

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

Md. Fuad Hasan<sup>\*1</sup>, S. M. Sohel Mahmud<sup>2</sup>, Ayesha Akter<sup>3</sup> and Faisal Mahmud Sakib<sup>4</sup>

1 Lecturer, Department of Environment Protection, German University Bangladesh (GUB), Gazipur-1702, Bangladesh, e-mail: fuad.dm.pstu@gmail.com

2 Associate 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

4 Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, e-mail: fmsakibbuet@gmail.com

**\*Corresponding Author**

### 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  $\geq 26$  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  $\geq 50$  mm ranges maintain stable rates but heighten injuries. High rates of accidents (7.2%), fatalities (5.1%), and injuries (7.6%) are also associated with wet roads, defined as having a rain exceeding 2.5 mm. 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 ( $<15^\circ\text{C}$ ) 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 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 10<sup>th</sup> 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 & Joshi, 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 et al., 2015) and characteristics influenced by local economic activities, population density, and infrastructure development (Pasha et al., 2016).

Analyzing Khulna and Barishal sheds light on the intricate interplay between climatic factors and local traffic dynamics, offering a more nuanced comprehension of the risks associated with road crashes. 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 Methods**

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 were 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°C, 15-30°C, 30°C) is established based on Bangladesh's reported (World Bank, 2021) average daily temperature range (15°C to 26°C). Temperatures below 15°C or above 30°C 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**

An important part of this research is done in this section. Two types of data were collected for this research including crash and weather data. These data were collected from the secondary sources including ARI, Bangladesh Police, and BMD. Entire databases are rechecked, and necessary cleaning is done. It is to be noted that crash data mainly remains in aggregate form and necessary segregation and reorganization is needed under different characteristics and factors (e.g., location, time, wet or dry etc.) to accumulate with the other data. Rain data is organized according to the level of precipitation.

Total available seven district-level weather stations data were obtained for the two divisions (four stations of Khulna namely Chuadanga, Jessore, Khulna, Satkhira and three stations of Barishal namely Barisal, Bhola, Patuakhali) from the BMD. As a result, our analysis focused on these seven districts and the divisional analysis was limited to those districts.

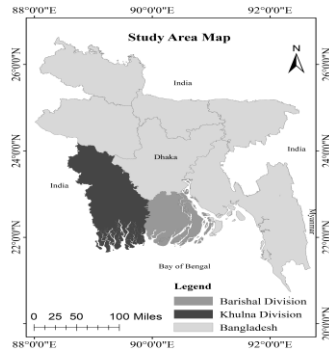


Figure 1: Study Area Map

## 2.3 Equations

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

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

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

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

Fatality rate is also calculated like injury rate.

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

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

$$t = \frac{\sum d}{\sqrt{\frac{n(\sum d^2) + (\sum d)^2}{n-1}}} \dots \dots \dots (\text{Ross et al., 2017; Xu et al., 2017}).$$

Where,  $\sum d$  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 degrees Celsius, the mean temperature ranges from 28.07 to 28.79 degrees Celsius, and the minimum

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

The district Chuadanga remained devoid of reported accidents, injuries, and fatalities throughout the years 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 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.

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.

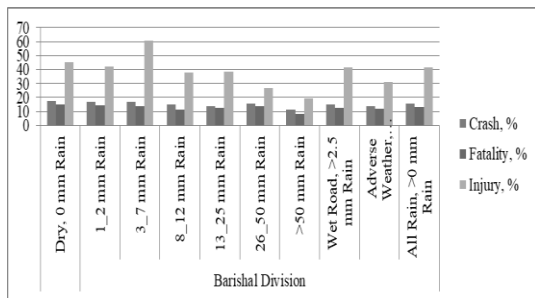


Figure 2: Impact of Rainfall on Crash Rate in Barishal Division

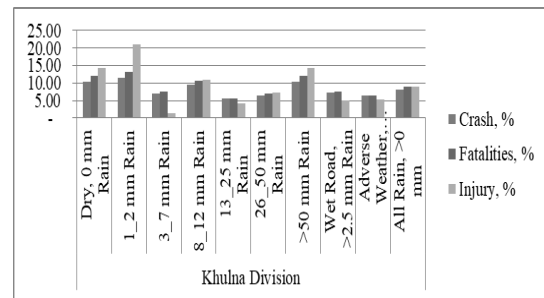


Figure 3: Impact of Rainfall on Crash Rate in Khulna Division

### 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.

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.

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., 2022), 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.

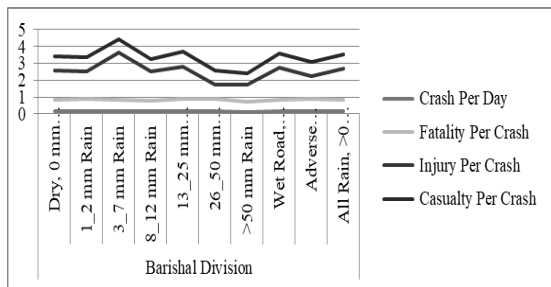


Figure 4: Impact of Rainfall on Crash Severity in Barishal Division

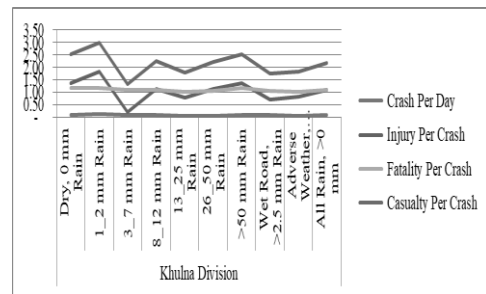


Figure 5: Impact of Rainfall on Crash Severity in Khulna Division

**Table 1** presents 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.

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.

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)



### 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.

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.

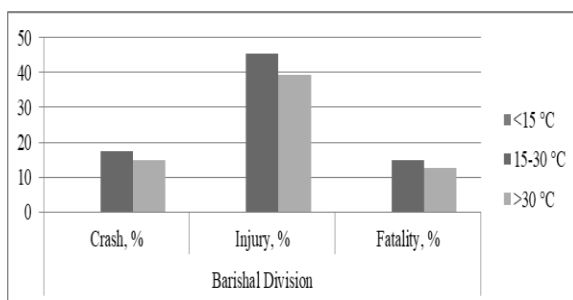


Figure 6: Impact of Temperature on Crash Rate in Barishal Division

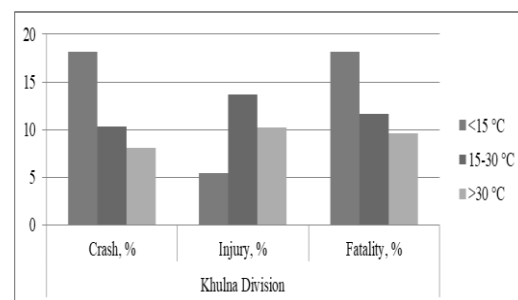


Figure 7: Impact of Temperature on Crash Rate in Khulna Division

#### 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).

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).

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.

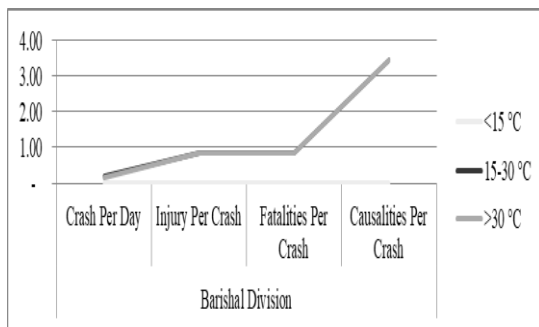


Figure 8: Impact of Temperature on Crash Severity in Barishal Division

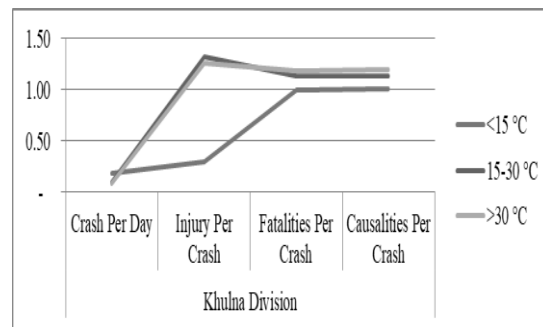


Figure 9: Impact of Temperature on Crash Severity in Khulna Division

The t-test examining the significance of road accident risk and severity specifically below 15°C temperature compared to other temperature ranges in both Khulna and Barishal divisions did not yield statistically significant results at the 0.05 level (2-tailed).

### 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 extends to a range of 3-5 km, the crash rate experiences a decline to 16.59%, accompanied by a reduced fatality rate of 13.70% but a heightened 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.

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. 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.

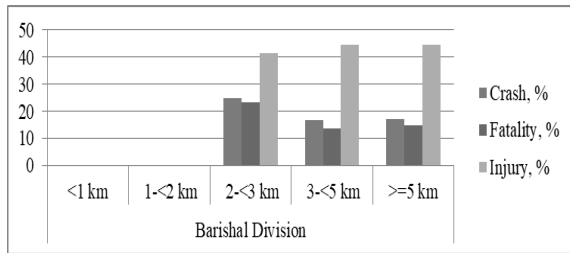


Figure 10: Impact of Visibility on Crash Rate in Barishal Division

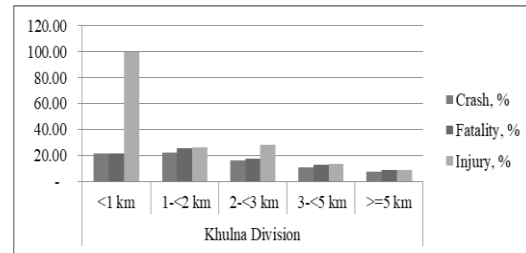


Figure 11: Impact of Visibility on Crash Rate in Khulna Division

### 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.

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).

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.

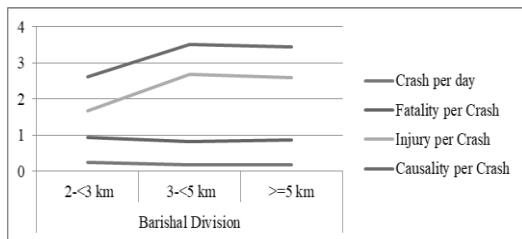


Figure 12: Impact of Visibility on Crash Severity in Barishal Division

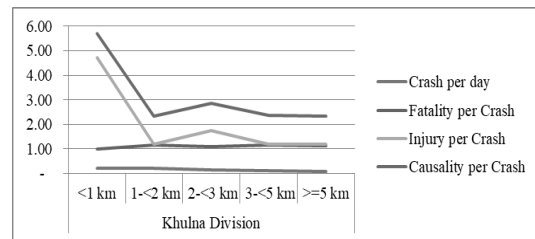


Figure 13: Impact of Visibility on Crash Severity in Khulna Division

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

An in-depth examination of road safety in Barishal and Khulna Divisions in relation to different levels of rainfall provides valuable insights into regional differences and subtle trends. Barishal Division displays a complex connection between the intensity of rainfall and the severity of crashes, showing notable fluctuations in crash, fatality, and injury rates across various precipitation levels. In this division the crash rate fluctuates with precipitation levels, initially decreasing from 16.76% in dry conditions to 14.59% in 1-2 mm rain but later increasing to 15.77% in 26-50 mm rain. Fatality rate rises from 37.84% to 41.38% in wet road conditions (>2.5 mm water depth). Injury rate varies with rainfall. On the other hand, Khulna Division demonstrates a more straightforward pattern, aligning with global trends that indicate an increased risk of crashes during rainfall. In Khulna, a linear pattern is observed with a modest increase in crash rate from 10.3% in dry conditions to 11.5% in 1-2 mm rain. Fatality rate surges from 14.2% to 20.9% in the same conditions. Injury rate remains stable with slight precipitation. Dry conditions in both regions reveal distinct crash severity patterns. The linear progression of crash rates and the minimal impact on fatality and injury rates in response to varying precipitation levels in Khulna underscore a more consistent influence of rainfall on road safety. The consistency observed in Khulna, aligning with global studies, emphasizes the universal impact of rain on the likelihood of crashes.

The comparative analysis of the relationship between daily average temperature and road crash outcomes in Barishal and Khulna divisions highlights distinct patterns, emphasizing the need for region-specific safety measures. Barishal demonstrates a somewhat unexpected decrease in crash severity with rising temperatures, challenging conventional wisdom suggesting adverse weather conditions increase crash risk. In Barishal, temperatures below 15°C associate with zero recorded accidents. In the 15-30°C range, the daily crash rate is 17.48, with a 45.47% injury rate and a 14.86% fatality rate. Above 30°C, crashes decrease to 14.99 daily, with lower injury and fatality rates. In crash severity (15-30°C), the daily crash rate is 0.17, but the injury and fatality rates are 0.85 each, resulting in a causality rate of 3.45. Above 30°C, crashes remain consistent with similar injury and fatality rates. Conversely, Khulna exhibits a more complex relationship, aligning with prior research indicating higher crash rates in colder temperatures. The notable severity of crashes at temperatures below 15°C in Khulna, characterized by a high fatality rate, underscores the need for targeted interventions during colder weather conditions. In Khulna, temperatures below 15°C result in an 18.18% crash rate and high injuries (5.45%) and fatality (18.18%) rates. Beyond 30°C, Khulna sees decreased crash rates and associated injuries and fatalities. In crash severity, below 15°C, the daily crash rate is 0.18, with an injury rate of 0.30 and a fatality rate of 1.00. Between 15-30°C, the daily crash rate decreases to 0.10, but injury and fatality rates increase, indicating more severe accidents. Above 30°C, crashes decrease, but fatality rates slightly increase. The decreasing crash severity as temperatures rise above 30°C in Khulna supports the idea that warmer weather is associated with overall less severe crashes, contributing to a nuanced understanding of the temperature-crash severity relationship.

The relationship between visibility ranges and road crash outcomes in Barishal and Khulna divisions unveils distinct patterns, put emphasis on the necessity the safety interventions considering the local context. This division demonstrates an intriguing absence of reported crashes in extremely low visibility conditions, potentially indicating effective avoidance strategies or reduced crash occurrence. No crashes are reported for visibility less than 1 km or between 1-2 km, suggesting potential avoidance in extremely low visibility. For 2-3 km, the daily crash rate is 24.82%, with a fatality rate of 23.36% and an injury rate of 41.61%. At 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  $\geq 5$  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 observed decrease in both crash and fatality rates with improved visibility aligns with established literature and reinforces the importance of good visibility for road safety in Barishal. On the other hand, Khulna reveals a distinct pattern with higher overall severity levels, especially in the lowest visibility category. The notably elevated crash rate, fatality rate, and injury rate in visibility less than 1 km highlight the urgent need for targeted safety measures in this specific condition. In Khulna Division, visibility  $< 1$  km has the highest crash, fatality, and injury rates at 21.21%. Visibility 1-2 km has a higher crash rate (22.05%) with elevated fatality (25.38%) and injury (26.28%) rates. As visibility improves, crash rates decrease to 10.91% at 3-5 km, with lower fatality (12.72%) and relatively high injury (13.13%) rates. Visibility  $\geq 5$  km exhibits the lowest crash (7.56%), fatality (8.63%), and injury (8.96%) rates. Visibility  $< 1$  km has a daily crash rate of 0.21, the highest, with a causality rate of 5.71, indicating severe injuries and a fatality rate of 1.00 per crash. Improved visibility leads to a slightly increased daily crash rate, but causality rates decrease, suggesting less severe outcomes. Fatality rates per crash remain relatively consistent across visibility categories, ranging from 1.15 to 1.19. While both divisions exhibit a general trend of decreasing crash rates with improved visibility, Khulna's data underscores the importance of addressing unique regional challenges related to visibility, with an emphasis on reducing severe outcomes, particularly in adverse weather conditions.

The complex regional variations highlighted in the study underscore the need for context-specific interventions to enhance road safety. Policymakers and traffic management authorities should acknowledge the diverse impacts of weather patterns on road safety and tailor their strategies accordingly. The findings emphasize that a one-size-fits-all approach may not be effective, urging the importance of considering local climate characteristics and regional factors. Specifically, the study identifies distinct precipitation ranges and temperature thresholds associated with varying crash severity, providing a basis for targeted interventions during specific weather conditions. Barishal consistently experiences severe crashes across temperature ranges, while Khulna exhibits a more dynamic pattern, demonstrating the need for tailored strategies in each region. The research highlights the importance of considering regional variations in visibility-related crash outcomes and suggests implementing safety measures informed by these variations. Ultimately, this research contributes valuable knowledge to the field of road safety, emphasizing the necessity for dynamic and context-specific approaches to mitigate the impact of adverse weather conditions on road users. Policymakers and authorities can use these insights to formulate effective safety measures, fostering safer road environments and enhancing overall traffic safety in Barishal and Khulna divisions.

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