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An Econometric Analysis of Weather Effects on Roadway Crash Severity in Bangladesh: Evidence from the Dhaka Metropolitan Area

Nazmul Islam [1,*], Sanjida Afroz Iqra [2], Armana Sabiha Huq [3] and Aniqa Tasnim [4]

[1] Department of Humanities, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
[2] Department of Civil, Environment and Construction Engineering, University of Central Florida, Orlando, FL 32816, USA; iqra@knights.ucf.edu
[3] Accident Research Institute (ARI), Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh; ashuq@ari.buet.ac.bd
[4] Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh; 1611023@mme.buet.ac.bd
* Correspondence: nazmul786humbuet@gmail.com; Tel.: +880-1737440176

Abstract: This study identifies how weather-related factors affect crash severity and the number of fatalities from roadway crashes. We use pooled cross-section data for weather-related variables from the National Aeronautics and Space Administration (NASA) and crash data from the Dhaka Metropolitan Police (DMP). The novelty of our paper compared to existing research is the use of weather-related factors as regressors in a multinomial logit model. We use crash severity as the dependent variable. The results show that a unit increase in the specific humidity is associated with a change in the odds of fatal crashes by a factor of 0.2195, keeping other contributory factors constant. This research also shows that an increase in temperature is associated with an increase in the odds of a fatal accident. Moreover, it is observed that a one-unit increase in precipitation results in a 1.1151-unit increase in the odds of the risk of fatal crashes compared to that of non-fatal crashes. After a detailed inspection, wind speed was discovered to be an insignificant weather parameter with regard to accident severity. Furthermore, the number of fatalities is displayed graphically in a time series to thoroughly examine the fatality trend's relationship with the monthly averaged weather variables. It is expected that the findings of this research will provide policy makers with insights into the weather-related causes of crash severity and assist in the execution of necessary measures to decrease unexpected and avoidable losses on Bangladesh's roads.

Keywords: crash severity; fatality; weather effects; multinomial logit model

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1. Introduction

Road traffic accidents (RTAs) are frequent and complex occurrences in most developing nations [1–3]. The road transport system is an essential infrastructure in nearly every region of the world, with most people having to use it daily despite being aware of the potential risks [4]. For instance, Germany recorded 300,143 road accidents with injuries in 2019, resulting in 3046 fatalities [5]. Different factors can affect the likelihood of a crash, such as technical or weather conditions, and driver behavior.

According to the World Health Organization (WHO), between 2008 and 2016, about 93% of all RTA fatalities occurred in low- and middle-income nations [6,7]. Although many governments in these developing nations frequently assert that their efforts have resulted in a drop in the RTA rates, RTA incidences have risen with time [8]. This may cause a nation's social and economic activities to suffer [8–13].

Roadway traffic crashes affect low- and middle-income countries the most compared to developed countries, which have lower accident rates [14,15]. The gross domestic product (GDP) loss due to roadway crashes is projected to be near 3% in most countries [16]. Bangladesh, a developing country, suffers significant economic losses due to its high roadway crash rates. The fatalities caused by roadway crashes are also higher in low-income countries like Bangladesh [17–19]. Every year, the lives of approximately 1.3 million people are cut short due to road traffic crashes, and roughly 32 people are killed in roadway crashes in Bangladesh every day [17]. Furthermore, 20 to 50 million people suffer non-fatal injuries, with many incurring disabilities [20]. The country is ranked 106th in the world for having the most road-accident-related deaths among 183 countries [7].

There are many factors behind these accidents. Researchers found that these factors can be divided into four major categories, road user characteristics, vehicle characteristics, roadway factors, and environmental factors [21–23]. It is expected that the absence of issues related to the above four factors can prevent roadway crashes [23]. Environmental factors such as temperature, precipitation, humidity, wind speed, and lighting conditions can adversely affect the occurrence of roadway crashes. The number of roadway crashes varies every year depending on weather conditions. To comprehend these changes, it is necessary to understand how each environmental factor influences the occurrence of roadway crashes [24]. However, few previous studies in Bangladesh focus on the weather-related influences on roadway crashes. Weather determinants strongly impact the risk of accidents, as suggested by previous studies [25]. A study from Wales, United Kingdom, shows a strong relationship between the number of road accidents and rainy or foggy weather [24]. Another study in Iran, a middle-income country, claims that weather conditions such as lighting conditions and wet and slippery road surface conditions due to precipitation directly correlate with road accidents [26].

A model showed that it was possible to make accurate predictions of crash probabilities using weather forecast data. But the model did not consider traffic volume; it assumed it was a diurnal cycle. The model only looked at weather-related crashes that the police said were caused by road conditions (e.g., slippery roads caused by water, snow, or ice) [27]. The model included the hourly traffic volume and the effects of rain, temperature, sun, and wind. Instead of using weather station data (which was common in the past), the meteorological predictor variables were derived from gridded radar and reanalysis products. Classic logistic regression models were replaced by generalized additive models (GAMs) for dichotomized target variables. The models were created for 78 different types of crashes in a consistent approach to see how the weather effects and the predictive power of different speed limits, types of crashes, and crash severities compare [27].

Anarkooli et al. found that injury severity is significantly correlated with factors such as poor visibility, rainy weather, the presence of a central median, the involvement of a heavy vehicle, improper overtaking, vehicle age, traffic volume and composition, the number of travel lanes, the speed limit, the undulating terrain, and the vehicle type [28]. Similar observations were made by the authors of [29,30] about the key contributing factors to serious traffic accidents in Hong Kong and Taiwan, respectively.

Temperature is a powerful weather element influencing road accidents [14]. A study from both Athens and France suggested that temperature is positively related to the number of injury accidents, and a 1 °C higher average temperature during a month can increase the number of such accidents by 1–2 percent in that month [21]. Kalankesh et al. showed the relationship between temperature and humidity and trauma deaths in Kerman, Iran; the result of this study indicates that the warm season has a higher overall trauma death rate [31]. Kalankesh et al. also found 3117 traumatic fatalities in total, of which 2946 instances were the result of accidents, and 171 cases were the result of deliberate causes [31]. However, other studies opine that the road surface temperature's impact on the roadway crash rate is strikingly binary, and that the hazards above and below the freezing point differ significantly [32–34]. A study in the Netherlands showed that the association between absolute temperature and crash frequency is statistically and economically significant. Lower temperatures cause more crashes than higher temperatures, with temperatures below zero being the most significant [34]. On the contrary, a study in Saudi Arabia states that roadway crashes are more likely to occur between noon and three in the afternoon during the summer months when there is intense sunshine, plenty of traffic, and an average temperature of 42 °C [35,36]. Previous research implies that a drastic shift in temperature, whether positive or negative, is associated with roadway crash fatalities.

According to several studies, precipitation (snowfall and rainfall) causes the most accidents [37]. Various studies found that precipitation strongly influences accident risk [38]. A study in Canada found that precipitation is directly correlated to a 75% growth in traffic crashes and a 45% increase in injuries as compared to normal seasonal conditions [39]. Rainfall positively correlates with roadway crashes in France and the Netherlands [21]. When comparing the different accident types, multi-vehicle impacts are more likely during heavy precipitation than single-vehicle crashes. In contrast, single vehicles face a higher risk of crashing during light showers [32]. A study in Melbourne, Australia, found that collision risk typically rises with precipitation from small scales to several hundred percent [40]. Eisenberg found rainfall to be highly significant with respect to the number of crashes in all three models used in his research, where the variable 'intensity of rain,' being the ratio between daily precipitation amount and daily precipitation duration, is positively significant [41].

The effects of wind speed have not been thoroughly investigated in connection to traffic accidents in earlier studies [42]. The majority of studies do not concur that wind speed might raise the frequency and fatality rates of traffic accidents, which suggests more research is needed to determine the potential impacts of wind speed. A study in Pakistan found that strong wind is a significant weather factor affecting roadway crashes [24]. Strong winds can force heavy vehicles—such as buses, lorries, and delivery vans—to turn over in hazardous conditions. The findings demonstrated that constant wind raised fuel costs. Moreover, the severe wind impacted two-wheeled motor vehicles and pedestrians. However, some studies show that wind has no significant effect on vehicle crashes [34,43–45].

Research finds that crash risk increases with surface slipperiness on two- and multiple-lane roads [32]. It is evident that when a roadway crash occurs on dry roads, other elements, such as speeding behavior and erroneous operations of drivers, are behind. On the other hand, the majority of crashes occur on wet roads due to their surface condition [46].

A study carried out in South Florida shows that the influence of daylight on the decreasing probabilities of a fatal injury is greater than the effect of any other light condition [47]. Another study conducted on the national highways of Bangladesh deduces that reduced visibility and drowsiness cause less control over vehicle operation, leading to severe accidents [19]. The number of fatal accidents is smaller during daytime, followed by dawn, but it is the highest at nighttime [46].

Asefa et al. and Mekonnen found that factors such as location, time of the collision (day or night), exceeding the speed limit, driving carelessly, vehicle type, not giving priority to other vehicles, pedestrians, and pedestrian errors were significantly associated with RTA fatality rates [48,49]. Almeida examined the key victim, road, and vehicle characteristics as well as the risk factors in Brazil and discovered that driving without a license, collisions with pedestrians, fixed obstacles, motorcyclists, the presence of inexperienced drivers, being a man, traffic on roads under federal jurisdiction, and early morning hours were the most frequently accountable factors for accidents and severe injuries [50]. Similarly, in Taiwan, refs. [30,51] discovered comparable outcomes. According to ref. [52], traffic offenses pose a serious risk to road safety in China, and young, single, and inexperienced drivers, as well as the quality of street lighting, the outside temperature, and visibility levels, all have a significant role in how serious an accident will be.

Due to the lack of rail and other major public transportation networks in Bangladesh, road transportation systems are the main method for moving people and products. Roadways are the primary means of moving people and products, yet for many vulnerable persons, they frequently pose serious RTA dangers [18,53]. RTAs are a rising topic of concern in Bangladesh, where the situation has steadily worsened over time [9,18]. They are now one of the leading causes of serious injury and violent death in the country.

RTA-related death rates are 6.8/100,000 population annually, or more than 12,000 persons in the population at large, according to [54]. The WHO (2015) calculated that 21,316 persons died in traffic accidents in 2012 in Bangladesh. According to estimates from the same year, RTAs cost between 2% and 3% of Bangladesh's GDP [18,55]. Dhaka, the capital of Bangladesh, is ranked as the ninth largest city and twenty-eighth most densely populated city in the world, with an annual growth rate of 3.39% [56,57]. This city is characterized by rapid unplanned urbanization [58], chronic traffic congestion, low-quality public transport service, lack of comfort and safety for pedestrians, and growing air pollution [17]. It also has the highest death toll due to traffic accidents in the country [17].

The effects of RTAs in Dhaka City are particularly pronounced, as the city is a popular destination for those seeking employment and business opportunities. Ahmed et al. and Chowdhury reported that Dhaka metropolitan areas had twice the number of deaths as other major cities due to the combination of population and vehicle congestion [59,60]. Consequently, these areas have seen an alarming increase in RTAs and serious injuries. Furthermore, weather plays a major role in the severity of crashes. To identify ways to reduce these issues, it is essential to identify the key factors significantly linked to road accidents and serious injuries. In particular, [61] demonstrates the association between weather and road accident incidence in Bangladesh and provides a detailed analysis of the spatial incidence of road accidents in Bangladesh and unfavorable weather conditions. The most probable cause is unfavorable weather (e.g., rainfall, topological elevations, etc.). Since RTAs cause enormous economic and human losses, particularly in developing economies, significant research efforts must be made to identify the main risk factors that significantly impact accidents and severity. While Dhaka sees an alarming increase in traffic-related fatalities and serious injuries, Bangladesh has yet to collect substantial RTA data [62].

Despite the recent rise in RTAs in Bangladesh, the country has yet to implement significant efforts to collect data on road accidents. It has not implemented sufficient road safety policies to prevent this problem [9,18,54,55,60]. In addition, despite the vast quantity of studies on the subject, in Bangladesh, only a small number of studies have looked at how weather influences the severity of traffic crashes. Most studies [9,18,55,60,63] have concentrated on fatal accident risk factors within different areas and factors influencing pedestrian–vehicle crash severity. We concentrated on examining the impacts of climatic conditions on roadway crash severity, including all vehicle types (buses, trucks, motorbikes, bicycles, and three-wheeled vehicles), which sets the current study apart from earlier studies on RTAs in Bangladesh.

To contribute to the design and implementation of relevant prevention policies for roadway crashes in Bangladesh (and possibly elsewhere), the primary objective of this study was to analyze the main weather-related factors associated with roadway crashes and their impact on severity. The results will help to develop and implement policies for preventing the severity of roadway crashes resulting from weather-related factors in Bangladesh (and elsewhere).

By understanding these influencing factors, authorities can take precautionary measures, such as setting permanent speed limits or improving road designs. Temporary restrictions or warnings can also be implemented in relation to variable risk factors, such as adverse weather conditions. To identify measures that can improve road safety, it is necessary to provide quantitative knowledge of the relationship between weather and the probability of crash severity. However, weather is not the only factor that influences the risk of a crash. The multinomial logit model is applied in the current study to determine the weather-related factors that influence how severe an accident occurs on a given route. In earlier research conducted in Bangladesh's Dhaka Metropolitan Area, this was not determined or addressed. Thus, we think the recent discovery will bring a fresh perspective to the efforts to lessen the severity of weather-related highway crashes.

The specific research questions of this research are: (i) What are the weather-related factors affecting the roadway crash severity? (ii) Which individual weather-related factors, such as temperature, relative humidity, lighting condition, wind speed, and precipitation, best explain the number of fatalities due to roadway crashes?

The study uses police report data, which in some cases were wrong and incomplete. There was little information on people's understanding of safety procedures because the respondents were not usually the victims or eyewitnesses involved in the incidents. Future research can directly gather data from accident victims and witnesses and assess their safety knowledge to close these knowledge gaps.

The remainder of this paper is organized as follows: Section 2 presents the methodology of the study, which explores the sources of data and the methods followed; Section 3 provides the descriptive analysis of the core sample; Section 4 analyzes and discusses the results; and Section 5 puts forward conclusions.

2. Methodology

2.1. Approach

In our study, we conduct a two-stage analysis to show the weather effects on roadway crash severity. First, we show the correlation between the number of fatal and non-fatal crashes and the weather-related variables of rainfall, average temperature during the day, wind speed, relative humidity and specific humidity. Second, we apply the multinomial logit model to identify the meteorological variables which are responsible for the roadway crash severity.

2.2. Crash Data

The Bangladesh Police Authority preserves the accident report form (ARF) containing accident information, which is filled out by the responsible police officer at the scene of the accident. The Accident Research Institute (ARI) of Bangladesh University of Engineering and Technology gathered the accident information from ARFs. The research utilized the data collected by the ARI. The study examined the police-reported roadway crashes in the Dhaka Metropolitan area for four years, from 2017 to 2020.

The accident data included eleven accident types: left turn, right turn, u turn, crossing road, overtaking, going ahead, reversing, sudden start, sudden stop, parked vehicle, etc. Accident severity was divided into four categories: fatal accident, grievous accident, simple accident, and property damage. Additionally, due to major drops in traffic volume, extreme occurrences like the COVID-19 pandemic impacted the number of observations in 2020.

2.3. Weather-Related Data

The meteorological factors were collected daily by five variables: the rainfall, measured in millimeters; the average temperature during the day, measured in degrees Celsius; the wind speed at 10 m reference height; the relative humidity; and the specific humidity. The average and extreme values of these weather variables were obtained from the official website of the National Aeronautics and Space Administration (NASA).

The missing data were controlled by including the missing data in the categories with the highest frequency. Previous studies used this method to handle the missing values in the roadway crash dataset [64]. In terms of the serial number, date of the accident, and series of code names, duplicates were eliminated.

2.4. Model

This section demonstrates the crash severity multinomial logit model. Generally, in a multinomial logit model of crash severity outcomes, the propensity of crash i towards severity category j is denoted by the severity propensity function, V_{ji}, as expressed in Equation (1) [65]:

$$V_{ji} = \lambda_j + \gamma_j X_{ji} + \varepsilon_{\mathrm{ji}} \tag{1}$$

where λ_j is a constant parameter for crash severity category j; γ_j is a vector of the estimable parameters for crash severity category j; $j = 1, \ldots, \mathrm{J}$ (J = 2 in the paper), demonstrating the two severity levels of fatal (F) and non-fatal (NF); X_{ji} stands for a vector of independent variables impacting the crash severity for i at severity category j (geometric variables, environmental conditions, driver characteristics, etc.); ε_{ji} is a random error term following the Type I generalized extreme value (i.e., Gumbel) distribution; i = 1; ...; n where n is the total number of crash events included in the model. Equation (2) reveals how to estimate the probability for each crash severity category. Let $P_i(j)$ be the probability of crash i finishing in crash severity category j, [66] so that

$$P_i(j) = \frac{exp(\lambda_j + \gamma_{ji}X_{ji})}{\Sigma_{\forall j} exp(\lambda_j + \gamma_{ii}X_{ji})} \tag{2}$$

In this paper, an attempt has been made to analyze the effect of daily weather factors on the crash severity. In this regard, the multinomial logistic regression model was established by taking crash severity as a dependent variable (j = 1, if fatal and j = 0 if non-fatal). We consider grievous, simple injury and property damage as non-fatal crashes. We used the natural log of the daily weather determinants (temperature, wind speed, rainfall, etc.) associated with the crash as variables of interest. The above model considers other variables, such as roadway environment determinants (traffic control system, etc.) and road user determinants (seat belt usage, vehicle maneuver, etc.), as control variables.

The multinomial logit model is derived under the assumption that the unobserved factors are uncorrelated over the alternatives or outcomes, also known as the independence from irrelevant alternatives (IIA) assumption [67]. This assumption is the most notable limitation of the multinomial logit model since it is very likely that the unobserved factors are shared by some outcomes. Despite this limitation, the IIA assumption makes the multinomial logit model very convenient, thus explaining its popularity.

3. Descriptive Analysis

For the descriptive analysis of qualitative variables, frequency and frequency percent were utilized, as shown in Table 1.

Table 1. Descriptive analysis of variables related to roadway crashes.

Variable Name	Category	Percentage	Frequency
Traffic control	No control	22.48	202
	Centerline	7.93	71
	Pedestrian crossing	3.47	31
	Police controlled	53.06	476
	Traffic lights	1.49	13
	Police + traffic lights	2.31	21
	Stop/give way	0.33	3
	Others	8.93	80
Collision type	Head on	2.81	25
	Rear end	8.43	76
	Right angle	0.17	2
	Side swipe	5.62	50
	Overturned vehicle	0.83	7
	Hit object on road	0.83	7
	Hit object off road	1.16	10
	Hit parked vehicle	0.99	9
	Hit pedestrian	77.02	692
	Others	2.15	19

Table 1. *Cont.*

Variable Name	Category	Percentage	Frequency
Lighting condition	Daylight	46.78	420
	Dawn/dusk	15.54	140
	Night (lit)	32.73	294
	Night (unlit)	4.96	45
Road geometry	Straight + flat	91.90	825
	Curve only	4.46	40
	Slope only	2.48	22
	Curve + slope	0.99	9
	Crest	0.17	2
Surface condition	Dry	97.52	876
	Wet	1.65	15
	Other	0.83	7
Surface quality	Good	94.38	848
	Rough	3.14	28
	Under repair	2.48	22
Road feature	None	97.19	873
	Bridge	0.83	7
	Culvert	0.17	2
	Speed breaker	1.82	16
Vehicle maneuver	Left turn	3.97	36
	Right turn	1.65	15
	U turn	1.65	15
	Crossing road	2.64	24
	Overtaking	9.09	82
	Going ahead	70.08	629
	Reversing	2.48	22
	Sudden start	0.83	7
	Sudden stop	0.50	4
	Parked	0.17	2
	Other	6.94	62
Year	2017	27.60	248
	2018	26.94	242
	2019	30.08	270
	2020	15.37	138

Table 1 displays that most roadway crashes occur in a traffic control system mostly operated by police. Among nine types of roadway crash, the hitting of pedestrians is the most prominent. Also, it shows that most accidents occur on roads with straight geometry and good surface quality.

Table 2 shows that the mean temperature from 2017 to 2020 is 25.27 °C. It is observed that from 2017 to 2018, the temperature slightly decreases by a value of 0.62. It increases again from 2019 and maintains an upward trend. The specific humidity, however, continues a decreasing trend from a mean value of 16.61 in 2017 to 15.59 in 2020. Precipitation shows a declining trend from 2017 to 2019; however, an upward trend is observed from 2019 to 2020. The wind speed shows random variation from 2017 to 2020. It decreases slightly from 2017 to 2018, increases from 2018 to 2019, and shows a descending trend from 2019 to 2020. The lighting condition of the roads, which includes both daylight and nightlight, maintains a downward trend at first, continuing up to 2018. Then, it starts rising upward and maintains the trend up to 2020.

Table 2. Descriptive analysis of weather-related variables and dummy variables.

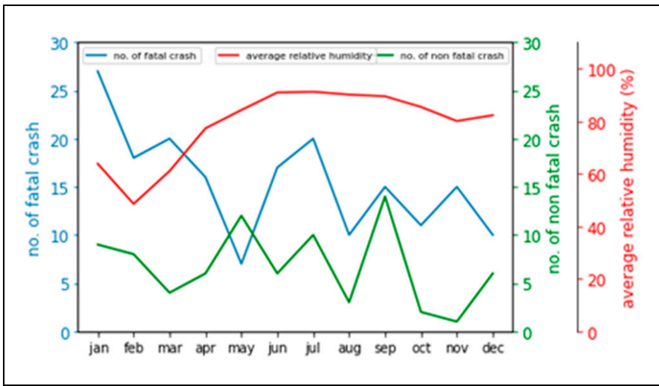
Variable Name	All Year (2017–2020)		2017		2018		2019		2020	
	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
Weather-related factors										
Temperature (°C)	25.27	4.26	25.69	3.25	25.07	4.39	25.49	4.37	24.51	5.10
Specific humidity	15.96	5.60	16.61	5.67	16.00	5.38	15.59	5.56	15.59	5.94
Precipitation (mm)	7.59	12.77	11.52	18.24	6.85	10.05	5.33	9.99	7.03	9.69
Wind at 10 m (ms^{-1})	2.72	1.18	2.83	1.27	2.59	1.00	2.77	1.20	2.67	1.25
Roadway-environment-related factors										
Traffic control system (Police controlled = 1, Others = 0 (no control, traffic light, stop/give away))	0.53	0.50	0.46	0.50	0.51	0.50	0.62	0.48	0.50	0.50
Lighting condition (Daytime = 1, Other = 0 (dawn, dusk, night lit/unlit))	0.47	0.50	0.52	0.50	0.41	0.49	0.46	0.50	0.52	0.50
Presence of divider	0.73	0.44	0.52	0.43	0.78	0.41	0.64	0.28	0.77	0.42
Road geometry (Straight, flat = 1, Other = 0)	0.92	0.27	0.76	0.43	0.94	0.24	0.91	0.29	0.93	0.25
Surface condition (Dry = 1, Other = 0)	0.98	0.15	0.91	0.29	0.99	0.11	0.99	0.10	0.99	0.10
Surface quality (Good = 1, Rough = 0)	0.94	0.23	0.95	0.15	0.98	0.13	0.92	0.27	0.96	0.20
Road feature	0.97	0.17	0.98	0.15	0.97	0.17	0.96	0.20	0.99	0.10
Road-user-related factors										
Driver's age	37.25	6.68	38.13	6.30	36.67	7.12	37.52	6.26	36.36	7.13
Vehicle maneuver (Going ahead = 1, Others = 0 (left turn, right turn, crossing road, overtaking))	0.70	0.46	0.74	0.44	0.70	0.46	0.64	0.48	0.75	0.43
Collision type (Hit pedestrian = 1, Others = 0 (head on, rear end, side swap, hit object, right angle))	0.77	0.42	0.81	0.39	0.79	0.40	0.74	0.44	0.73	0.44

4. Results and Discussion

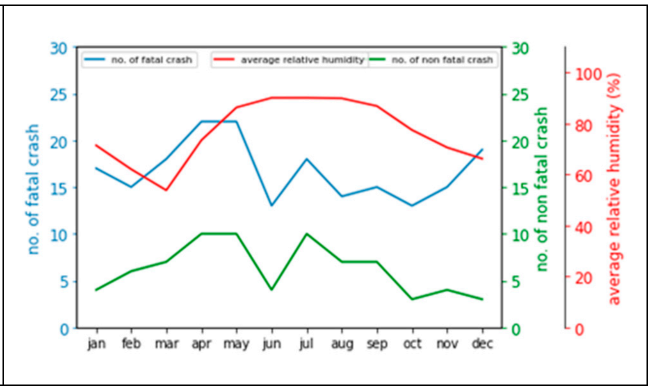
4.1. Graphical Analysis of Weather Effects on Roadway Crashes

4.1.1. Variation in the Number of Fatal and Non-Fatal Crashes with Average Relative Humidity

Daily weather data were averaged over the months, and, subsequently, fatality variation was assessed in a graphical representation over the four consecutive years shown in Figures 1–4. Also, the time series plot of the number of fatal crashes and non-fatal crashes that occurred during the month and the monthly averaged weather factors was analyzed to determine the yearly trend of the variable of interest.



(**a**)



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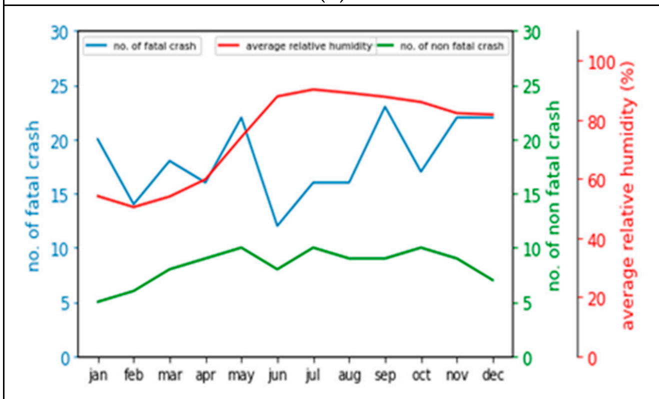

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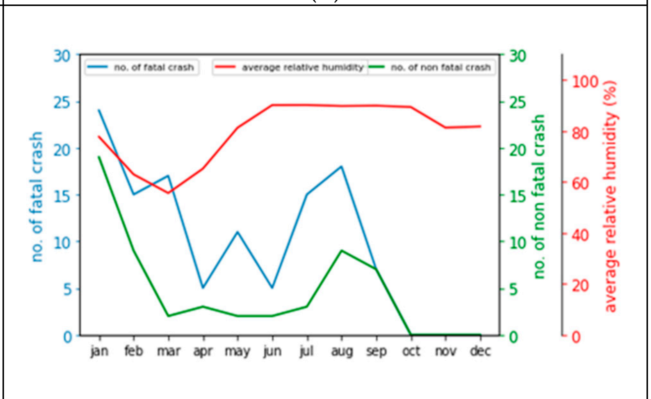

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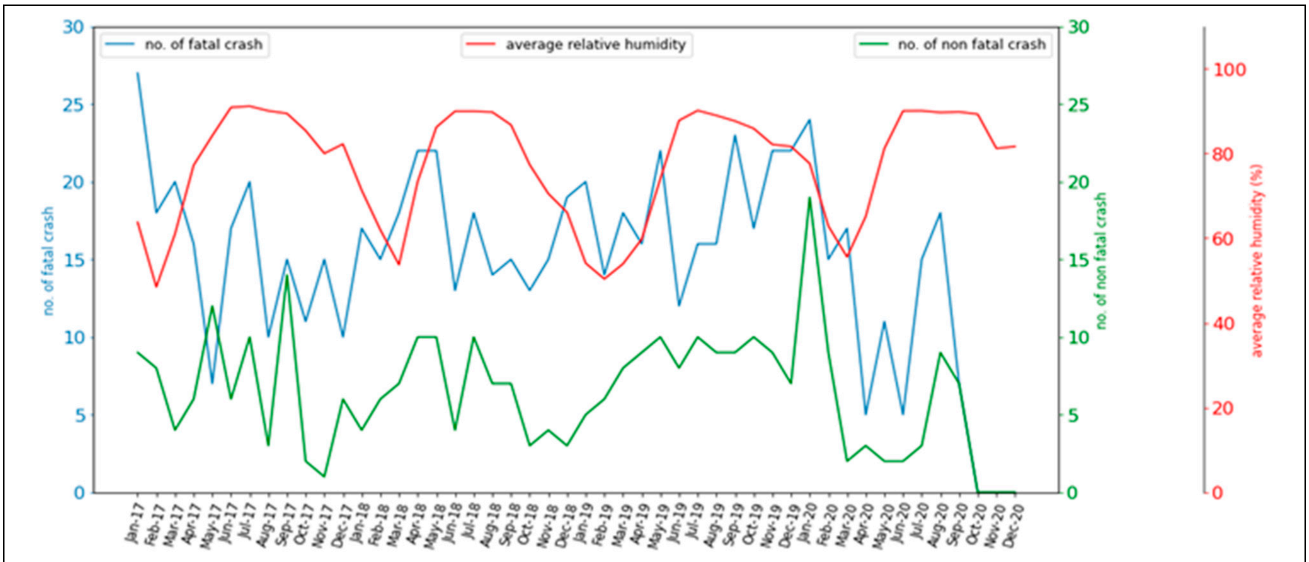

(**e**)

Figure 1. Month-wise variation in average humidity, number of fatal crashes, and number of non-fatal crashes: (**a**) month-wise variation in the number of fatal crashes and the number of non-fatal crashes with average relative humidity in 2017; (**b**) month-wise variation in the number of fatal crashes and the number of non-fatal crashes with average relative humidity in 2018; (**c**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average relative humidity in 2019; (**d**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average relative humidity in 2020; and (**e**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average relative humidity in 2017–2020.

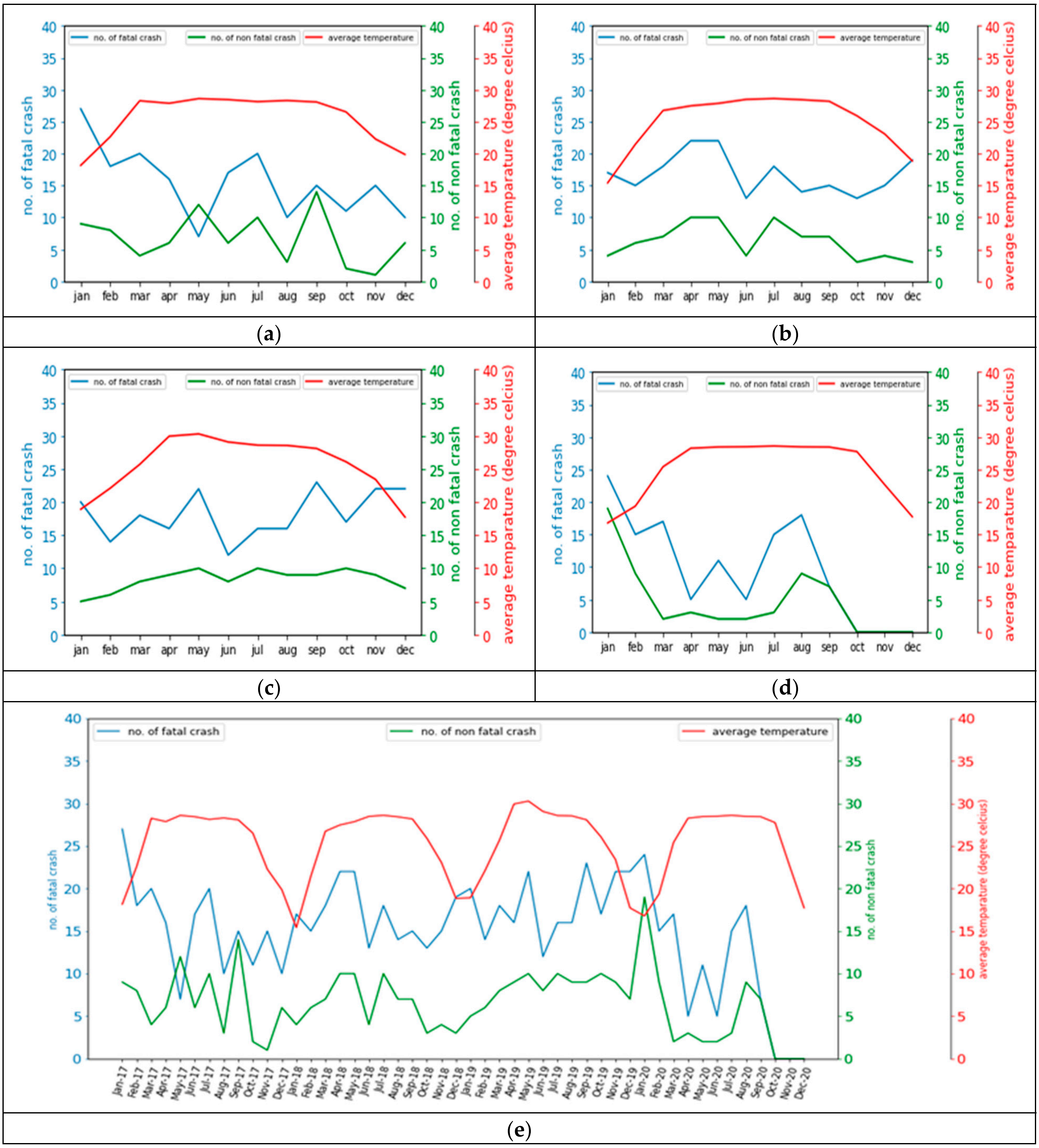

Figure 2. Month-wise variation in average temperature, number of fatal crashes, and number of non-fatal crashes: (**a**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average temperature in 2017; (**b**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average temperature in 2018; (**c**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average temperature in 2019; (**d**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average temperature in 2020; and (**e**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average temperature in 2017–2020.

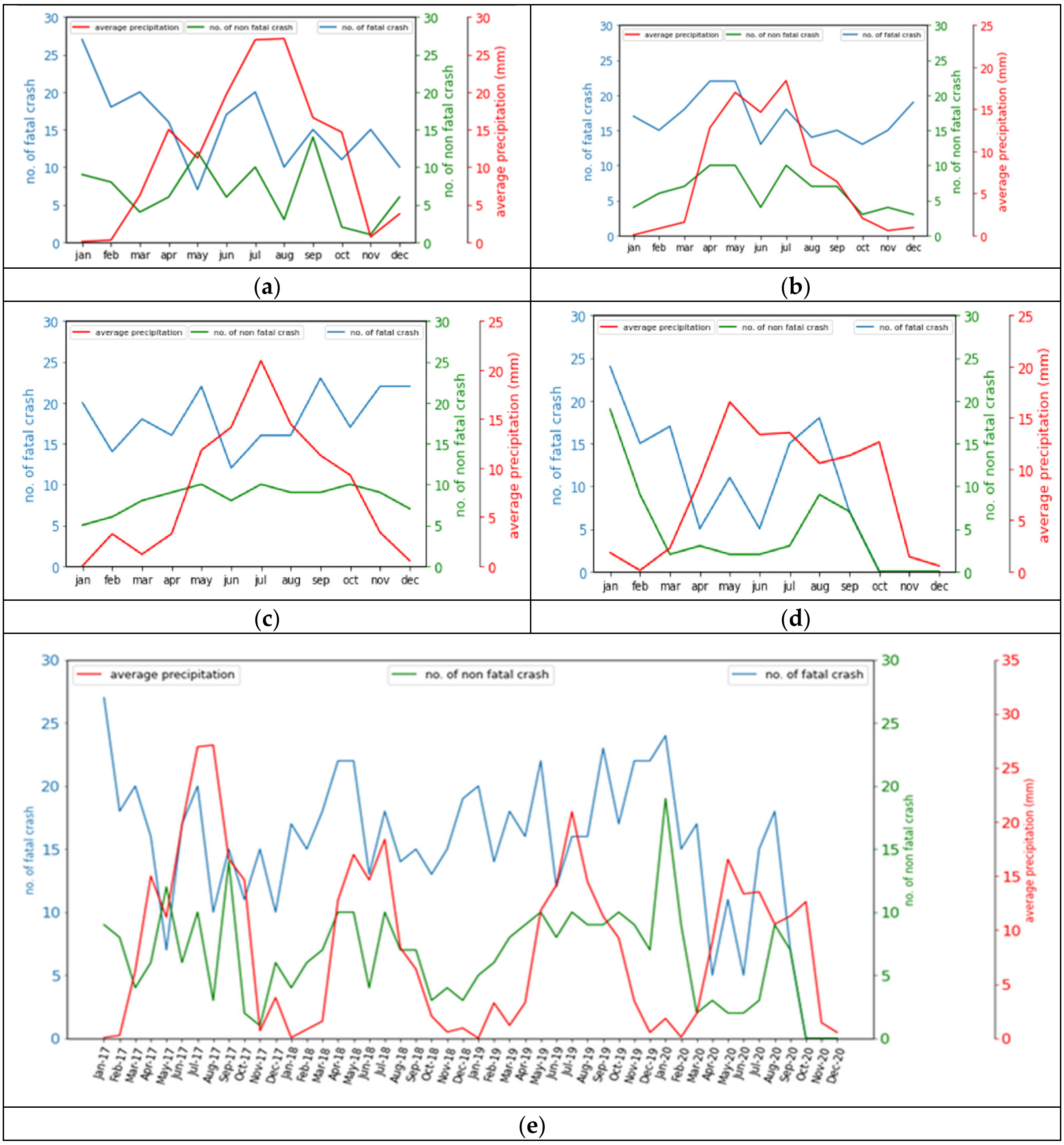

Figure 3. Variation in average precipitation, number of fatal crashes, and number of non-fatal crashes: (**a**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average precipitation in 2017; (**b**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average precipitation in 2018; (**c**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average precipitation in 2019; (**d**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average precipitation in 2020; and (**e**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average precipitation in 2017–2020.

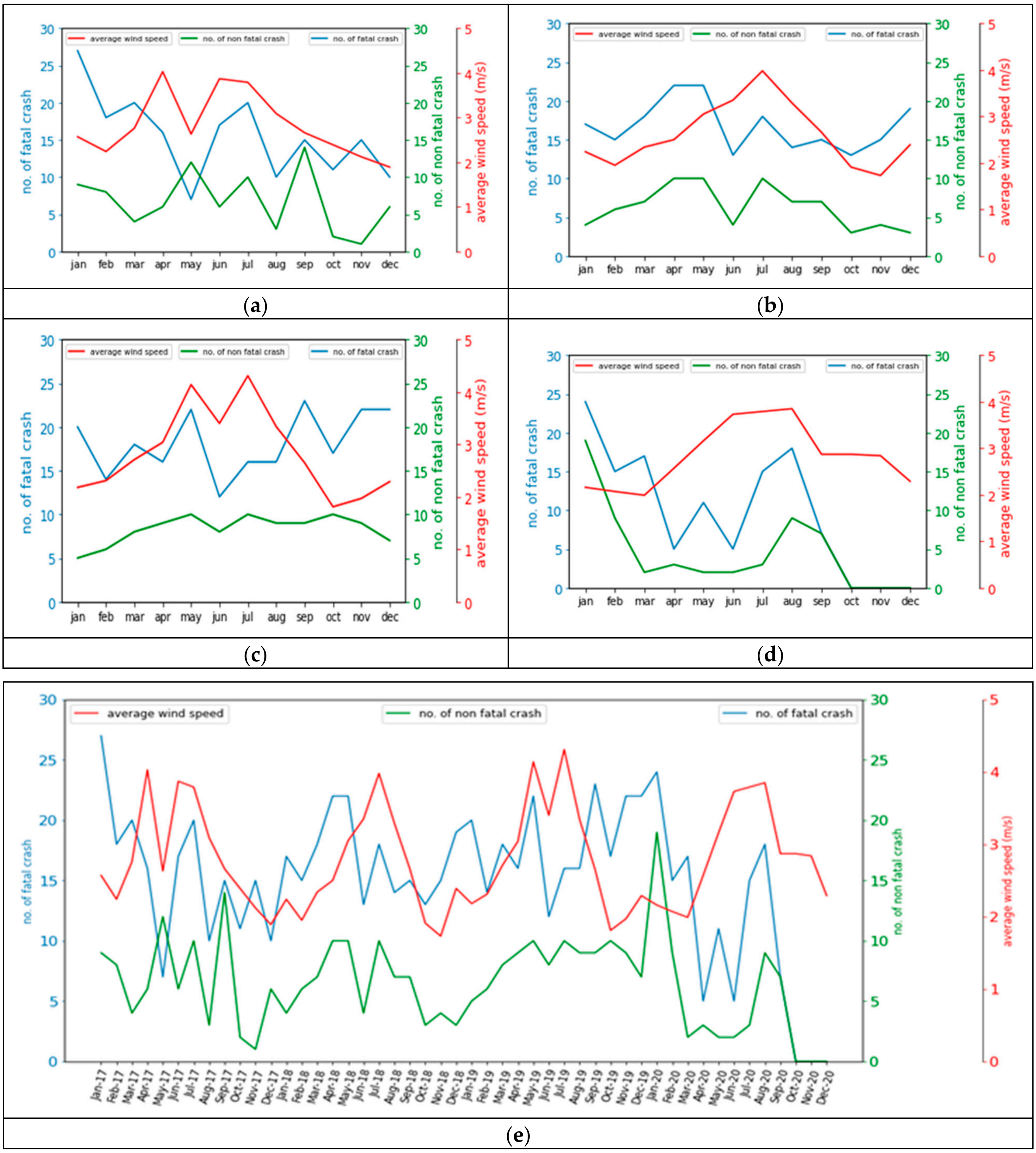

Figure 4. Variation in average wind speed, number of fatal crashes, and number of non-fatal crashes: (**a**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average wind speed in 2017; (**b**) month-wise variation in the number of fatal crashes and number of non-fatal crashes with average wind speed in 2018; (**c**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average wind speed in 2019; (**d**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average wind speed in 2020; and (**e**) month-wise variation in number of fatal crashes and number of non-fatal crashes with average wind speed in 2017–2020.

In Figure 1a, it is seen that in 2017, up to February, the number of fatal crashes as well as non-fatal crashes maintained a proportional relationship with humidity, showing a descending trend. From March to December, as average humidity increases, the number of fatal crashes shows a declining trend, whereas the number of non-fatal crashes increases up to March and decreases afterward up to May. It exhibits a decreasing trend after May which continues up to December. Figure 1b represents that in 2018, the number of fatal crashes decreases with average humidity. From March to July, average humidity shows an ascending trend while fatality increases up to April, then falls. From August to December, while average humidity decreases, the number of fatal crashes decreases slightly and then rises to some extent. On the other hand, the number of non-fatal crashes increases up to April and maintains that number up to May. After a sharp decline in June, it displays a declining trend up to December.

In 2019, while the average humidity and number of non-fatal crashes gradually increases from January to June, the number of fatal crashes decreases slightly in a linear trend. From July up to December, the change in average humidity and number of fatal crashes is insignificant, and the number of fatal crashes shows random changes, as shown in Figure 1c. In Figure 1d, it can be seen that for the year 2020, the average humidity and number of non-fatal crashes fall abruptly up to March, whereas the number of fatal crashes increases and then decreases. From April to June, with an increase in humidity, the number of fatal crashes does not maintain any trend. In the case of non-fatal crash number, it does not show any significant change up to July. From June to November, average humidity remains constant, and the number of fatal and non-fatal crashes shows a decreasing trend, which might have resulted from the lockdown due to the COVID-19 pandemic.

In November–December, average humidity and fatal crashes remain constant, whereas the number of non-fatal crashes reduces to zero. In 2020, no significant correlation is found except for the September to December period, where the two variables remain constant. Figure 1e shows that from 2017 to 2020, the number of fatal crashes decreases. There is a sharp decline in the number of fatal crashes in 2020. However, the relative humidity shows an increasing trend from January 2017 to November 2017, which continues to decline until October 2018. It rises slowly until August 2019 and then shows a sharp upward trend.

4.1.2. Variation in the Number of Fatal and Non-Fatal Crashes with Average Temperature

Figure 2a shows that the average temperature continually increases up to March 2017. It remains in a steady state, whereas the change in the number of fatal crashes and the number of non-fatal crashes vary abruptly, rising and falling alternately. From March to October, the temperature remains constant; it then decreases up to December. No correlation is observed between the variation in the two variables. In Figure 2b, it is found that temperature shows a similar trend in change to 2017. In contrast, the number of fatal crashes and the number of non-fatal crashes rise till April and then continue to fall abruptly to October. No significant correlation is found between the number of fatal crashes and the average temperature. Figure 2d shows that the average temperature and number of fatal and non-fatal crashes nearly maintain an inverse relationship from January 2020 up to May 2020.

From June to December, the number of fatal crashes changes randomly with a decreasing average temperature. In 2020, as shown in Figure 2d, the number of fatal crashes shows random changes with average temperature from January to October. From October to December, it is observed that the number of fatal and non-fatal crashes maintains a zero state while the temperature drops remarkably. In Figure 2e, showing the period from 2017 to 2020, the average temperature maintains a trend. On the other hand, the number of fatal crashes shows a decreasing trend and then increases with a small amount of change. From June 2019, the figure shows a continuous decrease in fatal crashes. Every year, the number of non-fatal accidents stays lower than the number of fatal accidents, and the correlation is mostly abrupt with temperature change throughout the four years.

4.1.3. Variation in the Number of Fatal and Non-Fatal Crashes with Average Precipitation

Figure 3a demonstrates that in 2017, there is no significant correlation between average precipitation and the number of fatal crashes. In the April–May and September–October periods, the relationship between the number of fatal and non-fatal crashes with average precipitation shows proportionality for short intervals. As of 2018, as represented in Figure 3b, it is observed that from January to May, the number of fatal and non-fatal crashes almost increases with the rise of precipitation. A proportional variation change is observed between the two variables from May to July. Figure 3c shows that in 2019, from January to June, the trend of number of fatal crash-es decreases then it starts to rise. From January to May, the number of non-fatal crash-es increases linearly, it drops in June and after that it remains constant until October. On the other hand, the average precipitation does not show any trend in variation. From June to December except October, the gap between the number of the two crash types widens with a downward trend of the average precipitation.

In 2020, as shown in Figure 3d, except for a decreasing trend in average precipitation and the number of fatal and non-fatal crashes from October to December, no correlation is discovered between the variation in average precipitation and the other two parameters. Figure 3e displays that with all years from 2017 to 2020 combined, average precipitation decreases insignificantly up to March 2018, while fatal and non-fatal crash counts continuously increase. From March 2018 to June 2019, it is found that average precipitation increases, and after that period, the variable faces a sharp downfall. In this period, both types of crashes change irregularly.

4.1.4. Variation in the Number of Fatal and Non-Fatal Crashes with Average Wind Speed

Figure 4a shows that in 2017, while average wind speed maintains a nearly constant value, the number of fatal and non-fatal crashes undergoes random variation. In Figure 4b, no significant correlation is found between variation in average wind speed and these types of crashes. In 2019, as shown in Figure 4c, from January to May, the average wind speed increases slightly while the number of fatal crashes decreases. From June to December, while average wind speed decreases moderately, the number of fatal crashes changes somewhat.

In Figure 4d, no significant correlation is found except for the period in 2020 from September to December, where the two variables remain constant. In Figure 4e, with all the years from 2017 to 2020 merged, no significant correlation between wind speed and fatal and non-fatal crash numbers is found. The wind speed maintains a linear trend throughout the period, whereas the number of fatal crashes decreases up to March 2018 and increases up to June 2019. After that, the number of fatal crashes declines sharply.

Figure 5 shows that the total fatality from 2017 to 2020 decreases.

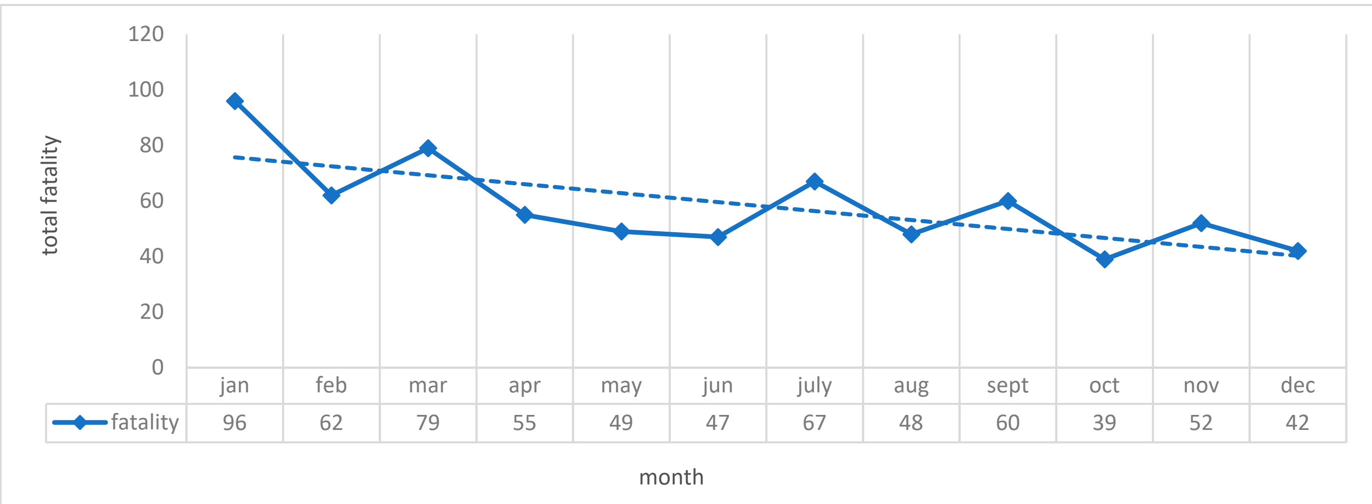

Figure 5. Month-wise variation in fatality from 2017 to 2020.

4.2. Regression Results

Table 3 shows that a 1-unit increase in the specific humidity is associated with the odds of a crash being fatal (versus non-fatal) increasing by a factor of 0.2195, when other factors remain constant, at a 95% confidence interval, since the p-value is less than 0.05.

Table 3. Regression results using a multinomial logit model.

Variable Name (Dependent Variable: Accident Severity (1 = Fatal, 0 = Non-Fatal))	Odds Ratio	Standard Deviation	$p > z$
Weather-related factors			
Ln (Specific humidity)	0.2195	0.1505	0.027
Ln (Wind speed)	1.1438	0.2515	0.541
Ln (Temperature)	7.0581	8.1876	0.092
Ln (Precipitation)	1.1151	0.0691	0.079
Roadway-environment-related factors			
Surface quality (Good = 1, Rough = 0)	2.6711	0.8978	0.003
Lighting condition (Daytime = 1, Other = 0 (dawn, dusk, night lit/unlit))	0.7878	0.1425	0.187
Traffic control system (Police controlled = 1, Others = 0 (no control, traffic light, stop/give away))	0.6972	0.1271	0.048
Road-user-related factor			
Usage of seat belt (Worn = 1, Not worn = 0)	0.5032	0.1684	0.040
Vehicle maneuver (Going ahead = 1, Others = 0 (left turn, right turn, crossing road, overtaking))	1.2564	0.2408	0.234
Collision type (Hit pedestrian = 1, Others = 0 (head on, rear end, side swap, hit object, right angle))	3.0908	0.4765	0.000
N = 617			
R^2 = 0.1062			

Table 3 also shows that a 1-unit temperature increase increases the odds of fatal accidents by a factor of 7.06 (versus non-fatal accidents). Other factors are kept unchanged, and their significance is associated with a 90% confidence interval, as the p-value ranges between 0.05 and 0.1. This finding is supported by both [21,22]. A probable reason behind this phenomenon could be increased temperature, resulting in a higher driving error rate due to factors such as watchfulness and multitasking [33]. According to a German study, people become more emotional and sensitive as the temperature rises. They also become more irritable and fatigued, and lose their patience and attention more frequently, thus increasing response times.

Moreover, a 1-unit increase in precipitation results in a 1.115 times increase in the odds of fatal accidents compared to non-fatal accidents, at a 90 percent confidence interval when other contributory factors stay unchanged. Previous research also indicates a similar finding [23,36,40,41]. Rain has a negative impact on roadway crashes by reducing the friction between the road's surface and the tires. Rainfall causes reduced visibility on windscreens. Also, spray coming from other vehicles worsens the conditions [24]. Consequently, rainfall increases the rate of roadway crashes due to decreased visibility and hazardous surface conditions [68]. It is also found that the proportion of roadway crashes increases after a lengthy dry period because pollutant levels during rainfall, particularly during the monsoon season, stay higher than during the non-monsoon season [25,69].

This model exhibits wind speed as an insignificant weather determinant associated with fatality. Similar research also supports this finding [26]. Studies show that except for severe storms and huge vehicles, wind is not found to be significant [18,27–29]. And from the graphical representation of wind data in Figure 4, it is found that in Dhaka city, wind speed is not severe.

5. Conclusions

Using accident data from the Dhaka Metropolitan Region from 2017 to 2020, this study investigates the weather and road factors contributing to crash severity and fatalities. In this study, the variables of interest are weather factors such as precipitation, temperature, specific humidity, lighting condition, and wind speed and their effect on accident severity in the multinomial logit model. We use road geometry, usage of seatbelt, vehicle maneuver, traffic control system, and crash type as control variables. While using a multinomial logit model, we find precipitation, specific humidity, lighting condition, and temperature statistically significant. The results show that a 1-unit increase in the specific humidity is associated with the odds of the crash being fatal (versus non-fatal) increasing by a factor of 0.2195 when other factors remain constant. In addition, this study demonstrates that an increasing temperature increases the odds of fatal accidents. Moreover, it is determined that a 1-unit increase in precipitation results in a 1.115 times increase in the odds of fatal accidents compared to non-fatal accidents at a 90 percent confidence interval, while other contributory factors stay unchanged.

Policy makers can address the study's findings on the causes of crash severity and fatality to prevent unexpected and avoidable damage on Bangladesh's roads. Specific humidity, precipitation, lighting conditions, and temperature are weather and environmental elements beyond human control. However, the damage caused by these factors on the roadways can be reduced if certain policy measures are designed and implemented, such as designing weather-resistant roads, raising awareness to increase adherence to traffic laws, setting speed limits, and other precautionary measures considering weather factors such as rainfall, high temperature, and heavy wind, such as wearing seat belts and so on.

Furthermore, funding for road safety measures should be raised to ensure roads that can withstand bad weather and to raise awareness about traffic regulations. Road durability, signage, marking, signalization, and vehicle fitness should all be ensured, especially during adverse weather.

Weather data were obtained from NASA, and accident data were obtained from police-reported data for this study. However, police-reported data are used for the analysis due to a paucity of accident data from other sources in Bangladesh. We discovered that the number of fatal accidents was disproportionately greater than other severity levels of accidents, indicating a tendency of accident underreporting.

All of Bangladesh's metropolitan cities can be examined for future research. Furthermore, adopting a more extended study time can increase the amount of data.

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