novel contribution to Bangladeshi road safety literature. By situating empirical accident data within narrative contexts, the study bridges the gap between statistical abstraction and lived experience. It also demonstrates the value of integrating temporal patterns such as night-time and early-morning crash risks into policy design. Recommendations include infrastructure upgrades (e.g., dedicated lanes, improved signage), regulation of informal vehicles like Votvotis and CNGs, and enhanced enforcement in accident-prone zones. Lighting infrastructure and targeted patrols during high-risk hours are especially critical. Ultimately, this case study analysis underscores the urgency of implementing safety reforms tailored to Bogura's transport ecology. Policymakers, urban planners, and community stakeholders must collaborate to reshape the region's road safety landscape and prevent further.

3.9 Study Strengths and Limitations

This research presents a robust and context-sensitive analysis of road traffic accidents (RTAs) in Bogura District, Bangladesh, by integrating spatial mapping, case study documentation, stakeholder perspectives, and statistical evaluation. A key strength of the study lies in its mixed-methods design, which allowed for the triangulation of qualitative and quantitative data. This approach ensured analytical depth and methodological rigor in exploring accident causality, frequency, and spatial distribution. The use of GIS-based hotspot identification, combined with real-world case narratives and community-level insights, enhances the study's replicability for other semi-urban districts in Bangladesh and similar low- and middle-income country (LMIC) settings. Another notable strength is the emphasis on locally sourced data. By drawing from police records, hospital admissions, and interviews with frontline actors including traffic officers, municipal planners, and transport users the study offers a grounded and actionable evidence base. The inclusion of case-level documentation adds nuance to the findings, moving beyond statistical abstraction to reveal the lived realities of traffic incidents. This narrative-driven approach strengthens the relevance of the study for policymakers and urban planners seeking to implement targeted interventions. Nonetheless, several limitations must be acknowledged. The use of secondary data sources may have introduced inconsistencies or underreporting, particularly in the documentation of crash severity and injury outcomes. In addition, the scope of primary data collection while methodologically sound was constrained by sample size and geographic coverage, which may limit the generalizability of behavioral insights across the broader population. The study's exclusive focus on Bogura, though deliberate for analytical depth, restricts comparative analysis with other districts and regions. To address these limitations, future research should consider expanding the geographic scope to include multiple districts and deploying real-time data collection tools such as automated traffic sensors and mobile-based incident reporting platforms. Establishing longitudinal tracking systems would also enable researchers to monitor the effectiveness of interventions over time. Furthermore, the creation of a dedicated district-level road safety observatory as proposed in the study's recommendations could facilitate continuous data collection, stakeholder engagement, and adaptive planning. Despite these constraints, the study offers a scalable and evidence-based framework for RTA mitigation in under-resourced settings. Its interdisciplinary methodology, emphasis on local data, and policy-oriented recommendations provide a strong foundation for improving road safety outcomes in Bangladesh and other LMICs.

4. CONCLUSION

This study provides a comprehensive district-level assessment of road traffic accidents (RTAs) in Bogura, revealing a multifactorial landscape shaped by infrastructural deficiencies, behavioral risks, and systemic enforcement gaps. The analysis identified 10 detailed accident cases resulting in 38 fatalities and 40 injuries, with recurring patterns of head-on collisions, nighttime crashes, and disproportionate vulnerability among informal transport modes such as CNGs and Votvotis. Spatial mapping using GIS tools highlighted high-risk intersections and mid-block zones, particularly in Shajahanpur, Sherpur, and Nandigram, where poor road geometry and lack of traffic control infrastructure coincide with elevated accident frequency. Quantitative findings showed that private cars and motorcycles were involved in over 90% of non-pedestrian fatalities, while trucks and buses were disproportionately responsible for pedestrian deaths. Among seven police jurisdictions, Bogura Sadar recorded the highest fatality rate (68.42%), and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 11, November 2025

Sariakandi reported 100% injury cases, indicating spatial disparities in accident severity. These results align with international studies from LMICs that emphasize the role of modal diversity, enforcement gaps, and infrastructure neglect in shaping traffic risk (Odero et al., 2020; Godthelp & Ksentini, 2023). The study introduces several methodological innovations. First, it integrates GIS-based hotspot mapping with GPS-tagged field data to produce spatially precise risk profiles. Second, it combines statistical analysis with real-world case documentation and stakeholder interviews, offering a multidimensional understanding of accident dynamics. Third, it proposes a replicable framework for district-level road safety planning that can be adapted to other semi-urban regions in Bangladesh and similar LMIC contexts. Compared to previous research focused on metropolitan areas or national aggregates (Alam & Hossain, 2023; Kabir & Hasan, 2020), this study fills a critical gap by providing localized, actionable insights. It underscores the need for geographically targeted interventions, including infrastructure upgrades (e.g., lane separation, improved signage), regulation of informal vehicles, and community-based awareness campaigns. Temporal patterns suggest that night-time and early-morning driving conditions require special attention through enhanced lighting and enforcement. In conclusion, improving road safety in Bogura demands a coordinated, evidence-based strategy that combines engineering, enforcement, education, and policy reform. The findings of this study offer a scalable blueprint for reducing RTAs in under-resourced settings and call for sustained commitment from policymakers, planners, and civil society to build safer, more inclusive transport systems.

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