



Analyzing Traffic Patterns and Accident Hotspots in Isfahan: A Descriptive Study of Urban Traffic Dynamics

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Abstract

Objectives: This study aimed to identify high-risk municipal districts for urban traffic accidents in Isfahan, Iran.

Methods: A descriptive cross-sectional design was employed in 2023, analyzing 7,613 prehospital emergency missions from the latter half of 2022. Data were collected using a validated checklist capturing demographic and mission-specific variables.

Results: The majority of accident victims were male, with an average age of 33.09 ± 17.31 years. Although Districts 10 and 8 had the highest frequency of accidents due to their size and population, their accident-to-population ratios were relatively low—particularly in District 8, which also reported older victim ages. In contrast, Districts 1, 3, and 9 exhibited disproportionately high accident-to-area and accident-to-population ratios, with District 3 ranking highest. District-level disparities reflected a complex interplay of infrastructure density, pedestrian activity, and localized mobility patterns.

Conclusion: Urban traffic accident distribution in Isfahan is influenced not only by population size but also by the spatial positioning of commercial, recreational, historical, and healthcare hubs. Strategic relocation of high-traffic facilities may mitigate risk and support more equitable urban safety planning.

Keywords: Urban Traffic; Road Accidents; Prehospital Emergency; Isfahan; Risk Mapping.

Introduction

Accidents stem from human, technical, and environmental factors and remain major contributors to global mortality and morbidity ^[1]. Road traffic injuries, in particular, pose a persistent public health threat. As of 2023, the WHO reports approximately 1.19 million annual deaths and 20–50 million non-fatal injuries—many resulting in long-term disabilities ^[2]. These figures underscore the urgent need for data-driven urban safety strategies to reduce preventable harm. Increasing vehicle usage, changing lifestyles, and riskier behaviors have significantly raised accident rates ^[3]. Urban street design—including signage placement, traffic flow, and police enforcement—strongly influences both the frequency and severity of collisions ^[4, 5].

In 2020, non-communicable conditions—including road traffic injuries—caused 49.7 million deaths globally ^[6]. Traffic-related injuries now rank as the eighth leading cause of death, disproportionately affecting children and young adults ^[7]. Vulnerable road users (pedestrians, cyclists, and motorcyclists) represent over half of global traffic fatalities. These trends underscore the need to assess accidents by human mobility and exposure, not just vehicular volume, in densely populated areas ^[2, 3].

Road traffic deaths now surpass those from the global HIV/AIDS epidemic ^[8]. Although low- and middle-income countries host only 60% of vehicles, they account for over 90% of traffic fatalities, highlighting challenges in infrastructure, enforcement, and emergency care. This disparity reinforces the need for localized research, such as the present study in Isfahan ^[2–5].

Beyond health impacts, road traffic accidents impose substantial economic costs. Countries may lose up to 3% of GDP annually due to crash-related deaths, medical expenses, workforce disruptions, and disability. Preventive strategies such as urban traffic mapping, as applied in this study, are vital to reducing these burdens [2].

Efforts to curb road traffic accidents span driver education, public campaigns, road engineering, stricter penalties, speed monitoring, and police inspections. Policy measures, such as seatbelt laws, drunk-driving regulations, and infrastructure upgrades, have also been pivotal to injury prevention [9].

Given the multifactorial nature of traffic accidents, examining the roles of the driver, vehicle, environment, and post-event consequences is essential [10]. Epidemiological factors range from vehicle defects and reckless driving to poor road quality, adverse weather, and insufficient lighting [11, 12]. Although numerous studies address accident determinants, quantitative analyses of urban traffic patterns remain limited.

Recent studies emphasize spatial-temporal analysis to identify high-risk zones and guide targeted interventions. Using GIS and integrated emergency dispatch data yields strategic insights for urban planning and public health policy [13].

This study is among the first to use prehospital emergency dispatch data for spatial analysis of traffic accidents across Isfahan's 15 municipal districts. By integrating geographic mapping, referral pathways, and sociodemographic factors—such as victim age and infrastructure—it offers deeper insights into urban accident dynamics than conventional reports. Recommending the relocation of high-footfall public facilities to reduce congestion introduces a rarely highlighted but actionable strategy in safety planning. Accordingly, this study seeks to identify high-risk urban traffic zones in Isfahan and determine key factors influencing accident occurrence and severity.

Methods

This descriptive cross-sectional study was conducted across Isfahan's 15 municipal districts in 2023. It examined urban traffic accidents requiring prehospital emergency response, emphasizing spatial distribution, sociodemographic patterns, and mission characteristics. A census-based sampling approach captured all prehospital emergency missions for traffic accidents occurring on public roads during the second half of 2022. Only ambulance-dispatched incidents were included; domestic, industrial, fall-related, and non-ambulance cases were excluded. A total of 7,613 eligible missions were analyzed.

Data were retrospectively retrieved from the Prehospital Emergency Information System (PEIS)

using a structured checklist co-developed with the Trauma Data Registration Center at Al-Zahra University Hospital. The checklist captured variables across five domains: demographics, incident details, clinical indicators, emergency response metrics, and behavioral history. Content validity was confirmed through expert review and pilot testing within the registry framework. Trained data officers followed a standardized protocol to extract and record data in Excel. Automated validations ensured completeness, consistency, and the removal of duplicates. A city map of Isfahan's district boundaries supported the geographic analysis [Figure 2].

Descriptive statistics (mean, standard deviation) summarized key variables, while inferential tests including chi-square, t-test, ANOVA, and Pearson correlation examined relationships and trends. Geospatial analysis using GIS software identified accident hotspots and mission density variations across districts. Ethical approval was obtained from the Research Ethics Committee of Isfahan University of Medical Sciences (IR.MUI.MED.REC.1399.032). Data access and analysis involved anonymized emergency records, ensuring strict confidentiality under national protection protocols. The study reused previously approved anonymized data without direct patient contact.

Results

Isfahan is the fourteenth most populous metropolitan city in the Middle East and the third most populous city in the country, following Tehran and Mashhad [Figure 1]. The map displays the national boundaries of Iran, with Isfahan Province highlighted in orange to indicate its central position. An inset map provides a magnified view of Isfahan City, shaded in grey, offering spatial context for the study area.



Figure 1. Geographic location of Isfahan City within the Islamic Republic of Iran.

According to the 2016 census, Isfahan had a population of 2,243,249, with 1,975,176 individuals residing across its 15 municipal districts. The provincial population growth rate was reported as 0.97% [12]. In this study, a

total of 7,613 urban emergency missions were analyzed, with 77.2% involving male accident victims. The mean age of these victims was 33.09 ± 17.31 years. The accident-to-city-area ratio was calculated at 0.28, while the accident-to-population ratio stood at 3.85 per 1,000 individuals. Detailed demographic characteristics are presented in Table 1.

Regional rankings were based on accident-to-population ratios. Table 1 shows that Districts 12, 10, and 8 were the largest by area, while Districts 8, 10, and 7 had the highest populations. The highest numbers of accidents occurred in Districts 10, 3, and 8. Districts 3, 9, and 1 had the highest accident-to-population ratios

[Figure 2], and Districts 3, 1, and 14 had the highest accident-to-area ratios. The average ages of accident victims were notably higher in Districts 1 (35.67 ± 18.64), 3 (36.64 ± 17.88), and 8 (34.21 ± 17.5) than in other districts.

Conversely, the smallest districts by area were Districts 1, 14, and 2, while the lowest populations were recorded in Districts 11, 2, and 9. Districts 2, 11, and 13 had the fewest accidents. Accident-to-population and accident-to-area ratios were lowest in Districts 13, 2, and 8 (Figure 2). The average ages of accident victims were lowest in Districts 14 (29.99 ± 18.05), 2 (32.09 ± 16.19), and 7 (32.22 ± 16.21). District 3 reported the highest number of female accident cases, totaling 166 (6.9%).

Table 1. Demographic characteristics of the population.

Urban Areas	Area (Hectares)	Population (Person)	Total Number of Accident	The ratio of accidents to population	Rank of Area*	The ratio of accidents to Area	Gender		Age (mean $\pm$ SD)
							Male	Female	
Area 1	810	79943	486	6.08	3	0.6	384 (6.6)	100(5.8)	35.67 $\pm$ 18.64
Area 2	1031	72828	191	2.62	14	0.19	140 (2.4)	51 (3)	32.09 $\pm$ 16.19
Area 3	1152	110690	760	6.87	1	0.66	590(10.1)	166(9.6)	36.64 $\pm$ 17.88
Area 4	1135	139588	441	3.16	11	0.39	328 (5.6)	111(6.4)	33.98 $\pm$ 17.17
Area 5	1702	139384	626	4.49	6	0.37	492 (8.4)	132(7.7)	32.36 $\pm$ 16.63
Area 6	1255	121547	549	4.52	5	0.44	431 (7.4)	115(6.7)	33.76 $\pm$ 17.39
Area 7	1357	186218	634	3.4	9	0.47	491(8.4)	139(8.1)	32.22 $\pm$ 16.21
Area 8	2039	241652	651	2.69	13	0.32	507 (8.7)	141(8.2)	34.21 $\pm$ 17.59
Area 9	1054	76704	473	6.17	2	0.45	373 (6.4)	98 (5.7)	32.69 $\pm$ 17.74
Area 10	2164	204108	798	3.91	8	0.37	619(10.6)	178(10.3)	32.6 $\pm$ 17.03
Area 11	1140	58550	233	3.98	7	0.2	165 (2.8)	64(3.7)	33.63 $\pm$ 18.63
Area 12	8223	121278	644	5.31	4	0.08	496 (8.5)	145(8.4)	32.47 $\pm$ 16.51
Area 13	2010	145028	277	1.91	15	0.14	204 (3.5)	68 (3.9)	32.41 $\pm$ 17.26
Area 14	940	158553	466	2.94	12	0.5	345 (5.9)	116 (6.7)	29.99 $\pm$ 18.05
Area 15	1664	119105	384	3.22	10	0.23	281 (4.8)	98 (6.7)	32.55 $\pm$ 16.24
Total	27676	1975176	7613	3.85	-	0.28	5846(77.2)	1722(22.8)	33.09 $\pm$ 17.31

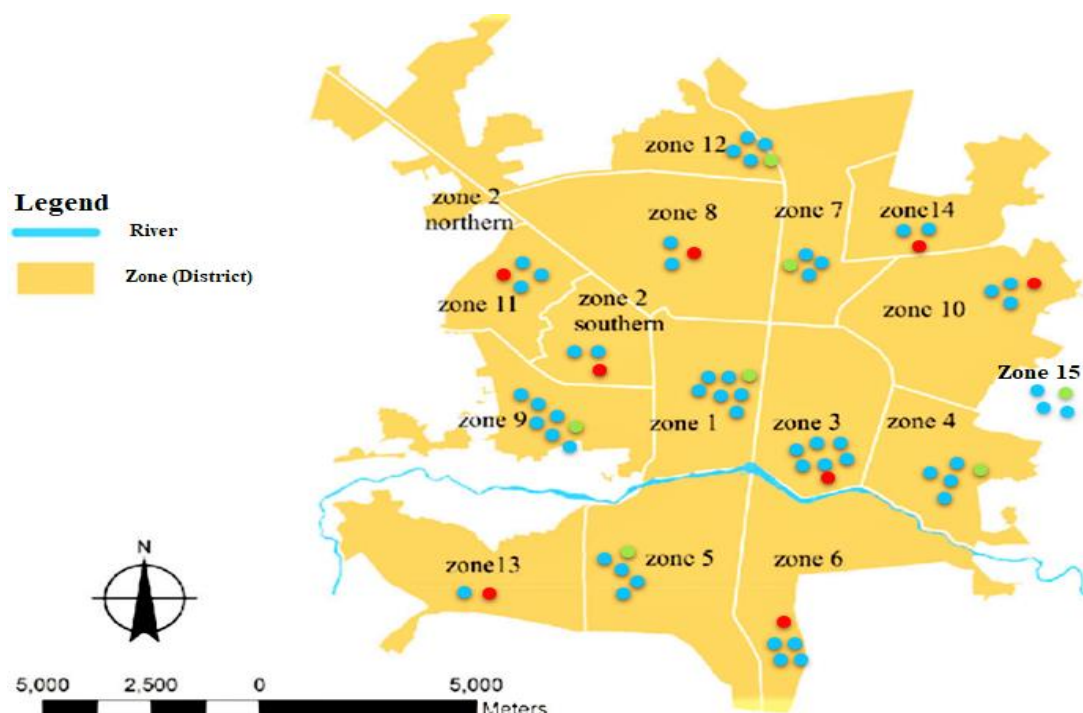


Figure 2. Spatial distribution of traffic accident frequency per 1,000 individuals across urban zones of Isfahan City.

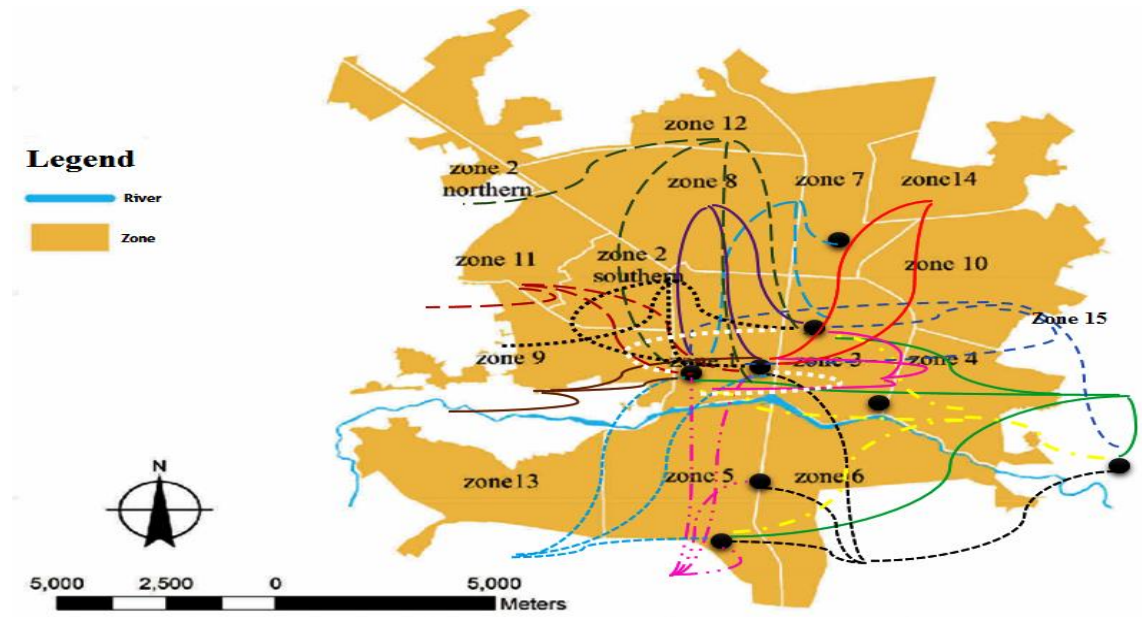


Figure 3. Inter-zone transfer routes for injured individuals to designated medical centers in Isfahan City.

The map presents the 15 municipal zones delineated in yellow, with accident frequency per 1,000 individuals depicted using colored circular markers: red (high), green (moderate), and blue (low). A river network (blue), scale bar, and compass provide geographic orientation. The legend specifies blue circles as one per 1,000 individuals, red as decimals above 0.5, and green as below 0.5. This visualization highlights district-level disparities in accident burden, supporting targeted urban safety interventions.

Figure 3 illustrates 15 municipal zones outlined in yellow, overlaid with solid and dashed lines representing ambulance transfer routes. Black dots mark trauma-receiving medical centers, and blue lines trace river pathways for geographic orientation. A scale bar and compass aid spatial interpretation. Numbers on the map indicate the percentages of injured individuals transferred to medical centers. The figure emphasizes emergency transport logistics and zone-specific accessibility to trauma care.

Of the 7,613 missions analyzed, 6,883 (90.4%) involved the transfer of injured individuals to medical centers, while 730 (9.6%) did not. As shown in Figure 2, most transfers were directed to seven facilities: Gharazi (District 7), Amin (District 3), Al-Zahra and Shariati (District 5), Isa Ibn Maryam and Kashani (District 1), and Farabi (District 4). Districts 12, 2, and 9 transferred patients to centers outside Isfahan due to geographic constraints. The greatest dispersion in transfers and dispatches was recorded in Districts 6 and 4, respectively.

Negative binomial regression analysis revealed a complex interaction between sociodemographic, infrastructural, and behavioral factors influencing urban traffic accident rates [Table 2]. Specifically, lower levels

of educational attainment, poor road conditions, delayed emergency medical response times, and absence of protective gear such as helmets or seatbelts were all significantly associated with increased accident frequency and severity.

Table 2. Predictors of Urban Traffic Accident Rates—Negative Binomial Regression Analysis.

Predictor	IRR	95% CI	P-value	Interpretation
Low education level	1.38	1.22 – 1.56	< 0.001	Higher accident risk among individuals with low education
Poor road conditions	1.61	1.37 – 1.90	< 0.001	Strong association with increased accident frequency
EMS response time (minutes)	1.29	1.08 – 1.54	0.003	Delayed response linked to greater accident severity
Helmet or seatbelt usage (no)	1.22	1.05 – 1.42	0.012	Lack of protective gear significantly associated with greater accident severity
Night time accidents	1.12	0.98 – 1.29	0.078	Borderline significance; higher uncertainty at night

IRR: Incidence Rate Ratio; CI: Confidence Interval

Discussion

The predominance of male and younger victims likely reflects higher exposure among working-age men due to commuting and job-related mobility. Accident clustering in Districts 10 and 8 may result from their large size, dense populations, and high-traffic corridors. Despite a modest global decline in road fatalities (1.19 million annually), urban areas continue to face disproportionate risks—especially for vulnerable users like pedestrians, cyclists, and motorcyclists^[14]. These patterns suggest that injury

rates are shaped more by urban design, infrastructure quality, and mobility dynamics than by population density alone.

District-level variations further highlight differentiated exposure risks: District 8, with fewer accidents but older victims, may indicate age-linked vulnerability; District 2 showed both low accident rates and younger victims, suggesting a possible impact of a safer driving culture, while District 1 revealed high incident density and older age distribution, likely due to dense road networks and increased elderly foot traffic.

Districts 3, 9, and 14, despite their small size, exhibited disproportionately high accident ratios, likely due to dense traffic, poor intersection design, and behavioral patterns. GIS data confirmed clusters near commercial zones, irregular junctions, and pedestrian-heavy areas ^[15]. As Zhang et al. ^[16] noted, aging infrastructure and historical layouts compound these risks, emphasizing the need for spatially targeted interventions.

These trends echo prior research. Arnau ^[17, 18] found that urban areas, especially those with smaller populations, show higher accident rates per capita. Temizel ^[19] reported a male-dominant injury profile with a low average age, highlighting gaps in infrastructure and trauma care. Kalantari ^[20] and Zainafree ^[21] linked accidents to roadway features, demographics, and protective gear use, while Olsen ^[22] challenged the notion that highway expansion guarantees improved safety, reinforcing the observed risks in District 14.

Alharbi et al. ^[23] noted a post-pandemic spike in trauma cases in Saudi Arabia, driven by young, inexperienced drivers and high-impact crashes, paralleling District 14's vulnerability and highlighting the need for youth-focused education and enforcement. These findings challenge the notion that infrastructure alone can curb accidents. A sustainable reduction requires behavioral reforms, smarter urban planning, and improved emergency response.

Although research on urban prehospital missions remains sparse ^[24, 25], available data suggest that small-population areas often face higher accident rates. Yet, Districts 8 and 2—with the largest and smallest populations, respectively—both show low accident ratios, underscoring the influence of well-designed road networks over population size.

Isfahani et al. ^[26] identified resource gaps and delayed EMS response in high-demand urban zones—mirroring trauma referral patterns from peripheral districts to central medical hubs and emphasizing the need for spatially optimized emergency care.

District 3 faces compounded accident risks due to aging infrastructure, dense commercial activity, and confusing road layouts. Despite decentralization efforts, centralized healthcare hubs drive heavy traffic, and unfamiliar drivers elevate collision probability.

District 9's dual identity as a recreational zone and a transport corridor results in high exposure and accident rates. District 1 shows similar trends, with older victims

likely impacted by outdated roads and elderly driving behaviors.

District 10, though lacking major attractions, sees elevated accident ratios, attributed to extensive inter-district commuting and exposure. Meanwhile, District 14's small size masks high accident rates tied to its young population's risky driving and traffic congestion.

This study advances a nuanced understanding of urban traffic injury patterns by integrating stratified geographic, demographic, and emergency data, offering insights aligned with contemporary safety frameworks and highlighting the utility of spatially informed public health analysis.

However, several limitations warrant consideration. Chief among them is the absence of a patient follow-up system, which constrained the evaluation of post-hospital outcomes and injury progression within 30 days of incidents. Likewise, the lack of post-crash tracking data, including trauma scores, ICU admissions, and recovery trajectories, limited the assessment of emergency intervention efficacy and clinical outcomes. Given that delayed EMS responses are linked to increased mortality, especially in high-speed or underserved zones ^[27-29], robust follow-up mechanisms remain critical for improving triage and trauma systems.

While the study primarily examined geographic correlations, the results emphasize the impact of behavioral and infrastructural determinants, such as road surface quality, enforcement intensity, and driver behavior. Existing literature attributes more than 70% of traffic accidents to human error, including distraction, speeding, and impaired driving, exacerbated by deficient infrastructure and inconsistent law enforcement ^[30-33].

Although the findings are informative within Isfahan's urban context, they may not be fully generalizable to cities with different infrastructure, transport behavior, or emergency service models. Sociocultural factors, such as urban planning norms, public transport access, and regulatory practices, likely mediate both accident occurrence and EMS responsiveness, necessitating caution when extrapolating the results.

Methodologically, the study employed preliminary regression analyses to explore associations between demographic and accident-related variables. Future research should incorporate advanced modeling techniques, such as multivariate and hierarchical approaches, to disentangle complex causal pathways and adjust for confounding influences, thereby deepening analytical rigor and informing more targeted policy interventions.

Conclusion

This study elucidates the multifactorial nature of urban traffic accidents across districts in Isfahan, highlighting pronounced spatial and demographic disparities in incident patterns. The findings demonstrate that accident rates are

shaped not solely by population density but by a complex interplay of road infrastructure quality, pedestrian activity, and the presence of high-mobility urban centers, such as commercial, recreational, historical, and healthcare hubs, that intensify inter-district movement. The strategic redistribution of relocatable facilities may alleviate traffic concentration and reduce injury risk in overloaded districts. These insights reinforce the imperative for integrative urban planning approaches that account for mobility demand, infrastructure resilience, and spatial exposure to road traffic injury risk.

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Competing interests

The authors declare that they have no competing interests.

Abbreviations

EMS: Emergency Medical Services; GIS: Geographic Information System; PEIS: Prehospital Emergency Information System; WHO: World Health Organization.

Authors' contributions

MNI and FH contributed to the conception and design of the study. DSH, HS, and FH collected the data. DSH and MNI performed the data analysis. MNI, FH, HS, and DSH contributed to data interpretation, drafting, and critical revision of the paper. All authors read and approved the final version of the manuscript.

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Availability of data and materials

The data supporting this study are available from the corresponding author (MNI) upon reasonable request, subject to institutional ethical approvals and confidentiality restrictions.

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013). Ethical approval was obtained from the Research Ethics Committee of Isfahan University of Medical Sciences (Approval No. IR.MUI.MED.REC.1399.032). The researchers had access only to anonymized data that did not permit identification of individuals; therefore, the ethics committee approved the utilization of such data without requiring individual patient consent.

Consent for publication

By submitting this manuscript, the authors declare their consent for the final accepted version to be considered for publication.

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