ASSESSING THE IMPACT OF CLIMATIC FACTORS ON ROAD SAFETY IN BANGLADESH

Md. Fuad Hasan*[1], S. M. Sohel Mahmud[2] and Ayesha Akter[3]

[1]*Lecturer, Department of Environmental Science and Technology (EST), German University Bangladesh (GUB), Gazipur-1702, Bangladesh, e-mail: fuad.dm.pstu@gmail.com*
[2]*Professor, Accident Research Institute (ARI), Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, e-mail: smsohelmahmud@gmail.com*
[3]*Professor, Department of Emergency Management (ERM), Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali-8602, Bangladesh, e-mail: ensayesha@gmail.com*

***Corresponding Author**

ABSTRACT

Climatic factors are recognized as critical factors influencing road safety in Bangladesh. This study aims to assess the impact of rainfall, temperature, and visibility on road crash occurrence and severity, providing evidence to support weather-responsive transportation safety strategies. Weather data were collected from the Bangladesh Meteorological Department (BMD), while road accident records were obtained from the Accident Research Institute (ARI) of BUET. The analysis utilized categorized crash data based on varying weather conditions as rainfall intensity, temperature ranges, and visibility levels. Key safety indicators examined include crash percentage, injuries and fatalities per crash, and average crash frequency per day. Statistical analysis was conducted using Pearson correlation coefficients to quantify the relationships between weather variables and crash metrics. Results indicate a strong negative correlation between rainfall intensity and crash percentage (-0.89, $p = 0.00$), with crash rates declining from 21.39% in dry conditions to 14.75% during heavy rain (>50 mm). Although crashes become less frequent during rainfall, crash severity increases, with injuries per crash rising from 1.76 (dry) to 2.13 (8–12 mm rain), and fatalities per crash increasing to 1.24. Temperature analysis also showed a decline in crash percentage from 33.46% at <15°C to 19.18% at >30°C, though the correlation was statistically insignificant ($r = -0.92$, $p = 0.26$). Visibility was found to have a major effect on crash outcomes; crash percentage dropped from 36.51% at <1 km visibility to 19.89% at ≥5 km, and injuries per crash fell from 3.26 to 1.67. Correlation values for visibility ranged from -0.77 to -0.79, with p-values just above conventional significance levels. The study demonstrates that adverse weather conditions, particularly low visibility and rainfall, are associated with reduced crash frequency but increased crash severity in Bangladesh. These findings underscore the need for enhanced safety measures, such as improved driver alerts, adaptive speed regulations, and real-time weather-responsive traffic management systems.

Keywords: *Crash severity, rainfall, road safety, temperature, visibility*

1. INTRODUCTION

Road traffic crashes are a major public health and development concern worldwide, particularly in low- and middle-income countries where infrastructure, enforcement, and safety awareness may be limited (WHO, 2018). Bangladesh, with one of the highest road traffic fatality rates in South Asia, experiences approximately 21,000 fatalities and over 100,000 injuries annually due to road accidents (Islam et al., 2019). These crashes not only result in loss of life but also impose severe economic burdens and social consequences, affecting families, communities, and the national economy (Blincoe et al., 2015).

Climatic and environmental factors are increasingly recognized as significant determinants of road safety. Adverse weather conditions, such as heavy rainfall, poor visibility, and extreme temperatures—can compromise driver behavior, road surface conditions, and vehicle control, leading to higher crash risks (Das et al., 2025; Mondal *et al*., 2011; Sadeghi & Goli, 2024; Shaheed *et al.*, 2016; Shahid & Minhans, 2016). In Bangladesh, the tropical monsoon climate brings high seasonal rainfall and frequent cyclonic events, which can increase the vulnerability of road networks, particularly in low-lying and coastal regions (Masum, 2019).

Previous studies have shown that rainfall reduces vehicle speeds and may lower crash frequency, but increases the severity of crashes due to slippery roads and reduced braking efficiency (Jung et al., 2014; Keay & Simmonds, 2006). Similarly, low visibility due to fog, heavy rain, or dust is associated with more severe collisions, while extreme temperatures may indirectly affect crash outcomes through driver fatigue or reduced attention (Wu et al., 2018). Despite these findings, there is a paucity of empirical studies in Bangladesh that systematically quantify the impact of climatic factors on crash occurrence and severity across multiple divisions and districts. Most research has been limited to single cities or short time periods, providing insufficient evidence for nationwide policy planning.

Given the growing threat of climate variability and extreme weather events, there is a critical need for data-driven assessment of climate impacts on road safety. Such analyses can inform the development of weather-responsive traffic management systems, adaptive speed regulations, and targeted infrastructure improvements. This study aims to fill this knowledge gap by examining the relationships between rainfall, temperature, and visibility and road crash frequency and severity across 23 districts in eight divisions of Bangladesh. By integrating meteorological data with crash records, this research seeks to provide a comprehensive understanding of how climatic variability affects road safety, offering insights for evidence-based policy interventions and sustainable transport planning.

2. METHODOLOGY

2.1 Study Design and Analytical Framework

This study adopts a matched-pair analytical framework to evaluate the relative risk of road crashes, injuries, and fatalities associated with varying climatic conditions across Bangladesh. The approach pairs rainy days with corresponding dry days of similar temporal and spatial characteristics to minimize confounding effects, following the procedure outlined in Hasan et al. (2024). By comparing crash patterns under comparable non-rainy and rainy conditions, this design enables an accurate estimation of weather-induced variations in road safety risk.

The research extends previous methodological applications by incorporating a broader spatial coverage, analyzing data from 23 meteorological stations across eight administrative divisions. The study further disaggregates analysis at both divisional and district levels to examine spatial heterogeneity in the impacts of rainfall, temperature, and visibility on crash occurrence and severity.

Comparative analyses were carried out to determine variations in crash frequency, injuries, and fatalities across divisions, with emphasis on identifying climatic thresholds that exacerbate road safety risks (Figure 1).

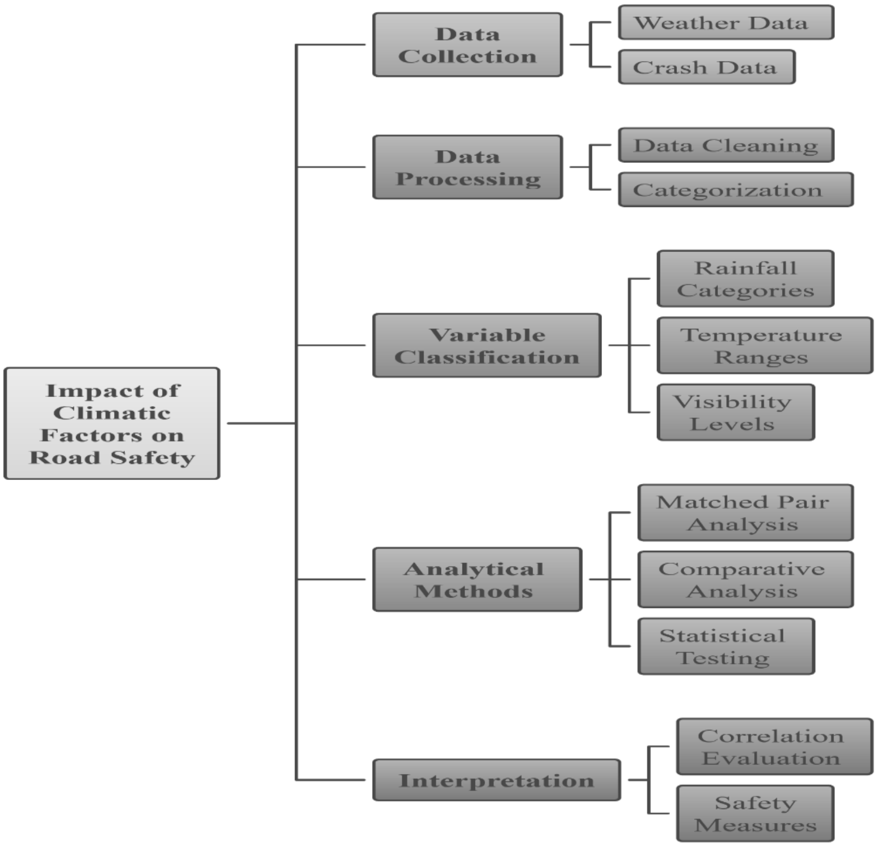

Figure 1: Methodological flow of weather impact assessment on road safety.

2.2 Data Collection

The study utilized secondary data encompassing both weather and road accident records.

- Weather Data: Daily rainfall (mm), temperature (°C), and visibility (km) data were obtained from the Bangladesh Meteorological Department (BMD) for 34 stations nationwide. However, district-level datasets were available for 23 stations, covering the following districts: Dhaka, Tangail, Faridpur, Madaripur, Mymensingh, Sylhet, Bogra, Rajshahi, Dinajpur, Rangpur, Chuadanga, Jessore, Khulna, Satkhira, Barisal, Bhola, Patuakhali, Chandpur, Chittagong, Comilla, Cox's Bazar, Feni, and Rangamati. The Chittagong Division contributed the highest number of districts (six), while Sylhet and Mymensingh had only one district each.
- Crash Data: Road accident data were collected from the Accident Research Institute (ARI), Bangladesh Police Headquarters, and other validated institutional datasets. The records were verified, cleaned, and reorganized to ensure consistency between crash characteristics (e.g., time, location, weather conditions) and meteorological data.

The integrated dataset allowed for multi-scalar assessment, with rainfall analyzed at both district and divisional scales, while temperature and visibility analyses were confined to divisional level due to data completeness and reliability constraints.

2.3 Variable Classification

Weather variables were categorized based on established standards and previous literature to reflect conditions relevant to Bangladesh's climatic regime:

Rainfall: Classified into intensity categories (1–2 mm, 3–7 mm, 8–12 mm, 13–25 mm, 26–50 mm, and >50 mm). A rainfall threshold of >2.5 mm/day was used to define wet road conditions, while >12.5 mm/day denoted adverse weather, following the criteria of Black et al. (2017), Bertness (1980), and Sherretz & Farhar (1978).

Temperature: Divided into three ranges: <15°C, 15–30°C, and >30°C, based on Bangladesh's average temperature range of 15–26°C (World Bank, 2021). Temperatures below 15°C and above 30°C were considered adverse thermal conditions.
Visibility: Grouped into five ranges: <1 km, 1 to <2 km, 2 to <3 km, 3 to <5 km, and ≥5 km, following the classifications of Chaabani et al. (2017) and Peng et al. (2017). Visibility below 2 km was considered poor, and below 1 km as adverse.

2.4 Analytical Techniques

Descriptive and inferential statistical analyses were performed to quantify the relationships between climatic variables and crash indicators.

$$Crash, \% = \frac{\sum Number\ of\ Crashes \times 100}{\sum Number\ of\ Days}$$ ……………......(Black *et al.*, 2017)

Injury% and fatality% are also calculated in the same way.

$$Crash\ Rate = \frac{\sum Number\ of\ Crashes}{\sum Number\ of\ Days}$$ ……………......(Black *et al.*, 2017)

$$Injury\ Rate = \frac{\sum Number\ of\ Injuries}{\sum Number\ of\ Crashes}$$ ……………......(Black et *al.*, 2017)

Fatality rate is also calculated like injury rate.

$$Casualty\ Rate = \frac{\sum Number\ of\ Injuries + \sum Number\ of\ Fatalities}{\sum Number\ of\ Crashes}$$ …(Elliott & Broughton, 2005)

To determine the strength and direction of the relationship between weather variables (rainfall, temperature, visibility) and crash outcomes (crash rate, injury rate, and fatality rate), Pearson's correlation coefficient (r) was calculated using the following equation:

$$Pearson's\ correlation\ coefficient \quad r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}$$ …...(Sedgwick, 2012)

Where, x_i= independent variable (e.g., rainfall intensity, temperature, visibility), y_i= dependent variable (e.g., crash rate, injury rate, fatality rate), $\bar{x}, \bar{y}$= mean values of the respective variables.
The p-value was used to test the significance of the correlation, with values less than 0.05 considered statistically significant. All analyses were performed using Microsoft Excel, ensuring accuracy in the computation of correlation, significance testing, and data visualization.

2.5 Methodological Continuity

The The methodological approach of this study closely follows the analytical framework developed in Hasan *et al.* (2024), which employed comparable statistical and modeling techniques using a smaller dataset covering the Khulna and Barishal divisions. Building upon this foundation, the present study substantially expands the spatial and analytical scope by incorporating data from 23 districts across all eight divisions of Bangladesh and utilizing additional weather stations. This broader coverage enables a more comprehensive and nationally representative assessment of climate-induced road safety risks.
A gross-level analysis is first conducted to present the prevailing road safety problems in the eight divisional cities, highlighting the magnitude, dimensions, and distinct characteristics of crashes, fatalities, and injuries. Subsequently, a comparative analysis among the divisional cities is performed using indicators such as crash rate and casualty index to identify spatial variations in road safety performance. This component primarily relies on questionnaire survey data collected from road users.
To capture behavioral and perceptual aspects, users' understanding—including drivers and vulnerable road users (VRUs)—their perceived risk, and perceived risk factors are analyzed using a combination of descriptive and inferential statistical techniques. Likert-scale responses are employed to quantify perceptions, which are further presented through appropriate visualizations to enhance interpretability.
Two parallel analytical streams are conducted using different datasets: (i) perceived risk assessment based on questionnaire surveys, and (ii) revealed compliance and crash outcome analysis based on observed crash and rainfall data.

Revealed compliance is quantified under varying rainfall intensities (1–5 mm, 6–10 mm, 11–15 mm, 15–20 mm, 20–30 mm, 30–50 mm, and >50 mm) across different spatial contexts, including the eight divisions and urban–rural settings. Advanced statistical techniques—such as data mining methods, paired comparisons, and matched-pair analyses—are employed to compare wet-weather conditions with corresponding dry-weather conditions. Through this process, the relative risk of crashes, fatalities, and injuries under different rainfall intensities is systematically estimated.

3. ANALYSIS AND RESULTS

3.1 Rainfall and Road Safety Outcomes

Crash data categorized by rainfall intensity revealed clear variations in road safety indicators (Figure 2,
Table 1). The average number of crashes per day declined steadily as rainfall increased, from 0.21 under dry conditions to 0.15 during heavy rainfall (>50 mm). The Pearson correlation between rainfall intensity and crash percentage was strongly negative (r = -0.89, p = 0.00), confirming a statistically significant reduction in crash frequency with higher rainfall levels.

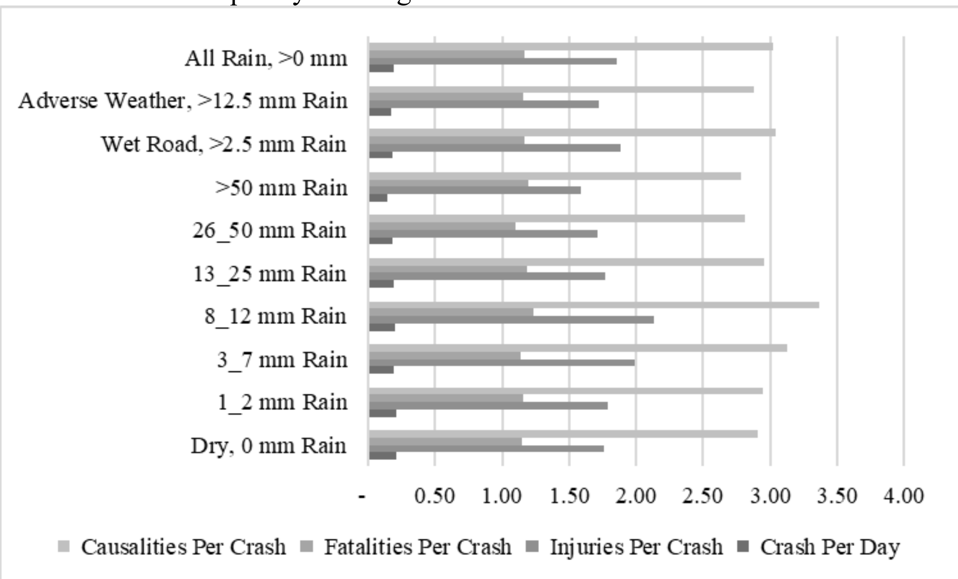

Figure 2. Impact of rainfall on road safety in Bangladesh

However, crash severity indicators increased during light to moderate rainfall. The average number of injuries per crash rose from 1.76 (dry) to a peak of 2.13 (8–12 mm rain), while fatalities per crash increased from 1.14 (dry) to 1.24 (8–12 mm). At rainfall intensities beyond 25 mm, injury and fatality rates gradually declined, reaching 1.59 and 1.19, respectively, under heavy rainfall (>50 mm).

Table 1. Correlation between rainfall intensity and crash metrics.

Metric	Correlation with Rain Intensity	P-value
Crash (%)	-0.89	0.00
Injury (%)	-0.88	0.00
Fatalities (%)	-0.88	0.00

Note: All correlations are significant at p < 0.01, indicating a strong positive relationship between rainfall intensity and crash-related outcomes.

The reduction in crash frequency during rainfall likely reflects adaptive driving behavior, as motorists often reduce speeds or avoid travel in poor weather conditions (Andrey & Yagar, 2013; Keay & Simmonds, 2006). Nevertheless, the increased severity under moderate rainfall highlights the hazardous effects of reduced tire–road friction, longer braking distances, and impaired visibility, which can lead to higher-impact collisions (Mkwata, 2024).

The decline in crash severity during heavy rainfall (>25 mm) may indicate that extreme conditions deter most drivers from traveling, thus lowering exposure and potential crash risk (Gu, 2025). This non-linear pattern- fewer crashes but greater severity during moderate rainfall is consistent with findings from other tropical and subtropical regions (Cheng *et al.*, 2017; Xing *et al.*, 2019).

3.2 Temperature and Road Safety Outcomes

Crash data categorized by temperature range showed noticeable variations in both crash frequency and severity (Figure 3, Table 2). The average number of crashes per day declined substantially from 3.35 at <15°C to 1.92 at >30°C, suggesting fewer crashes during hotter conditions. Correlation analysis revealed a strong negative but statistically insignificant relationship between temperature and crash percentage ($r = -0.92$, $p = 0.26$).

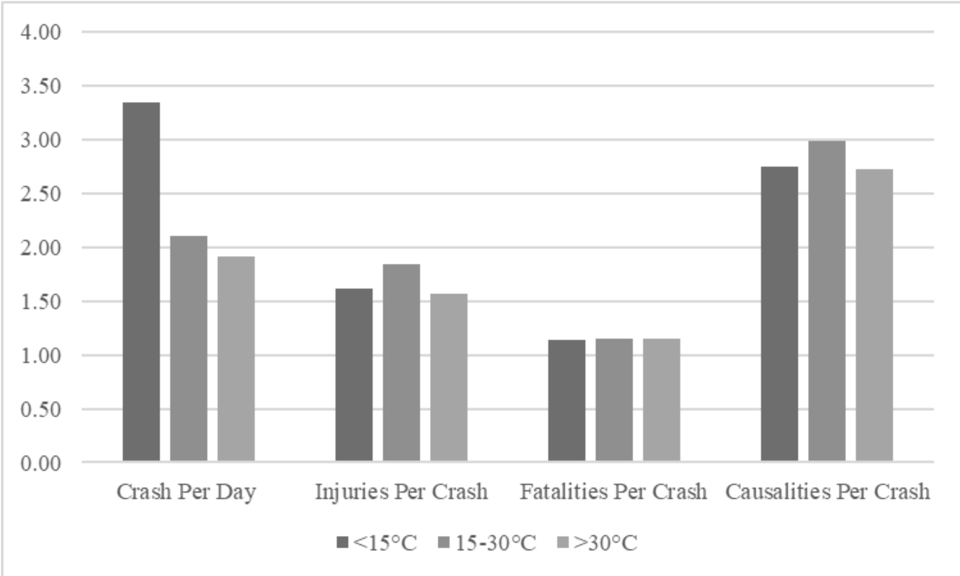

Figure 3. Impact of temperature on road safety in Bangladesh

Crash severity indicators, however, showed mixed responses. Injuries per crash slightly increased from 1.61 at <15°C to 1.84 in the 15–30°C range, before declining to 1.57 at >30°C. Fatalities per crash remained nearly constant (1.14–1.15), while total casualties per crash peaked at 2.99 in the mid-temperature range. Correlation coefficients for injury and fatality percentages ($r = -0.99$ and -0.92, respectively) also indicated negative relationships, though p-values (0.11–0.26) were above conventional significance thresholds.

Table 2. Correlation between temperature intensity and crash metrics

Metric	Correlation with Temperature	P-value
Crash (%)	-0.92	0.26
Injury (%)	-0.99	0.11
Fatalities (%)	-0.92	0.26

Note: No correlations are significant at $p < 0.05$

The decline in crash frequency at higher temperatures may result from favorable road surface conditions and better visibility, reducing the likelihood of skidding or vehicle instability (Sadeghi & Goli, 2024; Theofilatos & Yannis, 2014). Conversely, the slightly elevated crash rate at lower temperatures (<15°C) could be associated with fog formation, condensation, and early-morning travel hazards, which impair visibility and reaction time (Das *et al.*, 2025).

The rise in injury and casualty rates at moderate temperatures (15–30°C) may reflect increased traffic volumes and higher mobility, as this temperature range corresponds to peak commuting and economic activity periods (He *et al.*, 2023). While the correlations were statistically insignificant, the observed patterns suggest that temperature indirectly influences crash occurrence and severity through its effects on traffic flow, driver comfort, and environmental conditions.

3.3 Visibility and Road Safety Outcomes

Crash data categorized by visibility range reveal a clear influence of visibility on road safety indicators (Figure 4, Table 3). As visibility improved, both crash frequency and crash severity showed notable declines. The average number of crashes per day decreased from 0.37 at <1 km visibility to 0.20 at ≥5 km. Similarly, injuries per crash declined sharply from 3.26 to 1.67, and fatalities per crash fell slightly from 1.09 to 1.14, resulting in a total casualty rate reduction from 4.35 to 2.81 per crash.

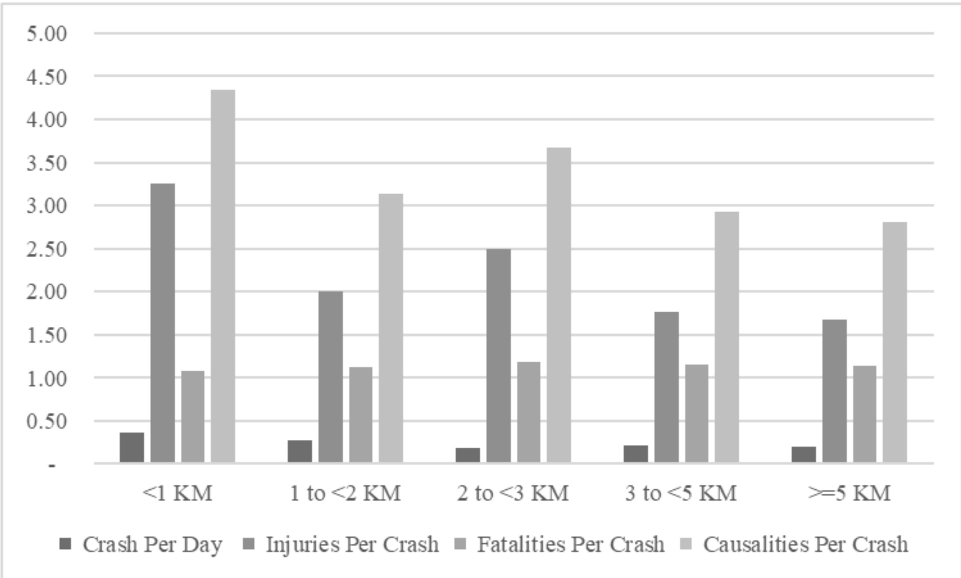

Figure 4. Impact of visibility on road safety in Bangladesh

Correlation analysis supported these patterns, indicating negative relationships between visibility and crash indicators: crash percentage ($r = -0.77$, $p = 0.13$), injury percentage ($r = -0.79$, $p = 0.11$), and fatality percentage ($r = -0.79$, $p = 0.11$). Although p-values were slightly above conventional significance levels, the strength of the correlations suggests a meaningful association between poor visibility and higher crash severity in Bangladesh.

Table 3. Correlation between temperature intensity and crash metrics

Metric	Correlation with Visibility	P-value
Crash (%)	(0.77)	0.13
Injury (%)	(0.79)	0.11
Fatalities (%)	(0.79)	0.11
Note: No correlations are significant at $p < 0.05$		

The results indicate that low visibility significantly elevates crash severity, even when crash frequency slightly decreases. This outcome aligns with previous research showing that fog, haze, and mist reduce drivers' perception–reaction time and distance judgment, increasing the likelihood of high-impact collisions (Andrey & Yagar, 1993; Peng *et al.*, 2017). Under poor visibility (<2 km), drivers often overestimate safe speeds and underestimate braking distance, leading to severe multi-vehicle crashes (Tanim, 2014).

The slight decline in crash frequency under very low visibility may reflect self-regulating driver behavior, as motorists tend to delay or cancel travel during dense fog conditions (Gandolfi, 2017).

However, those who continue driving face heightened risk, explaining the increased injury and fatality rates per crash.

3.4 Policy Implications

The study determines that rainfall, low visibility, and extreme temperatures significantly influence road crash severity in Bangladesh. Policy interventions should focus on weather-responsive road safety measures. These include the implementation of real-time driver alerts, adaptive speed regulations, and dynamic traffic management systems during adverse weather. Infrastructure improvements, such as enhanced drainage, reflective road markings, and improved street lighting, can mitigate the risks of rainfall and poor visibility. Additionally, integrating climate-sensitive risk assessment into transport planning and driver training programs will enhance preparedness and reduce crash casualties. Divisional-level variations highlight the need for region-specific strategies, particularly in high-risk districts. Overall, a proactive, data-driven approach combining technology, infrastructure, and public awareness can significantly improve road safety under changing climatic conditions, supporting Bangladesh's broader objectives for sustainable and resilient transport systems.

4. CONCLUSION

This study reveals how weather shapes road safety in Bangladesh, showing that climate is more than a backdrop, it directly influences lives on the road. Heavy rainfall reduced crash frequency from 0.21/day under dry conditions to 0.15/day during intense rain, yet injuries per crash rose from 1.76 to 2.13, and fatalities reached 1.24, highlighting that fewer crashes can still be more severe. Poor visibility was even more dangerous: under <1 km visibility, crashes averaged 0.37/day, but injuries soared to 3.26 per crash, with total casualties of 4.35. Temperature effects were subtler, with crashes dropping from 3.35/day (<15°C) to 1.92/day (>30°C), though moderate temperatures saw slightly higher injuries. These findings emphasize the need for practical, weather-responsive measures real-time alerts, adaptive speed limits, and better infrastructure. Future work should use dynamic traffic and climate modeling to identify high-risk areas, enabling targeted, data-driven interventions that save lives and make Bangladesh's roads safer and more resilient.

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➢ DECLARATION OF USE OF AI

The authors acknowledge the use of generative AI tools, specifically ChatGPT and DeepL, for the sole purpose of improving the language, clarity, and readability of the manuscript. These tools were not used to generate ideas, conduct data analysis, interpret findings, or contribute to the scientific content of the study. All intellectual work, including data collection, analysis, and formulation of conclusions, was performed independently by the authors. All AI-assisted outputs were carefully reviewed, corrected, and verified to ensure accuracy and compliance with academic standards.

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