JOURNAL FOR SOCIAL SCIENCE STUDIES
An International Peer-Reviewed Open Access Journal

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

WHERE AND WHEN ARE ROAD TRAFFIC CRASHES MOST SEVERE? A DISTRICT-LEVEL QUANTITATIVE ANALYSIS OF ROAD SAFETY IN PUNJAB, PAKISTAN

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DOI: https://doi.org/10.5281/zenodo.22702441

Keywords
road traffic crashes; road safety; injury severity; mortality; Punjab; Pakistan; district-level analysis; Safe System.

Article History
Received: 01 June 2026
Accepted: 23 August 2026
Published: 08 September 2026

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Abstract

Road traffic crashes (RTCs) are a significant public-health and transport-policy problem in Pakistan, but may mask significant spatial and temporal variations in the incidence of crashes, injury severity, and mortality at the provincial level. The study discusses the level and time of the most severe RTCs in the whole of Punjab as revealed from the monthly data of administrative records of 38 districts. There were 493,395 RTCs, 328,854 minor injuries, 248,326 serious injuries and 4,945 recorded deaths. The Exposure Measures for the 2023 PHC and registered vehicle stock were used. Descriptive statistics, population- and vehicle-adjusted rates, a district-month Poisson model, a study-defined severe outcome ratio, and Pearson and Spearman correlations and Friedman tests were used in the analysis. There was significant monthly variation for RTC, minor injuries, serious injuries and deaths but no significant monotonic January–December trend was identified. Lahore had the highest population-adjusted RTC rate (696.9 per 100,000), whereas Sheikhupura had the highest recorded mortality rate (6.62 per 100,000). Taunsa Sharif, Chakwal, and Attock exhibited particularly high severe-outcome ratios. Population-adjusted RTC incidence was moderately associated with population-adjusted mortality. In multivariable analysis, district population was strongly associated with annual RTC volume after adjustment for registered vehicles, while annual RTC frequency remained positively associated with recorded deaths after controlling for population. The findings demonstrate that crash incidence, casualty severity, and mortality are related but distinct dimensions of road safety. Punjab therefore requires geographically differentiated road-safety policy combining district risk profiles, speed management, motorcycle safety, targeted enforcement, improved crash-data integration, and strengthened post-crash care.

1. INTRODUCTION

Road traffic crashes remain a major global public-health, transport, and development challenge. The World Health Organization (WHO, 2023) estimates that approximately 1.19 million people die on the world's roads each year and identifies

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Volume 4 • Issue 5 • September 2026

road traffic injury as the leading cause of death among people aged 5–29 years. The burden falls disproportionately on low- and middle-income countries, where rapid motorisation frequently outpaces improvements in road design, vehicle safety, enforcement, protection of vulnerable road users, and trauma systems. Contemporary road-safety policy therefore increasingly treats serious injury and death as preventable system outcomes rather than unavoidable consequences of mobility.

All these challenges are also present in Pakistan. The risk environment is complex because of rapid urbanisation, population growth, mixed traffic, a high prevalence of motorcycles on the road, variable road surfaces, variable enforcement and unequal access to emergency and trauma care. Punjab has a special significance as it is the most populous province of Pakistan and has a number of metropolitan, industrial, agricultural, and inter-city transport corridors. It has a road network designed to support motorized and non-motorized transportation including cars, motorcycles, rickshaws, buses, trucks, agriculture vehicles, pedestrians and cyclists. This can mask significant differences in exposure and risk across districts within a province.

A previous study has shown spatial and temporal variation in RTCs across Punjab. GIS and monthly data of 2015–2018 were used by Mahmood et al. (2022) to quantify the significant spatio-temporal heterogeneity and high crash loads in Lahore, Faisalabad, Gujranwala and Multan. The highest-impact areas of crashes, however, are not always the same areas where residents are most likely to die or where crashes are most likely to have a serious impact. This distinction is key as absolute counts are highly sensitive to population and mobility.

In Pakistan, several studies also show the existence of analytical difference between the occurrence of crashes and the severity of crashes. Motorcycle injury severity in Pakistan is found to be different depending on the collision situation, such as collision with trucks and pedestrians, by Mansoor et al. (2023). Based on data from the prehospital environment in Punjab, Kumar et al. (2025) demonstrated that the characteristics of the road user, type of injury and time taken to respond to an emergency were linked with the mortality that occurred in the Prehospital Environment for older road users. The results of this research may help to encourage a move from counting crashes to an investigation of the conditions under which crashes become serious or fatal.

In the present study, the information related to RTC was used for 38 districts of Punjab for the months of January to December 2025 with the help of data related to population of districts and data related to registered vehicles. Administration records show there were 493,395 RTCs, 328,854 minor injuries, 248,326 serious injuries and 4,945 deaths recorded. Absolute burden and population-adjusted crash and mortality rates (where available), deaths per 100 RTCs, and a study-defined severe outcome ratio are evaluated.It also examines monthly variation, recorded cause categories, correlations, and multivariable associations.

1.1 Problem Statement

Road-safety reporting in Punjab has traditionally emphasised aggregate crash counts, while much of the available research focuses on particular cities, road-user groups, or injury types. This creates an analytical limitation because districts with the largest number of crashes may not experience the highest population-adjusted crash incidence, mortality, or casualty severity. Punjab's districts differ markedly in population, urbanisation, transport activity, road environment, and access to emergency care; annual provincial totals may also conceal important month-to-month variation. Comparatively little recent research has simultaneously compared crash incidence, serious injury, mortality, and casualty severity across Punjab districts while adjusting geographic comparisons for population exposure and examining temporal variation. Without this differentiation, policy may concentrate on high-

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volume locations while overlooking districts where crashes are disproportionately severe or fatal.

1.2 Research Questions

RQ1. What spatial patterns characterise road traffic crashes, serious injuries, and recorded deaths across the districts of Punjab in 2025?

RQ2. Which districts experience disproportionately high population-adjusted crash incidence, mortality, and casualty severity?

RQ3. Do road traffic crashes, injuries, and recorded deaths vary significantly across months of the year?

RQ4. To what extent are district population, registered vehicle stock, and crash frequency associated with RTC and mortality outcomes?

1.3 Hypotheses

H01: Road traffic crash outcomes do not vary significantly across months; H11: road traffic crash outcomes vary significantly across months.

H02: Population-adjusted RTC incidence is not significantly associated with population-adjusted road traffic mortality; H12: higher population-adjusted RTC incidence is significantly associated with higher population-adjusted mortality.

H03: District population is not significantly associated with annual RTC frequency after controlling for registered vehicle stock; H13: district population is positively associated with annual RTC frequency after controlling for registered vehicles.

H04: Annual RTC frequency is not significantly associated with annual recorded road traffic deaths after controlling for population; H14: annual RTC frequency is positively associated with recorded deaths after controlling for population.

2. Literature Review

2.1 Spatial and Temporal Heterogeneity

Spatially disaggregated road-safety research has become increasingly important because national and provincial averages can hide local concentrations of risk. Mahmood et al. (2022) used GIS time series technique on the RTC Punjab data and found that there are significant spatial and temporal variations. The work they've done sets a precedent for district sensitive analysis and was largely geared toward crash occurrence. In recent years, population-adjusted geographic analysis has also shown to be useful in the work of South Asia, particularly in district-level studies of mortality which have demonstrated that the use of either crude counts or mortality rates can yield different risk maps, reflecting the need for a distinction between service burden and population risk.

2.2 Crash Frequency, Severity, and Vulnerable Road Users

Road-safety scholarship increasingly distinguishes crash occurrence from injury outcome. Mansoor et al. (2023) used statistical and machine-learning models to analyse motorcycle crash injury severity in Pakistan and found that collision context materially affected the probability of fatal injury. This is particularly important in Pakistan, where motorcycles account for a large share of motorised mobility and more than half of crashes in the study cited by Mansoor et al. Their findings support severity-focused modelling rather than reliance on crash frequency alone.

Vulnerable road users also experience different consequences after collision. Kumar et al. (2025) analysed 34,345 road traffic injury cases among people aged 65 years and older from Punjab's prehospital system. Their study linked mortality with factors including head injury, pedestrian status, and response time. This suggests that district mortality can vary because of road-user mix and post-crash systems even when crash incidence is similar.

2.3 Exposure, Motorisation, and Measurement

Absolute crash and death counts are partly functions of exposure. Population is a widely available denominator, while registered vehicle stock provides a supplementary proxy for motorisation. Neither is equivalent to vehicle-kilometres travelled: population does not directly measure travel, and registered vehicles may

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operate outside their registration district. Nevertheless, where detailed mobility data are unavailable, population-adjusted and vehicle-adjusted indicators improve comparability and help distinguish large absolute burdens from disproportionately high risk.

2.4 Road-Safety Data Systems

Administrative data quality and linkage is key to the quality of road-safety analysis. Overall, there was significant fragmentation in road traffic data systems in the WHO Eastern Mediterranean Region, including excessive reliance on police data, low level of granularity, multiple stakeholders collecting some overlapping data, and limited permanent linkage in data sources (Puvanachandra et al., 2024). The results are applicable to Pakistan where information on ambulance, police, hospital, vehicle-registration and mortality is kept separately. Categories like 'carelessness' and 'other' may thus be of value for surveillance, but not for causal analysis.

2.5 Safe System Perspective and Research Gap

The WHO Safe System approach sees death and serious injury as the result of preventable aspects of the transport system, focusing on safer roads, speeds, vehicles, road users and post-crash care (WHO, 2023). This approach is particularly relevant for the current study since it is not the case that higher crash rates indicate higher mortality rates. Differences in the spatio-temporal aspects of crashes have already been documented in existing research in Punjab, with existing Pakistani severity studies identifying crash-context risk factors, and existing prehospital research identifying determinants of mortality. However, there was a relatively little research that combines district level crash incidence, mortality, severity, exposure and month-to-month variation on a district-wide perspective in the framework of the province of Punjab. This study fills this gap.

3. Conceptual Framework

Geography and time moderate the relationships in the study, which views road safety as a chain of events involving road exposure, the incidence of road crashes, casualty outcomes, and fatalities. Observed exposure proxies include population and registered vehicles. RTC frequency represents crash incidence. Minor injury, serious injury, and recorded death represent progressively more severe administrative outcomes. District and month capture spatial and temporal context. Unmeasured factors—including road design, operating speed, vehicle type, enforcement, weather, helmet use, and trauma accessibility—are recognised as potential mechanisms but are not treated as observed causal variables.

Conceptually: Exposure → Crash Incidence → Casualty Outcome → Serious Injury/Recorded Death. Geography and time operate across this sequence. This permits identification of high-volume districts, high-incidence districts, high-mortality districts, and high-severity districts as potentially different policy categories.

The study-defined Severe Outcome Ratio is: (Serious injuries + recorded deaths) / (Minor injuries + serious injuries + recorded deaths). It is an administrative severity indicator, not a clinical injury-severity scale.

4. Methodology

4.1 Research Design and Setting

The study employed a quantitative observational longitudinal ecological design using routinely collected administrative RTC data. The primary geographic unit was the district and the temporal unit was the month. Complete monthly crash observations for 38 districts over January–December 2025 produced a district-month panel of 456 observations. Because the data are aggregated, associations identified at district level cannot be interpreted as individual-level causal effects.

4.2 Data Sources and Variables

Monthly RTC records contained total road traffic emergencies, victims, recorded cause categories, first-aid cases, persons shifted for further treatment, and deaths. For analysis, Total

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Emergencies was treated as RTC events; First Aid as minor injury; Shifted as serious injury; and Dead as recorded deaths. The 'serious injury' classification is thus not a clinical scale of injury validated by the administration, but rather administrative disposition.

The exposure denominator for district population was taken from the 2023 Population and Housing Census. A supplemental exposure measure was registered vehicle stock. Data for 36 of the 38 districts reporting crashes (according to the source registration system) were available; no comparable data were available for Murree and Taunsa Sharif and were not imputed.

4.3 Derived Indicators

Annual RTCs per 100,000 population (per capita) were calculated as the annual number of RTCs per 100,000 population. Recorded mortality rate is the number of recorded deaths per 100,000 population. Vehicle-adjusted RTC and mortality indicators used registered vehicles as the denominator, and were reported per 10,000 vehicles. The number of deaths per 100 RTCs was obtained by dividing the number of deaths by the number of RTCs and multiplying by 100. The Severe Outcome Ratio was determined by dividing the number of serious injuries and deaths by the number of minor injuries and serious injuries and deaths.

4.4 Statistical Analysis

Descriptive statistics reported the annual totals, rates, central tendency, dispersion and ranking of the districts. The RTC, minor injury, serious injury and fatality were computed using monthly provincial totals.Because each district contributed repeated monthly observations and parametric assumptions could not be presumed, Friedman tests assessed whether outcomes differed across the twelve months. Spearman correlations between month number and provincial totals tested for a simple monotonic January–December trend.

Pearson and Spearman correlations examined district-level relationships among population, registered vehicles, annual RTCs, serious injuries, deaths, population-adjusted RTC rates, population-adjusted mortality rates, and the Severe Outcome Ratio. A two-sided alpha of .05 was used.

Two principal district-level log-linear OLS models with heteroskedasticity-consistent HC3 robust standard errors were estimated. Model 1 specified ln(Annual RTCs + 1) as a function of ln(Population + 1) and ln(Registered vehicles + 1). Model 2 specified ln(Annual deaths + 1) as a function of ln(Annual RTCs + 1) and ln(Population + 1). Coefficients in these log-log models are interpreted approximately as elasticities.

As a supplementary count-data analysis, a district-month Poisson generalised linear model estimated recorded deaths with log population as an exposure offset, RTCs per 100 as a predictor, and month indicators, with January as the reference month. Exponentiated coefficients are reported as incidence rate ratios (IRRs). The model is interpreted as associational and supplementary rather than causal.

4.5 Data Quality and Ethical Considerations

District names were harmonised across sources. Administrative-boundary differences were retained transparently rather than resolved through unsupported imputation. The study used aggregate administrative data and no personally identifiable information. Any institutional permission requirements applicable to the underlying administrative records should be satisfied before publication.

5. Results

5.1 Overall Burden

Across the 38 districts, 493,395 RTCs were recorded during 2025, involving 328,854 minor injuries, 248,326 serious injuries, and 4,945 recorded deaths. The combined casualty count was 582,125. Recorded deaths were equivalent to approximately 1.00 death per 100 RTCs, while

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serious injuries plus deaths accounted for 43.5% of recorded casualties.

Indicator	2025 total
Road traffic crashes	493,395
Minor injuries	328,854
Serious injuries	248,326
Recorded deaths	4,945
Total casualties	582,125
Deaths per 100 RTCs	1.00
Serious + fatal share of casualties	43.5%

5.2 District Distribution

Annual RTC counts varied markedly across districts. Lahore recorded 90,626 RTCs, followed by Faisalabad (32,999), Multan (30,560), Gujranwala (25,870), and Sheikhupura (17,738). However, population-adjusted rankings differed from raw-count rankings. Lahore remained highest at 696.90 RTCs per 100,000 population, followed by Multan (569.90), Nankana Sahib (525.73), Gujranwala (520.91), and Murree (511.33).

Rank	District	RTCs per 100,000
1	Lahore	696.90
2	Multan	569.90
3	Nankana Sahib	525.73
4	Gujranwala	520.91
5	Murree	511.33

5.3 Mortality and Severity

The geography of recorded mortality differed from the geography of crash incidence. Sheikhupura had the highest population-adjusted recorded mortality rate at 6.62 deaths per 100,000 population, followed by Hafizabad (5.76), Chakwal (5.71), Gujranwala (5.42), and Sahiwal (5.17). Thus, Lahore's exceptionally high crash incidence did not translate into the highest mortality rate.

Rank	District	Recorded deaths per 100,000
1	Sheikhupura	6.62
2	Hafizabad	5.76
3	Chakwal	5.71
4	Gujranwala	5.42
5	Sahiwal	5.17

The study-defined Severe Outcome Ratio also identified a different set of priority districts. Taunsa Sharif had the highest ratio (0.712), followed by Chakwal (0.707), Attock (0.698), Khushab (0.647), and Mianwali (0.620). These results indicate that some relatively low-volume districts experienced a disproportionately severe casualty profile.

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Rank	District	Severe Outcome Ratio
1	Taunsa Sharif	0.712
2	Chakwal	0.707
3	Attock	0.698
4	Khushab	0.647
5	Mianwali	0.620

5.4 Monthly Variation

Monthly RTC totals ranged from 37,386 in February to 45,287 in November. November also recorded the highest number of deaths (490), while August recorded the lowest (343). The pattern shows substantial intra-annual variation rather than a steady increase across the year.

Month	RTCs	Recorded deaths
January	38,802	401
February	37,386	375
March	42,547	422
April	43,991	431
May	39,978	435
June	41,383	370
July	38,878	387
August	40,282	343
September	42,067	403
October	44,831	466
November	45,287	490
December	37,963	422

Friedman tests showed statistically significant month-to-month differences for RTCs, χ^2 = 242.88, p < .001; minor injuries, χ^2 = 170.91, p < .001; serious injuries, χ^2 = 262.85, p < .001; and deaths, χ^2 = 29.08, p = .002. H01 was therefore rejected. However, Spearman correlations between month number and provincial totals were not statistically significant for RTCs (ρ = .322, p = .308), minor injuries (ρ = .357, p = .255), serious injuries (ρ = .308, p = .331), or deaths (ρ = .326, p = .302). The evidence therefore supports significant intra-annual variation but not a simple monotonic trend. Because only one year is analysed, recurring seasonality cannot be established.

Outcome	Friedman χ^2	p	Conclusion
RTCs	242.88	< .001	Significant monthly variation
Minor injuries	170.91	< .001	Significant monthly variation
Serious injuries	262.85	< .001	Significant monthly variation
Recorded deaths	29.08	.002	Significant monthly variation

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5.5 Reported Cause Categories

Among recorded cause categories, carelessness accounted for 211,954 observations (42.96%), followed closely by Other with 205,851 (41.72%). Over-speeding represented 54,027 (10.95%), wrong turn 13,822 (2.80%), U-turn 3,955 (0.80%), tyre burst 3,530 (0.72%), and one-wheeling 256 (0.05%). These categories are administrative classifications and should not be interpreted as verified causal mechanisms. The very large 'Other' category particularly limits causal inference.

Reported category	Count	Share
Carelessness	211,954	42.96%
Other	205,851	41.72%
Over Speed	54,027	10.95%
Wrong Turn	13,822	2.80%
U Turn	3,955	0.80%
Tyre Burst	3,530	0.72%
One Wheeling	256	0.05%

5.6 Correlations

Absolute district counts were strongly associated with exposure. Population correlated strongly with annual RTCs (Pearson $r = .913$, $p < .001$; Spearman $\rho = .901$, $p < .001$) and deaths ($r = .943$, $p < .001$; $\rho = .896$, $p < .001$). Registered vehicles were strongly correlated with annual RTCs in Pearson analysis ($r = .966$, $p < .001$), although the rank correlation was more moderate ($\rho = .621$, $p < .001$). Annual RTCs and deaths were also strongly associated ($r = .875$, $p < .001$; $\rho = .942$, $p < .001$). After adjustment for population, the association between RTC incidence and mortality was substantially weaker but remained statistically significant: RTCs per 100,000 correlated with deaths per 100,000 at $r = .379$ ($p = .019$) and $\rho = .470$ ($p = .003$). H02 was therefore rejected, but the moderate effect indicates that mortality is not explained by crash incidence alone

Variables	Pearson r	p	Spearman ρ	p
Population – Annual RTCs	.913	< .001	.901	< .001
Population – Recorded deaths	.943	< .001	.896	< .001
Registered vehicles – Annual RTCs	.966	< .001	.621	< .001
Annual RTCs – Recorded deaths	.875	< .001	.942	< .001
RTCs/100k – Deaths/100k	.379	.019	.470	.003

5.7 Regression Models

Model 1 explained approximately 80% of adjusted variation in annual RTCs (adjusted $R^2 = .799$; $N = 36$). Log population was strongly and positively associated with annual RTCs ($\beta = 1.042$, robust SE = .130, $p < .001$), whereas log registered vehicles was not independently significant after population was included ($\beta = .031$, SE = .080, $p = .700$). In elasticity terms, a 1% higher population was associated with approximately 1.04% higher annual RTCs, holding registered vehicle stock constant. H03 was rejected. The vehicle coefficient

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should not be interpreted as evidence that vehicles are unimportant; vehicle stock is an imperfect exposure proxy and is highly related to population.

Predictor	B	Robust SE	p	95% CI
Constant	-6.669	1.810	< .001	[-10.217, -3.121]
ln Population	1.042	.130	< .001	[.786, 1.298]
ln Registered vehicles	.031	.080	.700	[-.127, .189]

Model 2 explained approximately 88% of adjusted variation in annual recorded deaths (adjusted R^2 = .883; N = 38). Log annual RTCs was positively associated with deaths after controlling for population (β = .364, SE = .165, p = .028), while log population was also significant (β = .748, SE = .233, p = .001). A 1% higher annual RTC count was associated with approximately 0.36% higher annual deaths, holding population constant. H04 was therefore rejected.

Predictor	B	Robust SE	p	95% CI
Constant	-9.804	2.326	< .001	[-14.363, -5.244]
ln Annual RTCs	.364	.165	.028	[.040, .687]
ln Population	.748	.233	.001	[.291, 1.205]

In the supplementary district-month Poisson model, RTCs per 100 were not significantly associated with expected deaths after the population offset and month indicators were included (IRR = 1.0006, p = .451). November, however, had approximately 22% higher expected fatality incidence than January (IRR = 1.220, p = .018; 95% CI [1.034, 1.440]). This model-specific ecological result does not imply that crashes are unrelated to fatalities; rather, it indicates that monthly district crash volume alone did not explain mortality after the specified exposure and temporal controls.

6. Discussion

6.1 A Large but Uneven Road-Safety Burden

The results reveal that the road traffic burden in Punjab is high and not evenly distributed. The number of RTCs recorded in the administrative data in 2025 nearly half a million, and there were almost 5,000 recorded deaths. This is similar to the global trend of higher proportion of road injury in LMICs as noted by WHO (2023). More important, the district analysis illustrates that total numbers by province mask varying risk profiles. The high crash burden in major urban districts is consistent with Mahmood et al. (2022) who earlier identified the urban centers of Lahore, Faisalabad, Gujranwala, and Multan as important locations with crash burden in the province of Punjab. However the current analysis of the population-adjusted data introduces an important caveat: the district with the highest number of crashes may not be the district with the highest number of fatalities or sever crashes. Sheikhupura had the highest mortality rate while Lahore had the highest RTC rate, and Taunsa Sharif had the highest severe outcome ratio.

6.2 Crash Incidence and Mortality Are Distinct

One of the key takeaways from the paper is the variance between incidence and mortality. There was a strong correlation between absolute RTCs and deaths; the correlation after population adjustment was moderate. This suggests that much of the correlation between raw counts and fatalities is due to exposure, and other factors are

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likely shaping the relationship between crashes and fatalities. This is confirmed by the severity research in Pakistan. Mansoor et al. (2023) determined that injury severity of motorcycle crashes was linked to the type of collision context, being more likely to increase the probability of a fatal injury when there was a truck or pedestrian involved. It's implied that the same strategies are not needed to prevent crashes as are needed to reduce their severity.

6.3 Severity and Post-Crash Systems

Some districts with a relatively lower amount of crashes may face a disproportionately high impact, as seen in high severe-outcome ratios of Taunsa Sharif, Chakwal, Attock, Khushab and Mianwali. Possible explanations include increased travelling speeds, varying road-user traffic, increased distance between cities and rural areas, roadside hazards, and inequity of access to trauma care. The mechanisms cannot be directly tested with the current data, however, Kumar et al. (2025) present evidence in this work for the specific case of Punjab that head injury, pedestrian status and response time are all associated with on-scene mortality of older road users. It is therefore important that severity be treated as a separate question from crash frequency, and thus be independently monitored.

6.4 Temporal Variation

All four key outcomes show marked variation from one month to the next, as indicated by the significant Friedman tests. The highest RTC and death figures occurred in November followed by a high number of deaths in October. The lack of an overall clear monotonic month-number trend, however, precludes a straightforward increase through 2025. Furthermore, there is only one year to determine seasonality. Appropriate interpretation is important intra-annual variation, which may be seasonal or calendar related; confirmation of this with multi-year data is required.

6.5 Behavioural Categories and Speed

Of the largest category, which was Carelessness, there was no more than one-fourth which was described explicitly, and the nearly equal proportion of Other makes causal interpretation difficult. Puvanachandra et al. (2024) also note the same shortcomings in regional road-safety data systems such as low granularity and a lack of data collection. This administrative term 'carelessness' could refer to distraction, fatigue, unsafe following, lane changing, failure to yield or other actions. The 10.95% attributed to over-speeding should also not be taken as the percentage of all over-speeding-related injuries as the speed could increase the severity of an injury even if another action is listed as the initiating cause.

6.6 Exposure and Vehicle Stock

To a greater degree, population was a strong predictor of annual RTC volume, whereas the registered vehicle stock remained non-significant when controlling for population. This probably contributes to collinearity and to limitations of measurement. Registered vehicles is not the same as traffic exposure: registered vehicles may be registered in one district and driven in another and annual stock does not indicate distance travelled.The result therefore supports improved exposure measurement rather than the conclusion that motorisation is unimportant.

6.7 Data-System Implications

The study also demonstrates the analytical value and limitations of administrative emergency data. Large-scale district-month records enable surveillance that would be difficult to reproduce through primary data collection, but the absence of linked road, police, hospital, and mortality information limits explanatory analysis. Puvanachandra et al. (2024) similarly emphasise the need for robust linked road-safety data systems across the Eastern Mediterranean Region. Punjab could substantially improve road-safety intelligence by linking Rescue 1122, traffic police, highway patrol, hospital trauma, Safe Cities,

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vehicle registration, road engineering, and mortality records.

7. Policy Implications

7.1 Adopt District Road-Safety Profiles

Punjab should move beyond a single province-wide crash ranking and develop annual district road-safety profiles containing at least RTCs per 100,000 population, serious injuries per 100,000, recorded deaths per 100,000, deaths per 100 RTCs, motorcycle-related indicators, and emergency-response measures. This would distinguish high-volume, high-incidence, high-mortality, and high-severity districts and allow interventions to be matched to local risk.

7.2 Establish a Risk-Based Hotspot Programme

Road-safety resources should be targeted using both absolute burden and adjusted risk. High-volume metropolitan districts may require intersection treatment, traffic management, automated enforcement, and motorcycle measures, while high-severity districts require investigation of speed environment, road geometry, trauma access, and vulnerable-road-user exposure. Geographic targeting is consistent with the spatial heterogeneity identified in both this study and Mahmood et al. (2022).

7.3 Strengthen Speed Management

Speed should be treated as a system-wide severity factor rather than only a recorded violation. Punjab should implement context appropriate speeds, design roads so they can self-regulate, install speed cameras, enforce the speed limits on the 'corridor', install speed bumps in pedestrian zones and conduct systematic surveys of speed. Mortality or severe-outcome ratios should be the basis for giving priority to districts for speed and road-engineering audits.

7.4 Prioritise Motorcycle and Vulnerable-Road-User Safety

As Pakistan has a highly motorcycle-dependent transportation system, and the magnitude of such incidents, reported by Mansoor et al. (2023), are extremely high, motorcycle safety should be a separate pillar of provincial policy. These measures include certified helmet use, passenger helmet enforcement, safer design of junctions, separation (when possible), management of speed, licensing system quality, and targeted protection for youth and pedestrians.

7.5 Integrate Road Crash and Trauma Data

Punjab should develop a linked Road Crash and Trauma Information System connecting prehospital, police, hospital, vehicle, road, enforcement, and mortality datasets through privacy-preserving identifiers and common crash definitions. More detailed fields should replace broad causal categories and capture location, road type, weather, vehicle type, road-user type, protective-device use, suspected speed, emergency response, hospital outcome, and 30-day mortality.

7.6 Use Time-Sensitive Deployment

The significant monthly variation justifies flexible deployment of enforcement and emergency resources. High-burden months—particularly the October–November period in the 2025 data—should trigger enhanced corridor enforcement, ambulance readiness, road-safety communication, and targeted operational planning. Multi-year analysis should be used before defining a permanent seasonal calendar.

7.7 Measure Outcomes, Not Only Activities

Provincial road-safety performance should increasingly be judged by outcomes such as population-adjusted deaths and serious injuries rather than only the number of challans, campaigns, or enforcement operations. The long-term goal should be to add exposure-sensitive measures such as fatalities and serious injuries per vehicle-kilometre travelled when reliable traffic-volume data become available.

JOURNAL FOR SOCIAL SCIENCE STUDIES
An International Peer-Reviewed Open Access Journal

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

8. Limitations

The findings should be interpreted within several limitations. First, the dataset captures administratively recorded emergency RTCs and may omit crashes not attended or reported to the emergency system. Second, recorded deaths may represent deaths identified at the scene or during the emergency episode rather than complete 30-day road traffic mortality. Third, 'serious injury' is operationalised as being shifted for further treatment and is not a validated clinical severity measure. Fourth, the broad cause categories, particularly 'carelessness' and 'other,' cannot establish causal mechanisms. Fifth, population denominators are from the 2023 census whereas RTC outcomes are from 2025, and registered vehicle stock is a proximate rather than contemporaneous measure of travel exposure. Sixth, registration district does not necessarily equal driving location. Seventh, newly created district boundaries are not represented consistently across all administrative sources. Eighth, the dataset lacks vehicle-kilometres travelled, road type and length, traffic volume, exact crash coordinates, weather, enforcement intensity, vehicle and road-user characteristics, helmet and seat-belt use, emergency response time, and hospital outcomes. Ninth, the ecological design precludes individual-level inference. Finally, the one-year observation window allows analysis of intra-annual variation but cannot establish recurring seasonal patterns or long-term trends.

9. Conclusion

The results of this study illustrate that the assessment of road safety in Punjab is not possible with the help of only crash data. Administrative data from 2025 show significant between geographic area and within geographic area variation in incidence, serious injury and mortality recorded of RTC. The incidence of RTC was highest in Lahore and the mortality highest in Sheikhupura while the severe-outcome ratio was highest in Taunsa Sharif when considering population density. Several month to month differences were found for each crash or casualty outcome but no simple monotonic trend was found for each year.

The statistical results confirm exposure/severity distinction. Absolute RTC volume was well explained by population and annual frequency of RTC was still related to deaths when corrected for population. However, the moderate correlation between the population-adjusted crash incidence and mortality rates indicate that crash rates don't always predict fatality risk. Additional mechanisms are likely, such as road environment, speed, and vulnerability of road users, road user mix, and post-crash care, but these require more detailed data.

The central policy recommendation, therefore, is a safe system strategy is needed for different types of safety in Punjab. High-level interventions do not automatically apply to districts that have high volume, high incidence, high mortality rates or are high severity. There is a need to develop more precise measures for reducing deaths and serious injuries that are based on district risk profiles, speed management, motorcycle and pedestrian safety, time-sensitive deployment of resources, trauma-system strengthening and integrated crash-data systems. Future studies should expand the panel to include additional years with the inclusion of road, traffic, enforcement, weather, vehicle, and trauma variables to be able to test the processes that explain the differences across the districts.

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ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

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