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Research article

Identification and analysis of accident black spots using Geographic Information System (GIS): A study on Kushtia-Jhenaidah national highway (N704), Bangladesh

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ABSTRACT

Road accidents, mostly on national highways, pose a significant public health and economic burden in Bangladesh, requiring in-depth analysis for road safety measures. This study comprehensively analyzes accident trends, characteristics, causes, and consequences by identifying the accident black spots on the Kushtia-Jhenaidah National Highway (N704). Accident records from 2017 to 2021 were collected from nearby police stations. Additionally, using a cluster random sampling approach, a questionnaire survey with 100 respondents (50% drivers and 50% general road users) was also conducted to capture diverse perceptions and behaviors. The study utilizes descriptive methods, such as trends analysis and frequency distributions, alongside spatial analysis techniques, including severity index, Kernel Density Estimation, and hotspot analysis. Findings indicate a decrease in accidents from 2018 to 2021, yet a concerning rise in fatalities in 2021. Trucks (47.9%) emerge as the primary contributor among 169 vehicles involved in accidents. Head-on collisions (36%) are prevalent, attributed to both human and environmental factors, including driver inexperience (56%), mobile phone use while driving (78%), lack of proper training (12%), overspeeding (28.3%), and nighttime driving (54%) influenced by seasons and land use. Mostly, victims aged from 20 to 40, where men are more affected by fatalities (70.7%) and women by injuries (86.3%). Out of 35 identified accident spots, including Battail, Bittipara Bazar, Laxmipur Bazar, Modhupur Bazar, IU Main Gate, Sheikhpara Bazar, and DM College Front, are designated as blackspot zones based on the frequency of accidents, deaths, and injuries. The study concludes by recommending targeted interventions, driver training, infrastructure improvements, regulatory measures, and victim assistance in collaboration with local and national agencies to enhance road safety and mitigate accident risks.

1. Introduction

Road traffic accidents (RTAs) are a significant concern for developing countries and substantially impact their development [1]. An RTA occurs when a motor vehicle collides with another vehicle, pedestrian, stationary item, or animal near the road, often resulting in various casualties, such as death, injuries, or property damage [2]. The areas where the frequency and characteristics of accidents are prominent over a long period (usually one to three years) due to factors such as traffic, road conditions, climate, and environment are called road accident black spots, also known as hazardous or high-risk locations [3–5].

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There are many reasons for RTAs, but human errors are the prominent cause of road accidents [6], including driving errors, excess speed, and violations of signals [7]. Other causes include environmental factors and road conditions, mechanical factors (older and less safe motor vehicles), the number of vehicles (bicycles, motorcycles, and three-wheeled motorized rickshaws), the expansion of road networks, national development projects, the mix of high-speed, heavy traffic with slower, smaller vehicles as well as pedestrians, ineffective enforcement of traffic laws, the absence of emergency services, and others [7–10]. The main variables that affect traffic fatalities are gender, age of the drivers, condition of the vehicles, overloading, inappropriate safety status, poor visibility, inadequate street lighting, weekends, passenger vehicles, experiences of drivers, morning rush hour, and stormy weather [11]. Several international studies [12–14] have found significant correlations between meteorological factors and the overall injury accident frequency. Depending on the type of route (rural roads, urban roads, or motorways), the sign and magnitude of these relationships vary [15].

Road accidents create both life and economic losses. Out of more than 50 individually documented causes in the most recent year, road traffic accidents were ranked as the eighth most common cause of disability or death, and each year, 1.35 million people die in traffic-related accidents [16], and as many as 50 million are injured [17], and the number is still rising. In those accidents, children and young adults aged 5 to 29 are primarily killed in road traffic accidents [18]. By 2030, road traffic accidents are expected to rise to fifth as the leading cause of death [19]. Developing nations account for 92% of worldwide traffic fatalities despite owning only 60% of the world's vehicles [18]. In addition, road traffic accidents cost developing nations between 1% and 3% of their annual GDP [20].

Road accidents are a significant concern in Bangladesh, claiming thousands of lives each year. Studies have consistently highlighted the alarming prevalence of road accidents in Bangladesh, with official police records suggesting annual crashes exceeding 2,500 and fatalities surpassing 3,000 [21,22]. However, underreporting is a significant concern, with estimates suggesting the actual figures could be four times higher [22]. Disturbingly, police records from 2015 indicate a staggering 84,000 road accidents over the past 21 years, leading to 56,000 fatalities and 63,000 injuries [23]. Despite the country's population expanding by 1.9 times between 1971 and 2007, the incidence of accidents and fatalities per 100,000 people increased, revealing a concerning trend [24]. Shockingly, Bangladesh records 1,064 traffic fatalities per 100,000 automobiles, translating to an average of eight daily road accident-related deaths [25,26].

Several research studies have focused on identifying high-risk locations (HRLs) and understanding the contributing factors to accidents. For example, GIS has been used to analyze crash data on the Dhaka-Aricha-Banglabandha highway, defining HRLs as locations with three or more fatal crashes within a specific stretch [27]. Other studies have identified HRLs on various highways, including Dhaka-Mawa-Barisal-Patuakhali [28], Dhaka-Sylhet-Tamabil [29], and Dhaka-Chittagong [30]. These studies highlight the importance of considering weather conditions, vehicle types, driver behavior, and road geometry in understanding accident patterns. Specific concerns have been raised regarding vulnerable road users like pedestrians, particularly within the 16–20 age group [31]. Rural areas and non-junction locations appear to be hotspots for accidents [28,31]. Additionally, studies have identified specific highway sections with a higher risk of fatalities, such as Kanchpur, Daudkandi, Mainamati, and Fani on the Dhaka-Chittagong Highway [30]. Furthermore, research has examined the impact of geometric parameters on accident occurrence. The selected segment of the Pabna-Sirajganj highway (N6) is hazardous, with people aged 25–44 most susceptible to accidents [32]. Head-on collisions were identified as a significant contributor to fatalities on the Pabna-Bera highway, with the death rate increasing during the rainy season [33]. Several studies have proposed solutions to improve road safety in Bangladesh. Traffic data have been analyzed to develop a 3D model for upgrading the Rajshahi-Sirajganj highway to four lanes [34]. In addition to identifying black spots, interventions like speed control measures and improved intersection design are also suggested on the Dhaka-Aricha highway [35]. Similarly, based on the analysis of accident data, safety improvements have been proposed for the Joydebpur-Jamuna Bridge National Highway [36].

The Kushtia-Jhenaidah Highway fosters regional connectivity, seaport access, and trade within the South Asia Subregional Economic Cooperation (SASEC) corridor, connecting Bangladesh with neighboring countries like India and Bhutan, leading to a higher volume of traffic on the highway, unfortunately causing a high frequency of road accidents. However, there is a lack of knowledge regarding accident trends, characteristics, and black spots that hinder effective interventions for improved safety on this route. This study aims to fill this critical gap by employing a comprehensive approach, utilizing geospatial methods alongside detailed surveys. By analyzing five years of accident data and conducting field surveys, the study will identify hazardous locations and examine the root causes and consequences of accidents, offering valuable insights for targeted interventions. Furthermore, visualizing accident-prone areas through GIS mapping will enhance understanding of the spatial distribution of risks. This study's findings hold immense potential to inform data-driven road safety strategies, infrastructure upgrades, and design modifications explicitly tailored to the context of the Kushtia-Jhenaidah highway. This study paves the way for a safer and more sustainable transportation linkage for Bangladesh and beyond by addressing the current knowledge gap and fostering evidence-based interventions.

2. Materials and methods

2.1. Study route

The Kushtia-Jhenaidah National Highway (N704) is situated in the Khulna division, connecting the northwest and southwest regions of Bangladesh. It is located between $23^\circ 54'$ and $23^\circ 33'$ north latitudes and between $89^\circ 07'$ and $89^\circ 10'$ east longitudes. It consists of three Upazilas under two districts, i.e., Kushtia Sadar of Kushtia district, Shailkupa, and Jhenaidah Sadar of Jhenaidah district. The total length of this highway is 82 km, but for the purpose of the study, a 45 km length (Fig. 1) has been selected along the entire route from Mojompur, Kushtia, to Arappur, Jhenaidah. It is a two-lane bituminous road.

2.2. Data collection

2.2.1. Primary data

Primary data were collected through a structured questionnaire survey and physical observation of the study area. To make data collection cost-effective, convenient, and manageable, a moderate sample size of 100 was considered (50 of whom were drivers, and the remaining 50 were general road users). The sample size was large enough to provide a good representation of the population as a cluster random sampling method was employed for data collection in this study. Having equal representation from both drivers and general road users is crucial for capturing a comprehensive understanding of the factors influencing driving behavior and road safety.

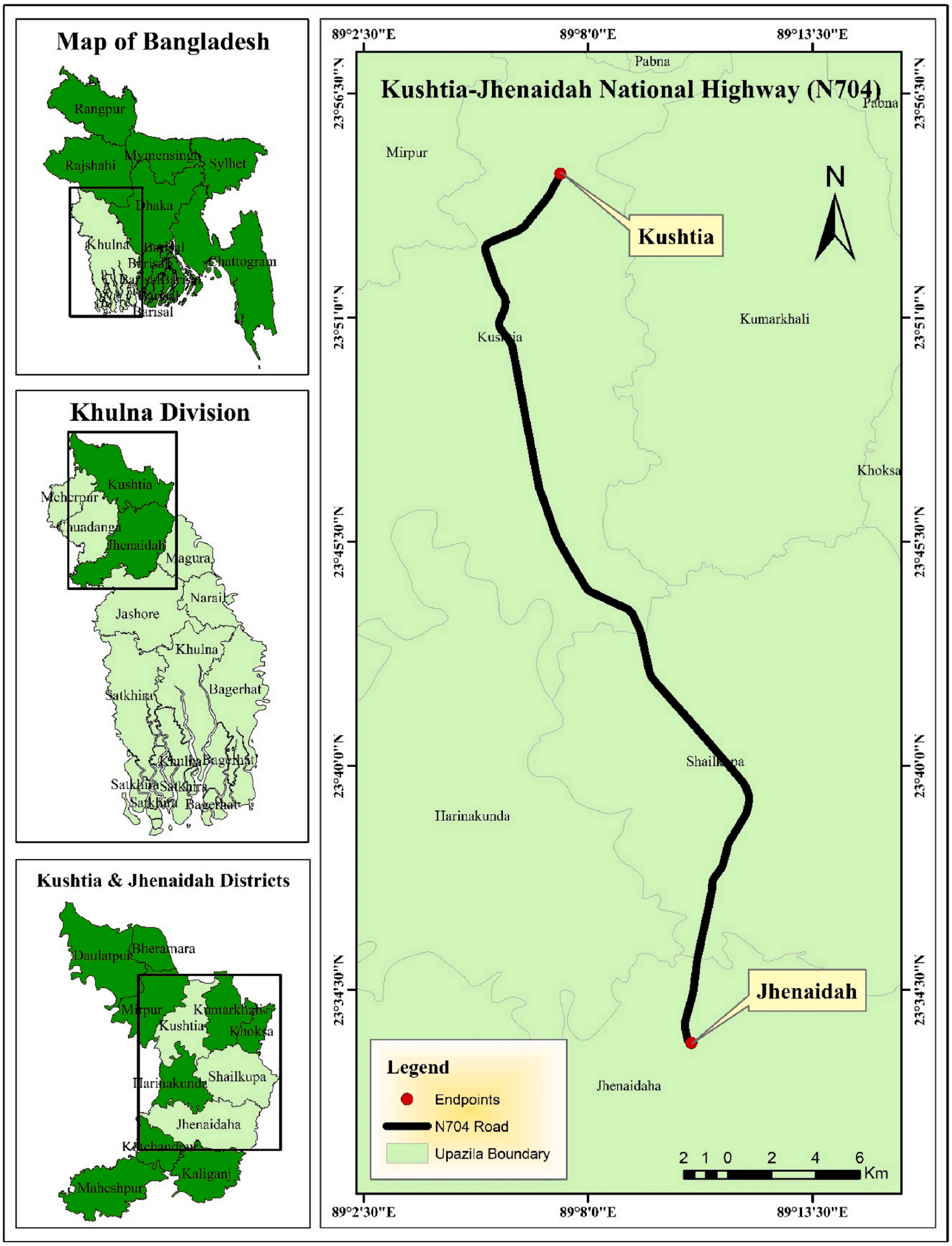

Fig. 1. Study area - Kushtia-Jhenaidah national highway (N704).

The Ground Control Points (GCPs) were collected within the selected road section to ensure accurate geospatial positioning of accident locations. These GCPs were acquired using a combination of Google Maps and precise coordinates measured using handheld GPS devices [37]. This dual approach helped to maximize data coverage and mitigate potential errors.

2.2.2. Secondary data

Secondary data were collected from various published sources, including research papers, books, online journals, census reports, government and non-government projects, and recently published thesis papers. Accident records (2017–2021) from nearby police stations as First Information Records (FIR) have been used to identify the accident-prone locations of the National Highway (N704). Information from the Bangladesh Road Transport Authority (BRTA) and the Roads and Highway Department (RHD) of both Kushtia and Jhenaidah Circles was also needed for this study to understand the causes and consequences of road accidents in the selected road section. To compensate for insufficient police reports, information about the crashes was also compiled from respected publications such as The Daily Star, Dhaka Tribune, Bdnews24.com, and New Age BD.

2.3. Data analysis

Both qualitative and quantitative methods were used for data analysis. The qualitative method includes all types of descriptive analysis, like accident trends, characteristics, causes, and consequences-related data, which were analyzed and visualized by Microsoft Excel 2021. On the other hand, quantitative methods, including spatial analysis techniques like density analysis, cluster analysis, and hotspot analysis, were done in ArcGIS 10.8, and these analyses are further discussed in the following sub-section.

2.3.1. Severity index

The accident severity index (SI) was determined to measure the seriousness of an accident based on five years of accident data. Without weighted data, it is extremely challenging to evaluate whether the observed clustering is accurate or not. A higher crash severity index indicates a more severe crash directly correlates with higher expenditures [38]. According to the Belgian severity weighting system for analyzing high and low clustering of accident data, individual weights of 5, 3, and 1 are provided for fatal, serious, and slight accidents, respectively [39]. Although there is no universally accepted standard severity index (SI) for identifying accident black spots, the location of more than 40 WSI values was considered an accidental black spot [40]. So, in this study, locations with SI greater than 40 are termed accident black spots. The severity index (SI) can be calculated for each location using the following equation (1) [38]:

$$\mathrm{SI} = 5\mathrm{D} + 3\mathrm{S} + \mathrm{L} \tag{1}$$

where SI is the severity index for each location, D is the total number of deaths, S is the total number of serious injuries, and L is the total amount of slight injuries.

2.3.2. Cluster analysis

Cluster analysis is a measure of spatial autocorrelation. It was performed to observe the distribution pattern of accidents. The spatial autocorrelation technique examines both the locations and values of features simultaneously [41] and measures whether the distribution of accidents is dispersed, clustered, or randomly distributed by taking the entire data set and producing a single output [42]. The value of Moran's I range from - 1 to 1 [43]. If the Moran's Index value is close to 1, the data contain spatial autocorrelation and a cluster pattern; if the Moran's Index value is close to −1, the data are discontinuous and scattered [44]. Based on the weight matrix, Moran's statistic is computed using the fundamental equation (2) as shown below [45]:

$$I = \frac{n \sum \sum w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{W \sum (x_i - \bar{x})^2} \tag{2}$$

Where,

x_i = The interval variable's value in areal units i

w_{ij} = Spatial weight between i and j

2.3.3. Kernel density estimation (KDE)

The kernel density estimation was performed to generate a subjective heat map of the variation in the range of traffic accident statistics from high to low. This measurement calculates the proportion of accidents likely to occur at any specific map location [41]. Cell size and bandwidth are the main parameters that influence the KDE method most. The selection of bandwidth is quite subjective [46]. A large bandwidth creates over-smoothed density estimation, whereas a small bandwidth produces inadequate smoothing [47]. A 1000 m bandwidth value and a 100 m cell size were considered in this study to visualize RTA hotspots easily. The kernel density estimation was carried out using the following equation (3) [46]:

$$f(x,y) = \frac{1}{nh^2} \sum_{i=1}^{n} K\left(\frac{d_i}{h}\right) \tag{3}$$

Where,

f (x, y) = The density estimate of the location (x, y)
n = The number of observations
h = Bandwidth
K = The kernel function,
di = Distance between the location (x, y) and the location of the observation.

2.3.4. Hotspots analysis

A hotspot analysis was performed using the number of accident records to determine where the accident cluster is located in the study route. Accidental hot spots are defined as sites with anomalous clustering of crash patterns [48]. Hotspot analysis is a form of spatial analysis and mapping technique that uses the Getis-Ord Gi* statistic to locate clusters of spatial occurrences [49]. This statistic computes the degree of suggestion that emerges from the concentration of weighted points and detects statistically significant hotspots and cold areas [50]. High-value points of data cluster more strongly when positive Z values reflect hot spots [51]. Similarly, the lower the z-score for statistically significant negative z-scores, the more concentrated the cluster of low values [52], and values close to zero point to a random distribution of clusters with significance [53]. The Getis-Ord local statistic can be proposed as the following equation (4) [54]:

$$G_i^* \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{x} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \tag{4}$$

where n is the number of features, x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weights between the feature i and j, and S is the standard deviation of all features.

3. Results and discussions

3.1. Road accident trend analysis

The general analysis of the accident data from 2017 to 2021 provides an overview of the accident trends. Fig. 2 shows that on the Kushtia-Jhenaidah national highway, 118 accidents occurred in the last five years, with deaths and injuries of 121 and 124, respectively. Here, all injuries are considered severe because of grievous collisions.

The highest number of accidents was found in 2018; this number was 9 in 2017, the least among the five years of data on road accidents. Though the trend line indicates that the number of accidents is decreasing from 2018 to 2021, the number of deaths again increased in 2021 compared to the previous years.

3.2. Accident characteristics analysis

Many factors are involved in the causes of road accidents on this section of the route. These factors are vehicle, human, and road environment factors are shown in Table 1.

Between 2017 and 2021, 169 vehicles were involved in road accidents. Trucks comprised nearly half (47.9%) of these accidents, with a staggering 81 implicated cases. This stark contrast is further highlighted by the minimal involvement of smaller vehicles like micro (3) and bicycles (4) over the five years. While trucks (47.9%) dominate the data, other vehicle types also contribute significantly.

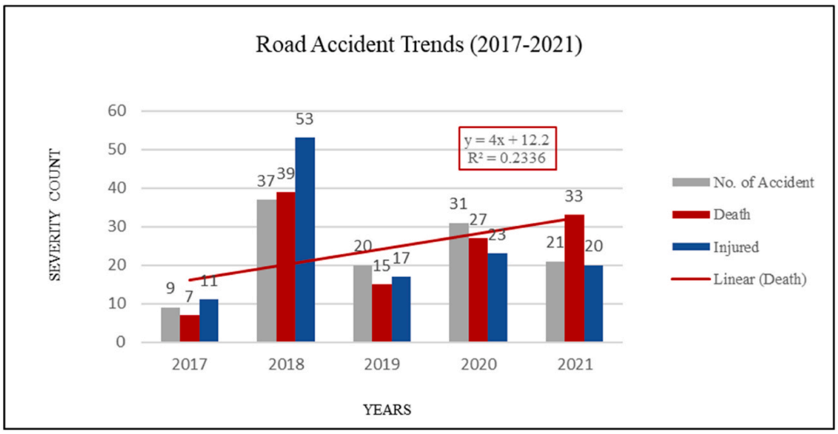

Fig. 2. Road accident trends in Kushtia-Jhenaidah national highway (2017–2021).

Table 1
Distribution of RTA variables.

Category	Variable	n	(%)
Vehicle Factors	**Vehicular Types**		
	Bus	11	6.5
	Truck	81	47.9
	Micro	3	1.8
	Car	7	4.1
	Pick-up	15	8.9
	3 Wheeler	26	15.4
	Motor cycle	22	13
	Bicycle	4	2.4
	Collision Types		
	Head on	36	36
	Rear end	21	21
	Side on	12	12
	Others	31	31
	Repairing Conditions		
	Regular	47	94
	Irregular	3	6
Human Factors	**Driving Experience**		
	<10 years	28	56
	11–20 years	12	24
	21–30 years	9	18
	>30 years	1	2
	Driving Skill		
	Formal	6	12
	Informal	34	68
	Both (Formal & Informal)	4	8
	No training	6	12
	Driving License		
	Yes	24	48
	No	26	52
	Driving Hours in a Day		
	0–6 h	3	6
	6–12 h	42	84
	12–18 h	5	10
	Weekly Driving Status		
	4 days	1	2
	5 days	5	10
	6 days	11	22
	7 days	33	66
	Use of Mobile Phone while Driving		
	Yes	39	78
	No	11	22
Road Environment Factors	**Land Use Types**		
	Residential	8	22.9
	Commercial	25	71.4
	Institutional	2	5.7
	Road Geometry		
	Straight	29	82.9
	Horizontal curve	6	17.1
	Junction Types		
	T-Junction	10	28.6
	Skewed Junction	5	14.3
	Cross Roads	2	5.7
	Skewed-cross Junction	6	17.1
	Staggered Junction	3	8.6
	Staggered and Skewed Junction	4	11.4
	Not Junction	5	14.3
	Surface Quality		
	Good	28	80
	Bad	5	14.3
	Under repair	2	5.7
	Accidents in Different Hours		
	12:00–06:00 a.m.	28	28
	06:00–12:00 a.m.	28	28
	12:00–06:00 p.m.	18	18
	06:00–12:00 p.m.	26	26
	Accidents in Different Seasons		
	Summer	13	13
	Rainy	57	57
	Winter	30	30

Source: Field Survey (June–July 2022)

Three-wheelers and motorcycles follow in second and third place as primary contributors to accidents, accounting for 15.4% and 13%, respectively. The analysis also delves into the types of collisions involved. Head-on collisions lead the pack, responsible for 36% of accidents. In many of these cases, sleepiness and loss of control were identified as the main reasons. While 94% of vehicles undergo regular repairs upon defect detection, financial constraints hinder immediate action for the remaining 6%.

A closer look at human factors reveals significant concerns on this highway. A striking 56% of drivers have less than 10 years of experience, while seasoned drivers with over 30 years of experience constitute a mere 2%. This paints a picture of a young driving population potentially lacking the skills and maturity for safe highway navigation. Furthermore, formal highway training only reaches 12%, primarily through NGOs, leaving the majority (68%) to rely on informal, potentially inconsistent on-the-job learning. Worryingly, 12% of drivers, primarily new ones, have received no formal or informal training, raising serious safety concerns. It is a matter of concern that the number of unlicensed vehicles on this highway is higher than that of licensed vehicles. 84% of drivers drive their vehicles on this route for 6–12 h daily because most are involved in other activities, especially businesses. Some even adjust their working schedules seasonally, further complicating the safety landscape. On the other hand, 10% drive for shorter durations (0–6 h), likely balancing part-time jobs or studies with driving. The frequency and duration of driving paint another concerning picture. 66% are on the road most days of the week, with no one driving less than four days. Additionally, 5–6 non-local drivers appear weekly, introducing unfamiliar driving patterns and potentially impacting traffic flow and safety. A worrying concern is that 78% of drivers use a mobile phone while driving. Mostly, the drivers of three-wheelers who drive on nearby roadways don't feel the necessity to use mobile phones. Meanwhile, long-distance bus and truck drivers justify their phone use despite the apparent risks of distraction.

Excluding IU Main Gate and DM College Front, the land surrounding this highway is primarily residential (22.9%) and commercial (71.4%). These commercial areas, often called Bazar locally, experience high traffic volumes and consequently account for most accident fatalities. Analyzing the roads, 82.9% are straight, with the remaining 17.1% featuring horizontal curves. Notably, 29 out of 35 accident points lie on these near-straight sections, highlighting their inherent danger. The remaining six are located at horizontally curved sections (Battail, Vadalia Bazar, Modhupur Bazar, Shantidanga, Modondanga Bazar, and Chandpur). While there are seven types of road junctions on the highway, accidents primarily occur at T-junctions, skewed intersections, skewed-cross junctions, and non-junctions. Despite 80% of the road surface being in good condition, 14.3% suffer deterioration due to bitumen and stone damage. An additional 5.7% is under repair, raising concerns about long-term durability despite ongoing construction efforts. Interestingly, accident distribution is skewed towards nighttime (54%) compared to daytime (46%). This discrepancy is attributed to drivers exceeding speed limits at night, particularly between June and October and January to February. The rainy season (June to October) and winter months (November to February) become the primary reason for these accidents due to heavy rainfall and foggy conditions impacting visibility. Trucks and other large vehicles are particularly vulnerable during these periods, while increased traffic volume can cause drivers to lose control, worsening the situation. Finally, the abundance of earthen access points along the highway contributes further to the overall accident rate.

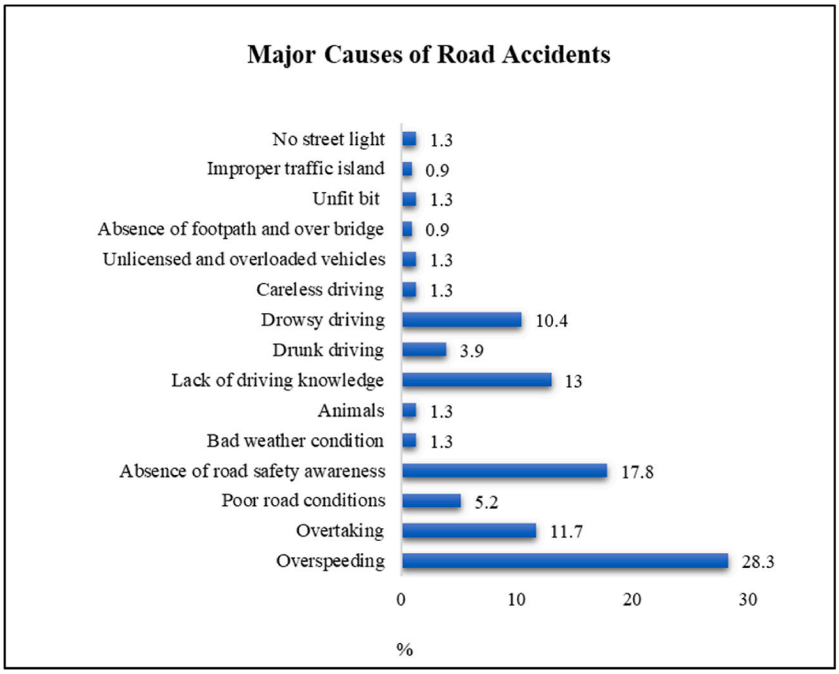

Fig. 3. Major causes of road accidents.

In essence, the surrounding land use, combined with specific road characteristics like near-straight sections and horizontal curves, contribute to a complex web of factors influencing accident patterns on this highway. Addressing these factors, from managing traffic flow and enforcing speed limits to improving visibility during weather extremes, will reduce accidents and ensure safer travel for all.

3.3. Causes of RTAs

Fig. 3 highlights two significant contributors to road accidents: overspeeding at 28.3% and a lack of safety awareness at 17.8%. These factors pose a significant threat, especially in hazardous road locations where additional causes like lack of driving skills (13%), overtaking (11.7%), and drowsy driving (10.4%) come into play. While less frequent, poor road conditions (5.2%) and drunk driving (3.9%) should not be overlooked as contributors to these accidents.

3.4. Accident black spots identification analysis

3.4.1. Cluster pattern of the accidents

Fig. 4 depicts the findings of the spatial autocorrelation (Moran's I) statistic of accident data for five years. The observed z-score value is 1.32, which indicates that the spatial pattern is standard deviations above the mean, and the p-value is 0.18, which is more than the conventional significance level of 0.05, showing that there's insufficient proof to reject the null hypothesis that the observed spatial pattern is no different from random. It displays the data for the total number of accidents; the pattern is otherwise random, and there is no overall accident clustering for the five years.

3.4.2. Accident severity

Based on the deaths and injuries, severity index (SI) values are calculated, and black spots are identified and ranked below in Table 2. These nine black spots – Battail, Vadalia Bazar, Bittipara Bazar, Laxmipur Bazar, Modhupur Bazar, IU Main Gate area, Sheikhpara Bazar, Modondanga Bazar, and Bhatai Bazar – stand out due to their higher SI values, indicating a greater concentration of serious accidents. Notably, the remaining 26 locations along the highway exhibit lower to the lowest severity values and, therefore, aren't classified as black spots. Interestingly, the central section of the highway displays a higher prevalence of severe accidents than the other segments.

3.4.3. Density analysis

In Fig. 5, red, yellow, and blue colors highlight locations with high, medium, and low collision intensity based on accident number.

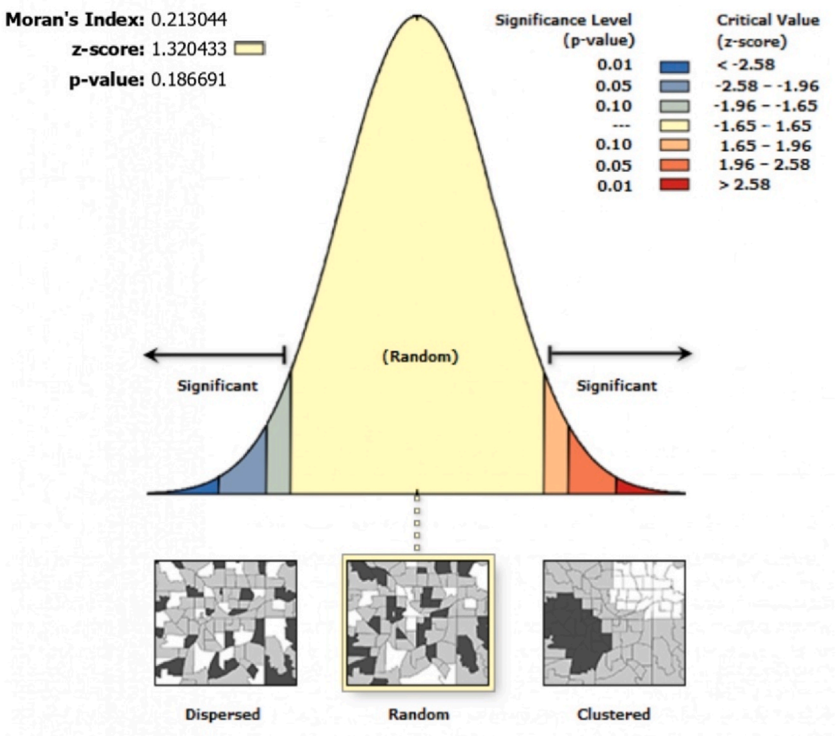

Fig. 4. Spatial autocorrelation report of the five-year accident data.

Table 2
Ranking of accident black spots based on SI value.

SI No.	Accident Black Spots	SI Value	Ranking
1	Laxmipur Bazar	107	1st
2	IU Main Gate	94	2nd
3	Sheikhpara Bazar	79	3rd
4	Modhupur Bazar	60	4th
5	Bittipara Bazar	49	5th
6	Vadalia Bazar	48	6th
7	Battail	48	7th
8	Modondanga Bazar	45	8th
9	Bhatai Bazar	43	9th

Source: Accident Records (2017–2021) from Police Stations

This subjective map doesn't indicate the statistical significance of the areas with high or low accident frequency across the study route. However, this map shows that locations with high accident frequency are generally associated with road intersections. In addition, more accident frequency is found in the southern part of the density map than in the northern part, and a high accident frequency is located in the middle part (Bittipara Bazar, Laxmipur Bazar, Modhupur Bazar, Shantidanga, IU Main Gate area, Sheikhpara Bazar, DM College Front, and Sreerampur) of the study area.

3.4.4. Accident hotspots

Fig. 6 represents the sub-clusters of the highly accident-prone and less accident-prone areas in five years. The red and blue colors represent significant spatial clustering of high values (hotspots) and spatial clustering of low values (cold spot) locations, respectively, and the yellow color represents insignificant areas. Accident rates are higher in hotspot areas than in coldspot areas. With 95%–99% confidence levels, from 35 accidental locations, 6 locations are found to be accidental hotspots, which are shown in Table 3. The remaining locations are either accidental cold spots (18 locations) or not confident locations (11 locations).

3.5. Physical characteristics of blackspot locations

A total of 12 places are found to be blackspot zones from three different analyses in this study: severity index, KDE, and hotspot analysis. 71 out of 118 accidents occurred in those blackspot zones. Table 4 presents the physical characteristics of the 12 blackspot locations identified. All the hotspot locations lack streetlights and traffic signals, although traffic signs are available there. Again, the traffic signs are not properly placed, and most are broken or unreadable. Only the IU Main Gate has a speed breaker, and the rest of the places do not. In addition, road markings are not available in 5 out of 12 accident black spots, and they are almost obscure.

3.6. Consequences of RTAs

Consequences of road accidents are evaluated according to fatal and non-fatal accidents based on victim categories (driver, helper, passenger, and pedestrian), gender approach (male, female, and children), and age range of the victims. The impact of road accidents can also be accounted for by assessing the property losses of the victims. On a broader scale, disruptions caused by accidents on this road can ripple through the country's GDP, affecting connectivity, trade, and overall economic efficiency.

An analysis of Table 5 reveals a striking pattern: passengers constitute the majority of fatalities and injuries recorded on this highway. This observation holds for both death and injury rates. This pattern likely reflects the prevalence of public transportation on this particular route compared to private vehicles. Further, the data highlights a concerning gender disparity. Men consistently exhibit higher death and injury rates, likely due to their overrepresentation as drivers and helpers in the transportation sector. In contrast, women and children appear to be more vulnerable as passengers and pedestrians, contributing significantly to the overall casualty figures.

Fig. 7(A) portrays a concerning picture of age-related vulnerability in road accident fatalities. Drivers between 40 and 50 years old exhibit the highest mortality rate, while for helpers, it's the 20–40 age group, and for passengers, the 30–40 range. Pedestrians present a more complex picture, with vulnerability peaking in both the 30–40 age group and those over 50. Fig. 7(B) further reveals gender-specific patterns. Young children under 20 are most vulnerable, followed by men in the 30–40 age group and women in the broader 20–50 range. These insights from the data spanning 2017 to 2021 highlight the need for targeted safety interventions tailored to specific demographics most at risk on this roads.

An analysis of both injury and death statistics paints a concerning picture of vulnerability on this highway. Examining Figs. 7 and 8 together reveals a clear trend: middle-aged individuals, specifically those between 20 and 40 years old, bear the brunt of road accident consequences. This age group appears most frequently among both fatalities and injuries, highlighting their heightened exposure to risk on this roadway.

Further dissection by gender adds another layer of complexity. When it comes to fatalities, males are disproportionately affected, accounting for 70.7% of deaths compared to 46.2% for females. However, the picture flips when analyzing injuries. Here, females emerge as the more vulnerable group, with a staggering 86.3% of injuries in the 20–40 age range compared to 52.8% for males.

Accidents' aftereffects are more severe, i.e., vehicle owners most often lose their vehicles, and lives are lost along with the

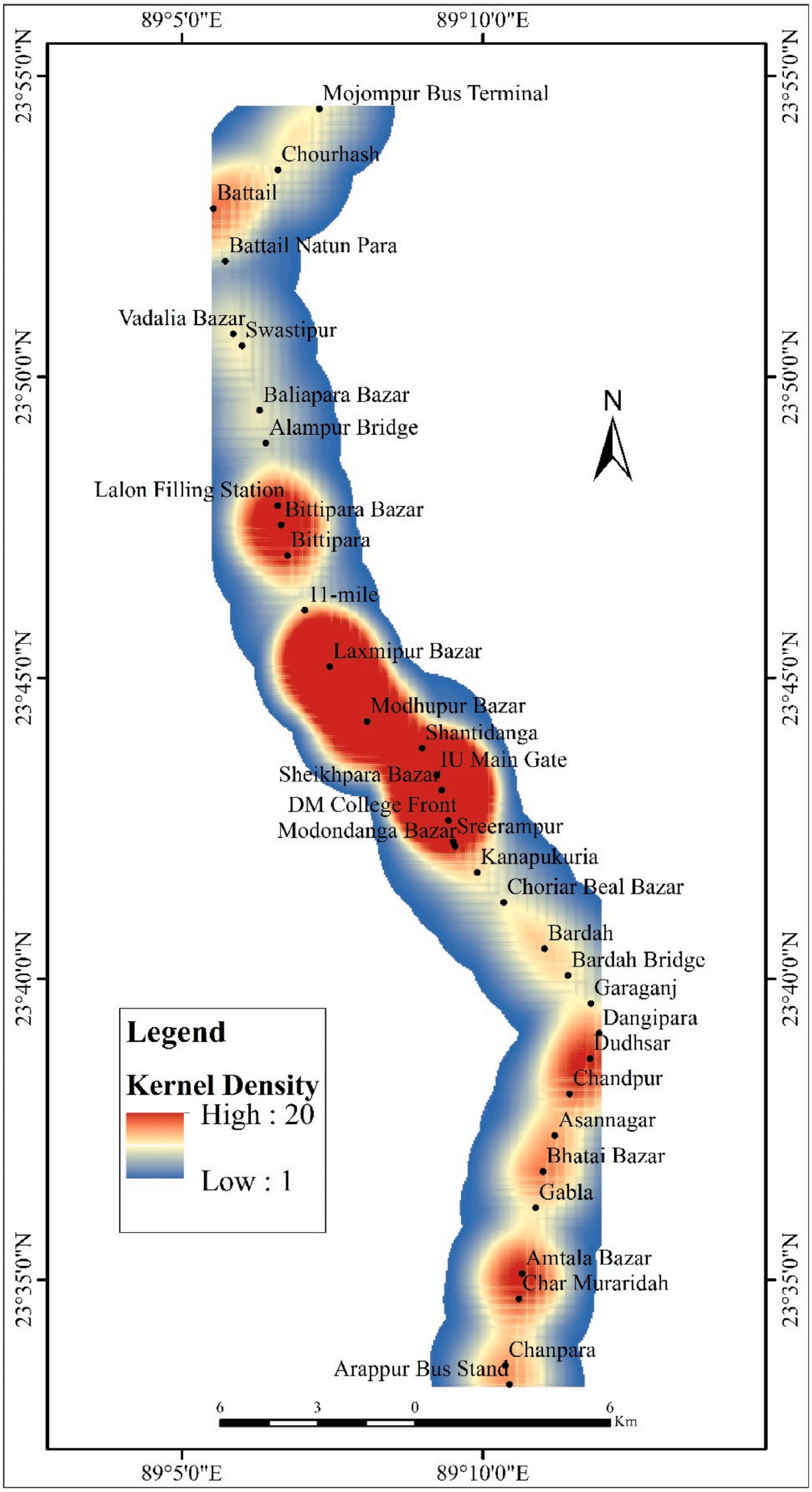

Fig. 5. RTA hotspot map for 2017–2021 using Kernel Density Estimation.

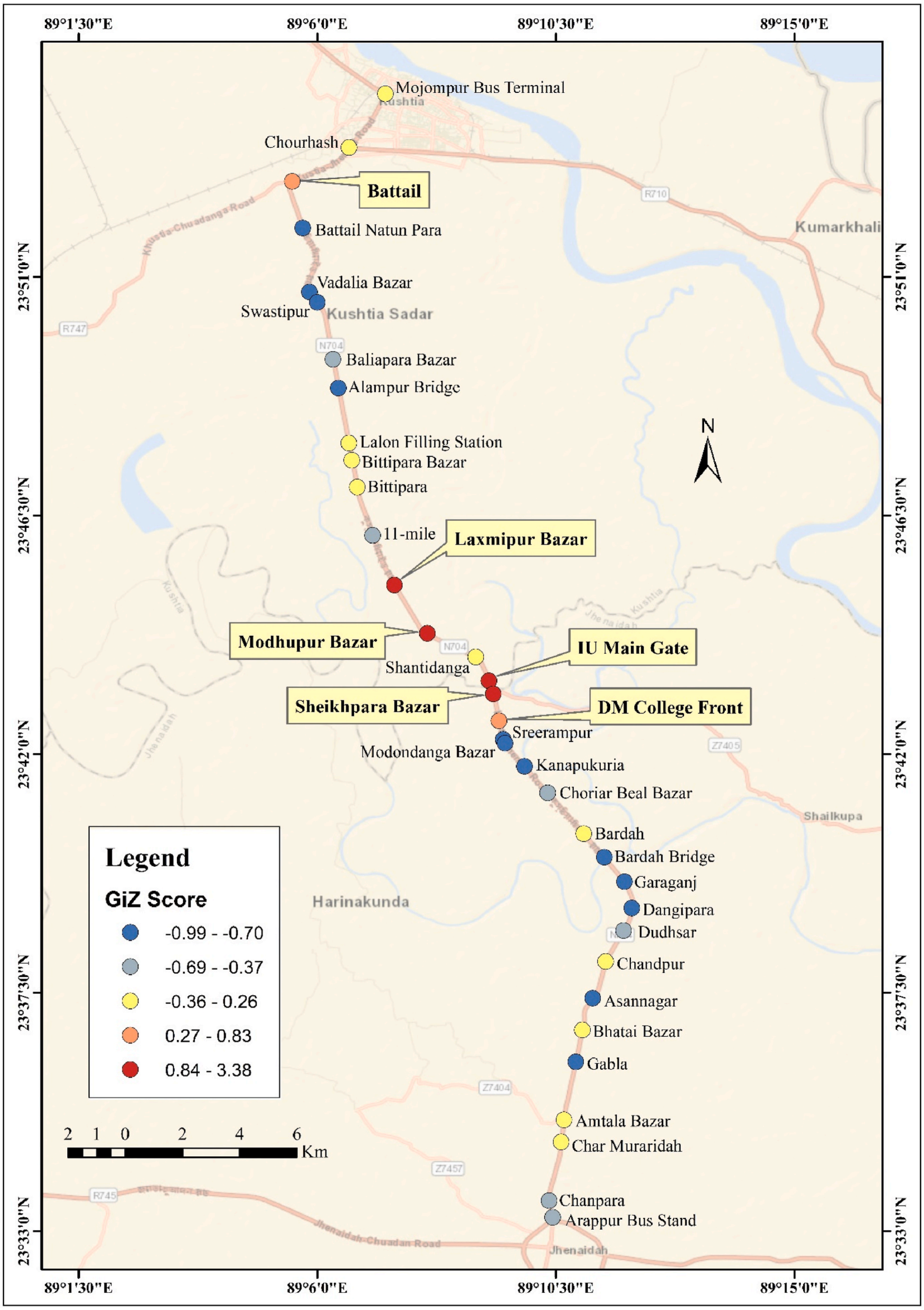

Fig. 6. Accident hotspots (red to reddish) based on accident records of 2017–2021.

Table 3
Accidental hotspots areas in the study route from 2017 to 2021.

No.	Name of the place	Location	Number of accidents	Confidence level
1	Battail	23.88, 89.09209	5	95%
2	Laxmipur Bazar	23.75313, 89.12426	15	99%
3	Modhupur Bazar	23.73795, 89.13461	12	99%
4	IU Main Gate	23.72301, 89.15397	7	99%
5	Sheikhpara Bazar	23.71889, 89.15534	13	99%
6	DM College Front	23.71048, 89.15716	4	95%

Source: Accident Records (2017–2021) from Police Stations

Table 4
Physical characteristics of blackspot locations.

SI No.	Place Name	Road Markings	Speed Breaker	Street Light	Traffic Sign	Traffic Signal
1	Battail	Not Exist	Not Exist	Not Exist	Exist	Not Exist
2	Vadalia Bazar	Exist	Not Exist	Not Exist	Exist	Not Exist
3	Bittipara Bazar	Exist	Not Exist	Not Exist	Exist	Not Exist
4	Laxmipur Bazar	Exist	Not Exist	Not Exist	Exist	Not Exist
5	Modhupur Bazar	Exist	Not Exist	Not Exist	Exist	Not Exist
6	Shantidanga	Exist	Not Exist	Not Exist	Exist	Not Exist
7	IU Main Gate	Exist	Exist	Not Exist	Exist	Not Exist
8	Sheikhpara Bazar	Not Exist	Not Exist	Not Exist	Exist	Not Exist
9	DM College Front	Exist	Not Exist	Not Exist	Exist	Not Exist
10	Sreerampur	Not Exist	Not Exist	Not Exist	Exist	Not Exist
11	Modondanga Bazar	Not Exist	Not Exist	Not Exist	Exist	Not Exist
12	Bhatai Bazar	Not Exist	Not Exist	Not Exist	Exist	Not Exist

Source: Field Survey (June–July 2022)

Table 5
Statistics of death and injury related to victim types.

Category	Variable	n	(%)
Death	**Road Users**		
	Driver	32	30.2
	Helper	5	4.7
	Passenger	56	52.8
	Pedestrian	13	12.3
	Gender		
	Male	94	88.7
	Female	11	10.4
	Children	1	0.9
Injury	**Road Users**		
	Driver	43	39.4
	Helper	5	4.6
	Passenger	51	46.8
	Pedestrian	10	9.2
	Gender		
	Male	88	80.7
	Female	16	14.7
	Children	5	4.6

Source: Field Survey (June–July 2022)

destruction of public property. Sometimes, patients who are involved in accidents may sustain permanent injuries. The actual economic loss can't be assessed because the victims, as well as their families, are affected both immediately and over time by these financial damages, such as medical costs, the repair costs of vehicles, legal and court fees, etc.

3.7. Discussions

The accident trend line indicates that the number of accidents decreased from 2018 to 2021, but the number of deaths increased in 2021 compared to the previous years. All injuries are considered severe because of grievous collisions during this period. One of the significant factors behind this is the coronavirus pandemic. COVID-19 also resulted in fewer accidents and injuries and a decrease in road safety performance, but significantly more severe accidents [55].

The findings of the accident analysis underscore the need for focused interventions and improvements in various areas, including

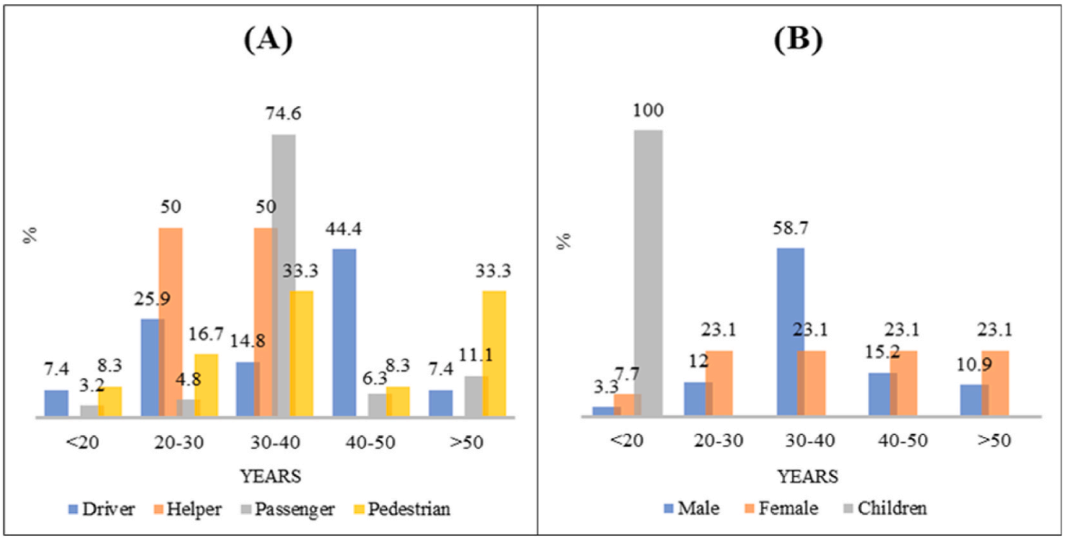

Fig. 7. Death related to Victim's age.

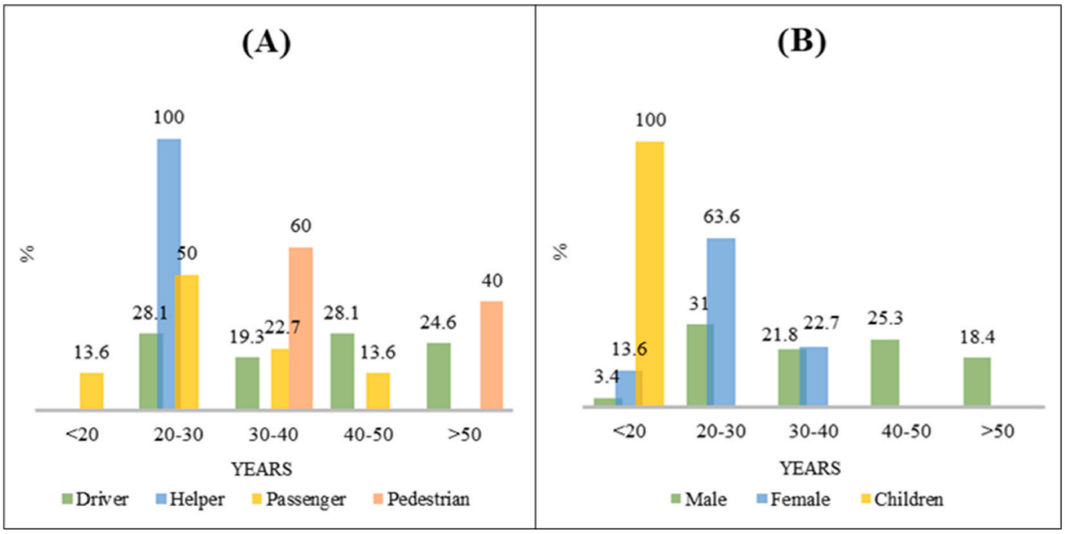

Fig. 8. Injury Related to Victim's Age. (A)paints a stark picture: drivers aged 20–30 and 40–50 bear the brunt of severe injuries. Meanwhile, (B) shows that across genders, the 20–30 age group suffers the highest incidence of injuries, with a worrying peak for children under 20. Notably, both figures point to the vulnerability of pedestrians aged 30–40 and above 50, further emphasizing the need for targeted safety measures.

driver training, vehicle maintenance, traffic regulation enforcement, and road infrastructure improvements. Implementing effective methods based on these observations can potentially reduce highway accidents, injuries, and fatalities. The Highway Act 2021 marks a significant step towards improving Bangladeshi highway infrastructure and promoting public safety. One of its key provisions prohibits the construction of any markets or structures within 10 m of either side of the highway [56], and implementation of this act will reduce traffic congestion around highways and reduce the risk of accidents involving pedestrians and vehicles.

In this study, the main reasons include excessive speeding and a lack of road safety awareness, followed by variables such as a lack of driving knowledge, overtaking, fatigued driving, poor road conditions, and drunk driving. Reckless driving by drivers and violating traffic laws cause road accidents in Bangladesh [57]. So, speed limitations have been suggested to lower the number of road fatalities [58].

The black spots recognized by the Severity Index (SI) are Laxmipur Bazar, IU Main Gate, Sheikhpara Bazar, Modhupur Bazar, Bittipara Bazar, Vadalia Bazar, Battail, Modondanga Bazar, and Bhatai Bazar. On the other hand, the density map demonstrates that sites with high accident frequency are related to traffic intersections. The southern section of the highway has a higher accident frequency than the northern section, with the intermediate section (Bittipara Bazar, Laxmipur Bazar, Modhupur Bazar, Shantidanga, IU Main Gate area, Sheikhpara Bazar, DM College Front, and Sreerampur) having a high accident frequency. The hotspot study identified six places as accidental hotspots, with a much greater rate of accidents than other areas. Battail, Laxmipur Bazar, Modhupur Bazar, IU Main Gate area, Sheikhpara Bazar, and DM College Front are among these localities. The common blackspot zones identified in three analyses are Battail, Bittipara Bazar, Laxmipur Bazar, Modhupur Bazar, IU Main Gate area, Sheikhpara Bazar, and DM College Front. The physical characteristics of the blackspot locations suggest safety infrastructure shortcomings. Most of the hotspot locations lack streetlights, traffic signals, and speed limiters. While traffic signs are present in most locations, road markings are not. Pavement width, road curve type, shoulder width, and position are such factors found to be significant contributors to accidents' black spots [59]. Addressing these flaws and implementing suitable safety measures might help minimize accident risks in these high-risk areas.

According to the accident data, passengers account for the most significant percentage of fatalities (52.8%) and injuries (46.8%). This implies that public transit users, such as buses, pick-ups, and 3-wheelers (locally known as Nasimon, Karimon, and auto rickshaws), are more susceptible to accidents than road users using private vehicles. However, it has been announced that it will stop the movement of vehicles such as Nasimon, Karimon, Bhatvati, Easybike, etc., along with three-wheeler control on the national highway [60]. But, in contrast, there are higher dangers involved with using privately owned vehicles [61]. Drivers and pedestrians are also engaged in a sizable percentage of fatal and injury incidents. Men make up the majority of casualties of death, but in the injury category, women are leading, highlighting the increased risk that men face on this highway. The data also shows that adults between 20 and 40 are more likely than children to be involved in accidents on this highway. Again, 41.67% of victims were between the ages of 20 and 35 years old [62].

While overall accidents have reduced, the increase in fatalities and injuries on this roadway and the likelihood of major collisions necessitate an immediate multi-pronged response. Addressing issues including speeding, driver awareness, and strengthening infrastructure in recognized black spots is critical. Implementing the Highway Act 2021 and emphasizing public transportation safety are both potential measures towards a safer highway. The reasons behind the vulnerable age group and gender aspects are also urgent to focus on saving lives and creating a safer transportation system for all.

4. Conclusion

The findings of this study on road accidents on the Kushtia-Jhenaidah national highway over the past five years reveal several noteworthy trends and characteristics. 118 accidents resulted in 121 deaths and 124 injuries, with the highest incident rate observed in 2018. However, a positive trend emerges as the overall number of accidents decreases from 2018 to 2021, despite a rise in deaths in 2021 compared to preceding years. Vehicle-related factors play a significant role, with trucks accounting for 47.9% of accidents, followed by three-wheelers (15.4%) and motorcycles (13%). Head-on collisions (36%) are prevalent, emphasizing the need for targeted safety measures. Human factors, including driver inexperience (56% with less than 10 years of experience) and mobile phone usage while driving (78%), contribute to the complexity of the safety landscape. Concerns about driver training, with 12% lacking formal or informal training, highlight potential areas for intervention. Environmental factors such as accidents being skewed towards nighttime (54%) and seasonal influences during the rainy and winter months add further dimensions to the analysis. The identification of black spots through severity index analysis underscores areas with a higher concentration of serious accidents, often characterized by a lack of streetlights and improperly placed or unreadable traffic signs. The consequences of road traffic accidents reveal a gender disparity, with men more affected by fatalities and women by injuries. The vulnerability of young to adult-aged individuals (20–40 years) emphasizes the importance of tailored safety interventions for specific demographic groups.

Furthermore, an in-depth accident analysis with a causality investigation focusing on the specific factors contributing to the upward and downward trends in accident severity over different periods (2017–2018, 2018–2019, and 2019–2021) can assist in identifying any specific events, changes in road conditions, or traffic patterns that may have influenced the trends. Continuous data collection and monitoring systems can follow accident patterns, identify new black spots, and analyze the efficiency of actions taken. Besides, governmental long-term policies collaborating with local authorities to make harmless and operative use of the national highway by enhancing road safety alertness operations, driver training and licensing, road infrastructure developments, road safety inspections, traffic guidelines research on vehicle safety features, and an insurance system for the victims to cope with the economic instability can be effective ways to reduce road accidents, injuries, and fatalities.

Ethics statement

This research was conducted in collaboration with the principles and approval of the Ethical Committee of Islamic University, Kushtia-7003, Bangladesh (Approval Number: FBS-IU-2022/010).

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Most Suria Khatun: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Md Anik Hossain:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Md Anisul Kabir:** Writing – review & editing, Supervision. **Md Asikur Rahman:** Writing – review & editing, Visualization, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25952.

References

[1] M.S. Hossain, M.O. Faruque, Road traffic accident scenario, pattern and forecasting in Bangladesh, Journal of Data Analysis and Information Processing 7 (2) (2019) 29, https://doi.org/10.4236/jdaip.2019.72003.
[2] F. Haque, A.S. Huq, Z.S. Ishmam, M.M. Fuad, Visualizing the Hot Spots of Adverse Weather Induced Traffic Accidents in Bangladesh (No. TRBAM-22-03996), 2022.
[3] F. Haghighi, E. Karimi, Evaluation and statistical validation of black-spots identification methods, International Journal of Transportation Engineering 6 (1) (2018) 1–15, https://doi.org/10.22119/ijte.2017.52977.
[4] W. Cheng, S.P. Washington, Experimental evaluation of hotspot identification methods, Accident Analysis & Prevention 37 (5) (2005) 870–881, https://doi.org/10.1016/j.aap.2005.04.015.
[5] R. Elvik, State-of-the-art Approaches to Road Accident Black Spot Management and Safety Analysis of Road Networks, Transportøkonomisk institutt, Oslo, Norway, 2007.
[6] K. Bucsuházy, E. Matuchová, R. Zůvala, P. Moravcová, M. Kostíková, R. Mikulec, Human factors contributing to the road traffic accident occurrence, Transportation research procedia 45 (2020) 555–561, https://doi.org/10.1016/j.trpro.2020.03.057.
[7] S. Ansari, F. Akhdar, M. Mandoorah, K. Moutaery, Causes and effects of road traffic accidents in Saudi Arabia, Public Health 114 (1) (2000) 37–39, https://doi.org/10.1038/sj.ph.1900610.
[8] B.R. Sharma, Road traffic injuries: a major global public health crisis, Public Health 122 (12) (2008) 1399–1406, https://doi.org/10.1016/j.puhe.2008.06.009.
[9] U. Schmucker, R. Dandona, G.A. Kumar, L. Dandona, Crashes involving motorised rickshaws in urban India: characteristics and injury patterns, Injury 42 (1) (2011) 104–111, https://doi.org/10.1016/j.injury.2009.10.049.
[10] C. Wangdi, M.S. Gurung, T. Duba, E. Wilkinson, Z.M. Tun, J.P. Tripathy, Burden, pattern and causes of road traffic accidents in Bhutan, 2013–2014: a police record review, International journal of injury control and safety promotion 25 (1) (2018) 65–69, https://doi.org/10.1080/17457300.2017.1341930.
[11] G. Zhang, K.K. Yau, G. Chen, Risk factors associated with traffic violations and accident severity in China, Accident Analysis & Prevention 59 (2013) 18–25, https://doi.org/10.1016/j.aap.2013.05.004.
[12] J. Gao, X. Chen, A. Woodward, X. Liu, H. Wu, Y. Lu, L. Li, Q. Liu, The association between meteorological factors and road traffic injuries: a case analysis from Shantou city, China, Scientific Reports 6 (1) (2016), https://doi.org/10.1038/srep37300.
[13] J.A. Hansen, Weather Components and Employee Accidents in a Psychiatric Hospital, 1988, https://doi.org/10.58809/kcyx1786.
[14] A. Drosu, C. Cofaru, M. Popescu, Relationships between Accident Severity and Weather and Roadway Adherence Factors in Crashes Occurred in Different Type of Collisions, Springer eBooks, 2019, https://doi.org/10.1007/978-3-030-32564-0_30.
[15] R. Bergel-Hayat, M. Debbarh, C. Antoniou, G. Yannis, Explaining the road accident risk: weather effects, Accident Analysis & Prevention 60 (2013) 456–465, https://doi.org/10.1016/j.aap.2013.03.006.
[16] WHO, SDG Target 3.6 Road Traffic Injuries, 2023. Retrieved, https://www.who.int/data/gho/data/themes/topics/sdg-target-3_6-road-traffic-injuries. (Accessed 10 July 2023).
[17] WHO, World Report on Road Traffic Injury Prevention, 2004. Retrieved, https://www.who.int/publications/i/item/world-report-on-road-traffic-injury-prevention. (Accessed 2 July 2023).
[18] WHO, Road Traffic Injuries, 2022. Retrieved, https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries. (Accessed 12 July 2023).
[19] WHO, Global Status Reports on Road Safety 2015, 2015. Geneva, Switzerland. Retrieved, http://www.who.int/violence_injury_prevention/road_safety_status/2015/en. (Accessed 2 July 2023).
[20] B.P. Loo, T.K. Anderson, Spatial Analysis Methods of Road Traffic Collisions, CRC Press, 2015 (*).
[21] H.M. Ahsan, A. Sufian, M.A. Raihan, Road traffic accident statistics and Countermeasures for NMVs in Bangladesh, in: 1st International Conference on Advances in Civil Engineering, CUET, Chittagong, Bangladesh, 2012.
[22] M.M. Hoque, M.S. Hossain, M.A. Rahman, S.M.A. Islam, Safer motorcycling and safer roads: the context of Bangladesh, in: Proceedings of South East Asia Road Safety Summit (SEARSS), 2014 (Bali, Indonesia).
[23] S. Paul, An Estimation of Socio-Economic Costs of Road Traffic Accidents in Bangladesh, Accident Research Institute (ARI), BUET, Dhaka, Bangladesh, 2007.
[24] M.S. Alam, S.S. Mahmud, M.S. Hoque, Road accident trends in Bangladesh: a comprehensive study, in: 4th Annual Paper Meet and 1st Civil Engineering Congress, 2011, December, pp. 172–181.

[25] M.M. Hoque, M.F. Rahman, M. Ashrafuzzaman, S. Sarkar, Observational studies of hazardous road locations on national highways in Bangladesh, in: Research into Practice: 22nd ARRB ConferenceARRB, 2006.
[26] K.M. Maniruzzaman, R. Mitra, Road accidents in Bangladesh, IATSS research 29 (2) (2005) 71.
[27] M. Rahman, S. Newaz, Development of a GIS based hazardous road location identification system for National Highways of Bangladesh, Tojsat 3 (2) (2013) 72–85.
[28] F. Rahman, F. Uddin, M. Rahman, A. Islam, A. Ahmed, Identification of hazardous road locations and black spots on Dhaka-Barisal national highway, in: First International Conference on Advances in Civil Infrastructure and Construction Materials, 2015, pp. 911–919.
[29] S. Sarkar, M.M. Hoque, M.R. Alam, F. Ahamed, A. Rokon, Identification of High Risk Road Locations on National Highway N2 of Bangladesh Using GIS, 1st Bangladesh Civil Engineering SUMMIT, BUET, Dhaka, Bangladesh, 2016, pp. 120–127.
[30] M. Alam, H.M. Ahsan, Identification and characterization of hazardous road locations on Dhaka-Chittagong national highway, Global Journal of Research In Engineering 13 (4) (2014).
[31] S.K. Sinha, M.A. Rahman, Accident prone locations (black spots) identification at Bhanga-Mawa-Dhaka highway by using GIS, in: Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development, ICCESD 2016, 2016, February.
[32] M.R. Haque, S.M. Jamil, M.S. Rahman, M.I. Islam, Identification of factors in road accidents of Pabna-Sirajgonj highway, International Journal of Engineering and Management Research (2019), https://doi.org/10.31033/ijemr.9.5.23.
[33] M.T. Miah, M.S. Rana, An Exploratory Analysis of Highway Traffic Accident: A Study on Pabna-Bera Highway, 2021, https://doi.org/10.13140/RG.2.2.13993.52329.
[34] M.M. Islam, R.B. Ali, F.K. Chowdhury, M.A. Sobhan, Road Accident Analysis and Prevention Measures of Rajshahi-Sirajganj Highway in Bangladesh vol. 126, World Scientific News, 2019, pp. 209–221.
[35] M.Y. Jamil, M.M. Rahman, S. Sharmin, Accident hotspot identification using geometric problems and characteristics in selected road of the Dhaka-Aricha highway (N5), Journal of Transportation Engineering and Traffic Management 2 (3) (2021) 19–35, https://doi.org/10.5281/zenodo.5541199.
[36] D. Goswami, M.M. Morshed, M.S. Hasan, Implication of GIS Technology in Accident Research in Bangladesh, Journal of Bangladesh Institute of Planners ISSN, 2015, p. 9363, 2075.
[37] G. Apparao, P. Mallikarjunareddy, S.G. Raju, Identification of accident black spots for national highway using GIS, International Journal of Scientific & Technology Research 2 (2) (2013) 154–157.
[38] K.G. Le, P. Liu, L.T. Lin, Determining the road traffic accident hotspots using GIS-based temporal-spatial statistical analytic techniques in Hanoi, Vietnam, Geo-spatial Information Science 23 (2) (2020) 153–164, https://doi.org/10.1080/10095020.2019.1683437.
[39] K. Geurts, G. Wets, T. Brijs, K. Vanhoof, Identification and ranking of black spots: sensitivity analysis, Transportation Research Record 1897 (1) (2004) 34–42, https://doi.org/10.3141/1897-05.
[40] P. Kashid, Y. Shinde, S. Dhavare, H. Pokharkar, Identification and analysis of accidental blackspots on NH-48, International Research Journal of Engineering and Technology 6 (6) (2019) 2497–2503.
[41] A. Afolayan, S.M. Easa, O.S. Abiola, F.M. Alayaki, O. Folorunso, GIS-based spatial analysis of accident hotspots: a Nigerian case study, Infrastructures 7 (8) (2022) 103, https://doi.org/10.3390/infrastructures7080103.
[42] V. Prasannakumar, H. Vijith, R. Charutha, N. Geetha, Spatio-temporal clustering of road accidents: GIS based analysis and assessment, Proc. Soc. Behav. Sci. 21 (2011) 317–325, https://doi.org/10.1016/j.sbspro.2011.07.020.
[43] K. Liu, B. Lin, Research on influencing factors of environmental pollution in China: a spatial econometric analysis, Journal of Cleaner Production 206 (2019) 356–364, https://doi.org/10.1016/j.jclepro.2018.09.194.
[44] M. Nejadrekabi, S. Eslamian, M.J. Zareian, Spatial statistics techniques for SPEI and NDVI drought indices: a case study of Khuzestan Province, International Journal of Environmental Science and Technology 19 (7) (2022) 6573–6594, https://doi.org/10.1007/s13762-021-03852-8.
[45] J. Lee, D.W. Wong, Statistical Analysis with ArcView GIS, John Wiley & Sons, 2001.
[46] T.K. Anderson, Kernel density estimation and K-means clustering to profile road accident hotspots, Accident Analysis & Prevention 41 (3) (2009) 359–364, https://doi.org/10.1016/j.aap.2008.12.014.
[47] F. Ouni, M. Belloumi, Spatio-temporal pattern of vulnerable road user's collisions hot spots and related risk factors for injury severity in Tunisia, Transportation research part F: traffic psychology and behaviour 56 (2018) 477–495, https://doi.org/10.1016/j.trf.2018.05.003.
[48] P. Songchitruksa, X. Zeng, Getis–ord spatial statistics to identify hot spots by using incident management data, Transportation Research Record: Journal of the Transportation Research Board 2165 (1) (2010) 42–51, https://doi.org/10.3141/2165-05.
[49] ESRI, How hot spot analysis (Getis-Ord GI*) works—ArCGIS pro | documentation, Retrieved, https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm, 2023. (Accessed 22 December 2023).
[50] A. Getis, J.K. Ord, The analysis of spatial association by use of distance statistics, Adv. Spatial Sci. 61 (2010) 127–145, https://doi.org/10.1007/978-3-642-01976-0_10.
[51] M.A. Hossain, M.I. Haque, M.A. Parvin, M.N. Islam, Evaluation of iron contamination in groundwater with its associated health risk and potentially suitable depth analysis in Kushtia Sadar Upazila of Bangladesh, Groundwater for Sustainable Development 21 (2023) 100946, https://doi.org/10.1016/j.gsd.2023.100946.
[52] H. Xu, A. Demetriades, C. Reimann, J.J. Jiménez, J. Filser, C. Zhang, GEMAS Project Team, Identification of the co-existence of low total organic carbon contents and low pH values in agricultural soil in north-central Europe using hot spot analysis based on GEMAS project data, Science of the Total Environment 678 (2019) 94–104, https://doi.org/10.1016/j.scitotenv.2019.04.382.
[53] A. Abdulhafedh, A novel hybrid method for measuring the spatial autocorrelation of vehicular crashes: combining Moran's index and getis-ord G i* statistic, Open Journal of Civil Engineering 7 (2) (2017) 208, https://doi.org/10.4236/ojce.2017.72013.
[54] A. Getis, L. Anselin, A. Lea, M. Ferguson, H. Miller, Spatial analysis and modeling in a GIS environment, in: A Research Agenda for Geographic Information Science, CRC Press, 2004, pp. 157–196.
[55] M.E. Shaik, S. Ahmed, An overview of the impact of COVID-19 on road traffic safety and travel behavior, Transportation Engineering 9 (2022) 100119, https://doi.org/10.1016/j.treng.2022.100119.
[56] GoB, Highways Act, 2021. Law of Bangladesh, 2021. Retrieved, http://bdlaws.minlaw.gov.bd/act-1393.html. (Accessed 24 December 2023).
[57] N. Razzaque, Road accident in Bangladesh: issues & legal study, Journal of Social and Political Sciences 5 (3) (2022), https://doi.org/10.31014/aior.1991.05.03.359.
[58] B.E. Horn, A.H. Jansson, Traffic safety and environment–conflict or integration, IATSS research 24 (1) (2000) 21–29, https://doi.org/10.1016/S0386-1112(14)60014-5.
[59] A. Mbarek, M. Jiber, A. Yahyaouy, M.A. Sabri, Black spots identification on rural roads based on extreme learning machine, International Journal of Power Electronics and Drive Systems 13 (3) (2023) 3149, https://doi.org/10.11591/ijece.v13i3.pp3149-3160.
[60] GoB, Road Transport Act, 2018. Law of Bangladesh, 2018. Retrieved, http://bdlaws.minlaw.gov.bd/act-1262.html. (Accessed 24 December 2023).
[61] S.D. Dharmaratne, M. Stevenson, Public road transport crashes in a low income country, Injury Prevention 12 (6) (2006) 417–420, https://doi.org/10.1136/ip.2005.008797.
[62] M.M.H. Mamun, M.M. Miah, M.I. Islam, Present condition of road traffic accident: a Case study of Rajshahi City, Bangladesh, International Journal of Computer Applications 111 (7) (2015), https://doi.org/10.5120/19554-1279.