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Understanding road accident injury dynamics in Iran: a growth mixture modelling perspective

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ABSTRACT

Objectives Road traffic injuries represent a significant public health concern globally. In Iran, road accidents have become a leading cause of death and disability, necessitating urgent attention to injury prevention strategies. This study aims to analyse the trends in injuries resulting from road accidents over a decade. Understanding these trends is crucial for informing targeted interventions and resource allocation, ultimately contributing to the reduction of road traffic injuries.

Design Ecological study.

Setting The data were obtained from the official database of the Iranian Legal Medicine Organization, which includes the injury rates of all provinces due to road accidents, from 2012 to 2021.

Participants All records registered with injuries due to road traffic accidents across Iranian provinces.

Outcome measures The incidence and average annual percentage of injury rates across provinces were illustrated using a map. A piecewise linear mixed-effects model was employed to estimate trends in injury rates, by gender. To identify distinct clusters of provinces exhibiting similar trends in injury rates, a growth mixture model was used over the 10 years.

Results Among provinces, Qom (95% CI 18.99 to 37.21) and Sistan and Baluchestan (95% CI 5.41 to 7.66) had the highest and lowest injury rates over the decade, respectively. The annual rate of injuries in Iran increased by 0.52% from 2012 to 2018 and then gradually decreased by 1.16% after 2018. Four distinct classes were identified for the trend of injury rates over the decade: one cluster exhibited a significant decline, two clusters showed sharp increases and the last one had a steady trend.

Conclusions These results contribute valuable insights into the dynamics of road accident-related injuries in Iran, offering a nuanced understanding of both overarching national trends and the unique patterns observed across provinces. Such knowledge can serve as a foundation for targeted interventions and policy formulations aimed at mitigating the impact of road accidents on public health and safety.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ National scope: This study analysed data from all 31 provinces in Iran, providing a comprehensive overview of injury trends related to road accidents. The findings are significant for public health as they reflect the widespread impact of road injuries across diverse regions.
- ⇒ Longitudinal analysis and gender-specific approach: A longitudinal analysis spanning a 10-year time frame allowed for the identification of dynamic patterns and changes in injury rates. The differentiation of trends between men and women highlights potential disparities in vulnerability and outcomes, which are critical for developing gender-sensitive public health interventions.
- ⇒ Advanced statistical methods and spatial visualisation: The study used advanced statistical techniques, including piecewise linear mixed-effects models and growth mixture modelling, to uncover nuanced insights into variations in injury trends. Spatial visualisation through mapping effectively illustrated geographical differences in injury rates, enabling targeted health interventions based on regional needs.
- ⇒ Focus on injury rates: While the study provided valuable insights into injury rates, it did not analyse specific causes or contributing factors to road accidents. This limitation constrains the understanding of the underlying reasons for observed trends.
- ⇒ Omission of socioeconomic and policy factors: Factors such as socioeconomic variables, infrastructure development and policy changes were not explicitly considered, which may have significant implications for interpreting the results and developing comprehensive public health strategies.

INTRODUCTION

Road accidents constitute a substantial and persistent global challenge, with an estimated 1.2 million fatalities and 50 million injuries annually. In Iran, these incidents pose a significant threat, with an average of 22 185 traffic-related deaths recorded over the past decade.[1 2] Notably, 70% of these accidents occur on intercity roads, primarily affecting young adults and resulting in a 10% mortality rate. These incidents, often sudden and unforeseeable, result in grievous harm, fatalities and extensive property damage.[3] The catastrophic consequences encompass not only the immediate victims and their

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families but also extend to the broader society. Physically, they leave survivors with life-altering injuries, debilitating trauma and financial burdens.[4] Socially, they strain healthcare systems, incite legal complexities and foster a culture of fear and uncertainty.[5] Economically, the financial burden associated with road accidents is staggering, depleting national resources that might otherwise be allocated to more productive avenues.[6]

The toll is staggering, as these alarming statistics underscore the critical need for effective road safety measures in Iran. Road accidents constitute a substantial and persistent global challenge, with an estimated 1.2 million fatalities and 50 million injuries annually. In Iran, these incidents pose a significant threat, with an average of 22 185 traffic-related deaths recorded over the past decade. While the consequences of road accidents are a global concern, Iran faces unique challenges due to the specific demographics of victims and accident locations. This study aims to investigate the trends of injuries resulting from road accidents in Iran over the course of a decade. Understanding the factors influencing road accident occurrence in Iran can contribute to developing targeted interventions and evidence-based policies to improve road safety in the country.

Effective road safety management necessitates a comprehensive understanding of incident patterns and contributing factors.[7–9] Incident analysis is instrumental in identifying key trends, evaluating risk factors and developing targeted interventions to reduce the occurrence and severity of accidents.[10 11] Statistical analysis, in particular, plays a pivotal role in uncovering hidden patterns, providing insights into causative factors and aiding policy formulation.[12 13] Statistical methods permit the exploration of multivariate relationships, the detection of anomalies and the development of predictive models that can inform preventive measures.[14] Rigorous analysis is essential to transcend anecdotal assessments and anecdotal wisdom, enabling evidence-based decisions for road safety initiatives.[15] The application of statistical techniques can aid in the development of a deeper understanding of road accidents‘dynamics and evolution over time.[16]

In the domain of road accident analysis, several statistical methodologies have traditionally been employed. These include established techniques such as linear regression,[17–19] clustering methods[20–22] and time series analysis.[23–26] While these conventional approaches possess inherent strengths, they also exhibit limitations when confronted with the complex and heterogeneous nature of road accident data. In contrast, growth mixture models (GMMs) offer a powerful solution to these challenges by recognising latent subpopulations within the data and modelling their unique growth patterns over time.[27–29] Moreover, the application of GMMs in injury rates due to road accident analysis is novel, making this investigation innovative.

The primary objective of this study is to use GMMs to identify latent subpopulations of injuries due to road accident incidents and delineate distinct injury trajectories within these subpopulations, ultimately gaining deeper insights into the underlying dynamics of road accidents in Iran. This research contributes to the existing literature by providing a more nuanced understanding of the evolving road accident landscape in Iran, offering evidence-based insights for policy formulation, resource allocation and targeted interventions aimed at enhancing road safety. Ultimately, this study serves as a crucial step toward mitigating the devastating consequences of road accidents and enhancing the overall well-being of the Iranian population.

MATERIALS AND METHODS

Data sources

The data for the present study were obtained from the official database of Forensic Medicine in Iran, which is a reliable and comprehensive source of information on the causes and consequences of injuries in the country. The primary data consisted of injury rates resulting from road accidents, extracted year by year from 2012 to 2021 and subsequently imported into Excel for further analysis. The data were organised by the 31 provinces of Iran, each of which has distinct geographical, cultural and socioeconomic characteristics. Injuries were also categorised by gender, as this is an important factor influencing patterns and trends in injury rates. To calculate the injury rates for each province, the number of injuries was divided by the number of road accidents in that province for each year. Additionally, to cluster the trends in injury rates using the GMM, the weighted estimates of injury rates were derived by dividing the injury rate of each province by the total injury rate for the entire country.

Data analysis

Descriptive statistics including mean and SD of the accident injury rates due to the road accidents were reported by gender and province between 2012 and 2021. Moreover, the boxplots of the accident injury rates are depicted in online supplemental figure S1. The linear mixed random effects and GMM were fitted to the data to examine the heterogeneity and variability of the injury trends across the provinces and genders. Initially, the trend of injury rates for all provinces indicated that there are different intercepts and growth slopes in the injury rate among the provinces under study especially based on gender. At the second step, the mean of observed data for all provinces in each year based on gender was plotted and presented that the injury rate gradually increased from 2012 to 2018 and then slightly decreased until 2021 (online supplemental figure S1). Consequently, to evaluate the trend of the mean injury rate in these provinces from 2012 to 2021, a piecewise linear mixed effects model was assumed, with a knot at 2018. This model incorporates an intercept and two slopes: one for the changes in the mean rate before 2018 and another for the changes after 2018. The model can be specified as Eq. 1.

$$\mathrm{E}\left(\mathrm{Y_{ij}}|b_i\right) = \beta_1 + \beta_2\mathrm{time_{ij}} + \beta_3\left(\mathrm{time_{ij}}\right)_+ \\ + \mathrm{b_{1i}} + b_{2i}time_{ij} + b_{2i}\left(time_{ij}\right)_+ \quad (1)$$

Where $\mathrm{time_{ij}}$ denotes the year of j_{th} measurement on i_{th} province before or after 2018, $\left(\mathrm{time_{ij}}\right)_+ = \mathrm{time_{ij}}$ if $\mathrm{time_{ij}} > 2018$ and $\left(\mathrm{time_{ij}}\right)_+ = 0$ if $\mathrm{time_{ij}} \leq 2018$. $\left(\beta_1 + \mathrm{b_{1i}}\right)$ is the intercept for i_{th} province, $\left(\beta_2 + \mathrm{b_{2i}}\right)$ and $\left[\left(\beta_2 + \beta_3\right) + \left(b_{2i} + b_{3i}\right)\right]$ are ith province's slope before and after 2018.[30 31] Furthermore, the GMM is specified as Eq. 2.

$$y_{it}^k = \eta_{i0}^k + \eta_{i1}^k \lambda_t^k + \varepsilon_{it}^k \quad (2)$$

where y_{it}^k represents the injury rate for the i_{th} province at time t, η_{i0}^k and η_{i1}^k are latent variables, λ_t^k is the time score that can be specified as linear or nonlinear polynomial functions of time, or as free time scores, and ε_{it}^k is the residual term for the i_{th} province at time t. The latent variables are further defined as Eq. 3 and Eq. 4.

$$\eta_{i0}^k = \eta_{00}^k + \sum_j \beta_{01j}^k x_j + \varsigma_{i0}^k \quad (3)$$

$$\eta_{i1}^k = \eta_{10}^k + \sum_j \beta_{11j}^k x_j + \varsigma_{i1}^k \quad (4)$$

Where y_{it}^k is the injury rate for ith province at the time t; η_{i0}^k and η_{i1}^k are latent variables, λ_t^k is time score which can be specified as linear, nonlinear polynomial functions of time or free time scores; ε_{it}^k is residual term for ith country at time t; $\eta_{00}^k$and η_{10}^k are intercept coefficients representing the model estimated overall mean levels of initial and average rate of injury change over time; β_{01j}^k and $\beta_{11j}^k$are slope coefficients of covariates $\mathrm{x_j}$; ς_{i0}^k and ς_{i1}^k are error terms.[32 33] We used the robust estimation option to handle outliers.

Descriptive statistics were employed to summarise and present the key features of the data collected from a governmental organisation regarding injury rates across the provinces. Measures of central tendency, such as the mean and median, were calculated to provide insights into the average injury rates over the study period. Additionally, measures of variability, including the SD and IQR, were assessed to understand the dispersion of injury rates and how individual provinces deviated from the overall average. Frequency distributions were generated to illustrate the number of occurrences of different injury rate categories, offering a clear visual representation of the data. Graphical representations were also used to enhance understanding of the data distribution and identify potential outliers.

In the current study, the variables included in the GMM were carefully selected based on their relevance to the analysis of injuries due to road accident and their potential impact on injury rates. The GMM incorporates latent variables that represent the underlying trends in injury rates, with observed covariates such as demographic factors, geographical characteristics, social details and temporal aspects influencing these trends. The model development involved a systematic approach, including model specification, estimation and validation using Bayesian information criteria (BIC) to determine the optimal number of clusters. This ensures that the model accurately captures the heterogeneity among provinces and reflects distinct injury trends over time. Detailed descriptions of these variables, their roles in the model, and the rationale for their inclusion have been provided to enhance the clarity and validity of the GMM analysis.

What distinguishes GMMs is their capacity to embrace heterogeneous data without making prior assumptions regarding the number or attributes of subpopulations.[34] This adaptability is particularly advantageous when dealing with road accident data, which may exhibit varying trends, concealed patterns or temporal shifts.[35] GMMs possess the capability to unveil these latent subgroups, expose unobservable structures within the data, and capture nuanced dynamics that might elude other methodologies.[36] Moreover, GMMs are inherently well suited for the analysis of longitudinal data, aligning with the temporal nature accident records.[37] They enable an in-depth examination of how subpopulations evolve over time, yielding invaluable insights into trends, trajectories and shifts within data patterns.[38] By providing a comprehensive perspective, GMMs empower researchers to gain a deeper understanding of the underlying dynamics of injury rates due to road accidents, thus facilitating the development of well-informed strategies for accident prevention and mitigation. Then, the trends of the estimated averages of injury rates were shown for each cluster identified by the GMM, and the alterations in the average annual per cent in the injury rates were demonstrated within a map. The map was created using ArcMap V.10.8 and showed the spatial distribution and classification of the provinces based on the changes in the injury rates. The results of the statistical tests and the model fit indices were also presented and discussed to evaluate the significance and adequacy of the models. All analyses were performed at 0.05 significance levels using Stata (V.12.0), ArcMap V.10.8 and the Mplus (V.6.0), respectively.

The spatial factors in this study include the geographical distribution of the provinces selected for analysis, each representing different regions of the country. The focus was on provinces with varying population densities, economic activities and road infrastructure, which may influence the injury rates observed. Temporal factors encompass the specific time frame of the study, spanning from 2014 to 2020, allowing for an examination of trends and changes in injury rates over this period. This time frame was chosen to capture the dynamics of injury incidents regarding significant events or policy changes that may have occurred within the years studied. However, it is essential to acknowledge certain limitations in this research, particularly regarding unavailable factors that could provide a more nuanced understanding of the injury landscape. For instance, data on local weather conditions, socioeconomic variables and community-level interventions were not available, potentially affecting the

Table 1 The sorted 10-year injured rate based on road accident

	Total		
Id	Province	Mean (95% CI)	Median (IQR)
1	Qom	28.1 (18.99, 37.21)	27.95 (5.31)
2	Tehran	26.77 (20.35, 33.19)	26.78 (1.87)
3	Alborz	25.8 (17.87, 33.73)	25.63 (6.03)
4	Yazd	23.49 (14.88, 32.1)	22.82 (1.87)
5	Kohgiluyeh and Boyer-Ahmad	23.06 (10.5, 35.62)	22.34 (5.34)
6	Razavi Khorasan	22.59 (19.04, 26.14)	21.32 (4.94)
7	Isfahan	21.35 (16.94, 25.76)	21.06 (3.76)
8	Mazandaran	21.26 (17.3, 25.21)	20.39 (2.71)
9	Gilan	20.64 (16.72, 24.55)	19.94 (1.38)
10	Ardabil	20.34 (16.38, 24.31)	19.8 (2.2)
11	Ilam	19.63 (12.42, 26.83)	19.67 (2.4)
12	Kermanshah	19.61 (16.73, 22.49)	19.35 (2.1)
13	Golestan	19.51 (14.91, 24.11)	19.17 (1.7)
14	Khuzestan	19.32 (15.89, 22.75)	18.79 (1.95)
15	West Azerbaijan	19.13 (16.39, 21.87)	18.37 (2.29)
16	East Azerbaijan	18.41 (13.3, 23.53)	18.33 (5.12)
17	Lorestan	18.07 (15.04, 21.1)	17.71 (3.3)
18	Zanjan	17.99 (12.37, 23.62)	17.62 (0.9)
19	Kurdistan	16.75 (7.87, 25.63)	16.3 (2.38)
20	Qazvin	16.11 (10.52, 21.69)	16.03 (1.84)
21	Semnan	15.76 (11.54, 19.98)	15.93 (4.5)
22	Chaharmahal and Bakhtiari	15.69 (10.93, 20.46)	15.57 (3.8)
23	Hamadan	15.27 (12.86, 17.68)	15.28 (2.12)
24	North Khorasan	15.26 (8.2, 22.32)	15.07 (1.24)
25	Fars	15.24 (11.82, 18.65)	14.59 (2.93)
26	South Khorasan	14.38 (10.45, 18.31)	14.05 (4.52)
27	Bushehr	13.52 (8.51, 18.54)	13.69 (4.15)
28	Kerman	12.44 (9.79, 15.09)	12.64 (1.26)
29	Markazi	12.19 (10.03, 14.35)	12.16 (1.9)
30	Hormozgan	7.37 (5.62, 9.12)	7.43 (0.77)
31	Sistan and Baluchestan	6.54 (5.41, 7.66)	6.4 (0.58)

analysis of underlying causes and contextual factors influencing injury rates.

RESULTS

Injury rates by province and gender

The descriptive statistics of injury rates due to road accidents including mean (95% CI) and median (IQR) for all 31 Iranian provinces were calculated throughout the 10 years, broken down by gender and presented in table 1. Also, information by gender is provided in online supplemental table S1. Figure 1 A,B depicts the mapping of the 10-year injury rates across the study period. Among all provinces, Qom and Sistan and Baluchestan provinces recorded the greatest and lowest 10year incidence rates for injuries, with mean rates of 28.10 (95% CI 18.99 to 37.21) and 6.54 (95% CI 5.41 to 7.66) and median rates (IQR) of 27.95 (5.31) and 6.4 (0.58), respectively. The results in table 1 show that a higher rate of injuries was observed for males compared with females in all provinces; specifically, the highest and the lowest injury rates for males were recorded in Qom and Sistan and Baluchestan provinces, respectively, while for females, the highest and lowest rates were observed in Alborz and Sistan and Baluchestan provinces, respectively.

Trends in injury rates over time

As part of an exploratory analysis, the trend of injury incidence rates for each province during the decade was examined. Figure 2A and online supplemental figure S2 illustrate the results. A clear trend was not observed for all provinces during the decade; the injury rates in some provinces exhibited significant fluctuations, while others changed gradually or remained constant. The different intercepts and growth slopes in injury rates across the provinces underscored the need to use a linear mixed-effects model to estimate the mean trend of injury rates over the decade.

The mean observed trends in figure 2A indicated a linear increase from 2012 to 2018, followed by a slight linear reduction until 2021; however, a slight increase was noted after 2020. Thus, a piecewise linear mixed-effects model with a knot in 2018 was fitted to the data, comprising one intercept and two slopes (one for changes in the mean rate before 2018 and another after 2018) for both genders. The figure shows the observed and estimated mean of random effects obtained from the model, indicating concordance between the fitted and observed values and supporting the goodness of fit of the random-effects model used for analysis. The results from fitting this model, which estimates the trend of average injury rates over 10 years, are provided in table 2. The estimated slopes (regression coefficients related to time) for the total population, as well as the separate analyses of female and male rates, indicated that annual injury rates increased by approximately 0.52%, 0.20% and 0.32%, respectively, before 2018. After 2018, the rates decreased by approximately 1.16% (the sum of the two estimates of time and (time)+, ie, 0.52–1.68=–1.16), 0.48% and 0.67%. Additionally, sigma intercept, time and (time)+ which are the variances estimates for random effects of intercept and slopes (before 2018 and after 2018) are presented in table 2 and indicated that a notable fluctuations were existed in the trend (intercept and slopes) of injury rates across provinces especially before 2018 which were significant for total, male and female populations.

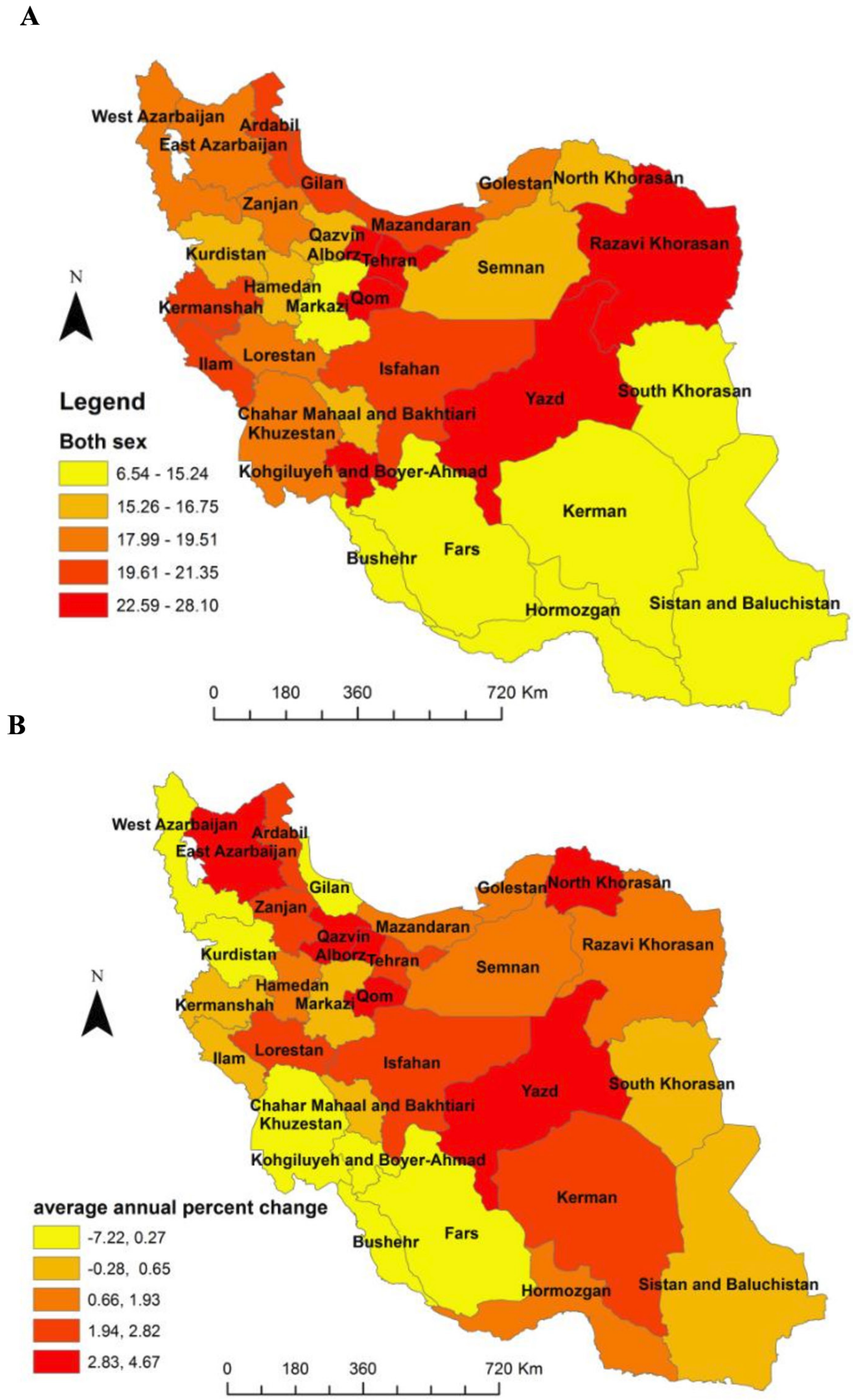

Figure 1 (A) The 10 years incident rate and (B) the estimated average annual per cent change in injury rates for all provinces within a map. Created by the author (EA).

Identification of distinct trends using GMM

According to the linear mixed-effects model, all subjects (provinces) are assumed to come from the same population (homogeneity), resulting in their trends varying randomly around the overall mean. However, as shown in online supplemental figure S2, the provinces were heterogeneous, suggesting that these trends should be considered as distinct classes. Therefore, GMM was used to identify clusters of provinces with similar trends over time. Various numbers of clusters (ranging from 2 to 6) were considered. The lowest BIC for four classes and the bootstrap likelihood ratio test for four-class model was not rejected, and conclusively the provinces were classified into four clusters based on the trends of injuries due to road accidents: a linear growth model with (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) time scores for all classes. Figure 2A depicts the estimated and observed trends of injury rates due to road accidents in Iran by gender during 2012–2021.

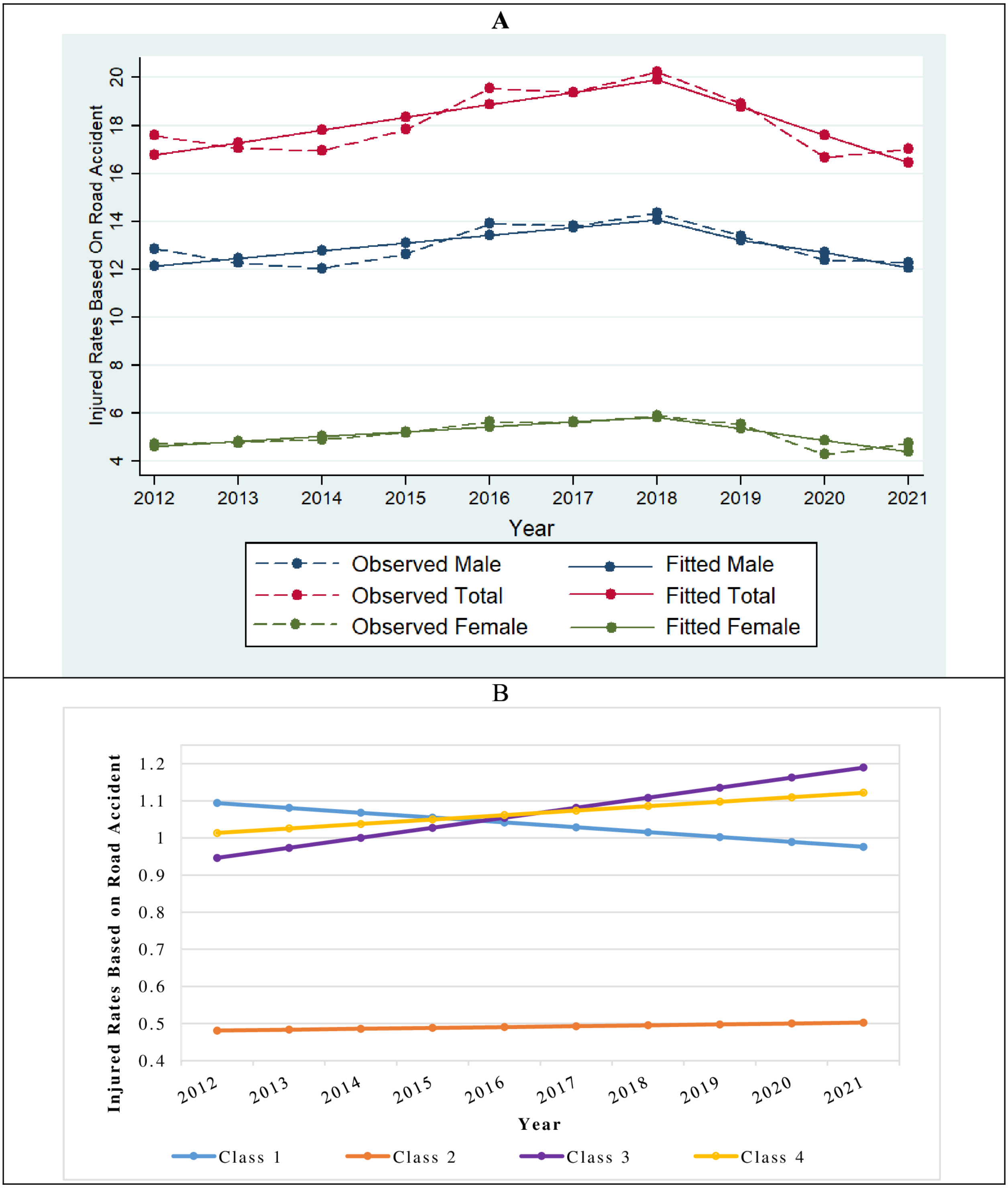

Figure 2 (A) Estimated and observed trends of injured rate based on road accident in Iran by gender during 2012–2021; (B) the estimated trends of injured rate based on road accident using GMM during 2012–2021. Created by the author (ET-G). GMMs, Growth Mixture Models.

Table 3 shows the parameter estimates obtained for the four-class GMM. Among the provinces, 14 provinces (45.2%) were classified in cluster 1 which includes Bushehr, Chaharmahal and Bakhtiari, Fars, Gilan, Golestan, Ilam, Kermanshah, Kurdistan, Kohgiluyeh and Boyer-Ahmad, Khuzestan, Markazi, Tehran, West Azerbaijan and Yazd; 3 provinces (9.7%) were classified in cluster 2 which including Hormozgan, Kerman and Sistan and Baluchestan; 8 provinces (25.8%) were classified in cluster 3 which including East Azerbaijan, Isfahan, North Khorasan, Qazvin, Qom, Razavi Khorasan, Semnan and Zanjan and 6 provinces (19.3%) were classified in cluster 4 which including Alborz, Ardabil, Hamadan, Lorestan, Mazandaran and South Khorasan.

Table 2 Estimate the trend of injured rate based on road accident in all provinces of Iran by gender using linear mixed effects model

Gender	Variable	Estimate	SE	P value
Female				
	Intercept	4.42	0.28	<0.001
	Time	0.20	0.03	<0.001
	$(\text{Time})_+$	−0.68	0.07	<0.001
	Sigma intercept	1.41	0.19	----*
	Sigma time	0.09	0.02	<0.001
	Sigma_(time)_+	1.08e-9	---	----*
	Sigma error	0.76	0.03	----*
Male				
	Intercept	11.82	0.68	<0.001
	Time	0.32	0.07	<0.001
	(Time)+	−0.99	0.16	<0.001
	Sigma intercept	3.52	0.48	----*
	Sigma time	0.21	0.04	<0.001
	Sigma_(time)_+	1.72e-9	8.34e-9	----*
	Sigma error	1.73	0.08	----*
Total				
	Intercept	16.24	0.94	<0.001
	Time	0.52	0.09	<0.001
	$(\text{Time})_+$	−1.68	0.22	<0.001
	Sigma intercept	4.88	0.67	----*
	Sigma time	0.30	0.07	<0.001
	Sigma_(time)_+	1.01e−7	3.86e−7	----*
	Sigma error	2.39	0.11	----*

sigma intercept, time and (time) + are the variances estimates for random effects of intercept and slopes (before 2018 and after 2018)
*Could not be computed
SE, Standard error.

According to the results presented in figure 2B and table 3, all clusters exhibited linear trends and slope loadings with 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 time scores. The injury rate due to road accident for cluster I was defined as high at baseline (interceptC1=1.09) and showed a significant decline over time with a slope of 1.09. Provinces in cluster 2 had the lowest intercept and a slight increasing slope (interceptC2=0.48, slopeC2=0.002), indicating a low road crash injury rate that remained relatively stable over time. Provinces in clusters III and IV had high intercepts at baseline (interceptC3=0.95 and interceptC4=1.01), similar to cluster I, but exhibited approximately sharp increases over time with significant slopes of 0.03 and 0.01, respectively, leading to different growth rates. Online supplemental figure S3 illustrates the predicted the spatiotemporal injury rates during the decade.

In the current study, the accident data were not separated by the type of vehicles involved, as the data provided by the government organisation did not include this level of detail. Additionally, the incident data lacked comprehensive information regarding weather conditions and seasonal breakdowns. While these limitations present challenges in fully understanding the nuances of crash rates and outcomes, the findings of this study remain credible and are based on the available data. Future research should strive to incorporate these variables for a more thorough analysis, which could further enhance insights into road safety issues.

DISCUSSION

The present study investigated a decade of road accidents in Iran, focusing on injury trends across the country's 31 provinces. The findings revealed substantial variations in the rates of injuries, providing valuable insights into the patterns and dynamics of road accidents. The exploration of a decade of injury rates trends across 31 provinces of Iran revealed significant variations in incidence of injury rates, providing crucial insights into the dynamics of road accidents. Moreover, it unveiled that Qom and Sistan

Table 3 Results of GMM for clustering the trend of injured rates for all provinces

Parameter	Class 1*	Class 2†	Class 3‡	Class 4§
N (%)	14 (45.2)	3 (9.7)	8 (25.8)	6 (19.3)
Intercept	1.09***	0.48***	0.95***	1.01***
Slope	−0.01***	0.002	0.03***	0.01***
Time Scores	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9)	(0, 1, 2, 3, 4, 5, 6, 7, 8, 9)

*** is significant at <0.001.
*Bushehr, Chaharmahal and Bakhtiari, Fars, Gilan, Golestan, Ilam, Kermanshah, Kurdistan, Kohgiluyeh and Boyer-Ahmad, Khuzestan, Markazi, Tehran, West Azerbaijan, Yazd.
†Hormozgan, Kerman, Sistan and Baluchistan.
‡East Azerbaijan, Isfahan, North Khorasan, Qazvin, Qom, Razavi Khorasan, Semnan, Zanjan.
§Alborz, Ardabil, Hamadan, Lorestan, Mazandaran, South Khorasan.
GMMs, growth mixture models.

and Baluchestan provinces exhibited the highest and lowest 10 years incidence rates, emphasising the need for targeted interventions in high-incidence areas. Furthermore, an analysis of gender differences highlighted consistently higher injury rates among males across all provinces. Moreover, the observed gender disparities underscored the importance of gender-sensitive road safety strategies, with Alborz and Sistan and Baluchestan provinces recording the highest and lowest rates for females. Alborz, characterised by higher urbanisation and economic development, displayed the highest rate of female injuries, possibly linked to greater female participation in driving activities in areas with more liberal social attitudes. Conversely, Sistan and Baluchestan, with the lowest rate of female injuries, reflect a more conservative cultural setting, limiting women's mobility and driving participation. These findings highlight the necessity of considering sociocultural contexts when interpreting injury trends and emphasise the potential impact of societal norms on the prevalence of female drivers. To address these disparities effectively, interventions should not only focus on road safety measures but also consider cultural nuances and societal norms influencing the prevalence of female drivers, promoting targeted awareness campaigns, education and policy changes to enhance road safety in diverse regions. In contrast to the findings of Najimi-Varzaneh and Gholami Fesharaki study,[39] which identified Gilan province with the highest and Fars province with the lowest rates of injury due to road accidents in Iran, the current study presents a notable discrepancy. The present investigation ranks Qom province highest in injury due to road accident-related deaths, while Sistan and Baluchistan province secures the last position. Furthermore, comparative analysis between the present study and the research conducted by Roudsari *et al*[40] underscores the evolution in the depth and scope of examining road accidents in the Iranian context. While they concentrated on the prevalence of car-related injuries, constituting 45% of incidents with a notable men/women ratio of 4.2/1, the current investigation extends this inquiry longitudinally and spatially across 31 provinces over a decade. Noteworthy distinctions manifest in the delineation of significant variations in injury rates and gender-specific disparities across provinces. This study's incorporation of the number of female drivers within distinct regions enriches the narrative on road safety dynamics. Furthermore, the current study extends beyond specific crash types to provide a comprehensive view of gender-sensitive road safety strategies, particularly elucidating variances in the rates of female drivers in provinces like Alborz and Sistan and Baluchestan. The inclusion of these nuanced insights amplifies the scholarly discourse on the multifaceted aspects of road safety dynamics in Iran.

In addition, contrasting the current study with the research conducted by Zangooei Dovom *et al*.[41] reveals notable distinctions in the examination of gender-related dynamics in road accidents. In the present study, the exploration of a decade of road accidents across Iranian provinces emphasises gender-specific variations in injury rates. Unlike them, the current research unveils that gender does play a significant role in injury rates, particularly highlighting consistently higher injury rates among males across all provinces. This nuanced understanding underscores the importance of gender-sensitive road safety strategies, contributing to a more comprehensive examination of the intricate relationship between gender and injuries due to road accident outcomes in the Iranian context. This stark divergence underscores the absence of a direct correlation between the probability and severity of road accidents across provinces. The disparity in rankings suggests that factors influencing the likelihood of road accidents may not necessarily align with those determining the severity of such incidents, emphasising the nuanced and multifaceted nature of road safety dynamics that extend beyond regional accident rates.

Additionally, the exploratory analysis of the incidence rate trends over the 10-year period demonstrated an overall increasing trend before 2018, followed by a subsequent decrease. This temporal pattern was corroborated by linear mixed-effects models, which indicated an annual increase in injury rates of 0.32%, 0.20% and 0.52% for the total population, females and males, respectively, before 2018. Furthermore, after 2018, a notable decline in these rates was observed, highlighting the potential impact of interventions or changes in road safety policies during this period. The observed temporal pattern of increasing injury rates before 2018, followed by a subsequent decrease, suggests that interventions or changes in road safety policies implemented after 2018 may have played a crucial role in mitigating the rising trend. Erfanpoor *et al*[42] observed a decline in the national mortality rate over time, a trend consistent with the current study's identification of a temporal pattern with a subsequent decrease in injury rates after 2018. The notable decline in injury rates post-2018 is indicative of the effectiveness of these interventions, potentially encompassing improved infrastructure, enhanced law enforcement, public awareness campaigns or policy initiatives addressing specific risk factors. This finding underscores the significance of dynamic and responsive road safety measures, suggesting that targeted interventions and policy adjustments can have a substantial impact on reducing injury rates over time. Further research and analysis of specific interventions implemented during this period would provide a more comprehensive understanding of the factors contributing to the observed decline in road accident injuries.

The findings from the GMM clustering of all provinces based on injury rates offer a multifaceted perspective that warrants a comprehensive discussion. Classifying provinces into distinct clusters reveals potential insights into various aspects of Iran's societal and infrastructural dynamics. Moreover, the distribution of provinces across different classes could signify underlying economic variations, with class I, encompassing economically significant regions like Tehran and Fars, potentially benefiting from more robust financial resources for road infrastructure and safety measures. Furthermore, the clustering might signify shared social and cultural factors influencing road safety, as seen in class II, which includes provinces like Hormozgan and Sistan and Baluchistan. Additionally, the inclusion of tourism-centric provinces in class III, such as Isfahan and Razavi Khorasan, indicates a potential connection between tourism activity and road safety challenges. Examining the GMM parameters, the intercepts and slopes provide valuable information on the temporal trends, shedding light on whether injury rates are increasing or decreasing over time within each class. The time scores associated with each class further contribute to understanding the temporal patterns of road safety. This interdisciplinary analysis, incorporating economic, social, cultural and infrastructural factors, is crucial for devising targeted interventions and policies tailored to the specific challenges faced by different provinces in Iran. In doing so, it paves the way for a more nuanced and effective approach to enhancing road safety nationwide. Moreover, it is imperative to acknowledge that further studies are necessary to delve deeper into the analysis of influential factors related to road accidents and to refine the understanding of the dynamics at play in each identified class.

Furthermore, despite the comprehensive nature of this study, certain limitations must be acknowledged. The analysis focused on injury rates and trends, but the specific causes and contributing factors to road accidents were not explored in depth. Additionally, external factors such as socioeconomic variables, infrastructure development and policy changes may influence the observed trends and were not explicitly considered in this study. Moreover, the sublimitation related to vehicle type distribution is noteworthy. In the present study, this aspect was not investigated due to a lack of data availability. It is important to highlight that in Iran, there is a prohibition on the use of motorcycles for women, and the utilisation of trucks and heavy vehicles is also exceedingly rare for women. This restriction in vehicle type distribution analysis underscores the need for future research to delve into the gender-specific patterns of vehicle usage, contributing to a more comprehensive understanding of road accident dynamics.

This study has several strengths that contribute significantly to the understanding of road safety in Iran. First, it uses a comprehensive dataset covering all 31 provinces over a decade, offering a detailed picture of injury rates and trends across the country. The application of advanced statistical methods, such as linear mixed-effects models and GMM, enhances the rigour of the analysis, allowing for the identification of distinct trends and underlying dynamics in road crash data. Furthermore, the findings contribute to the biomedical field by informing policy-makers and practitioners about the extent of road safety issues in Iran, thereby facilitating the development of targeted interventions to improve public health outcomes. However, there are limitations to this study that should be noted. The accident data could not be separated by vehicle type, as the information provided by the government organisation lacked this level of detail. Additionally, the study did not consider the influences of seasonal and weather conditions due to the absence of relevant data. Addressing these limitations in future studies would provide a more nuanced understanding of road safety factors, ultimately contributing to more effective safety strategies.

CONCLUSIONS

The presented study aimed to analyse trends in road accident-related injuries across Iranian provinces over a decade, with a particular focus on the disparities in injury rates by gender and region. The findings revealed four distinct classes of injury trends among the provinces: one cluster exhibited a significant decline in injury rates, suggesting effective interventions or improvements in road safety measures; two clusters demonstrated sharp increases, indicating urgent needs for further research and targeted intervention; and one cluster displayed a steady trend, reflecting regions where injury rates remained relatively unchanged. Importantly, the study highlighted that males experienced higher injury rates than females across all provinces, underscoring gender differences in vulnerability to road injuries. These insights have significant implications for the biomedical field, as they not only illuminate the public health challenges associated with road safety but also emphasise the need for data-driven interventions tailored to specific regional trends. Understanding the dynamics of road accident-related injuries can inform the development of targeted public health strategies aimed at injury prevention and health promotion. By leveraging these findings, healthcare professionals, policy-makers and researchers can collaborate to implement evidence-based interventions that effectively address the underlying factors contributing to road traffic injuries. Ultimately, this study contributes to the ongoing discourse on road safety and public health, highlighting the necessity of a multidisciplinary approach to mitigate the impact of road accidents on health outcomes in Iran.

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