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ADVERSE WEATHER IMPACT ON ROAD CRASHES: A COMPARATIVE ANALYSIS BETWEEN BARISHAL AND KHULNA DIVISIONS

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ABSTRACT

Bangladesh faces a troubling surge in road crashes, prompting the research on contributing factors. Research emphasizes adverse weather, particularly rainfall, temperature fluctuations, and visibility, as key catalysts. Investigating Khulna and Barishal divisions from 2018 to 2022, this study rigorously employs matched pair analysis. It aims to reveal the intricate interplay between adverse weather and crashes, assessing impacts on frequency, injuries, and fatalities. Findings show robust correlations between adverse weather, like intense rainfall and poor visibility, and increased crash, injury, and fatality rates. In Barishal, light rainfall (1-2 mm) offers a safety advantage, with a 14.59% lower injury rate, while moderate rainfall (3-7 mm) elevates risk with a 13.60% injury rate. Heavy rain (8-12 mm and ≥26 mm) significantly raises crashes and fatality rates, peaking at 41.38% fatalities. Conversely, Khulna responds differently. Even minor rain increments (1-2 mm) increase crashes and fatality rates to 11.5% and 20.9%, respectively. Higher rainfall (8-12 mm) links to intensify crashes and fatality rates, while 26-50 mm and ≥50 mm ranges maintain stable rates but heighten injuries. Wet roads (>2.5 mm water depth) associate with reduced crashes (7.2%), fatality (5.1%), and injury (7.6%) rates. The study conducts significance tests (t-test) in Khulna and Barishal Divisions, revealing in Khulna a substantial correlation between heavy rainfall (>12.5 mm) and increased crash risk and severity. In Barishal, wet road conditions significantly correlate with raised crash risk. Moderate temperatures (15-30°C) see a crash rate of 17.48 per day, with 45.47% injuries and 14.86% fatalities. Above 30°C, crashes decrease to 14.99 per day with lower injury and fatality rates. In Khulna, colder (<15°C) temperatures have higher crash rates (18.18%) with significant injuries (5.45%) and fatalities (18.18%). In 15-30°C range, crashes decrease, but injury rates rise. Visibility consistently affects road safety in both divisions. Improved visibility reduces crashes, fatality, and injury rates. This study made use of weather data from Bangladesh Meteorological Department (BMD) and reported crash data collected from Accident Research Institute (ARI). The study places a strong emphasis on preventative actions to lessen weather-related road safety risks, improving empirical understanding of the impact of weather dynamics on road crashes in Bangladesh, supporting targeted initiatives for road safety, and guiding policy decisions.

Keywords: *Road crash; safety; weather; impact; fatality; injury; rainfall; temperature; visibility.*

1. INTRODUCTION

The issue of motor vehicle crashes is a global concern, affecting both High Income Countries (HIC) and Low- and Middle-Income Countries (LMIC). Despite lower motorization rates, LMICs such as Bangladesh experience a disproportionately higher rate of crashes (WHO, 2015; WHO, 2018). Various factors contribute to these crashes, including driver-related issues like fatigue, alcohol consumption, and distractions (Andrey et al., 2013) and environmental factors like rainfall, temperature, adverse weather, snow, visibility, etc. While existing studies have explored the impact of different weather conditions on road safety, there is a notable gap in research on the effects of rainy weather (Bergel-Hayat et al., 2013), temperature (Bergel-Hayat et al., 2013; Brijs et al., 2008), and visibility (Levine et al., 1995; Ashley et al. 2015; Abdel-Aty et al. 2011), especially in LMICs like Bangladesh.

Given Bangladesh's consistent heavy rainfall (Basic Planet, 2022), there is a critical need to explore the impact of rain on road traffic crashes, with a focus on differentiating effects in urban and rural areas across the country's eight divisions. Similar attention needs to be given to the effects of temperature and visibility. Some studies showed the link between temperature and injury crashes in the Netherlands (Bergel-Hayat et al., 2013) and extreme temperatures and fatal car accidents in Italy (Gariazzo et al., 2021) and highlight the importance of

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understanding these factors. Additionally, reduced visibility, especially in foggy conditions, has been identified as a significant risk factor for road crashes in China (Wang et al., 2021).

Research by Sangkharat et al. (2021) underscores the direct relationship between rain and vehicle crashes. Rain affects driving by impairing visibility and diminishing the performance of vehicle lights, while wet roads reduce tire grip, heightening driving risks. Bangladesh, ranked 10th globally for average precipitation, experiences a significant proportion of crashes, fatalities, and injuries during rainfall, surpassing rates in many developed countries (Keay & Simmonds, 2006; Sangkharat et al., 2021; Black et al., 2017).

Moreover, extreme temperatures, both hot and cold, increase crash risks, with drivers' reduced concentration and slower reactions (Lobo et al., 2019; Wu et al., 2018). Bangladesh's historical climate, with temperatures ranging from 15°C to 34°C, shows a significant increase in road crashes below 15°C, indicating heightened accident severity (World Bank, 2021)

Apart from this, inadequate visibility, also crucial for road user safety, contributes to road crash risks in Bangladesh, particularly during dense fog in winter and heavy rain in the rainy season (Uddin & Awal, 2017; Rahman et al., 2021). An analysis done by Abdel-Aty et al. (2012) reveals that visibility below 1km in Dhaka Division correlates with higher crash, fatality, and injury rates, emphasizing the importance of visibility conditions in road safety. However, there is no comprehensive study on the impact of climatic factors such as rain, temperature, humidity, and/or visibility on road crashes and severities in Bangladesh. Recently a comprehensive study has been made to investigate the effects of climatic factors on road crashes in Bangladesh. As Bangladesh experiences diverse climatic conditions across different regions, the study explores the regional significance of the impact emphasizing urban and rural distinctions across the eight divisions. The study also explores key risk factors and their interactions, employing machine learning techniques to assess the model's accuracy and prediction capacity. The initial phase involves determining the relative risk of crashes, fatalities, and injuries in different divisions under varying weather conditions. This paper forms from a part of that extensive study which primarily focused on the adverse weather impact on road crashes in two major divisions i.e., Khula and Barishal. A comparative assessment has been made between those two divisions to see the regional disparities and complex patterns of impact on road crashes and casualties as a result of varying levels of rainfall, temperature, and visibility.

Khulna and Barishal, being separate divisions, have unique climatic factors (Gadgil, S., & Joshi, N. V., 1983), including variations in rainfall intensity, temperature extremes, and visibility conditions. Investigating these variations is crucial for a comprehensive understanding of the impact of adverse weather on road crashes. Each division may have specific traffic patterns (Dong, H. et al., 2015) and characteristics influenced by local economic activities, population density, and infrastructure development (Pasha, M. et al., 2016).

Examining Khulna and Barishal provides insights into how climatic factors interact with local traffic dynamics, contributing to a more nuanced understanding of road crash risks. Different regions may have distinct vulnerabilities to adverse weather conditions. Coastal areas, such as those in Khulna, might face unique challenges related to storms or cyclones, which could have repercussions on road safety. Exploring these vulnerabilities is essential for developing targeted and region-specific road safety strategies. In addition, including Khulna and Barishal in the research allows for a more comprehensive evaluation of the effectiveness of existing road safety policies and measures in diverse climatic contexts. The findings can inform regional policymakers about the specific challenges and potential solutions relevant to their areas.

2. METHODOLOGY

2.1 Analytical Approach

The research employs a matched pair analysis to assess the relative risk of crashes, injuries, and fatalities by pairing rainy days with dry days. A comprehensive analysis is conducted across the major two divisions of Bangladesh highlighting the dimensions and distinct characteristics of road safety issues. Comparative analyses are carried out, examining crash rates and casualty indices among the divisions.

The rainfall categories (1 to 2 mm, 3 to 7 mm, etc.) are based on previous studies, setting the threshold for wet road conditions at 2.5mm and defining adverse weather conditions as total daily rainfall exceeding 12.5mm (Black et al., 2017; Bertness, 1980; Sherretz, & Farhar, 1978). The temperature range (<15℃, 15-30℃, 30℃) is established based on Bangladesh's reported (World Bank, 2021) average daily temperature range (15℃ to 26℃). Temperatures below 15℃ or above 30℃ are considered adverse. The visibility range (<1km, 1 km to <2km, etc.) is determined from previous research indicating that visibility less than 1km and 1km to less than 2km are associated with increased crash and casualty rates, qualifying as poor or adverse conditions (Chaabani et al., 2017; Peng et al., 2017).

2.2 Data Collection

Data collection is a critical aspect of this research, involving two types of data: crash data and weather data. These datasets were obtained from secondary sources, including the Accident Research Institute (ARI), and the Bangladesh Meteorological Department (BMD).

I. Crash Data: Crash data were initially provided in aggregate form. These data required significant reorganization and segregation based on characteristics such as location, time of occurrence, and surface conditions (e.g., wet or dry). The reorganized crash data were then aligned with weather data for comprehensive analysis.

II. Weather Data: Weather data were collected from seven district-level weather stations under the BMD, covering two divisions (Figure 1):

- Khulna Division: Chuadanga, Jessore, Khulna, and Satkhira.
- Barishal Division: Barishal, Bhola, and Patuakhali.

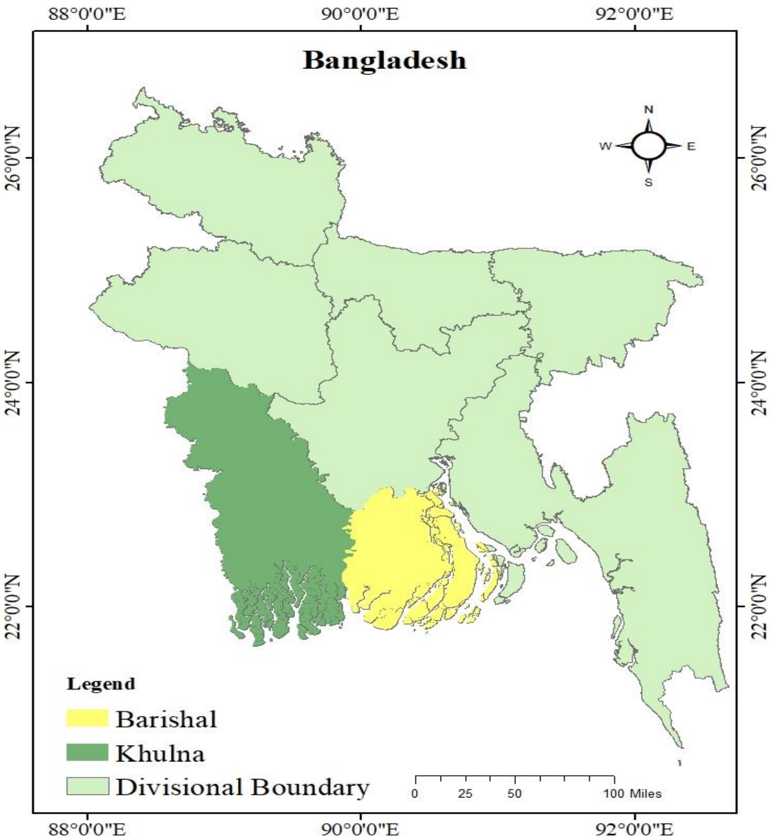

Figure 1: Study Area Map

The data covered the period from 2018 to 2022 and included the following weather parameters (Table 1):

- Rainfall: Measured in millimeters (mm), organized by precipitation levels.
- Temperature: Daily minimum and maximum temperatures (°C).
- Visibility: Daily average visibility (km)

Table 1: Weather Data Summary (2018–2022)

Parameter	Units	Data Source	Stations Covered	Temporal Resolution
Rainfall	mm	BMD	Chuadanga, Jessore, Khulna, Satkhira, Barishal, Bhola, Patuakhali	Daily
Temperature	°C	BMD	Same as above	Daily
Visibility	km	BMD	Same as above	Daily

2.3 Statistical Equations

This section outlines the statistical equations used for analyzing crash, injury, and fatality rates, as well as the casualty rate. These equations are essential for quantifying the extent of traffic-related incidents and their outcomes. Each metric provides insights into different aspects of traffic safety and accident analysis. The paired t-test formula is included for comparative statistical analysis of two sample means.

- $\boldsymbol{Crash}, \% = \frac{\sum \boldsymbol{Number\ of\ Crashes} \times \mathbf{100}}{\sum \boldsymbol{Number\ of\ Days}}$ (Black et al., 2017) (1)

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

- $\boldsymbol{Crash\ Rate} = \frac{\sum \boldsymbol{Number\ of\ Crashes}}{\sum \boldsymbol{Number\ of\ Days}}$ (Black et al., 2017) (2)
- $\boldsymbol{Injury\ Rate} = \frac{\sum \boldsymbol{Number\ of\ Injuries}}{\sum \boldsymbol{Number\ of\ Crashes}}$ (Black et al., 2017) (3)

Fatality rate is also calculated like injury rate.

- $\boldsymbol{Casualty\ Rate} = \frac{\sum \boldsymbol{Number\ of\ Injuries} + \sum \boldsymbol{Number\ of\ Fatalities}}{\sum \boldsymbol{Number\ of\ Crashes}}$ (Elliott & Broughton, 2005) (4)

The formula for the paired t-test (Paired two sample for means) is given below:

- $\boldsymbol{t} = \frac{\mathbf{\Sigma d}}{\sqrt{\frac{n(\Sigma d^2)+(\Sigma d)^2}{n-1}}}$ (Ross et al., 2017; Xu et al., 2017) (5)

Where, Σd is the sum of the differences and n is the sample size.

3. ANALYSIS AND RESULTS

3.1 Data Description

3.1.1 *Weather Data*

In Jessore district, the number of rainy days ranged from 79 to 114, the total rainfall ranged from 879 mm to 1963 mm, and the maximum rainfall in a day ranged from 65 mm to 122 mm between 2018 and 2022. In Khulna district, the number of rainy days ranged from 95 to 119, the total rainfall ranged from 1073 mm to 1967 mm, and the maximum rainfall in a day ranged from 90 mm to 217 mm between 2018 and 2022. In Satkhira district, the number of rainy days ranged from 97 to 110, the total rainfall ranged from 1143 mm to 1903 mm, and the maximum rainfall in a day ranged from 88 mm to 144 mm between 2018 and 2022. In Barisal district, the number of rainy days ranged from 95 to 123, the total rainfall ranged from 1418 mm to 2292 mm, and the maximum rainfall in a day ranged from 59 mm to 324 mm between 2018 and 2022. In Bhola district, the number of rainy days ranged from 102 to 127, the total rainfall ranged from 1513 mm to 2398 mm, and the maximum rainfall in a day ranged from 61 mm to 219 mm between 2018 and 2022. In Patuakhali district, the number of rainy days ranged from 112 to 143, the total rainfall ranged from 1765 mm to 2842 mm, and the maximum rainfall in a day ranged from 85 mm to 252 mm between 2018 and 2022.

In Jessore district, the maximum average daily temperature ranges from 31.70 to 32.90°C, the mean temperature ranges from 28.07 to 28.79°C, and the minimum temperature ranges from 15.00 to 20.90°C over the years 2018 to 2022. In Khulna district, the maximum average daily temperature ranges from 31.30 to 32.75°C, the mean temperature ranges from 28.23 to 28.90°C, and the minimum temperature ranges from 15.40 to 19.15°C over the years 2018 to 2022. In Satkhira district, the maximum average daily temperature ranges from 31.80 to 32.50°C, the mean temperature ranges from 28.23 to 28.81°C, and the minimum temperature ranges from 16.00 to 19.45°C over the years 2018 to 2022.In Barisal district, the maximum average daily temperature ranges from 31.30 to 32.13°C, the mean temperature ranges from 28.02 to 28.53°C, and the minimum temperature ranges from 16.43 to 20.30°C between 2018 and 2022. In Bhola district, the maximum average daily temperature ranges from 31.30 to 32.00°C, the mean temperature ranges from 28.00 to 28.61°C, and the minimum temperature ranges from 15.60 to 21.40°C between 2018 and 2022. In Patuakhali district, the maximum average daily temperature ranges from 31.10 to 31.75°C, the mean temperature ranges from 28.26 to 28.71°C, and the minimum temperature ranges from 15.70 to 23.65°C between 2018 and 2022.

In Chuadanga district, the maximum daily average visibility ranged from 5.60 km to 6.40 km, the mean of daily average visibility ranged from 5.19 km to 5.55 km, and the minimum daily average visibility ranged from 3.90 km to 4.40 km between 2018 and 2022. In Jessore district, the maximum daily average visibility ranged from 4.70 km to 6.10 km, the mean of daily average visibility ranged from 3.12 km to 3.65 km, and the minimum daily average visibility ranged from 0.80 km to 1.70 km between 2018 and 2022. In Khulna district, the maximum daily average visibility ranged from 6.40 km to 6.90 km, the mean of daily average visibility ranged from 5.57 km to 6.02 km, and the minimum daily average visibility ranged from 4.00 km to 4.50 km between 2018 and 2022. In Satkhira district, the maximum daily average visibility ranged from 6.10 km to 6.50 km, the mean of daily average visibility ranged from 5.81 km to 6.05 km, and the minimum daily average visibility ranged from 4.10 km to 4.90 km between 2018 and 2022. In Barisal district, the maximum daily average visibility ranged from 5.40 km to 5.90 km, the mean of daily average visibility ranged from 4.69 km to 5.12 km, and the minimum daily average visibility ranged from 2.30 km to 3.90 km between 2018 and 2022. In Bhola district, the maximum daily average visibility ranged from 5.50 km to 6.00 km, the mean of daily average visibility ranged from 4.54 km to 5.04 km, and the minimum daily average visibility ranged from 2.30 km to 3.40 km between 2018 and 2022. In Patuakhali district, the maximum daily average visibility ranged from 5.80 km to 6.10 km, the mean of daily average visibility ranged from 4.09 km to 4.70 km, and the minimum daily average visibility ranged from 1.60 km to 2.40 km between 2018 and 2022.

3.1.2 *Crash Data*

In Chuadanga there were no accidents, injuries, or fatalities reported in Chuadanga in 2018, 2019, and 2020. However, in 2022, there were 47 accidents, causing 12 injuries and 55 fatalities. In Jessore, there were 61 accidents in Jessore, causing 84 injuries and 68 fatalities in 2018. The number of accidents increased in 2019, with 84 accidents causing 96 injuries and 91 fatalities. In 2020, the number of accidents decreased to 56, causing 86 injuries and 66 fatalities. In 2021, the number of accidents decreased further to 41, causing 62 injuries and 51 fatalities. In 2022, the number of accidents increased to 61, with 123 injuries and 75 fatalities. In Khulna there were 32 accidents in Khulna, causing 49 injuries and 40 fatalities in 2018. The number of accidents increased to 42 in 2019, causing 98 injuries and 49 fatalities. In 2020, the number of accidents decreased to 32, causing 11 injuries and 34 fatalities. In 2021, the number of accidents remained almost the same, with 33 accidents causing 24 injuries and 40 fatalities. In 2022, the number of accidents increased slightly to 36, causing 18 injuries and 42 fatalities.

Satkhira: In 2018, Satkhira had 35 accidents, 82 injuries, and 38 fatalities. The number of accidents increased in 2019 with 54, but the number of injuries decreased to 52 and fatalities increased to 52. In 2020, the number of accidents decreased to 33, with 17 injured and 37 fatalities. In 2021, the number of accidents remained almost the same as the previous year with 32, but the number of injuries and fatalities increased to 40 each. In 2022, the number of accidents remained the same as the previous year with 32, but the number of injured decreased to 69 and fatalities decreased to 35. In Barisal had 99 accidents, 406 injuries, and 74 fatalities in 2018. The number of crashes increased in 2019 to 131, with 419 injured and 99 fatalities. In 2020, the number of accidents decreased to 98, with 259 injured and 67 fatalities. In 2021, the number of accidents increased to 110, with 476 injured and 67 fatalities. In 2022, the number of crashes decreased to 102, with 272 injured and 106 fatalities. In Bhola had 29 accidents, 49 injuries, and 31 fatalities in 2018. The number of accidents increased in 2019 to 48, but the number of injuries decreased to 28 and fatalities increased to 46. In 2020, the number of accidents decreased to 42, with 58 injured and 44 fatalities. In 2021, the number of crashes decreased to 35, with 32 injured and 36 fatalities. In 2022, the number of accidents decreased to 34, with 51 injured and 32 fatalities. In Patuakhali had 35 crashes, 114 injuries, and 31 fatalities in 2018. The number of crashes increased in 2019 to 43, but the number of injuries decreased to 79 and fatalities increased to 38. In 2020, the number of accidents decreased to 40, with 27 injured and 37 fatalities. In 2021, the number of accidents increased to 45, with 74 injured and 39 fatalities. In 2022, the number of accidents decreased to 40, with 80 injured and 43 fatalities.

3.2 Effect of Rainfall on Road Accident

3.2.1 *Effect of Rainfall on Crash Rate*

In the Barishal division (Figure 2), the crash rate undergoes a nuanced trajectory in response to varying precipitation levels. Initially, it registers a decline from 16.76% during dry conditions to 14.59% in the 1-2 mm rain range. However, a subsequent ascent is observed, reaching 15.14% in the 8-12 mm range and further increasing to 15.77% in the 26-50 mm range. In contrast, the Khulna division (Figure 3) exhibits a more linear pattern, with the crash rate experiencing a modest uptick from 10.3% in dry conditions to 11.5% in the 1-2 mm rain category. While a further increase is noted in the 8-12 mm range (9.6%), stability ensues in higher precipitation ranges.

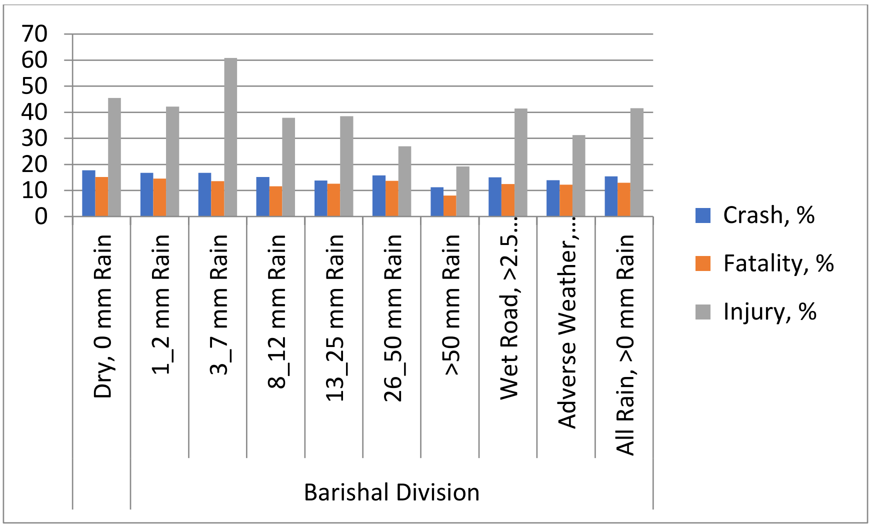

Figure 2: Impact of Rainfall on Crash Rate in Barishal Division

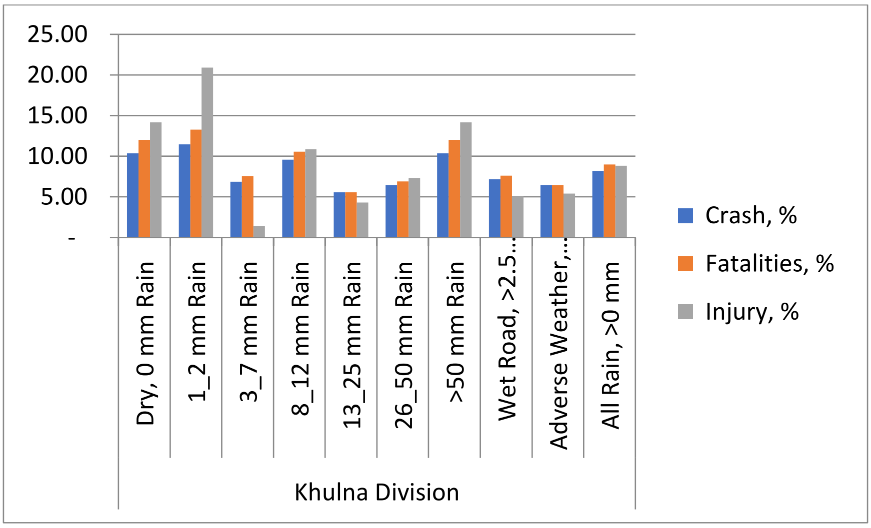

Figure 3: Impact of Rainfall on Crash Rate in Khulna Division

The fatality rate in Barishal exhibits an upward trend, escalating from 37.84% in the 8-12 mm rain category to 41.38% in instances of wet road conditions with water depth exceeding 2.5 mm. Conversely, in Khulna, a more pronounced impact is discerned as the fatality rate surges from 14.2% in dry conditions to 20.9% in the 1-2 mm rain category, surpassing the corresponding impact in Barishal.

The injury rate in Barishal follows a fluctuating pattern, decreasing in the 1-2 mm and 13-25 mm rain categories but escalating in the 3-7 mm range and adverse weather conditions featuring rainfall exceeding 12.5 mm. In Khulna, a contrasting trend emerges, with the injury rate increasing marginally with a slight rise in precipitation (1-2 mm) but maintaining relative stability in the 8-12 mm range. A significant surge is noted in higher rainfall categories.

The impact of wet road conditions with water depth exceeding 2.5 mm in Barishal substantially heightens accident risk, particularly manifesting in elevated fatality rates. In Khulna, the scenario differs markedly, with rainfall-induced wet roads yielding lower crash, fatality, and injury rates, implying a divergent influence compared to Barishal.

Both divisions align with prior research, affirming the significant influence of rainfall on road safety (Black et al., 2017; Shahid, & Minhans, 2016; Ashraf et al., 2019; Jung et al., 2014). However, distinctions emerge in the extent of fatality rate impact and the responsiveness of injury rates to varying precipitation levels. While Khulna exhibits heightened susceptibility to fatality rates with minimal rainfall, Barishal demonstrates a more intricate interplay between rainfall intensity and crash, fatality, and injury rates. Additionally, the divergent responses to wet road conditions underscore nuanced regional variations in the two divisions.

3.2.2 *Effect of Rainfall on Crash Severity*

The examination of crash severity in the Barishal and Khulna Divisions across diverse rain ranges and dry conditions provides valuable insights into regional disparities in road safety. In Barishal (Figure 4), dry conditions exhibit a peak in the crash rate at 0.1776, juxtaposed with comparatively lower fatality (0.85) and injury (2.56) rates. However, the causality rate remains notably high at 3.41, underscoring the severe consequences of accidents in the absence of rainfall. Conversely, in Khulna (Figure 5), a dry spell yields a crash rate of 0.10, a fatality rate of 1.16, and an injury rate of 1.37. All rain conditions (>0 mm) demonstrate diminished crash and fatality rates compared to dry conditions, with injury rates remaining comparable. Within the 3-7 mm rain range, Barishal experiences elevated fatality (0.81) and injury (3.65) rates, suggesting heightened severity during accidents within this precipitation band. In contrast, Khulna depicts a low crash rate (0.07) and marginal injury rate (0.21) in this range, indicative of relatively mild impacts. In 13-25 mm Rain Range, Barishal registers the highest crash rate at 0.13 in the 13-25 mm rain range. In Khulna, this range manifests a crash rate of 0.06, with comparatively lower fatality (1.00) and injury (0.77) rates. In the 26-50 mm rain range, Barishal records a relatively low fatality rate (0.87) and injury rate (1.71). Khulna exhibits a crash rate of 0.06, accompanied by moderate fatality (1.07) and injury (1.13) rates. In the >50 mm rain range, Barishal notes a high crash rate (0.112) without reported injuries. Khulna exhibits a crash rate of 0.10, with fatality (1.16) and injury (1.37) rates similar to dry conditions. Wet Road Conditions (>2.5) in Barishal experiences a slightly lower crash rate (0.1501) and fatality rate (0.83) compared to dry conditions, albeit with a slightly higher injury rate (2.75). In Khulna, the crash rate is 0.07, with lower fatality (1.06) and injury (0.70) rates compared to dry conditions. During adverse weather conditions (>12.5), Barishal observes a slightly lower crash rate (0.13) and injury rate (2.23) compared to dry conditions, accompanied by a slightly higher fatality rate (0.87). Conversely, in Khulna, the crash rate is 0.06, with lower fatality (1.00) and injury (0.83) rates compared to dry conditions.

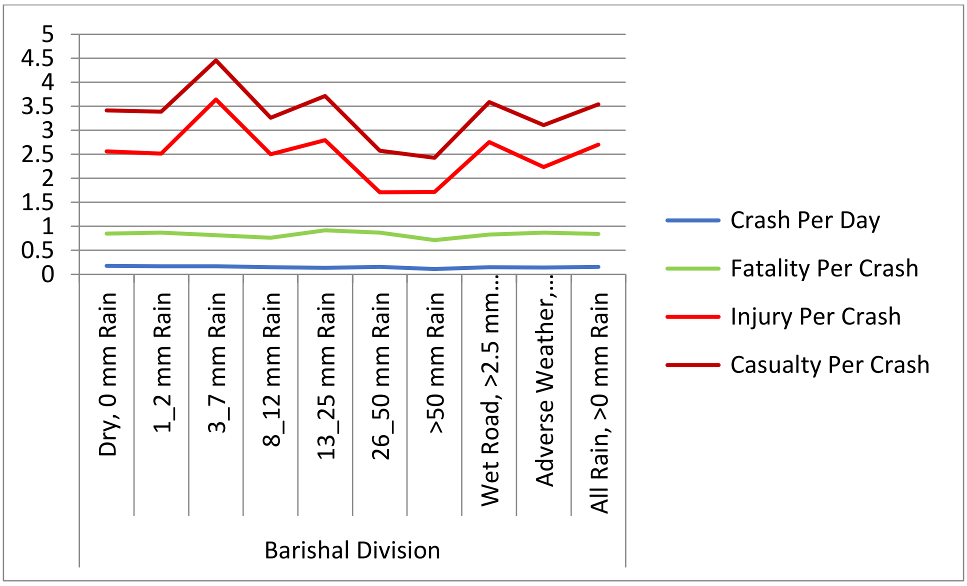

Figure 4: Impact of Rainfall on Crash Severity in Barishal Division

The findings from Barishal align with existing research on the correlation between rainfall and road crashes. A study conducted in India by Mondal, et al., 2011 highlighted a significant increase in the crash rate during rainfall compared to dry conditions. Similarly, research from Australia by Keay & Simmonds, 2006 underscored an elevated risk of severe crashes in wet weather conditions.

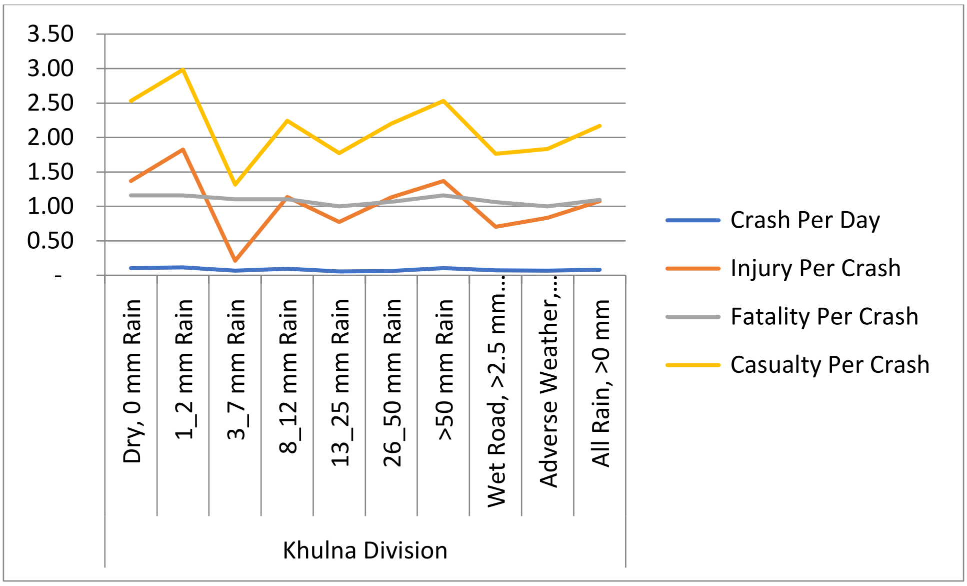

Figure 5: Impact of Rainfall on Crash Severity in Khulna Division

Particularly noteworthy in Barishal is the heightened injury rate in the 3-7 mm range, raising concerns about factors such as poor visibility, slippery road surfaces, and reduced traction. This observation resonates with prior studies, including one conducted in the United States by Pisano et al. (2008), which found an increased risk of injuries during wet weather conditions.

Comparatively, Khulna Division exhibits a consistency with global trends. Several studies conducted outside Bangladesh, including research in Malaysia (Rusli et al., 2017), the UK (Yannis & Karlaftis, 2010), Saudi Arabia (Islam et al., 2019), and India (Sumit et al., 2012), report a heightened likelihood of road crashes associated with rainfall. The congruence of these external studies with the results observed in Khulna Division further strengthens the understanding that rain intensifies the risk of road accidents.

The table presents (Table 2) the results of significance tests (t-test) comparing the risk and severity of road accidents between dry and rainy weather conditions in Khulna and Barishal Divisions. The p-values are reported for crash risk and crash severity for various rain ranges. Notably in Khulna, adverse weather due to rain, particularly when rainfall exceeds 12.5 mm, demonstrates a significant correlation with both increased crash risk and severity, as evidenced by lower P values. General rain conditions, irrespective of the amount, show moderate associations with both risk and severity. Furthermore, the study highlights that heavier rainfall, specifically in the ranges of 26-50 mm and more than 50 mm, exhibits stronger correlations with elevated crash risk and severity.

Table 1: Significance test (t-test) of risk and severity of dry weather condition's road accident with rainy weather condition's road accident

Rain Range	Khulna Division		Barishal Division	
	P Value (Crash Risk)	P Value (Crash Severity)	P Value (Crash Risk)	P Value (Crash Severity)
Wet Road Condition	0.09	0.13	0.02*	0.27
Adverse Weather Due to Rain (>12.5 mm Rain)	0.04*	0.10	0.19	0.17
Rain (>0 mm Rain)	0.07	0.11	0.04*	0.27
26-50 mm Rain	0.03*	0.04*	0.32	0.18
50 mm Rain	0.06	0.04*	0.18	0.12

* means this value is significant at the 0.05 level (2-tailed)

In Barishal, wet road conditions exhibit a significantly lower P value for crash risk (0.02*), emphasizing a strong correlation between wet roads and increased risk of accidents. However, this significance is not mirrored in crash severity, where the P value is 0.27, suggesting a lesser association with the severity of accidents. Adverse weather due to rain, specifically rainfall exceeding 12.5 mm, does not demonstrate a significant correlation with either crash risk or severity, as indicated by P values of 0.19 and 0.17, respectively. Rainfall in general (P = 0.04*) shows a statistically significant correlation with crash risk, but not with crash severity (P = 0.27). Interestingly, the heavier rain conditions of 26-50 mm and 50 mm do not exhibit significant associations with either crash risk or severity, suggesting that the impact of these rain ranges on road accidents in the Barishal Division may be less pronounced.

The asterisk (*) denotes values significant at the 0.05 level (2-tailed). These findings provide valuable insights into the nuanced relationships between different rain conditions and road accident outcomes in the Barishal and Khulna Divisions, offering guidance for targeted safety measures and interventions.

3.3 Effect of Temperature on Road Crashes

3.3.1 *Effect of Temperature on Crash Rate*

The comparative analysis between the Barishal and Khulna divisions reveals distinct patterns in the relationship between daily average temperature and road accident outcomes. In Barishal (Figure 6), where temperatures below 15°C were observed, there were no recorded accidents, indicating a potential avoidance or reduced occurrence during colder weather. Between 15-30°C, a temperature range considered moderate, Barishal experiences a relatively high rate of crashes at 17.48 per day, with a moderate injury rate of 45.47% and a fatality rate of 14.86%. Interestingly, temperatures above 30°C in Barishal show a slight decrease in the number of crashes to 14.99 per day, with lower injury and fatality rates. This contradicts previous studies (Basagaña et al., 2015; Gariazzo et al., 2021; Haynes et al., 2008; Hou et al., 2022) suggesting adverse temperatures increase accident risk. In contrast, Khulna exhibits a different trend. For temperatures below 15°C, the crash rate is relatively high at 18.18%, coupled with a significant injury rate of 5.45% and a high fatality rate of 18.18%. This suggests that colder temperatures contribute to relatively severe accidents with a higher risk of fatalities in Khulna. In the 15-30°C range, the crash rate decreases, but the injury rate increases, indicating less severe accidents in terms of fatalities but still resulting in a significant number of injuries. As temperatures rise above 30°C in Khulna, both the crash rate and associated injury and fatality rates decrease, indicating overall less severe accidents during warmer weather.

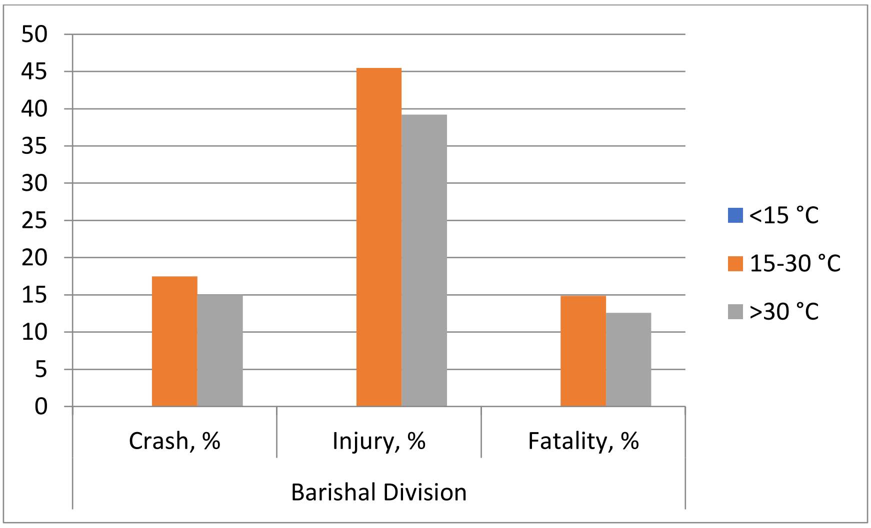

Figure 6: Impact of Temperature on Crash Rate in Barishal Division

Comparing the divisions, while Barishal shows a decrease in crash severity with rising temperatures, Khulna exhibits (Figure 7) more complex relationships. Colder temperatures in Khulna are associated with severe accidents, aligning with previous research (Brijs et al., 2008; Shaheed et al., 2016) suggesting a higher incidence of accidents in colder temperatures. However, as temperatures increase, Khulna experiences a decrease in crash severity, consistent with prior findings (Haynes, et al. 2008; Hou, et al., 2022). These variations underscore the importance of considering regional factors and local climate characteristics in understanding the temperature-accident relationship and tailoring safety measures accordingly in different divisions.

3.3.2 *Effect of Temperature on Crash Severity*

The comparative analysis between the Barishal and Khulna divisions reveals nuanced patterns in the relationship between daily average temperature and crash severity. In Barishal, the absence of recorded crashes for temperatures below 15°C suggests a potential avoidance or reduced occurrence of accidents in colder weather. Between 15-30°C, the relatively low number of crashes (0.17 per day) is offset by a high injury rate of 0.85 per crash and a fatality rate of 0.85 per crash. The causality rate is notably high at 3.45, indicating that although the frequency of crashes is low in this temperature range, they tend to be more severe, with a higher risk of fatalities per crash. Above 30°C in Barishal, the number of crashes remains similar, and the injury and fatality rates also maintain consistency, supporting the notion that crashes in this temperature range are consistently severe, aligning with findings from Bergel-Hayat et al., 2013.

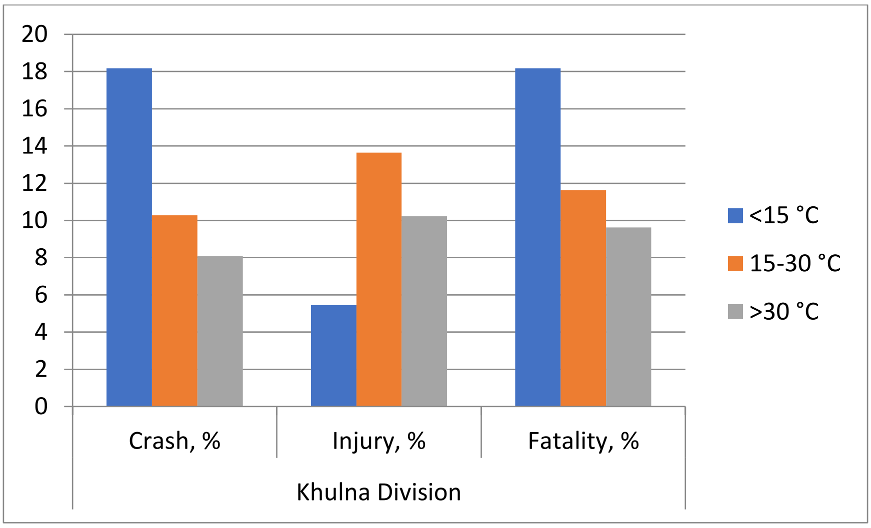

Figure 7: Impact of Temperature on Crash Rate in Khulna Division

In Khulna, temperatures below 15°C are associated with 0.18 crashes per day, a relatively high injury rate of 0.30 injuries per crash, and a fatality rate of 1.00 fatalities per crash. The causality rate is 1.01, indicating just over one casualty per crash on average. These figures suggest that crashes in this temperature range are relatively severe, with a higher risk of fatalities. Between 15-30°C, the number of crashes decreases to 0.10 per day, but the injury rate and fatality rate increase, along with a consistent causality rate. This suggests that although there are fewer crashes, they result in a higher rate of injuries and fatalities per crash. Above 30°C in Khulna, both the number of crashes and the injury rate decrease, but the fatality rate increases slightly, with a corresponding increase in the causality rate. This indicates that crashes in this temperature range are generally less severe overall, although the risk of fatalities per crash is slightly elevated, consistent with the findings of Bergel-Hayat et al. (2013).

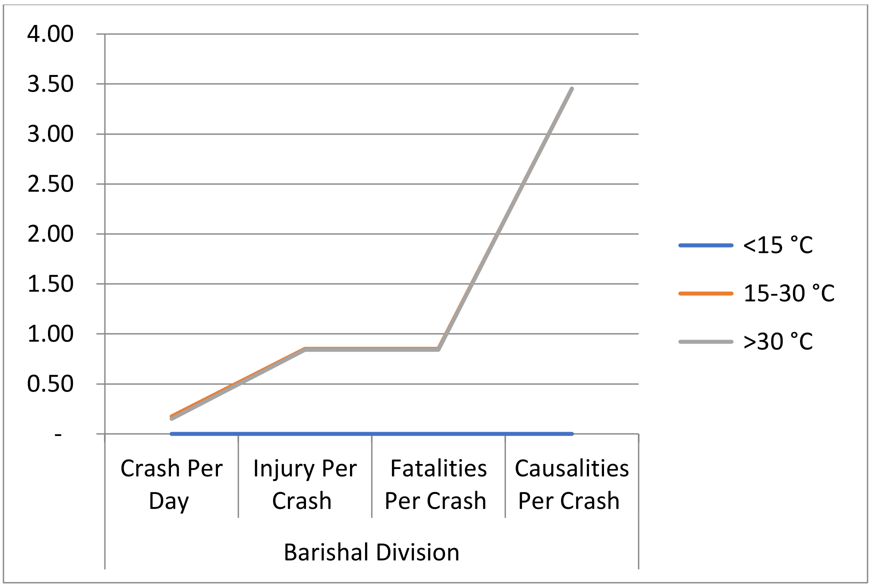

Figure 8: Impact of Temperature on Crash Severity in Barishal Division

Barishal experiences consistently severe crashes across temperature ranges, while Khulna exhibits a more dynamic pattern with varying severity levels. The comparative analysis underscores the importance of considering local climate characteristics and regional factors in understanding the temperature-crash severity relationship and implementing targeted safety measures accordingly. The t-test examining the significance of road accident risk and severity specifically below 15°C temperatures compared to other temperature ranges in both Khulna and Barishal divisions did not yield statistically significant results at the 0.05 level (2-tailed).

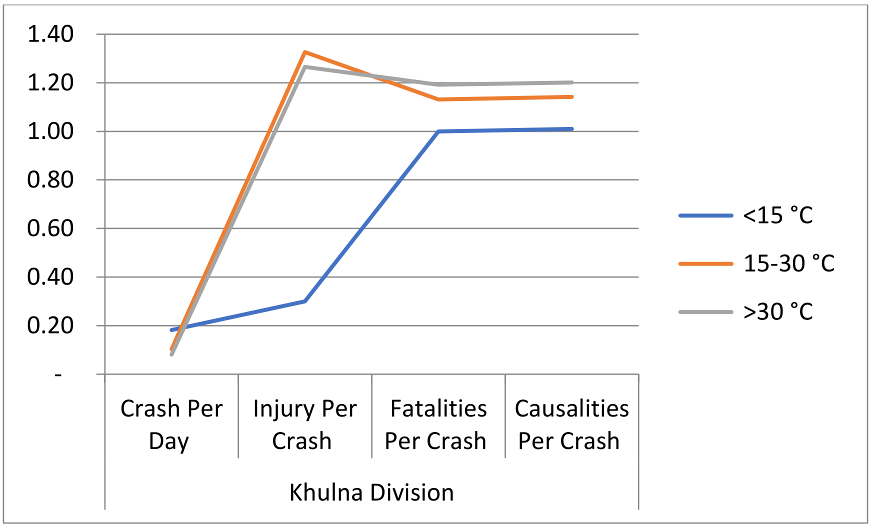

Figure 9: Impact of Temperature on Crash Severity in Khulna Division

3.4 Effect of Visibility on Road Accident

3.4.1 *Effect of Visibility on Crash Rate*

The comparative analysis between the Barishal and Khulna divisions regarding the relationship between visibility ranges and road accident outcomes reveals distinct patterns in their respective traffic environments. In the Barishal Division (Figure 10), there are no reported crashes for visibility ranges of less than 1 km or between 1-2 km, indicating a possible avoidance or reduced occurrence of accidents under extremely low visibility conditions. For the 2-3 km visibility range, a crash rate of 24.82% is reported, along with a fatality rate of 23.36% and an injury rate of 41.61%. As visibility improves to 3-5 km, the crash rate decreases to 16.59%, with a lower fatality rate of 13.70% but a higher injury rate of 44.44%. Visibility greater than or equal to 5 km sees a slightly higher crash rate of 17.18%, with a fatality rate of 14.96% and an injury rate of 44.38%. The trend in Barishal mirrors findings from previous studies, such as Theofilatos & Yannis (2014) and Wu et al. (2018), suggesting that as visibility increases, both crash and fatality rates tend to decrease.

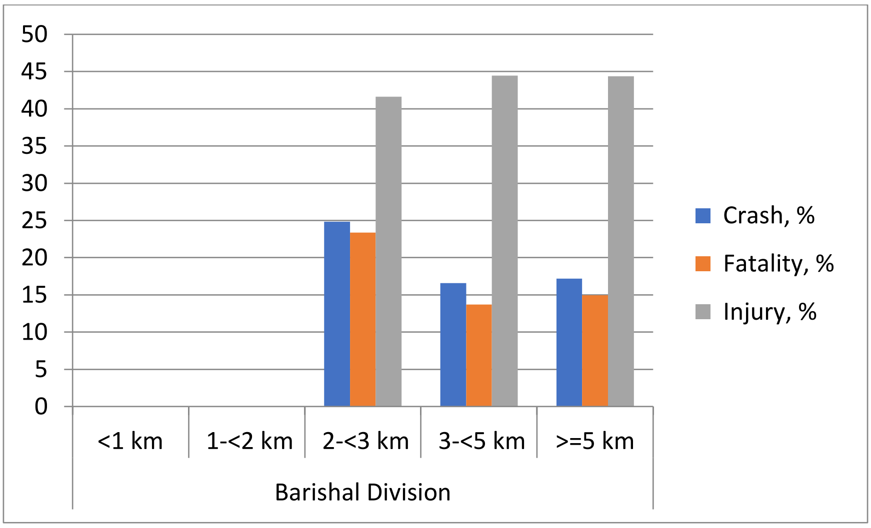

Figure 10: Impact of Visibility on Crash Rate in Barishal Division

In the Khulna Division (Figure 11), the analysis shows that visibility less than 1 km is associated with the highest percentage of crashes, fatalities, and injuries, each at 21.21%. Visibility between 1-2 km shows a slightly higher crash rate at 22.05%, with an elevated fatality rate of 25.38% and an injury rate of 26.28%. As visibility improves to 2-3 km and 3-5 km, the crash rates decrease to 15.98% and 10.91%, respectively. Notably, the fatality rates also decrease to 17.70% and 12.72%, while injury rates remain relatively high at 27.84% and 13.13%, respectively. Visibility greater than or equal to 5 km exhibits the lowest percentage of crashes (7.56%) and the lowest fatality and injury rates, both at 8.63% and 8.96%, respectively. These findings align with prior studies (Abdel-Aty et al., 2012; Theofilatos & Yannis, 2014; Wu et al., 2018), indicating that as visibility improves, the rates of crashes, fatalities, and injuries decrease.

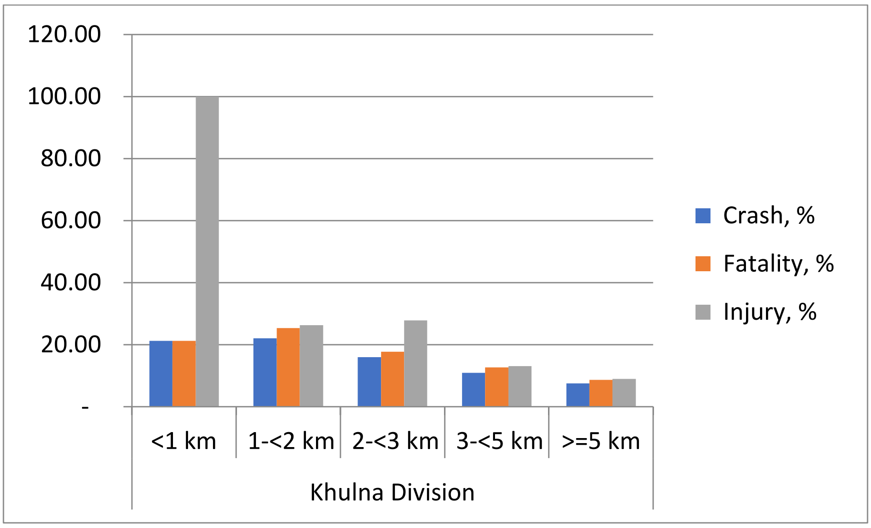

Figure 11: Impact of Visibility on Crash Rate in Khulna Division

While both divisions exhibit a general trend of decreasing accident rates with improved visibility, Khulna's data suggests higher severity in terms of fatalities and injuries, even as visibility increases. This underscores the need for tailored safety measures in each division, considering local factors influencing visibility-related accident outcomes.

3.4.2 *Effect of Visibility on Crash Severity*

The comparative analysis between the Barishal and Khulna divisions, focusing on the relationship between daily average visibility and crash severity, reveals distinctive patterns in how these factors interplay within each region. In the Barishal Division (Figure 12), visibility ranges below 2 km show a unique absence of reported crashes, indicating potential avoidance or reduced accident occurrence in extremely low visibility conditions. For the 2-3 km visibility range, the division reports a daily average of 0.248 crashes, with a fatality rate of 0.94 fatalities per crash and an injury rate of 1.68 injuries per crash. The causality rate, encompassing both fatalities and injuries, is 2.62 per crash. As visibility increases to 3-5 km and above 5 km, the daily average crash rate decreases to 0.166 and 0.172, respectively, accompanied by decreasing fatality and injury rates. The causality rates for these visibility ranges are 3.51 and 3.45 per crash, respectively. This aligns with findings from studies by Theofilatos & Yannis (2014) and Wu et al. (2018), suggesting a decrease in crash and fatality rates as visibility improves.

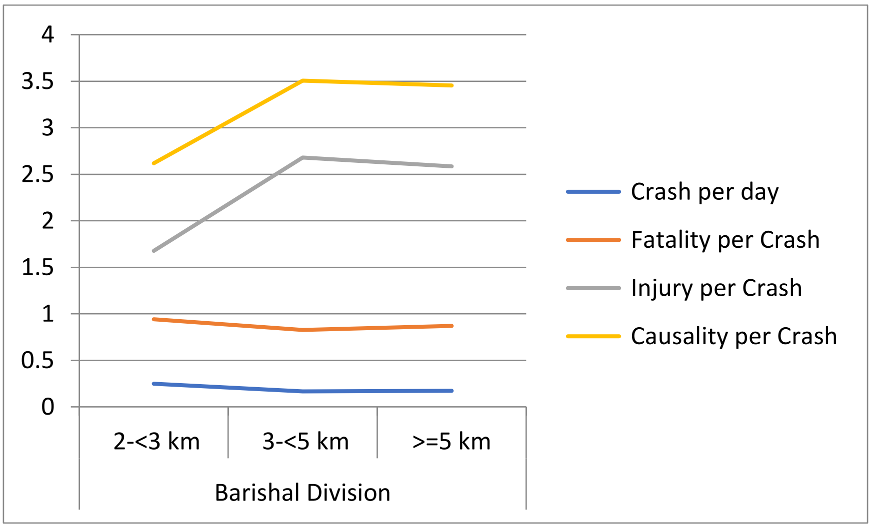

Figure 12: Impact of Visibility on Crash Severity in Barishal Division

However, in the Khulna Division (Figure 13), visibility less than 1 km is associated with a daily average crash rate of 0.21, the highest among all categories. The causality rate per crash is also the highest at 5.71, indicating severe injuries, with a high injury rate of 4.71 and a fatality rate of 1.00 per crash. As visibility improves to 1-2 km and beyond, the daily average crash rate slightly increases, but causality rates decrease, signifying less severe outcomes in terms of injuries and fatalities. The fatality rates per crash range from 1.15 to 1.19, indicating relatively consistent fatality risk across visibility categories. The injury rates per crash decrease as visibility improve, reflecting a general decrease in crash severity which is aligned with previous studies (Abdel-Aty et al., 2012; Abdel-Aty et al., 2011; Das et al., 2017; Khattak et al., 1998).

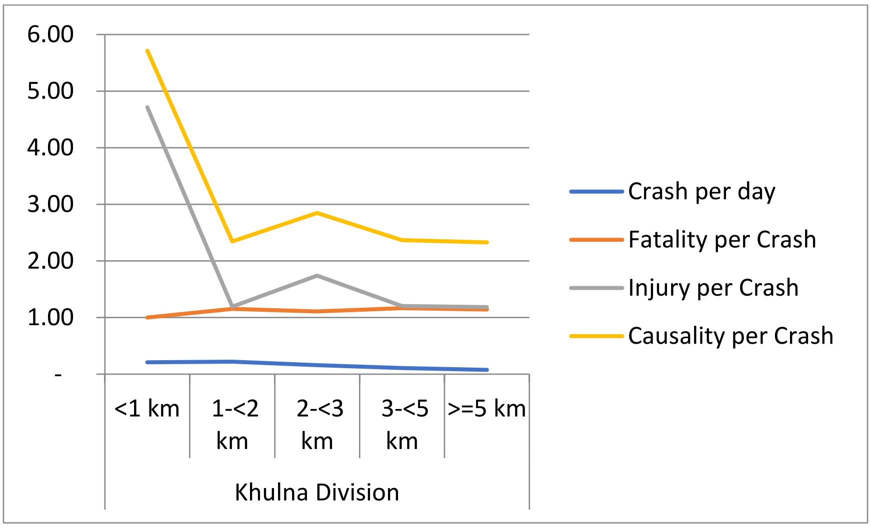

Figure 13: Impact of Visibility on Crash Severity in Khulna Division

Both divisions exhibit a trend of decreasing crash severity with improved visibility. However, the Khulna Division presents higher overall severity levels, particularly in the lowest visibility category. Barishal, on the other hand, showcases a distinct absence of crashes in extremely low visibility conditions. These variations underscore the need for tailored safety measures and interventions, considering the unique characteristics of each region in relation to visibility-related accident outcomes. The t-test examining the significance of road accident risk and severity specifically below 1 km visibility range compared to other visibility ranges in both Khulna and Barishal divisions did not yield statistically significant results at the 0.05 level (2-tailed).

4. CONCLUSIONS

This study provides valuable insights into the impact of weather conditions on road safety across Barishal and Khulna Divisions, highlighting regional disparities and the need for tailored safety measures. In Barishal, a complex relationship exists between rainfall intensity and crash severity, with moderate rainfall (3–7 mm) significantly increasing fatality and injury rates. Wet road conditions with over 2.5 mm water depth further elevate crash risks. Conversely, Khulna shows a linear progression of crash rates with rainfall, consistent with global patterns, but with minimal changes in fatality and injury rates, reflecting a more uniform impact of rainfall.

Temperature-crash dynamics also reveal regional differences. In Barishal, crash severity decreases with rising temperatures, and no crashes are recorded below 15°C, possibly due to reduced activity during colder weather. In contrast, Khulna experiences severe crashes at temperatures below 15°C, with a high fatality rate, while warmer conditions above 30°C correspond to reduced crash severity. These variations underscore the importance of addressing local factors like driving behaviors and infrastructure resilience.

Visibility conditions further differentiate road safety outcomes. Barishal exhibits reduced crashes in extremely low visibility, suggesting effective avoidance strategies, while Khulna records elevated crash and fatality rates in visibility under 1 km, demanding targeted interventions. Both divisions show improved safety with better visibility, aligning with broader studies.

Three major climatic factors such as rainfall, temperature and humidity, are considered the major climatic factors in this study. The impact of some other climatic factors, such as wind speed, light intensity, etc., could be tested using a more advanced modelling approach in further research. Consideration of crash-specific weather conditions data might provide better insight, which could also be considered as a future research direction.

The findings of this analysis highlight the necessity of region-specific road safety measures. Policymakers should consider precipitation levels, temperature thresholds, and visibility conditions to design targeted interventions. A uniform approach is ineffective; instead, dynamic strategies addressing local weather patterns and driving conditions are crucial for improving road safety in Barishal and Khulna divisions. This research offers a framework for enhancing traffic safety through informed, context-specific measures.

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REFERENCES

Abdel-Aty, M., Ekram, A.A., Huang, H. & Choi, K. (2011). A study on crashes related to visibility obstruction due to fog and smoke. Accident Analysis & Prevention, 43(5),1730-1737.

Abdel-Aty, M.A., Ahmed, M.M., Lee, J., Shi, Q. & Abuzwidah, M. (2012). Synthesis of visibility detection systems (No. BDK78 977-11). Florida. Dept. of Transportation.

Andrey, J., Hambly, D., Mills, B. & Afrin, S. (2013). Insights into driver adaptation to inclement weather in Canada. Journal of Transport Geography, 28, 192-203.

Ashley, W.S., Strader, S., Dziubla, D.C. & Haberlie, A. (2015). Driving blind: Weather-related vision hazards and fatal motor vehicle crashes. Bulletin of the American Meteorological Society, 96(5), 755-778.

Ashraf, I., Hur, S., Shafiq, M. & Park, Y. (2019). Catastrophic factors involved in road accidents: Underlying causes and descriptive analysis. PLoS one, 14(10), e0223473.

Basagaña, X., Escalera-Antezana, J.P., Dadvand, P., Llatje, Ò., Barrera-Gómez, J., Cunillera, J., Medina-Ramón, M. & Pérez, K. (2015). High ambient temperatures and risk of motor vehicle crashes in Catalonia, Spain (2000–2011): a time-series analysis. Environmental health perspectives, 123(12), 1309-1316.

Basic Planet (2022). "List of Top 10 Countries with Most Rainfall in the World", https://www.basicplanet.com/list-top-10-countries-rainfall-world/, accessed on 21-08-2022.

Bergel-Hayat, R., Debbarh, M., Antoniou, C., & Yannis, G. (2013). Explaining the road accident risk: Weather effects. Accident Analysis & Prevention, 60, 456-465.

Bertness, J. (1980). Rain-related impacts on selected transportation activities and utility services in the Chicago area. Journal of Applied Meteorology and Climatology, 19(5), 545-556.

Black, A. W., Villarini, G. & Mote, T. L. (2017). Effects of rainfall on vehicle crashes in six US states. Weather, climate, and society, 9(1), 53-70.

Brijs, T., Karlis, D. & Wets, G. (2008). Studying the effect of weather conditions on daily crash counts using a discrete time-series model. Accident Analysis & Prevention, 40(3), 1180-1190.

Chaabani, H., Kamoun, F., Bargaoui, H. and Outay, F. (2017). A neural network approach to visibility range estimation under foggy weather conditions. Procedia computer science, 113, 466-471.

Das, S., Brimley, B. K., Lindheimer, T. E., & Zupancich, M. (2018). Association of reduced visibility with crash outcomes. IATSS research, 42(3), 143-151.

Dong, H., Wu, M., Ding, X., Chu, L., Jia, L., Qin, Y., & Zhou, X. (2015). Traffic zone division based on big data from mobile phone base stations. Transportation Research Part C: Emerging Technologies, 58, 278-291.

Elliott, M.A. & Broughton, J. (2005). How methods and levels of policing affect road casualty rates. London: TRL Limited.

Gadgil, S., & Joshi, N. V. (1983). Climatic clusters of the Indian region. Journal of Climatology, 3(1), 47-63.

Gariazzo, C., Bruzzone, S., Finardi, S., Scortichini, M., Veronico, L. & Marinaccio, A. (2021). Association between extreme ambient temperatures and general indistinct and work-related road crashes. A nationwide study in Italy. Accident Analysis & Prevention, 155, 106-110.

Haynes, R., Lake, I.R., Kingham, S., Sabel, C.E., Pearce, J. & Barnett, R. (2008). The influence of road curvature on fatal crashes in New Zealand. Accident Analysis & Prevention, 40(3), 843-850.

Hou, K., Zhang, L., Xu, X., Yang, F., Chen, B. & Hu, W. (2022). Ambient temperatures associated with increased risk of motor vehicle crashes in New York and Chicago. Science of the total environment, 830, 154731.

Islam, M.M., Alharthi, M. & Alam, M.M. (2019). The impacts of climate change on road traffic accidents in Saudi Arabia. Climate, 7(9),103.

Jung, S., Jang, K., Yoon, Y. & Kang, S. (2014). Contributing factors to vehicle to vehicle crash frequency and severity under rainfall. Journal of safety research, 50, 1-10.

Keay, K., & Simmonds, I. (2006). Road accidents and rainfall in a large Australian city. Accident Analysis & Prevention, 38(3), 445-454.

Khattak, A.J., Kantor, P. & Council, F.M. (1998). Role of adverse weather in key crash types on limited-access: roadways implications for advanced weather systems. Transportation research record, 1621(1), 10-19.

Levine, N., Kim, K.E. & Nitz, L.H. (1995). Daily fluctuations in Honolulu motor vehicle accidents. Accident Analysis & Prevention, 27(6), 785-796.

Lobo, A., Ferreira, S., Iglesias, I. & Couto, A. (2019). Urban road crashes and weather conditions: Untangling the effects. Sustainability, 11(11), 3176.

Mondal, P., Sharma, N., Kumar, A., Bhangale, U. D., Tyagi, D., & Singh, R. (2011). Effect of rainfall and wet road condition on road crashes: A critical analysis (No. 2011-26-0104). SAE Technical Paper.

Pasha, M., Rifaat, S. M., Tay, R., & De Barros, A. (2016). Effects of street pattern, traffic, road infrastructure, socioeconomic and demographic characteristics on public transit ridership. KSCE Journal of Civil Engineering, 20, 1017-1022.

Peng, Y., Abdel-Aty, M., Shi, Q. & Yu, R. (2017). Assessing the impact of reduced visibility on traffic crash risk using microscopic data and surrogate safety measures. Transportation research part C: emerging technologies, 74, 295-305.

Pisano, P.A., Goodwin, L.C. & Rossetti, M.A., (2008, January). US highway crashes in adverse road weather conditions. In 24th conference on international interactive information and processing systems for meteorology, oceanography and hydrology, New Orleans, LA,20-24.

Rahman, M.H., Zafri, N.M., Akter, T. & Pervaz, S. (2021). Identification of factors influencing severity of motorcycle crashes in Dhaka, Bangladesh using binary logistic regression model. International journal of injury control and safety promotion, 28(2), 141-152.

Ross, A., Willson, V.L., Ross, A. & Willson, V.L. (2017). Paired samples T-test. Basic and Advanced Statistical Tests: Writing Results Sections and Creating Tables and Figures, 17-19.

Rusli, R., Haque, M.M., King, M. & Voon, W.S. (2017). Single-vehicle crashes along rural mountainous highways in Malaysia: An application of random parameters negative binomial model. Accident Analysis & Prevention, 102, 153-164.

Sangkharat, K., Thornes, J.E., Wachiradilok, P. & Pope, F.D. (2021). Determination of the impact of rainfall on road accidents in Thailand. Heliyon, 7(2), e06061.

Shaheed, M.S., Gkritza, K., Carriquiry, A.L. & Hallmark, S.L. (2016). Analysis of occupant injury severity in winter weather crashes: A fully Bayesian multivariate approach. Analytic methods in accident research, 11, 33-47.

Shahid, S. & Minhans, A. (2016). Climate change and road safety: a review to assess impacts in Malaysia. Jurnal Teknologi, 78(4).

Sherretz, L.A. & Farhar, B.C. (1978). An analysis of the relationship between rainfall and the occurrence of traffic accidents. Journal of Applied Meteorology and Climatology, 17(5), 711-715.

Sumit, K., Ross, V., Ruiter, R.A., Polders, E., Wets, G. & Brijs, K. (2022). An exploration of characteristics and time series forecast of fatal road crashes in Manipal, India. Sustainability, 14(5), 2851.

Theofilatos, A. & Yannis, G. (2014). A review of the effect of traffic and weather characteristics on road safety. Accident Analysis & Prevention, 72, 244-256.

Uddin, M.I. & Awal, Z.I. (2017, December). An insight into the maritime accident characteristics in Bangladesh. In 1st International Conference on Mechanical Engineering and Applied Science.

Wang, Y., Zhang, H. & Shi, N. (2021). Factors contributing to the severity of heavy truck crashes: a comparative study of Jiangxi and Shaanxi, China. Jordan Journal of Civil Engineering, 15(1).

WHO (2015). Global status report on road safety 2015 (ISBN 978 92 4 156506 6). Geneva, Switzerland: https://www.who.int/violence_injury_prevention/road_safety_status/2015/en/.

WHO (2018). Global status report on road safety 2018. Geneva: World Health Organization; 2018.: http://www.who.int/violence_injury_prevention/road_traffic/en/.

World Bank (2021). CLIMATE RISK COUNTRY PROFILE: BANGLADES. The World Bank Group.

Wu, C.Y., Zaitchik, B.F. & Gohlke, J.M. (2018). Heat waves and fatal traffic crashes in the continental United States. Accident Analysis & Prevention, 119, 195-201.

Xu, M., Fralick, D., Zheng, J.Z., Wang, B. & Changyong, F.E.N.G. (2017). The differences and similarities between two-sample t-test and paired t-test. Shanghai archives of psychiatry, 29(3), 184.

Yannis, G. & Karlaftis, M.G. (2010), January. Weather effects on daily traffic accidents and fatalities: a time series count data approach. In Proceedings of the 89th Annual Meeting of the Transportation Research Board,10, 14.