Injury profiles and epidemiology of single vehicle motorcycle fatalities in Tamil Nadu, India, 2009-2017

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Key Findings

- A total of 16,541 single-vehicle motorcycle crash reports linked with hospital data were analysed.
- Single-vehicle motorcycle fatalities were more common among male motorcyclists aged between 26 and 64 years.
- Fatal motorcyclists most commonly sustained head injuries, followed by injuries to multiple body parts.
- Highways, multilane roads, and specific junction types increase the likelihood of fatal crashes.

Abstract

This article investigates single-vehicle motorcycle crashes and crash risk where a rider is killed or injured in Tamil Nadu, India. Hospital data linked with police-reported crash data, including demographic information, injury characteristics, and environmental and road characteristics, were analysed for all single-vehicle motorcycle crashes between January 2009 and December 2017. A total of 16,541 single-vehicle motorcycle crashes resulted in injuries (fatal, serious, and minor injury) during the period, among which 7,447 were fatal crashes. The majority of fatal crashes involved male motorcyclists aged between 26 and 64 years (5,287). Those aged 18 and 25 years (1,897) were the next most frequent group of fatally injured motorcyclists. Among the fatal injured motorcyclists, 66.6% were wearing a helmet. When reported, 33.8% of motorcyclists did not have a valid driving licence at the time of the incident. Motorcyclists injured most commonly sustained head injuries (51.3%), followed by multiple injuries (20.1%), leg injuries (3.3%), and hand injuries (3.2%). Logistic regression results suggest that specific road characteristics and environmental factors increase the probability of fatal crashes: urban roads, express highways, multiple lane roads, night time, absence of median divider, cross and T-junctions, junctions with four arms, under-aged (<18 years) riders, not holding a valid licence and non-use of helmets. Appropriate countermeasures to mitigate motorcyclist trauma are recommended.

Keywords

motorcycle, crash characteristics, injury severity, hospital data, single-vehicle crashes

Glossary

LMICs:	Low- and Middle- income countries
MoRTH:	Ministry of Road Transport and Highways
RADMS:	Road Accident Database Management System
RTCs:	Road Traffic Crashes
WHO:	World Health Organization

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Introduction

Road Traffic Crashes (RTCs) continue to be a public health concern and the leading cause of death, killing more than 1.35 million worldwide. Road traffic deaths have made RTCs the eighth leading cause of death globally and the number one cause among 15 to 29 year-olds (WHO 2019). Fatalities due to RTCs rose by 46% between 1990 and 2013 (Lozano et al., 2012) and are expected to grow in the future continually. World Health Organization (WHO) also estimated that there would be a 40% increase in global deaths due to RTCs, and it may reach 1.9 million per year by the year 2030 if the current trend continues (WHO 2010). Low and middle-income countries (LMICs) are more susceptible to RTCs – despite having only 60% of the total registered vehicles, LMICs account for nearly 93% of road fatalities (WHO 2019). Road fatalities have emerged because motorcycles were a primary means of intra- and intercity transport in LMICs (Al-Hasan et al., 2015; Adeleye and Ogun, 2017; Adeleye et al., 2019; Rosenberg et al., 2020). Motorcycle riding is one of the high-risk modes of transportation that often results in severe injury or fatal deaths compared to other road users due to the lack of protection at the scene of the crash (Johnston, Brooks, & Savage, 2008; Keall & Newstead, 2012; Van Eslande & Elvik, 2012; Lin & Kraus, 2009; Thompson, Badlock & Lindsay,2020). According to the 2013 WHO report (WHO, 2013), almost a quarter (24%) of the world's road fatalities occur among motorcyclists, particularly in the South-East Asian region. A rapid increase in motorcycles in Asian countries is often associated with low purchasing cost, running cost, compactness and easy manoeuvring in congested areas.

India (an LMIC country) has the world's highest reported annual road crash fatalities (WHO 2018). It accounts for approximately 11% of the estimated 1.35 million global road crash deaths each year. India faces unique challenges that differ primarily from high-income countries due to a highly heterogeneous traffic mix (World Bank Group, 2020). More than 36% of crash fatalities in India are motorcycle riders (including scooters and mopeds). This was of particular concern because the number of registered motorcycles and the absolute number of crash-related hospitalisations and fatalities have increased in India over the past decade. The number of registered motor vehicles increased from 0.3 million in 1951 to 253 million in 2017, among which motorcycles represent a substantial portion accounting for 74% of all motorised vehicles in 2017 compared to 9% in 1951 (Road Transport Yearbook, 2017). The country's total number of registered motorcycles grew at a compound annual growth rate of 10% between 2007 and 2017. This reflects a preference for motorcycles as personalised means of transport in India, whereas there was a high car ratio in most developed nations. According to the annual report by the Ministry of Road Transport and Highways (MoRTH) transport research wing, 449,002 road crashes were reported in India during 2019, claiming 151,113 lives and causing injuries to 451,361 persons. Among these crashes, motorcycles account for the highest share of fatal crashes (37%). Among those crashes, 6% (3,537) were from the Tamil Nadu state. Compared to the previous year, the number of motorcyclists killed in road crashes has slightly decreased from 3,965 in 2018 to 3,537 in 2019 (MoRTH, 2020). Consequently, reducing severe casualty motorcycle crashes was a particular focus of the Indian National Road Safety Strategy (Delivering Road safety in India, WBG, 2020).

Single-vehicle crashes account for a large proportion of fatal crashes (Kim et al., 2013; Lang et al., 1996; Renski et al., 1999; Wu et al., 2016; Zhou et al., 2019). Due to the high frequency of fatalities caused by single-vehicle crashes, considerable research has been conducted to investigate the injury severity patterns and their influencing factors. In India, a significant proportion of crashes were single-vehicle motorcycle crashes. However, a clearer picture of single-vehicle crashes in these motorised two-wheeler crashes was unavailable. Single-vehicle motorcycle crashes were generally classified into two types: the motorcyclist collides with pedestrians (and) animals, and 'other' where the motorcyclist does not collide with other road users but were involved in a crash due to skidding and hitting a stationary object. These crashes were referred to as out-of-control single-vehicle motorcycle crashes and were the focus of our current study. The influence of roadway and environmental factors play a significant role in these crashes.

Several researchers have explored single-vehicle crash characteristics (Li et al., 2019a; Li et al., 2019b; Adanu, Hainen & Jones, 2018; Shaheed and Gkaritza, 2014). Some of the common factors that have been identified as contributing factors to single-vehicle crashes include excessive speed, driver fatigue, driving under the influence of alcohol or other drugs (DUI), or the effect of other geometric, weather, site characteristics, and vehicle factors. Studies have also investigated how these factors influence the occurrence and severity of single-vehicle crashes. However, limited research has been carried out to investigate the crash characteristics and injury patterns associated with single-vehicle motorcycle crashes. This research sought an in-depth understanding of the epidemiology and injury patterns among single-vehicle motorcycle crashes to help develop targeted countermeasures to reduce motorcycle injuries and fatalities.

Studies of fatal single-vehicle motorcycle crashes in India appear to be beneficial. They may provide valuable evidence for addressing motorcyclists' traffic safety issues. This would be more insightful as, among all road users, 74% of registered vehicles were motorcycles, and 37% of the victims of reported crash fatalities were motorcyclists (Road Transport Year Book, 2017 and MoRTH, 2019).

Purpose of the study

There has been a continuous increase in the number of registered motor vehicles from around 0.3 million in 1951 to 253 million in 2017, among which motorcycles represent a substantial portion accounting for 74% of all motorised vehicles in 2017 as compared to 9% in 1951 (Road transport yearbook, 2018). This study explored single-vehicle motorcycle crashes that resulted in injuries or deaths over nine years. In the state, numerous efforts were underway to address the rising burden of motorcycle crashes, particularly crashes of a single-vehicle nature. An understanding of the role of the motorcyclist and their behaviour in single-vehicle crashes were limited to date at both national and state levels, primarily due to the researchers focus on multi-vehicle motorcycle crashes. To address this limitation and explore the epidemiology of motorcyclist morbidity/mortality, the authors sought to examine the severity classifications among motorcyclists injured or killed in Tamil Nadu over nine years. While many studies have investigated the crash risk in single-vehicle motorcycle crashes, the evidence is still mixed. This article investigates some of the questions regarding single-vehicle motorcycle crashes and crash risk.

Further, the aim was to investigate if males, particularly younger males, have a higher risk of crash severity in motorcycle crashes than female motorcyclists. Finally, the causes and consequences of how single-vehicle motorcycle fatal crashes differ from non-fatal crashes more specifically were explored. The research questions that guided the study included:

1. What is the epidemiology of single-vehicle motorcycle crashes in Tamil Nadu in terms of person, road, and environmental characteristics;
2. What are the injury nature and injury profile (injury mechanism) of motorcyclists involved in fatal crashes;
3. What is the crash type, cause, and driver error for the fatal crashes reported?

The answers to these questions would help public health and transport practitioners meet motorcyclists' needs in single-vehicle crashes in the state and the country regarding regulation, infrastructure, and prevention.

Method

Data Source

Tamil Nadu is the tenth largest Indian state by area and the sixth largest by population. Over 50% of the state was urbanised, accounting for almost 10% of the country's urban population while only comprising 6% of India's total population (Census, 2011). According to the 2011 India census, Tamil Nadu had a population of 720 million. Two-wheelers constitute around 84% of the total vehicles in the state. With the increase in the number of vehicles in the state, the number of crashes has also increased. The recent report by MoRTH highlights that Tamil Nadu has recorded the highest number of road crashes for the past few consecutive years, contributing to 14.1% of its total road crashes.

This study uses the aggregated data (2009-2017) provided by the Road Accident Database Management System (RADMS) administered by the Government of Tamil Nadu. RADMS is a dataset commonly cited within the literature used to examine motor vehicle crashes in India, particularly in Tamil Nadu (Sivasankaran and Balasubramanian, 2020a, 2020b, 2020c, 2020d; Panicker and Ramadurai, 2020). Its usefulness comes from its national reach and robust archive of collected data points per case and event. RADMS information comes from numerous data sources, including police incident reports, driver's licence papers, hospital records, and death certificates. Hospital records were a subset of crash records, where the hospital authority will notify police to collect Road Traffic Crash (RTC) data from the hospital as per the policies administered in the Tamil Nadu State. More specifically, the RADMS dataset is freely available and open to public health and transportation professionals as a tool for promoting crash preventive efforts. RADMS data have been compiled since 2009, including the district-wise census of all fatal traffic crashes in Tamil Nadu, India. The RADMS database includes information related to road crash case reports from police headquarters located throughout the state. The information in the database is compiled by Tamil Nadu police personnel who investigate the crash at the scene or collect information from the hospital and record it in the registry. The responsibility for data collection, data recording, and reporting lies with the Additional Director General of Police (ADGP), State Traffic Planning Cell (STPC) Tamil Nadu. Further, trained police officials compile the crash data all over the state using the same instruction manual.

The entire dataset consists of three sub-datasets: the crash dataset, the vehicle dataset, and the driver dataset. The crash dataset documents crash-level information regarding collision types, crash location, road geometry, and weather conditions. The vehicle dataset illustrates detailed characteristics of each vehicle, occupant injury outcomes, and vehicle-specific information. The driver dataset provides the demographic and behaviour information of each driver involved in crashes. Each crash data record has a unique crash identification number which is standard in different datasets in order to link the records together.

Data Preparation

All motorcycle-involved crashes between 2009 and 2017 were retrieved. Single-vehicle motorcycle crashes that occurred during the 2009-2017 periods were extracted using the following terms: Colliding Vehicle type = "Motorcycles", "Scooters", "Mopeds" and Crash type = "Single-vehicle".

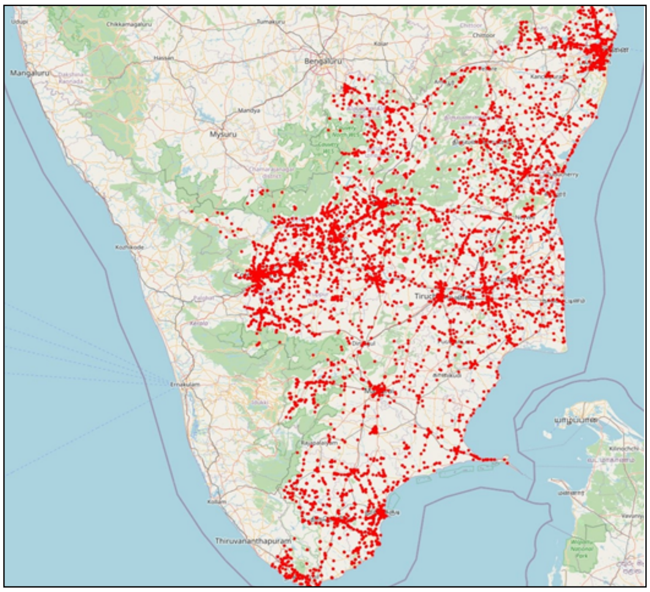

Fig 1. Locations of Fatal Single-Vehicle Motorcycle Crashes in Tamil Nadu between 2009 and 2017

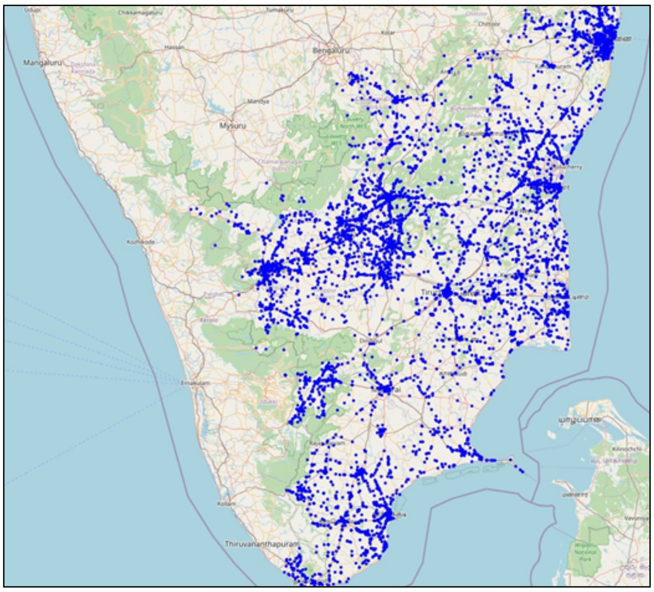

Fig 2. Locations of Non-fatal Single-Vehicle Motorcycle Crashes in Tamil Nadu between 2009 and 2017

There were 21,335 single-vehicle motorcycle crashes retrieved. It was decided only motorcycle riders at fault were to be considered, which reduced the number to 16,541 fatal crashes. Motorcycle riders in not-at-fault crashes were excluded as the study focussed on out-of-control single-vehicle motorcycle crashes. Five injury severity levels were initially defined in the dataset including no injury, possible injury, or minor injury (non-hospitalised), visible injury or minor injury (hospitalised), incapacitating injury or serious injury, and fatality. A fatality is defined in India as a road user who was involved in a vehicle crash and has died within 30 days of the traffic crash. A serious injury is defined as a person who has been hospitalised for 24 hours or more resulting from a traffic crash. Minor injuries are defined as when the road user suffers a traffic injury and is hospitalised for less than 24 hours.

Statistical Analyses

Driver characteristics (age, gender, licence type), crash characteristics (day of the week, number of lanes, traffic control, junction type, presence of road separator, speed limit, light, weather, and road conditions), and injury patterns and severity (injury nature, injury descriptors, hospitalisation delay, hospitalisation mode) were examined for motorcycle riders. Comparisons were made between fatal and non-fatal (serious injury and minor injury) motorcycle crashes. Descriptive statistics were used to describe road infrastructure characteristics, vehicle information, and motorcyclist information. Frequencies and percentages were used for categorical variables. All data were coded and analysed using the open-source statistical package R (https://www.r-project.org/). For all analyses, an alpha level of 0.05 was used for statistical significance. Two injury severity levels were considered in this analysis – fatal and non-fatal crashes. Figure 1 and Figure 2 illustrate the study zone with the location of fatal and non-fatal crashes in Tamil Nadu from 2009 to 2017.

Results

Analysis of Motorcyclist Demographics and Injury Severity

The age, gender, licence status, alcohol/drug use and helmet use distribution of the total sample of crash-involved single-vehicle motorcycle riders are shown in Table 1. Analysis of motorcyclist demographics identified that in the case of fatal crashes the majority involved male motorcyclists (99.3%). Motorcyclists between the age group 26-64 years comprised nearly 70% of all fatal crashes. The analysis also identified that males aged 26-64 years were (Chi-square =53.28, $p < 0.001$) significantly overrepresented compared to other demographic age groups in fatal crashes.

Helmet use was reported in 4962 (66.6%) fatal cases. Among the reported fatal cases, female motorcyclists (93/142) were more likely to wear a helmet (Chi-square =0.00, p=0.996), with nearly one-third of males (5039/16399, 30.7%) found not to be wearing a helmet at the time of the crash, when the police reported helmet use. Within the four age groups, lower helmet usage rates were found among the less than 17 years old age group, where only 62.4% of injured motorcyclists in this age group were wearing a helmet at the time of the crash. Analysis of the alcohol/drug usage reports identified that alcohol content was detected in 128 (1.7%) fatal cases, respectively. Male motorcyclists were the most intoxicated in motorcycle crashes; however, they were not significantly overrepresented for alcohol/presence compared to female motorcyclists (Chi-square =0.951, p=0.321). According to the police reports, not wearing a helmet was also significantly associated with detecting alcohol/drug use (Chi-square =16.20, p<0.01).

Comparison of Injured Body Regions and Injury Nature among fatal and non-fatal Single-Vehicle Motorcycle Crashes

Table 2 provides the summary of the main body regions injured for single-vehicle motorcyclists. The majority of the crashes resulted in motorcyclists sustaining head injuries (31.9%) and multiple injuries (18.5%), followed

Table 1. Demographics of Crash-Involved Single-Vehicle Motorcyclists.

		Fatal % (7447)	Non-Fatal % (9094)	Total % (16541)
Driver gender	Female	0.7	1.0	0.9
	Male	99.3	99.0	99.1
			Total	100
Driver Age	<17	1.5	1.0	1.2
	18-25	25.5	26.4	26.0
	25-64	71.0	71.7	71.4
	>65	2.1	0.9	1.4
			Total	100
Valid Licence	No	33.8	28.5	30.9
	Yes	66.2	71.5	69.1
			Total	100
Helmet Use	No	33.4	28.6	30.8
	Yes	66.6	71.4	69.2
			Total	100
Alcohol/ Drug use	No	98.3	98.7	98.5
	Yes	1.7	1.3	1.5
			Total	100
Mobile Use	No	99.9	99.8	99.8
	Yes	0.1	0.2	0.2
			Total	100

Table 2. Single-Vehicle Motorcycle Injury Severity Disaggregated by Body Regions.

	Fatal % (7447)	Non-Fatal % (9094)	Total % (16541)
Back Injury	0.1	0.2	0.2
Chest Injury	0.9	0.7	0.8
Face Injury	1.8	6.9	4.6
Hand Injury	3.2	7.1	5.3
Head Injury	51.3	16.2	31.9
Hip Injury	0.4	1.4	0.9
Knee Injury	0.7	3.9	2.4
Leg Injury	3.3	16.0	10.3
Multiple Injuries	20.1	17.2	18.5
Neck Injury	0.2	0.6	0.4
Unknown	17.6	28.7	23.7
Shoulder Injury	0.3	1.2	0.8
Total	100	100	100

by leg injuries (10.3%). The most prevalent injury type for the fatal injuries were head injuries (51.3%), followed by multiple injuries (20.1%), leg injuries (3.3%), and hand injuries (3.2%). In contrast, the most commonly injured regions in the case of non-fatal injuries (28.7%) included injuries to multiple body regions (17.2%) followed by the head (16.2%) and leg injuries (16.0%). The injury pattern among body regions for the single-vehicle motorcycle crashes differed significantly for fatal and non-fatal crashes (Chi-square =6066.55, p < 0.01). Motorcyclists who reported not wearing a helmet at the crash time were significantly more likely to sustain head injuries than helmeted motorcyclists. The nature of the injury types (refer to Table 3) differed significantly for both fatal and non-fatal crashes (Chi-square =3930.22, p< 0.01). The majority of the crashes that resulted in motorcyclist injuries include wounds/cuts (38.7%), non-injury (23.4%), followed by severe coma (10.7%). Most notably, in the case of fatal crashes, motorcyclists were more likely to suffer from wounds/cuts (28.3% vs 45.4%) and severe coma (22.3% vs 1.2%) compared to non-fatal crashes. Privation of any member or joint (<1%) means permanent impairing of any member or joint.

Table 3. Single-Vehicle Motorcycle Injury Severity Disaggregated by Injury Type.

	Fatal	Non-Fatal	Total
	Frequency (%)	Frequency (%)	Frequency (%)
Abrasion	284 (3.8)	1093 (12.0)	1377 (8.3)
Blunt Abdominal Trauma	34 (0.5)	18 (0.2)	52 (0.3)
Chest Trauma	133 (1.8)	40 (0.4)	173 (1.0)
Contusion	181 (2.4)	486 (5.3)	667 (4.0)
Cranial Trauma	703 (9.4)	154 (1.7)	857 (5.2)
Fracture or Dislocation of Bone or Tooth	254 (3.40	377 (4.1)	631 (3.8)
Permanent Disfigurement of Head or Face	754 (10.1)	73 (0.8)	827 (5.0)
Privation of Any Member or Joint	44 (0.6)	39 (0.4)	83 (0.5)
Severe Coma	1661 (22.3)	107 (1.2)	1768 (10.7)
Wounds/Cut	2105 (28.3)	4129 (45.4)	6234 (37.7)
Not Injured	1294 (17.4)	2578 (28.3)	3872 (23.4)
Total	7447 (100)	9094 (100)	16541 (100)

Hospitalisation mode and Hospitalisation Delay in Single-Vehicle Motorcycle Crashes

Hospitalisation delay refers to the time the vehicle takes to reach the hospital from the crash scene. The summary of hospitalisation mode and hospitalisation delay for single-vehicle motorcycle crashes for fatal and non-fatal injuries is shown in Tables 4 and 5 respectively. The motorcyclist's hospitalisation delay differed significantly for fatal and non-fatal crashes (Chi-square =94.88, $p< 0.01$, df=4). In fatal crashes, nearly 30% of motorcyclists were reported to the hospital within 30 minutes following the crash. Concerning the hospitalisation mode, the victims were predominantly transported by ambulance. The hospitalisation mode differed significantly in fatal and non-fatal crashes (Chi-square =94.87, $p< 0.01$, df =4).

Driver Error, Crash Type and Crash Cause Associated with Fatal and Non-Fatal Single-Vehicle Motorcycle Crashes

Police record crash type, crash cause and driver error data were available in the RADMS database during the specified years. Table 6 shows the distribution of crash type for the motorcyclists included in single-vehicle crashes. A statistically significant difference (Chi-square =215.56, $p < 0.01$) was found between fatal and non-fatal crashes. Skidding and hitting objects were more common among motorcyclists apart from others that resulted in fatal crashes. Tables 7 and 8 show the crash cause or contributory factor and the driver error for the motorcyclists involved in single-vehicle crashes. The most common cause attributed to the crashes is excessive speed i.e., exceeding speed limits that include excessive speed such as driving above the speed limit and inappropriate speed (such as driving within the speed limit but too fast for the given conditions). The results show that a high incidence of motorcyclist crashes was due to speed (89.7% fatal crashes versus 88.8% non-fatal crashes). Other contributing factors that led to fatal crashes among motorcyclists were, inattentive turning (3.1%), animal involved in the crash (2.3%), changing lane without due care (0.3%), dangerous overtaking (0.5%), not giving right of way rule violation (0.6%), and alcohol abuse (0.9%). The difference between the two distributions was statistically significant (Chi-square =16.87, $p< 0.05$). Motorcyclists under the age of 25 years were more likely to sustain fatal injuries due to exceeding speed limits compared to other age groups.

Regarding driver error, violation of a traffic rule (44.3%) was the single most significant contributor to fatal crashes among motorcyclists. Traffic violation constituted various sub-levels: exceeded lawful speed, disregarded police officer, disregarded stop sign, disregarded traffic light signal, and failed to give any signal. Furthermore, 318 crashes occurred due to carelessness (4.3%), 108 due to

Table 4. Single-Vehicle Motorcycle Injury Severity Disaggregated by Hospitalisation Delay.

	Fatal	Non- Fatal	Total
	Frequency (%)	Frequency (%)	Frequency (%)
Hospital within 30 minutes after crash	2311 (31.0)	2759 (30.3)	5070 (30.7)
Hospital between 30 minutes and 1 hour after crash	1995 (26.8)	2159 (23.7)	4154 (25.1)
Hospital between 1 hour and 2 hours after crash	1356 (18.2)	1461 (16.1)	2817 (17.0)
Hospital more than 2 hours after crash	90 (1.2)	74 (0.8)	164 (1.0)
Not hospitalised	1695 (22.8)	2641 (29.0)	4336 (26.2)
Total	7447 (100)	9094 (100)	16541 (100)

Table 5. Single-Vehicle Motorcycle Injury Severity Disaggregated by Hospitalisation Mode.

	Fatal	Non- Fatal	Total
	Frequency (%)	Frequency (%)	Frequency (%)
Arrived alone	59 (0.8)	159 (1.7)	218 (1.3)
Families Friends or Relatives	490 (6.6)	779 (8.6)	1269 (7.7)
Not Hospitalised	1705 (22.9)	2666 (29.3)	4371 (26.4)
People Near the Crash	854 (11.5)	1627 (17.9)	2481 (15.0)
Transported by Ambulance	4339 (58.3)	3863 (42.5)	8202 (49.6)
Total	7447 (100)	9094 (100)	16541 (100)

Table 6. Single-Vehicle Motorcycle Injury Severity Disaggregated by Crash Type.

	Fatal	Non-Fatal	Total
	Frequency (%)	Frequency (%)	Frequency (%)
Hit Object	1084 (14.6)	987 (10.9)	2071 (12.5)
Hit Parked Vehicle	32 (0.4)	40 (0.4)	72 (0.4)
Hit Tree	541 (7.3)	290 (3.2)	831 (5.0)
Other	2634 (35.4)	3675 (40.4)	6309 (38.1)
Ran Off-Road	231 (3.1)	274 (3.0)	505 (3.1)
Skidding	2925 (39.3)	3828 (42.1)	6753 (40.8)
Total	7447 (100)	9094 (100)	16541 (100)

Table 7. Single-Vehicle Motorcycle Injury Severity Disaggregated by Crash cause.

	Fatal	Non-Fatal	Total
	Frequency (%)	Frequency (%)	Frequency (%)
Alcohol Abuse	65 (0.9)	49 (0.5)	114 (0.7)
Animal Involved in Crash	168 (2.3)	277 (3.0)	445 (2.7)
Changing Lane Without Due Care	20 (0.3)	339 (0.4)	53 (0.3)
Dangerous Overtaking	38 (0.5)	60 (0.7)	98 (0.6)
Driving Against Flow of Traffic	37 (0.5)	40 (0.4)	77 (0.5)
Excessive Speed	6682 (89.7)	8080 (88.8)	14762 (89.2)
Inattentive Turn	231 (3.1)	306 (3.4)	537 (3.2)
Non-Respect of Rights of Way Rules	47 (0.6)	79 (0.9)	126 (0.8)
Unknown	1608 (2.2)	170 (1.9)	329 (2.0)
Total	7447 (100)	9094 (100)	16541 (100)

Table 8. Single-Vehicle Motorcycle Injury Severity Disaggregated by Driver Error.

	Fatal	Non-Fatal	Total
	Frequency (%)	Frequency (%)	Frequency (%)
Carelessness	318 (4.3)	426 (4.7)	744 (4.5)
Distraction	108 (1.5)	130 (1.4)	238 (1.4)
None	1275 (17.1)	1815 (20.0)	3090 (18.7)
Others	253 (3.4)	324 (3.6)	577 (3.5)
Unknown	2192 (29.4)	2837 (31.2)	5029 (30.4)
Violation of rule	3301 (44.3)	3562 (39.2)	6863 (41.5)
Total	7447 (100)	9094 (100)	16541 (100)

Table 9. Characteristics of Crashes Involving Fatal and Non-Fatal Single-Vehicle Motorcycle Crashes.

Variable	Test statistic	Nature of difference
Season	Chi sq.=30.26; p<0.001, df=3	Fatal crashes more common during monsoon season (24% vs. 32%)
Day of the week	Chi sq.=0.07; p=0.795, df=1	No difference
Region	Chi sq.=32.60; p<0.001, df=3	Fatal crashes more common in western regions of Tamil Nadu (28% vs. 25%)
Number of lanes	Chi sq.=3606.46; p<0.001, df=2	Fatal crashes more common on two-lane roads (45% vs. 10%)
Central Divider	Chi sq.=3083.38; p<0.001, df=1	The absence of a central divider can significantly influence fatal crashes (56% vs. 15%)
Junction type	Chi sq.=1393.52; p<0.001, df=7	Fatal crashes were common in spots that were not junctions (on-road segments) (80% vs. 66%)
Traffic control	Chi sq.=7.60; p=0.268, df=2	No difference
Road category	Chi sq.=1994.64; p<0.001, df=4	Fatal crashes were common on state highways (44% vs. 70%)
Weather conditions	Chi sq.=21.71; p=0.001, df=5	Fatal crashes were common in fine weather conditions (97% vs. 98%)
Road Conditions	Chi sq.=12.71; p=0.05, df=4	No difference
Light conditions	Chi sq.=65.47; p<0.001, df=3	Fatal crashes were common in daylight conditions (54% vs. 57%)
Population setting	Chi sq.=0.07; p=0.795, df=1	Fatal crashes were common on rural roads (84% vs. 80%)

*df = degrees of freedom

distraction (1.5%), and 1275 cases of no significant driver error but external factors (17.1%) were identified. No significant difference was found regarding any particular age group of motorcyclists involved in fatal crashes and related to driver error (Chi-square =19.86, p= 0.177).

Environment and Road Characteristics Associated with Injury Severity in Fatal Single-Vehicle Motorcycle Crashes

Table 9 compares fatal single-vehicle crashes involving motorcyclists to those involved in non-fatal crashes for a range of variables. Fatal crashes among motorcyclists were overrepresented during monsoon season, in western Tamil Nadu, on two-lane roads, in the absence of a centre median divider, at locations where the road narrowed, on state highways, during fine weather, during daylight, and on rural roads.

Logistic Regression Model Analysis

Table 10 presents the multivariate logistic regression analysis results examining the risk factors for injury severity due to single-vehicle motorcycle crashes. Demographic variables of the motorcyclists, road and environmental variables were thought to be theoretically important in influencing the outcome variable and were included in the model. In the logistic regression, motorcyclist age, licence status, helmet use, and mobile use were statistically associated (p<0.05) with fatal crashes. Regarding road characteristics and environmental variables considered in the study such as, season, region, collision type, number of lanes, junction type, road category, presence of road separators, weather conditions and light conditions were found to be statistically significantly related to fatal single-vehicle motorcycle crashes in police-reported crashes.

Table 10. Results of Logistic Regression Model for Single-Vehicle Motorcycle Crashes.

Characteristic	Variable	Estimate	Standard Error	p	OR (Odds Ratio)
Season - Ref: Monsoon	**Post Monsoon**	-0.138	0.061	0.025	0.871
	Winter	-0.171	0.053	0.001	0.843
Region - Ref: Central	**North**	-0.417	0.071	0.000	0.659
Collision Type - Ref: Hit Object	**Hit Tree**	0.489	0.111	0.000	1.631
	Other	-0.419	0.066	0.000	0.658
	Skidding	-0.396	0.065	0.000	0.673
Number Of lanes - Ref: Multiple	**Single**	-2.718	0.089	<0.001	0.066
	Two	-0.615	0.091	0.000	0.541
Central Divider - Ref: No	**Yes**	-1.353	0.048	<0.001	0.258
Junction Type - Ref: Bridge (Flyover)	**Cross Junction**	0.514	0.249	0.039	1.673
	Junction with More Than 4 Arms	0.925	0.377	0.014	2.521
	T Junction	0.784	0.243	0.001	2.190
Road Category - Ref: District Road	**National Highway**	-1.952	0.095	<0.001	0.142
	Other Roads	-1.458	0.100	<0.001	0.233
	State Highway	-2.328	0.083	<0.001	0.097
	Village Roads	-1.729	0.103	<0.001	0.178
Weather Conditions - Ref: Inclement	**Fine**	-0.412	0.189	0.029	0.662
Light Conditions - Ref: Dark - lighted	**Daylight**	-0.109	0.049	0.025	0.897
Population Setting - Ref: Rural	**Urban**	0.465	0.058	0.000	1.592
Driver Age - Ref: <17	**18-25 Years**	-0.668	0.179	0.000	0.513
	25-64 years	-0.674	0.176	0.000	0.510
Licence Status - Ref: No	**Yes**	-0.097	0.045	0.032	0.907
Mobile Use - Ref: No	**Yes**	-1.236	0.530	0.020	0.291
Helmet Use - Ref: No	**Yes**	-0.175	0.046	0.000	0.840
(Intercept)		5.121	0.957	0.000	

*Ref: Reference level

Regarding the age group of motorcyclists, 18 to 25 and 25 to 64 years old riders (primarily the working-age group) had lower odds of a fatal injury in a crash than motorcyclists <18 years old and who were underage (OR = 0.51 for both age groups). Motorcyclists who hold a valid driving licence have a lower likelihood of fatal injury in a crash (OR=0.91) compared to unlicensed riders. Similarly, the use of mobile phones while driving resulted in lower odds of a fatal injury in a crash (OR=0.29) compared to those motorcyclists who were not using mobile phones at the time of the crash. Compared to motorcyclists who wear a helmet, motorcyclists who did not wear a helmet generally had an increased odds of fatal injury in a crash.

Discussion and Conclusions

To the authors' knowledge, this appears to be the first such study to examine crash characteristics, injury outcomes, and risk factors for injury severity among single-vehicle motorcycle crashes in Tamil Nadu, one of the leading states with the highest number of road crashes in India. The study findings showed that motorcycle injuries represent a significant public health issue in Tamil Nadu, with nearly half of the injured motorcyclists in crashes sustaining a fatal injury. The study examined fatal and non-fatal cases involving single-vehicle motorcycle crashes in Tamil Nadu between 2009 and 2017. The variables included in the study were road characteristics and environment, including season, day of the week, region, number of lanes, presence of a central (median) divider, junction type, traffic control, road category, road conditions, weather conditions, light conditions and population setting at the time of the fatal crash. The motorcyclist's demographic characteristics, injury nature and body regions, hospitalisation mode and delay, crash cause, crash type and motorcyclist error were studied. Results suggest that specific road characteristics and environmental factors increase the probability of fatal crashes: urban roads, express highways, multiple lane roads, night time, absence of central (median) divider, cross and T-junctions, junctions with four arms, under-aged young motorcycle riders, not holding a valid licence and non-use of helmets.

The concentration of motorcycle fatalities was higher in the north and west zones than in Tamil Nadu's central and south zones as per the classification of traffic police in the state. Both north (28.5%) and west zones (28.6%) showed a higher concentration of motorcycle fatalities in the highly urbanised cities (such as Chennai, Coimbatore, and Tirupur), likely the result of and increasing demand for two-wheeler mode of transport.

Motorcyclists involved in crashes were mainly of a working-age group (18 to 64 year old), more commonly male (Times of India, 2014) with a valid license. Earlier studies in India have indicated that age plays a crucial role in adherence to traffic regulations (Mohan, 2009). Older motorcyclists follow traffic regulations more often than younger motorcyclists and were less likely to be involved in single-vehicle motorcycle fatal crashes. However, similar studies elsewhere highlighted those older motorcyclists were vulnerable due to age-related factors such as poor eyesight (Akanbi et al., 2009). The regression analysis results highlight those younger motorcyclists (less than 18 years) were more likely to be involved in single-vehicle motorcycle fatal crashes. However, the legal age for motorcycle riding in India is 18 years. Under-aged motorcycle riding identified in this study can be attributed to the inadequate implementation of the state's existing road safety rules. Thus, it indicates that existing traffic rules without enforcement yield poor results, as highlighted in a previous study by Mittal, 2008. The findings showed that crash-involved motorcyclists were more commonly male, and riding was more prevalent amongst males (TOI report, 2018). They were mainly breadwinners of the family and were more often on the roads. Earlier studies have shown that males took greater risks than females (Harris, Jenkins, & Glaser, 2006; Waldron, McCloskey, & Earle, 2005). It is possible that this is occurring in Tamil Nadu, hence further exacerbating the over representation of male riders in crashes. A further study will be required to understand whether this is a contributing factor.

The present study also found that nearly one-third of motorcyclists who died were unlicenced drivers in single-vehicle crashes. Furthermore, unlicenced motorcyclists had a greater risk of fatal injury than licenced motorcyclists in single-vehicle crashes. This is consistent with previous studies in south-east Asian countries such as Malaysia and Vietnam that indicated that riding without a licence was associated with a greater likelihood of being killed or injured in a motorcycle crash (Isa et al., 2011; Doan and Hobday, 2019). Unlicenced motorcyclists may be older, with a higher risk of fatal injury due to age-related factors (Ferreira et al., 2017). Unlicenced motorcyclists may also be more likely to participate in dangerous riding activities such as speeding, riding while intoxicated, and not wearing a helmet. These findings illustrate the need to strengthen India's existing motorcycle licensing system and enforcement to ensure that all motorcyclists have the necessary training before riding on the roads (MoRTH 2021).

It was widely accepted that alcohol increases crash risk and injury severity for motorcyclists (Lin and Kraus, 2009; Doan and Hobday, 2019). The present study results show that only 1.5% of the total motorcyclists who died and were injured were under the influence of drugs/alcohol. No conclusions from the data could be drawn, as there were different ways drug/alcohol use was assessed. In the first method in regards to alcohol use, the police officer stopped the rider and started a conversation to determine if there was any odour of alcohol use. There were also campaigns screening riders at coordinated traffic stops. The only judicially admissible evidence regarding consumption of alcohol while riding can only be accepted from a blood alcohol level (BAC) test carried out at designated laboratories.

Risky behaviours for motorcyclists involving fatal crashes include not wearing a helmet, mobile phone use while driving, and speeding by unlicenced riders (Mustafa, Ahmad, and Khairil 2020). The present study also found that nearly one-third of the fatal motorcyclists were not wearing a helmet. Motorcyclists' high proportion of head injuries highlights the importance of increasing motorcycle helmet wearing in India. It is also important that helmets comply with national government standards. According to the motor vehicle act, 2015, under section 129 in Tamil Nadu, helmet wearing is compulsory for the rider and the pillion rider.

In a similar context, the government of Vietnam has continuously improved its laws and regulations to promote helmet-wearing by motorcyclists, including a provision that holds parents responsible for ensuring that their children wear appropriate helmets when they are pillions on motorcycles. Helmet-wearing rates have remained above 95% since the motorcycle helmet law was introduced in Vietnam (Boa et al., 2017). Hence, similar efforts can reduce motorcycle fatalities in the state of Tamil Nadu.

The results of the present study indicate that the loss of vehicle control precipitates further crashes for single-vehicle motorcyclists. Indeed, examination of the past nine years' data, for which information on the crash type, crash cause and motorcyclist error were available, found that motorcyclists were overrepresented in loss of control skidding, when hitting an object/animal, and when hitting trees in road crashes. Earlier research has found that loss of control in crashes was the most common motorcycle crash type, leading to serious injury (Fredriksson and Sui., 2016). The common causal factor for crashes was excessive speed (i.e., driving above the speed limit) and inappropriate speed (driving too fast for the given conditions despite travelling within the speed limit).

Regarding driver error identified in this study, traffic rule violation was the single largest contributor to fatal crashes. Almost 99% (16,539) of crashes occurred on a good road surface which suggests a loss of control event in single-vehicle motorcycle crashes.

Motorcyclists had a higher level of injury severity in single-vehicle crashes and were more likely to sustain injuries to multiple body regions. The injured regions for fatal motorcyclists, from most to least common, were to multiple body regions, i.e., head, legs, face, chest, knees, hip, shoulder, neck and back regions. This differed slightly for non–fatal injuries, with the injured regions from most to least common were to the head, legs, hands, face, knee, hip, shoulder, chest, neck and back regions.

These findings are consistent with earlier findings that head injuries occur with greater frequency for motorcyclists in the absence of helmets and represent the highest proportion of fatal crashes among single-vehicle crashes (Van Elsande and Elvik., 2012; Thompson, Baldock and Lindsay, 2020).

This study found that 50% of motorcycle-related fatalities in Tamil Nadu resulted in head injuries. Furthermore, the head injuries observed in non-fatal crashes were typically mild or moderate. Lower rates and less severe head injuries in non-fatal crashes may be due to motorcyclists' self-disciplined strict adherence to helmet laws and strict limitations on the number of passengers on a motorcycle at any one time.

Motorcycle riders also often sustain multiple injuries in a crash, and the most common site of injury was to the lower extremities, followed by the upper extremities. The present study results also show that injuries to the lower and upper extremities were most common for motorcyclists in fatal and non-fatal crashes, similar to Lin and Kraus, 2009; Rosenberg et al., 2020. Both the severity of injuries and the most frequent injury site was due to the unprotected nature of motorcycle riding. When a rider falls on the road or makes contact with a roadside barrier, the extremities will be the first point of impact (Thompson, Baldock and Lindsay, 2020). The nature of injuries for fatal motorcyclists, from most to least common, were wounds/cuts, severe coma, permanent disfigurement of the head or face, cranial trauma, abrasion, fracture or dislocation of bone or tooth, contusion, chest trauma, immobilisation of any member or joint and blunt abdominal trauma. This differed slightly for non–fatal injuries, where the injured regions ranged from the most to least common injury being wounds/cuts, abrasion, contusion, and cranial trauma, followed by other injury types.

Victims of motorcycle crashes require prehospital care to lower complications. The Emergency Management and Research Institute (EMRI) in Tamil Nadu provide care at the scene to victims involved in road crashes and transport them to the nearby health care facility. The transport time from the crash scene to the nearby health facility has significantly improved in recent years. The study results showed that more than 30% of the crash victims were taken to the nearby health care centre for appropriate interventions. The victims' most common modes of transport to the nearest health care centre were ambulance services. Prehospital services in low-income and middle-income countries (LMICs) like India have to be strengthened to decrease emergency department utilisation. This reduces overcrowding of crash victims in emergency rooms. More recently, the Tamil Nadu Emergency Care Initiative (TAEI) has been established to assist with this. This initiative addresses the needs of RTC victims, optimises the resources available at the emergency rooms and lowers the response time of the ambulance paramedics to the crash scene. Prehospital care is not well established in LMIC settings, including India. Hence, trauma care must consistently apply vital interventions to develop and implement context-specific trauma care for RTC victims.

Lastly, the results from the logistic model regarding crash injury severity in single-vehicle motorcycle crashes in Tamil Nadu were generally consistent with previous studies from other regions, including developed nations. With respect to the contributing factors, this study found that some of the variables such as season, collision type, junction type, road category, light condition, weather condition, number of lanes, median divider and population setting have similar associations in regards to crash causation factors to those in other regions (Wu et al., 2016; Li et al., 2019; Shaheed and Gkaritza, 2014).

The main strength of this study is that it is a population-based study focussing on single-vehicle motorcycle crashes in India's particular state of Tamil Nadu. It is felt that the results could generally be extrapolated to other citywide, state-wide, or nationwide similar settings. Many of the risk factors for single-vehicle motorcycle crashes identified in this study are consistent with previous studies. This study examined crashes which considered the rider/pillion, place, time, and fatality cause; many studies combine several factors, making specific investigation difficult.

Factors contributing to the crash and rider error that significantly influenced single-vehicle crashes could be examined. In addition, this study contributes to the analytic utility of RADMS data, especially those related to single-vehicle crashes. Hence, it was possible to gain an understanding of the crash characteristics and thus propose evidence based preventive countermeasures for such single vehicle crashes.

Another strength of this study was the in-depth information collected, including motorcyclist, injury and crash characteristics linked to each motorcyclist's RADMS and trauma hospital records. Thus, via this data linkage study, it was possible to include information about motorcyclist crashes resulting in hospitalisation and detailed information on the nature of the injury as well as individual motorcyclist characteristics. A detailed analysis and categorisation of the various factors contributing to mortality in single-vehicle crashes was also presented. Using an extensive database and generating an acceptable degree of statistical validity, this study established many predictors of mortality in single-vehicle motorcycle crashes. This research also provided that unlicenced riding and non-use of helmets can result in significant trauma for motorcyclists in crash events.

This study has some limitations. While an overall sample size of nine years of data were collected, this analysis restricts the potential for specific variables to draw statistical inferences; for example, the low prevalence of drug and alcohol detection made it challenging to determine their contributions. Furthermore, while police reports include a wealth of data, they do not provide every factor at play and may lack data. The police officer does not have the scope to record factors such as the reason for mobile phone use or other distractions (e.g., music, eating, scenery, etc.) that were not captured at the crash scene. Hence, there is no clear category for the officer to classify this activity. Though these data were not considered in this study, they are potentially important factors that merit future research. In addition, reporting by the police of certain variables such as precise geometric location, weather condition, and road alignments may not be correct. The police relied on witnesses of the crash in their reporting, contributing to the description variation.

This study is the first and one of its kind, possibly one of the few studies in India. It investigates multiple contributing factors to fatal motorcycle crashes in India related to single-vehicle crashes. In fatal motorcycle crashes, most risk factors can be mitigated. One way to reduce the risk of being killed in a motorcycle crash is to wear an approved helmet, ride at slower speed, and not drink and ride. Motorcycle-friendly roadside barriers are recommended for motorcyclists to protect against hitting trees, lighting poles, etc. Maintenance of road surface and road markings is also important, and curve speed markings need to be explored further to assess if they reduce approach speed at curves. It is also proposed that motorcyclists be segregated from primary traffic by implementing motorcycle only lane along high-speed roads to minimise multiple vehicle crashes involving motorcycles and other vehicles.

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Author Contributions

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Conflict of Interest

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

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