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SPANNING THE NATION: A SPATIAL INVESTIGATION OF TRAFFIC ACCIDENTS DURING IRAN'S NOWRUZ HOLIDAYS

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ABSTRACT

Particularly in low- and middle-income countries with varied geographic and infrastructure conditions, road safety during high-travel times presents a major public health issue. Over seven years (2017–2023), this study examines the spatiotemporal trends of road traffic accidents in Iran during Nowruz, a significant holiday marked by millions of travels. Using advanced spatial analysis methods, including global Moran's I and local Getis-Ord Gi*, the study identifies and evaluates accident hotspots all around the country. Results show ongoing high-risk areas in northern and eastern provinces caused by factors such as tourism, challenging geography, and poor infrastructure. The COVID-19 pandemic substantially altered traffic and accident patterns, reducing total accident counts while increasing fatalities due to higher speeding rates under low traffic conditions. The study offers nuanced insights into regional safety disparities by including accident frequency and cluster density into a scoring system. This approach highlights provinces where concentrated hazards exist despite relatively low accident counts. These findings highlight the need of customized, spatially informed safety interventions and provide policymakers a framework for optimizing resource allocation during peak travel periods.

Keywords: spatiotemporal analysis, traffic accident hotspots, Getis-Ord Gi*, Covid-19 Pandemic, Nowruz Holiday.

ABARCANDO LA NACIÓN: UNA INVESTIGACIÓN ESPACIAL DE LOS ACCIDENTES DE TRÁFICO DURANTE LAS VACACIONES DE NOWRUZ EN IRÁN

RESUMEN

En particular, en los países de ingresos bajos y medios con condiciones geográficas y de infraestructura diversas, la seguridad vial durante los períodos de alta movilidad constituye un importante problema de salud pública. A lo largo de siete años (2017–2023), este estudio examina las tendencias espacio-temporales de los accidentes de tráfico en Irán durante Nowruz, una importante festividad caracterizada por millones de desplazamientos. Utilizando métodos avanzados de análisis

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espacial, incluidos el índice global de Moran (Moran's I) y el estadístico local Getis-Ord Gi*, el estudio identifica y evalúa los puntos críticos de accidentes en todo el país.

Los resultados muestran la persistencia de áreas de alto riesgo en las provincias del norte y del este, debido a factores como el turismo, una geografía compleja y unas infraestructuras deficientes. La pandemia de COVID-19 modificó significativamente los patrones de tráfico y accidentalidad, reduciendo el número total de accidentes pero aumentando la mortalidad debido a mayores niveles de exceso de velocidad en condiciones de baja densidad de tráfico. El estudio aporta una visión detallada de las desigualdades regionales en materia de seguridad vial al incorporar la frecuencia de los accidentes y la densidad de conglomerados en un sistema de puntuación. Este enfoque permite identificar provincias donde existen riesgos concentrados a pesar de registrar un número relativamente bajo de accidentes. Estos hallazgos ponen de manifiesto la necesidad de aplicar intervenciones de seguridad personalizadas y basadas en el análisis espacial, y proporcionan a los responsables de la formulación de políticas públicas un marco para optimizar la asignación de recursos durante los períodos de máxima movilidad.

Palabras clave: análisis espaciotemporal, puntos calientes de accidentes de tráfico, Getis-Ord Gi*, pandemia de COVID-19, vacaciones de Nowruz.

1. Introduction

With almost 1.19 million deaths or injuries annually resulting from road traffic accidents (WHO 2023), road safety remains a major global concern. Low- and middle-income countries, where 90 % of road accident deaths occur, bear disproportionately more of the burden of these events. Although they possess only 60 % of the world's motor vehicles (WHO 2023), the risk of death in these areas is three times higher than in high-income countries.

The spatial nature of accidents makes spatial analyses essential for spotting high-risk areas. By identifying hazardous areas, these analyses help to guide targeted interventions and effective use of resources, reducing accident frequency and severity and improving public safety. Among the geospatial tools used to identify hotspots, Getis-Ord Gi*, Anselin's Moran's I, and kernel density estimation (KDE) have widely been employed in road safety research (Watson & Ryan 2024).

In high-income countries, robust data availability, advanced technological infrastructure, and favorable social and economic factors facilitate the application of spatial indices to identify hotspots. Successful applications has been indicated in past studies in North America (Alam & Tabassum 2023; Alsahfi 2024, Habib *et al.* 2023, Song *et al.* 2021, Yuan *et al.* 2023, Zhang *et al.* 2024), Canada (Blazquez *et al.* 2018, Rad & El-Basyouny 2024, Vaz *et al.* 2017), Europe (Mekonnen *et al.* 2023, Mesquitela *et al.* 2022), and Australia (Hovenden & Liu 2020, Truong & Somenahalli 2011). Low or middle-income countries in return, often characterized by rapid urbanization, inadequate infrastructure, and limited enforcement of traffic laws, experience the overwhelming majority of the world's road traffic deaths despite possessing only a small portion of the global vehicle population. These countries have also utilized spatial analysis in their accident analysis efforts. Examples include in Asia (Butt *et al.* 2017, Hazaymeh *et al.* 2022, Khatun *et al.* 2024, Qalb *et al.* 2023, Sababhi *et al.* 2024), and Africa *(Afolayan et al. 2022, Berhanu et al. 2023, Telima et al.* 2023).

The geographical extent of the study area and the temporal scale of the study period are other challenging issues in accident analysis. Data collection and hotspot identification are challenging in geographically diverse regions with disparate infrastructure, traffic patterns, and geographic characteristics.

Seasonal fluctuations and changing traffic patterns further complicate consistent long-term modeling. Furthermore, timely safety interventions are hampered by data reporting delays, particularly during high-risk times like holidays.

Iran, a low-middle-income country with a large geographic extent, faces major difficulties in road safety due to a combination of factors including high traffic volumes, poor road maintenance, dangerous driver behavior, and inadequate traffic law enforcement. Recent studies have utilized various spatial analysis techniques such as KDE, Getis-Ord Gi*, and other GIS-based methods, to identify traffic accident hotspots, offering valuable insights into improving road safety in the country's roads.

Zandi *et al.* in 2023, conducted a spatial analysis on the Qazvin–Abyek Freeway over four years using global Moran's I, local Moran's I, local Getis-Ord Gi*, and KDE. Their findings highlighted significant accident hotspots, particularly within a 52 km segment of the freeway, where high accident densities were linked to low traffic volumes and high speeds, especially during early morning hours (Zandi, Kashani, & Okabe, 2023). This is consistent with the study in Pakistan which specified higher incidence of accidents at 7:00 AM (Qalb *et al.* 2023). Kavousi *et al.* in 2020 analyzed pedestrian traffic accidents across 31 Iranian provinces using local Getis-Ord Gi* statistics and geographically weighted regression Models. The study analyzes the impact of factors such as urban infrastructure, traffic density, and weather conditions on the frequency and severity of these accidents (Kavousi *et al.* 2020). Additionally, (Mohaymany *et al.* 2013) employed new method of NetKDE to analyze accident density along the Arak-Khomein rural road. This method provided a continuous density surface, revealing stable high-risk segments.

Examining accidents during particular times, such as holidays of Nowruz (Iranian New Year, from March 15 to April 3 every year), gets even more challenging. In Nowruz 2023, The Ministry of Roads and Urban Development has reported that more than six and a half million passengers travel by road during the 2023 Nowruz holiday. Since this holiday season's higher vehicle number on roadways increases the likelihood of accidents, studying road safety is especially important at this time.

However, in the context of Nowruz, studies on road safety in Iran are quite limited. Azami *et al.* in 2020 investigated road accident mortality during the 2018 Nowruz Holidays, in Hamadan (one of the Iran's tourist provinces) revealing that most fatalities were young, single men, particularly motorcyclists with head trauma. The study highlighted the need for targeted traffic safety education and awareness campaigns to reduce mortality rates among this demographic (Azami *et al.* 2020). In another study, road accidents during the 2016 and 2017 Nowruz holidays, were analyzed by identifying unnecessary speeding as the leading cause of over 55 % of accidents. Their research focused on provinces with the highest accident rates, such as Tehran, Khorasan Razavi, Isfahan, and Fars, and recommended cultural education, improved vehicle safety, and enhanced road infrastructure to mitigate these incidents (Daranjani & Rezaeizadeh 2020).

This research investigates the spatial analysis of road traffic accidents in Iran, a large geographic country, during the Nowruz holidays, a time characterized by increased travel and heightened accident risk. Although studies have examined accident-prone areas on rural roads, a comprehensive nationwide analysis focused specifically on the Nowruz holiday period has yet to be conducted. Using spatial analysis methods, including Getis-Ord Gi* and Moran's I, the study aims to identify hotspot regions and clarify the spatial-temporal dynamics of accidents. Addressing a gap in the literature, this study examines a large and heterogeneous region where accidents are influenced by diverse seasonal, geographic, and cultural factors. Additionally, the results of this study can provide insights to guide targeted interventions, prioritizing resource allocation and enhance road safety strategies during high-risk periods.

2. Study Area

The study area for this research is Iran, located in the Middle East, covering an area of approximately 1,648,195 square kilometers, making it the 17th largest country in the world. The nation is divided into 31 provinces, each governed by local authorities, and it comprises a total of 429 cities, which together facilitate regional administration and development.

Iran is bounded to the north by Armenia, Azerbaijan, and Turkmenistan; to the east by Afghanistan and Pakistan; to the south by the Persian Gulf and the Gulf of Oman; and to the west by Iraq and Turkey. Iran includes major mountain ranges such as the Alborz and Zagros, as well as extensive desert regions (Wikipedia 2025). Iran's vast territory and diverse topography make accident analysis essential to enhancing traffic control and road safety. Because of difficult driving conditions, poor visibility in some places, and more traffic in cities, the mountainous terrain and dense population can increase the likelihood of accidents. By using accident analysis to understand these geographic characteristics, high-risk areas can be found and focused interventions can be made to improve road safety nationwide.

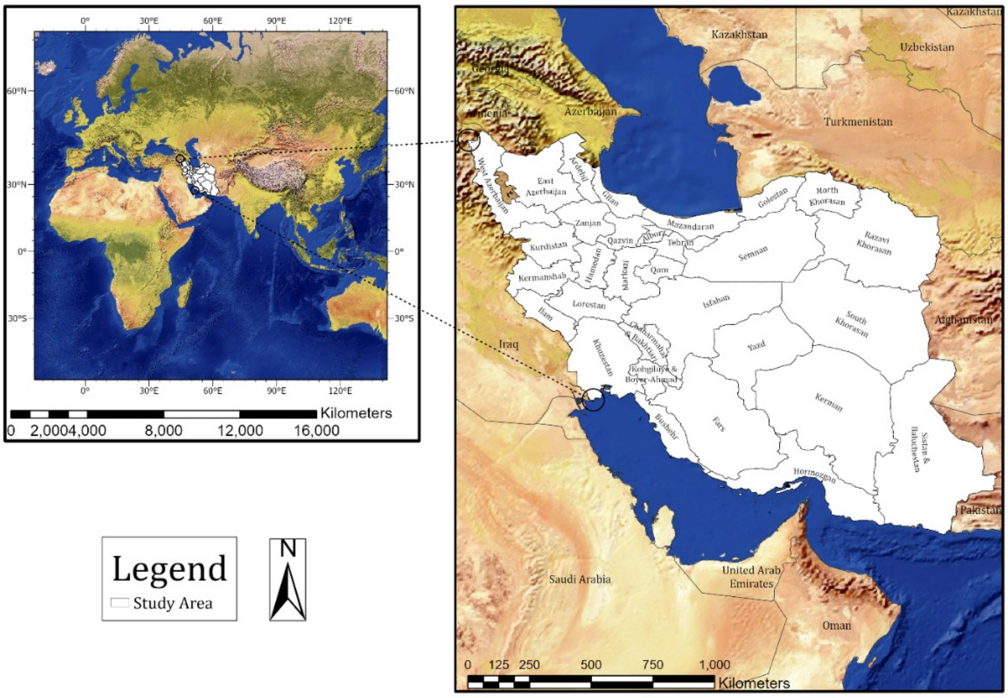

Figure 1. Geographical extent of the study area

3. Data Collection

Data for this study, including administrative divisions of provincial borders, were obtained from national censuses, vital registration systems, and administrative records. The Iranian Red Crescent Society (IRCS) provided data on fatal and injury accidents for the study, which spanned seven years from 2017 to 2023. This analysis focused on accidents that occurred during Nowruz, the Iranian New Year, which begins on the spring equinox (typically March 20 or 21) and lasts 13 days, ending on April 2 each year. The IRCS plays an important role in collecting and reporting traffic accident data, especially during the holiday season when travel increases significantly, increasing the likelihood of accidents. Because the basic units in spatial analyses are the country's cities, all data was aggregated at the city level for analysis.

Regarding data completeness, the accident database provided by the IRCS had already undergone preliminary verification and preprocessing by the responsible authorities before acquisition. Cities with limited or partially incomplete records were carefully reviewed. Since the proportion of missing data was relatively small and did not substantially affect the national spatial distribution patterns, no cities were excluded from the analysis. However, records lacking sufficient spatial reference information for reliable geographic allocation were omitted from the final dataset.

Accidents occurring on interurban and rural roads were assigned to the corresponding municipal boundaries based on the official administrative location recorded in the database. This aggregation approach was intentionally adopted because the objective of the study was to investigate large-scale spatial patterns of accident occurrence at the city level rather than along individual roadway segments. Using a consistent municipality-based spatial framework also improved the comparability of hotspot patterns across different regions and study years.

4. Methodology

This research initially assesses the spatial autocorrelation of traffic accidents across the study area by employing the global Moran's I statistic. This initial step determined if accidents were randomly distributed or concentrated in specific locations.

A local Getis-Ord Gi* index is utilized to identify and assess the spatial distribution of clusters with high and low accident counts across the provinces. Each province's safety performance was then evaluated using a scoring system and was assigned count and score rankings. Each province's score ranks (SRs) and count ranks (CRs) were statistically compared using the Wilcoxon signed-rank test in order to find significant differences. Figure 2 shows the study flowchart.

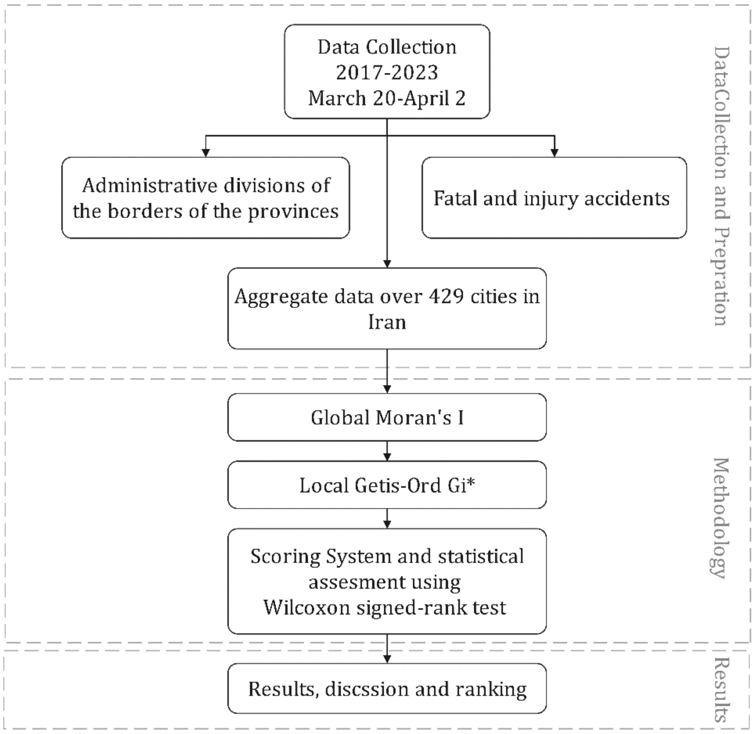

Figure 2. **Flowchart of the study**

4.1. Global Moran's I

Moran's I is a statistical measure that assesses spatial autocorrelation, or the similarity or dissimilarity of values in geographic space. Moran introduced Global Moran's I in 1948 to determine whether high or low values of a variable are clustered or dispersed across an area (Moran, 1948). The calculation of Moran's I uses the following formula:

$$I = \frac{N \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij} (x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij} \sum_{i=1}^{N} (x_i - \overline{x})^2} \quad (1)$$

Where, N is the number of spatial units, x_i and x_j are values of the variable at locations i and j, $\overline{x}$ denotes the mean of the variable, and w_{ij} is the spatial weight between locations i and j.

In this study, the spatial weights matrix (w_ij) was constructed based on contiguity relationships between neighboring spatial units. Spatial units sharing common boundaries were assigned non-zero weights, while non-adjacent units received a weight of zero. The weights matrix was subsequently row-standardized to ensure comparability among spatial units. Although alternative approaches such as distance-based weighting, inverse-distance methods, and k-nearest neighbor techniques are commonly used in spatial analyses, the contiguity-based approach was selected due to the administrative nature of the study units and the importance of direct geographic adjacency in interregional travel patterns during the Nowruz holidays. This method was considered more suitable for capturing spatial interactions and spillover effects between neighboring provinces and cities, while also minimizing distortions caused by substantial variations in province size across the country. Moran's I index ranges from -1 to 1. Positive values indicate positive spatial autocorrelation, implying that similar values (high or low) cluster together. Negative values mean negative spatial autocorrelation, showing that dissimilar values are close together. Values near zero indicate a random spatial pattern with no significant clustering. To determine the significance of Moran's I, a hypothesis test is performed under the null hypothesis that there is no spatial autocorrelation (i.e., the data is distributed randomly). A p-value is computed; if it is less than a predetermined significance level (usually 0.05), the null hypothesis is rejected, indicating significant spatial clustering or dispersion in the data.

4.2. Local Getis-Ord Gi*

Local clusters with high and low values are found using the Getis-Ord Gi* statistics. This local indicator of spatial association, which was first presented by Getis and Ord in 1992, finds statistically significant clusters referred to as hotspots (high values) and cold spots (low values) (Getis & Ord, 1992). Unlike global Moran's I, which provides a single measure for the entire study area, the local Getis-Ord Gi* statistic focuses on each location and its surroundings to determine if the clustering of high or low values is statistically significant. The Gi* statistic is calculated using the following equation:

$$G_i^* = \frac{\sum_{j=1}^{N} w_{ij} x_j - \bar{x} \sum_{j=1}^{N} w_{ij}}{S \sqrt{\frac{\sum_{j=1}^{N} w_{ij}^2 - \left(\sum_{j=1}^{N} w_{ij}\right)^2}{N-1}}} \tag{2}$$

Where, x_j is the value of the variable of interest at location j, w_{ij} is the spatial weight between locations i and j, $\bar{x}$ denotes the mean of the variable of interest, and S is the standard deviation of the variable of interest.

4.3. Scoring System

To evaluate the safety performance of various provinces, a scoring system was developed. Given that Iran's provinces encompass multiple cities, it was essential to apply a standardized method for meaningful comparisons after utilizing Getis-Ord Gi* statistics to identify hotspots. Due to the variability in the number of cities across provinces, a straightforward comparison based solely on the number of hotspots would be inadequate. Accordingly, each city identified as a hotspot with 90 % confidence reduced its province's score by 1. Each cold spot city with the same confidence increased the score by 1. Cities without statistical significance did not affect the province's score.

The annual score for each province was determined by adding up the score units from all its cities and then dividing this sum by the total number of cities in the province. To calculate the overall provincial score across the seven-year period, the total score units were divided by the product of the number of cities and the number of study years This method suggests a reliable way to compare safety performance across provinces, which considers the different number of cities in each province. To compare accident frequency between provinces, the yearly and total accident counts were normalized based on each province's area in square kilometers. Each province was ultimately given a score rank (SR) and a count rank (CR) each year and in total. Safer provinces received lower ranks, while more dangerous provinces received higher ranks. Additionally, the Wilcoxon signed-rank test was used to compare the SRs and CRs of each province over the seven years. This nonparametric test is ideal for assessing matched data because it determines whether the median difference between two paired sets of ranks is significantly different from zero (Woolson, 2005). The purpose of the analysis was to ascertain whether the differences between the SR and the CR for each province were statistically significant.

5. Results and Discussions

Initially, the findings from the Moran global Index are discussed, giving insights into the overall spatial autocorrelation of the data. Next, the paper identifies specific hotspots using the Getis-Ord Gi* index, highlighting areas of significant clustering. Lastly, the scoring results are detailed, offering a comprehensive evaluation of spatial characteristics of data and their implications.

5.1. Results of Global Trends Using Global Moran's I

Table 1 summarizes the findings of global Moran's I for accident data, encompassing both injury and fatal incidents, from 2017 to 2023. The findings indicate a persistent pattern of positive spatial autocorrelation over a seven-year period.

Table 1. Results of Moran's I and corresponding Z-score and P-values from 2017-2023

Year	Moran's I	Z-Score	P-value
2017	0.09	2.62	0.00
2018	0.15	4.34	0.00
2019	0.10	3.03	0.00
2020	0.23	6.58	0.00
2021	0.22	6.59	0.00
2022	0.14	4.04	0.00
2023	0.14	4.01	0.00

Moran's I values fluctuate from 0.09 in 2017 to a maximum of 0.23 in 2020, followed by elevated values in the subsequent years (0.22 in 2021, declining to 0.14 in 2022 and 2023). The positive values indicate that similar accident occurrences are spatially clustered, implying that regions with elevated accidents are close to other high-accident zones. The Z-scores, which indicate values' deviation from the mean, provide support to the interpretation of Moran's I scores. Z-scores exceeding 2 denote statistical significance, with all years exhibiting Z-scores significantly above this threshold (from 2.62 in 2017 to 6.59 in 2021). The P-values for all years are 0.00, indicating substantial statistical significance. The rising trend in Moran's I values until 2020 suggests that clustering may have intensified during that time, followed by a minor decline in the subsequent years while still retaining significance.

5.2. Results of Local Getis-Ord, Clusters of Traffic Accidents

The data from the Getis-Ord Gi* statistic over seven years provide significant insights into the spatial distribution of traffic accidents, as illustrated in Figure 3. Similar to earlier studies (Alkaabi 2023, Obaid *et al.* 2024, Rad & El-Basyouny 2024, Yuan *et al.* 2023), this analysis demonstrates the efficiency of the Getis-Ord statistic in detecting patterns of road traffic accidents. The maps from this study depict these clusters visually by indicating areas where traffic accidents are significantly more clustered than random distribution. The results are supported by z-scores and p-values, with higher z-scores suggesting better clustering of high values. Hotspots with z-scores greater than 1.645 are considered statistically significant at the 90 % confidence level.

Based on Figure 3, it can be inferred that accident hotspots appear mainly in the northern regions of the country, which is mostly due to geographical and socio-economic factors. During Nowruz, many travelers visit the Northern provinces because of the pleasant weather and natural attractions like forests and the Caspian Sea. Travelers' unfamiliarity with local roads significantly contributes to accidents in these areas. Furthermore, the road network design and poorly placed commercial areas often force pedestrians and motorcyclists to cross in unsafe locations, leading to frequent accidents.

Additionally, the spread of hotspots to eastern regions from 2019 to 2023 in Figure 3, implies a growing tendency in accident concentration in these areas. Desert features in the eastern provinces, especially in Semnan, possibly explain this pattern. Rural roads with monotonous landscapes and limited roadside facilities may contribute to driver fatigue and psychological disengagement, thereby increasing accident risk. Monotonous scenery, insufficient infrastructure, and limited roadside facilities may increase distractions, speeding behavior, and inattentive driving. Low traffic density gives drivers a false sense of security, prompting them to engage in risky behaviors such as mobile phone use and irresponsible lane changes. The lack of rest areas and service stations may reduce opportunities for drivers to rest, negatively affecting concentration and reaction time. Accidents are much more likely when isolated road conditions, inadequate maintenance, restricted visibility, and few emergency services are combined. The introduction of new hotspots in southwestern Iran in 2023 draws even more attention to the dynamic character of traffic patterns shaped by road quality and regional growth.

5.3. National Trends in Accident Counts and Spatial Clusters

The incidence of accidents across the nation exhibits considerable variation, providing a broad perspective. A notable discrepancy is observed when comparing the variations in the total number of injuries or fatalities from accidents (Figure 4a) with the changes in the number of hotspots (Figure 4a).

The first three years of the survey logged the most deadly or injured accidents with an average drop of 15 % over the last two years. Conversely, the average number of hotspots increased by 8 % over the same period. All things considered, even if the accident count suggested a downward trend, the cluster count increased. This suggests that although accidents are usually declining, they have become more concentrated and more disparities among provinces have emerged, therefore reflecting unequal progress across areas.

The trends are greatly shaped by the COVID-19 epidemic. In 2020, the patterns in the total number of accidents closely matched those of hotspots. Following government restrictions on New Year's travel, the number of accidents sharply declined by 40 % in 2020 and remained relatively stable in 2021, with only a slight increase. In 2020, the patterns in the total number of accidents closely matched those of hotspots. Following government restrictions on New Year's travel, the number of accidents sharply declined by 40 % in 2020 and remained relatively stable in 2021, with only a slight increase.

This matches with global trends since many studies have found notable drops in road traffic accidents during the COVID-19 pandemic caused by travel limitations (Qian & Li 2023, Rad & El-Basyouny 2024, Zhuang *et al.* 2024).

Similar to the findings of (Yasin, Grivna & Abu-Zidan, 2021), although the total number of injured or fatal accidents decreased in 2020 and remained still low in 2021, the number of fatal accidents increased by 64 % from 2020 to 2021 (Figure 4c). This is while traffic mobility has stayed constant and the total number of injured or fatal accidents has too. Increased speeding and aggressive driving behaviors following prolonged restrictions may explain this rise, as drivers took advantage of reduced congestion (Rad & El-Basyouny, 2024). This underlines the requirement of keeping safety measures even with low traffic and stresses the need of focused initiatives including speed control and more police presence.

Accidents and hotspots increased significantly in 2022 after travel restrictions were removed. The number of cities designated as hotspots increased by 49 %, while the overall number of accidents increased by 29 %. It took nearly two years post-quarantine for accident figures to approach the reductions seen in 2020. The single-year drop of 819 accidents in 2020 was in distinct contrast to the combined increase of 763 accidents in 2022 and 2023. This shows that significant events take time to recover from, indicating that traffic managers had time to put policies in place to slow the rate of increase.

Excluding the years of the COVID-19 pandemic, there was a marked acceleration in the increase of accidents towards the end of the study period. Accidents rose by 5 % from 2017 to 2018 and by 14 % from 2022 to 2023, suggesting a significantly steeper rate of increase in recent years relative to earlier years. This trend can be attributed to the significant increase in private vehicle ownership in recent years, in contrast to earlier periods of the study, alongside the system's inability to adapt and implement sufficient safety measures.

5.4. Results of Scoring Analyses

Results at the national level provide a comprehensive view of regional safety performance. To effectively address region-specific safety problems, prioritize focused actions, and identify localized challenges, it is imperative to examine performance at the provincial level.
Each province was assigned two rankings: one based on accident counts and the other on computed scores. The presence of tied scores among some provinces resulted in shared SRs. Conversely, due to the varying accident rates per area across provinces, each province was assigned a distinct CR. As a result, the province with the highest CR (31) and the highest score rank (29) differs. To facilitate a meaningful comparison, the SRs were adjusted to align with the CRs.

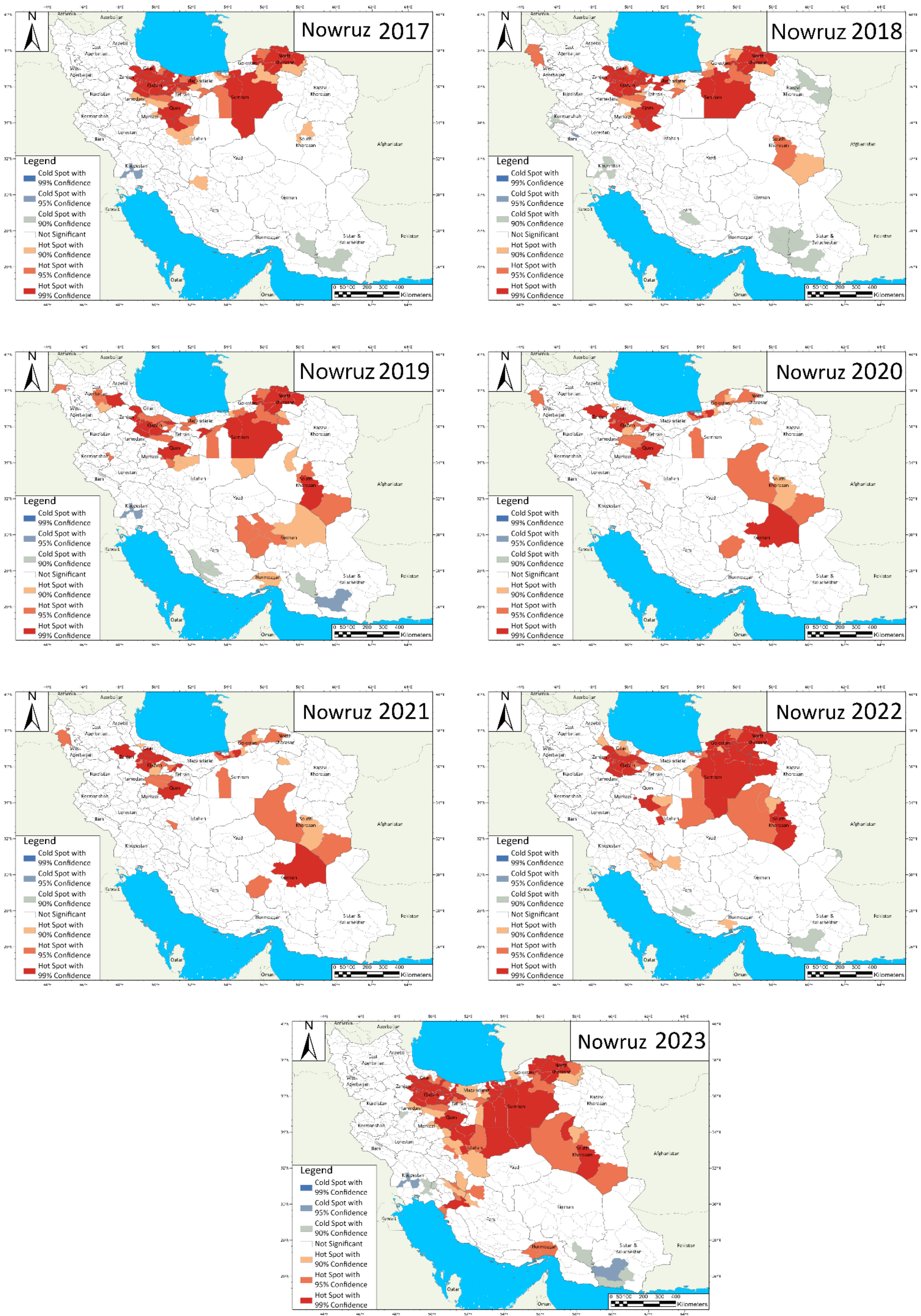

Figure 3. Results of clustering traffic accidents across the country during Nowruz, 2017-2023

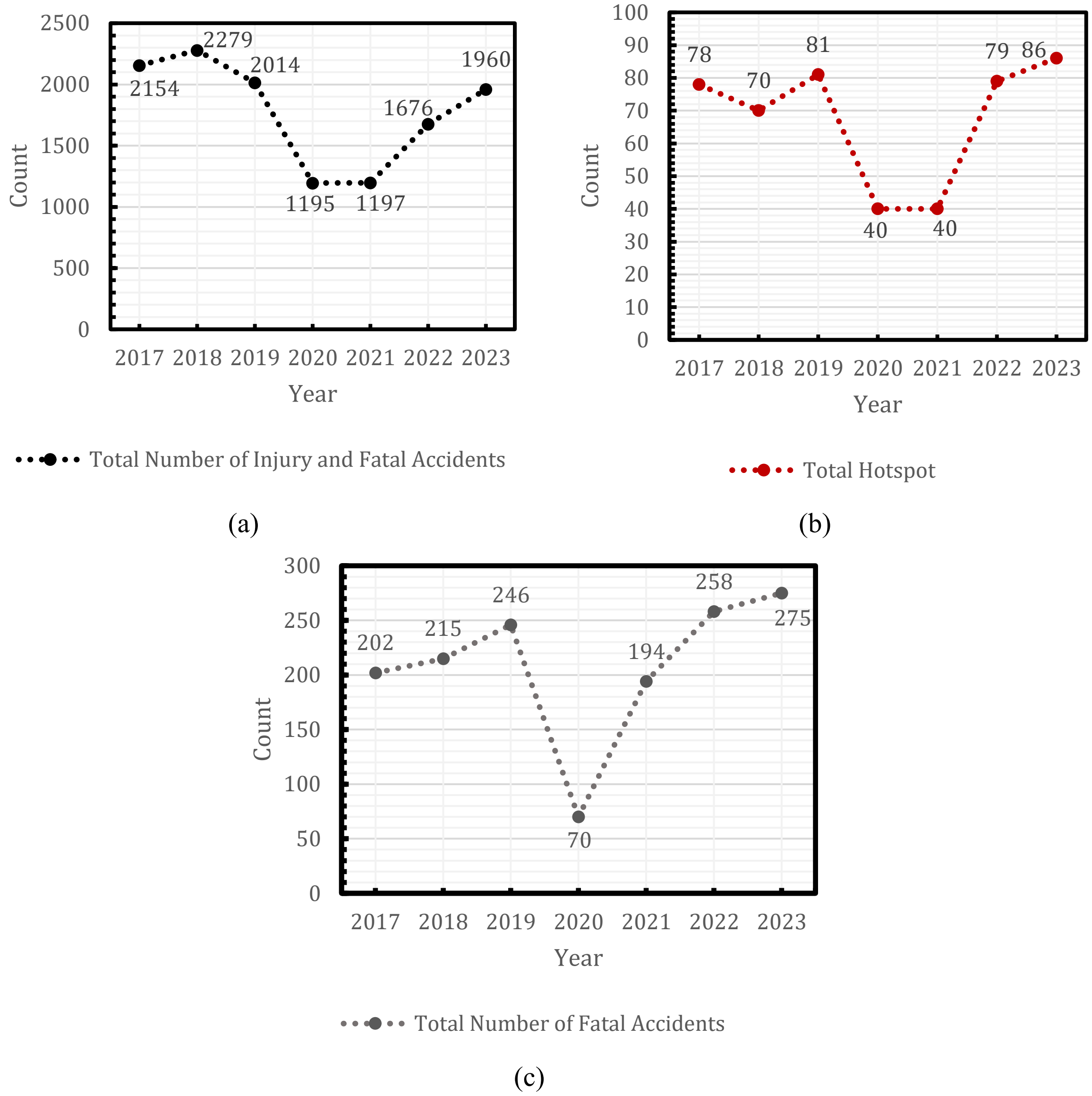

Figure 4. a) Total number of injury and fatal accidents b) Total number of hotspots c) Total number of fatal accidents (Nowruz 2017 - Nowruz 2023), across the study area

Figure 5 shows a clear difference between the rankings based on accident counts and scores. Notably, Alborz had the highest accident CR over seven years, whereas Qazvin held the top score rank. Figure 5 highlights the average total ranks, total CRs, and total SRs of the provinces. By sorting the average total ranks from largest to smallest, the least safe provinces—those with the highest number of accidents and with accidents more clustered in their corresponding provinces can be found, making specific cities particularly dangerous destinations for tourists during Nowruz. This information can guide the prioritization of national resources to address both the high number of accidents and existing hotspots.

The most hazardous provinces, all with total average ranks over 20, are Qazvin, Golestan, Alborz, North Khorasan, Zanjan, Mazandaran, Gilan, Tehran, and Markazi. Qazvin exhibited the poorest overall performance, likely becauseits highways serve as major transportation corridors connecting several Iranian cities. In contrast, Sistan and Baluchestan, with both its score and CRs at 1, has the best performance, probably due to limited car travel as tourists often fly in rather than drive.

As explained earlier, a Wilcoxon signed-rank test was used to check if the CRs and SRs of provinces over the seven-year study period are statistically different (Table 2). The results show that for Isfahan, Ardebil, Golestan, Fars, Razavi Khorasan, North Khorasan, Kurdistan, Hormozgan, Sistan and Baluchestan, and Yazd, the ranks are not significantly different.

For these provinces, the total accident counts closely match the spatial patterns of accidents. In provinces where the ranks are similar, broad province-wide strategies may effectively address safety concerns. Therefore, safety interventions in these areas can confidently use either metric (count or score) for decision-making. However, in provinces with notable variation, the two ranks emphasize various elements of traffic safety. Interventions in this situation should concentrate on high-risk regions (hotspots) indicated by the scoring system since these places could have concentrated hazards not reflected by total accident counts.

Several notable discrepancies show up when one compares total SRs with total CRs across provinces. While some provinces have a much higher CR than their SR, others have a far higher SR than their CR. For example, Semnan, which has one of the lowest accident counts (Figure 5), has a high total SR. This indicates that although the province experiences relatively few accidents during Nowruz, these accidents are highly concentrated in specific areas, making it a hotspot in the country.

Another example is Kermanshah, which, despite having a high CR (Figure 5), ranks among the safest provinces in Iran over the past seven years based on its total SR. This implies that although there are many accidents, they are distributed throughout the province rather than concentrated in certain areas. Rather than modifying safety strategies across the entire province, policymakers in provinces such as Semnan could focus on specific hotspot cities through targeted interventions.

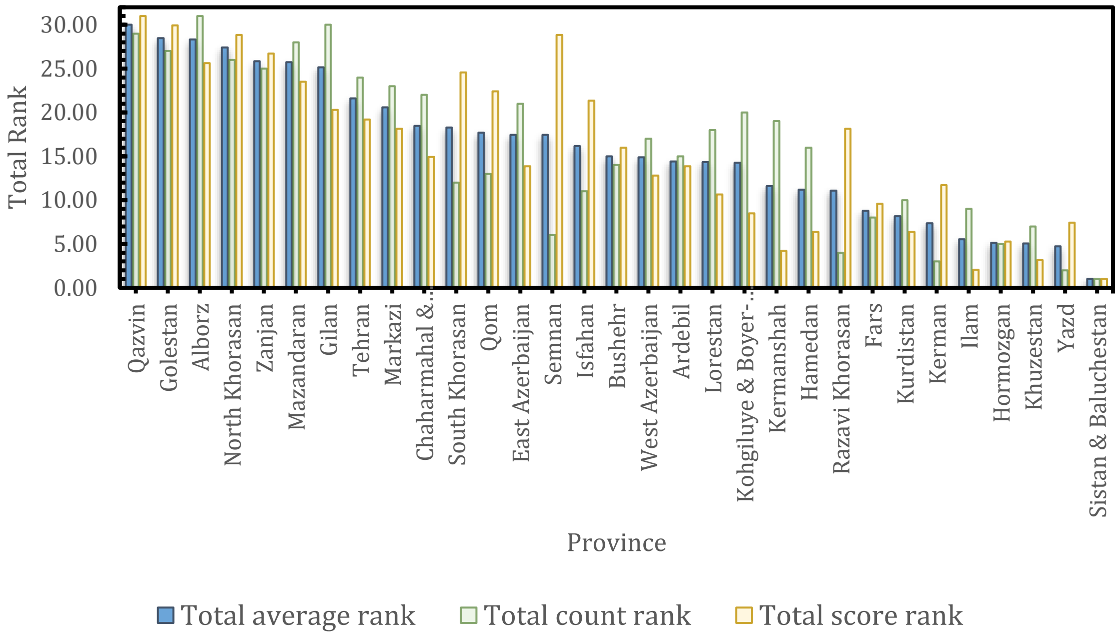

Figure 5. Total average rank, CR, and SR of provinces

Conversely, in provinces like Kermanshah, widespread accidents make all its cities equally hazardous for visitors, thus it is vital to look at safety policies all across the province. Planners and decision-makers can find tracking yearly patterns in counts and score rankings (Figure 6a and Figure 6b) especially useful during extraordinary events like travel limitations set under the COVID-19 pandemic. Examining such trends together with possible causes may help them be better ready for and reduce the effects of next crises, including possible pandemics. Figure 9a shows the clear effect of the COVID-19 pandemic as most provinces had notable drops in their SRs. Gilan, on the other hand, was the only province in 2020 whose SR rose over 2019; its CR stayed constant.

Table 2. Wilcoxon signed-rank test results for the comparison between provinces' CRs and SRs

Province	Z-Score	P-Value	Province	Z-Score	P-Value
East Azerbaijan	-2.371	0.018 *	Fars	-0.736	0.462
West Azerbaijan	-2.366	0.018 *	Qazvin	-2.428	0.015 *
Ardebil	-1.859	0.063	Qom	-2.366	0.018 *
Isfahan	-1.362	0.173	Kurdistan	-1.185	0.236
Alborz	-2.375	0.018 *	Kerman	-2.371	0.018 *
Ilam	-2.201	0.028 *	Kohgiluye & Boyer-Ahmad	-2.366	0.018 *
Bushehr	-2.371	0.018 *	Kermanshah	-2.375	0.018 *
Tehran	-2.371	0.018 *	Golestan	-0.508	0.611
Chaharmahal & Bakhtiari	-2.371	0.018 *	Gilan	-2.371	0.018 *
South Khorasan	-2.366	0.018 *	Lorestan	-2.371	0.018 *
Razavi Khorasan	-1.863	0.063	Mazandaran	-2.371	0.018 *
North Khorasan	-0.170	0.865	Markazi	-2.371	0.018 *
Khuzestan	-2.371	0.018 *	Hormozgan	-0.851	0.395
Zanjan	-2.201	0.028 *	Hamedan	-2.375	0.018 *
Semnan	-2.366	0.018 *	Yazd	-1.863	0.063
Sistan & Baluchestan	-1.225	0.221			

*: Statistically significant at the 0.05 level

Tracking annual patterns in count and score rankings (Figure 6a and Figure 6b) could help planners and decision-makers, particularly during unusual events like COVID-19 travel restrictions. Examining these trends and determining what could be driving them helps to better prepare for and reduce future crises, including potential pandemics.

Figure 6a depicts the impact of the COVID-19 pandemic, with most provinces experiencing significant declines in their SRs. Gilan, on the other hand, was the only province whose SR rose from 2019 to 2020 while its CR remained unchanged.

Another noteworthy finding is that several provinces showed convergent patterns between their SRs and CRs in 2020, the first year of the COVID-19 epidemic, relative to 2019. Specifically, Ardabil, Chaharmahal & Bakhtiari, Golestan, Isfahan, Qom, Razavi Khorasan, West Azerbaijan, and Zanjan experienced an increase in their CR while their SR decreased. This suggests that these provinces saw a relatively uniform rise in accident numbers across their entire regions. Recent years are more significant than earlier years, as they are likely to be the most similar to future conditions. An interesting trend is observed in Ilam, Kurdistan, and Qom. In 2022, their SRs rose following the lifting of restrictions. The SRs of these provinces, however, have decreased in 2023 probably as a result of safety measures that were put in place to offset the prior increase. In comparison to 2021, the second year of travel restrictions, their CRs dropped in 2022, and they did so again in 2023.

Of the provinces, Hamedan is the most noteworthy example in the years following COVID-19. Its SR and CR both rose in 2022, but in 2023, Hamedan almost reversed the gains in SR and CR.

5.5. Recommendations

To improve road safety in diverse regions, targeted interventions and strategic distribution of resources are crucial to tackle the distinct challenges encountered by provinces exhibiting different accident patterns and risk factors.

To reduce accidents involving pedestrians and motorcyclists in northern provinces, it is advisable to adopt a range of comprehensive road safety strategies. These may include the construction of dedicated motorcycle lanes, the establishment of clearly marked pedestrian crossings equipped with traffic-calming elements, and the installation of physical barriers designed to separate vehicular from non-vehicular traffic.

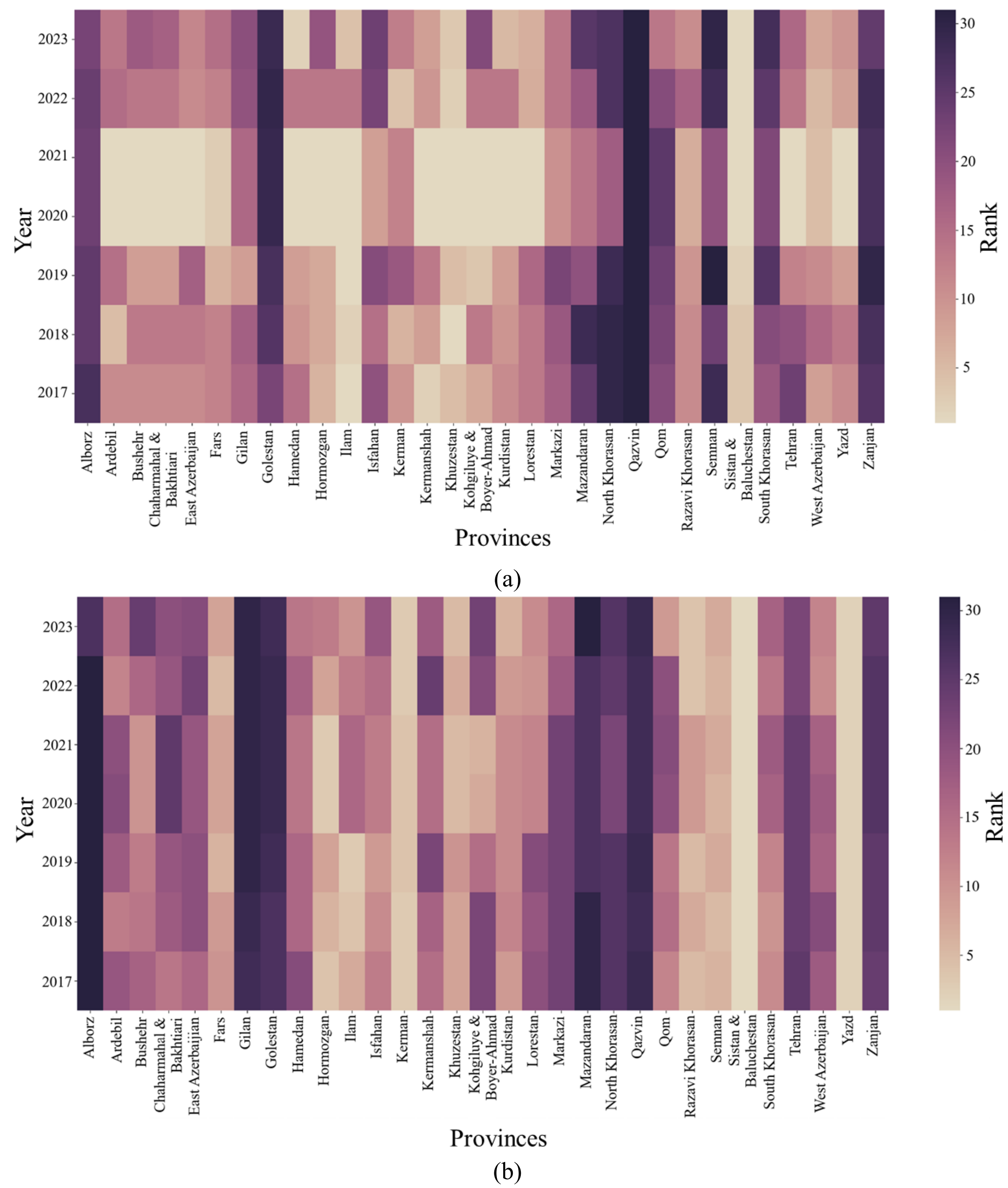

Figure 6. Heatmap of provinces' a) SR and b) CR, Nowruz (2017-2023)

In the eastern provinces, it is recommended to establish service areas and roadside resorts along major thoroughfares to minimize continuous travel durations. This initiative would offer drivers essential rest opportunities, consequently decreasing the probability of accidents.

Provinces' total average rank should guide allocation of road safety intervention resources. Provinces with a high total average rank should be given first priority since this suggests not only a high number of accidents but also their concentration in particular cities, therefore requiring focused and effective distribution of resources. The second priority should be given to provinces showing an increasing trend in their SR, as this suggests that accidents are becoming more concentrated in particular cities. These "hot cities" could benefit from direct investigation and immediate intervention by planners. The third priority ought to be allocated to provinces exhibiting an upward trend in their CR, signifying a deteriorating condition regarding the incidence of accidents throughout the province. Addressing these pervasive safety concerns may necessitate an extended timeframe, as it entails a comprehensive analysis of all urban areas within the province. Moreover, it would be beneficial for safety planners to examine the factors that contributed to the positive safety trends observed in provinces like Hamedan in 2023 in comparison to 2022, as effective strategies may be applicable to other areas that are facing similar challenges.

It is imperative for authorities and planners in each province to conduct a thorough analysis of the trends observed in their SRs and CRs. Through a systematic analysis of the decisions and strategies executed on an annual basis, it is possible to ascertain the extent to which particular actions have impacted these rankings. This reflective methodology has the potential to yield significant insights for future planning, allowing provinces to formulate more efficient safety strategies. The implementation of such initiatives is essential for enhancing safety conditions for both residents and tourists during Nowruz, a time when the significance of road safety is markedly elevated. Advancing in this field, the integration of temporal factors into spatial analysis has the potential to yield more profound insights. It is recommended to conduct spatio-temporal analyses to evaluate and compare accident trends within a province against those of adjacent regions over the previous year. This methodology facilitates the monitoring of spatial spillover effects and enables the derivation of significant conclusions regarding potential risks that may arise when spatial patterns are neglected.

6. Conclusion

This study presents an extensive spatial examination of road traffic accidents in Iran during the Nowruz holidays, a timeframe characterized by elevated travel activity and an augmented likelihood of accidents. Utilizing sophisticated geospatial methodologies, such as global Moran's I and local Getis-Ord Gi* statistics, we pinpointed enduring accident hotspots and assessed regional safety inequalities throughout the nation. The results indicate that the northern and eastern provinces consistently present as high-risk areas, influenced by elements including tourism, difficult geographical conditions, and inadequate infrastructure. The analysis reveals that Qazvin, Golestan, Alborz, North Khorasan, Zanjan, Mazandaran, Gilan, Tehran, and Markazi are categorized as the provinces with the highest levels of danger, arranged in descending order of risk. The provinces demonstrate average total ranks exceeding 20, indicating both high accident frequencies and significant spatial clustering of accidents relative to other regions. The COVID-19 pandemic markedly changed accident trends, resulting in a significant decrease in total accident numbers while concurrently leading to a concerning rise in fatal incidents attributed to heightened speeding in low-traffic scenarios. The post-restriction recovery period exhibited a significant nearly two-year delay before accident Figures reverted to pre-pandemic levels. This observation highlights an essential transition phase for planners to examine safety vulnerabilities and enact strategies aimed at maintaining reduced accident rates over the long term.

The incorporation of accident frequency and cluster density into a scoring system facilitated a detailed assessment of regional safety performance. Based on the results of the Wilcoxon signed-rank test, in provinces where the proposed rankings are statistically significant, either metric can effectively guide safety interventions. In contrast, in provinces exhibiting significant rank disparities, the two metrics reveal different aspects of risk—underscoring the importance of focusing on localized hotspots identified via the scoring system. These areas frequently hide concentrated risks that aggregate counts may not reveal, requiring highly specific measures to tackle the underlying vulnerabilities

The findings of this study suggest broader implications that extend past immediate policy modifications. The study emphasizes the importance of implementing adaptive safety strategies to address disruptions like the pandemic, where changes in traffic patterns and driver behavior can unpredictably affect accident dynamics.

This research enhances the existing literature on spatial analyses related to road safety in low- and middle-income countries by offering a comprehensive geospatial analysis of accident patterns during a significant travel period. The findings highlight the necessity of integrating spatial analysis with overarching accident trends to enhance resource allocation and customize interventions. The proposed framework provides a strategic approach for Iran to mitigate traffic injuries and improve public safety in response to ongoing road safety challenges.

Declaration

The authors declare no conflict of interest.

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References

Afolayan, A., Easa, S. M., Abiola, O. S., Alayaki, F. M., & Folorunso, O. (2022). GIS-Based Spatial Analysis of Accident Hotspots: A Nigerian Case Study [Article]. *Infrastructures*, *7*(8), 23, Article 103. https://doi.org/10.3390/infrastructures7080103

Alam, M. S., & Tabassum, N. J. (2023). Spatial pattern identification and crash severity analysis of road traffic crash hot spots in Ohio [Article]. *Heliyon*, *9*(5), 12, Article e16303. https://doi.org/10.1016/j.heliyon.2023.e16303

Alkaabi, K. (2023). Identification of hotspot areas for traffic accidents and analyzing drivers' behaviors and road accidents [Article]. *Transportation Research Interdisciplinary Perspectives*, *22*, 15, Article 100929. https://doi.org/10.1016/j.trip.2023.100929

Alsahfi, T. (2024). Spatial and Temporal Analysis of Road Traffic Accidents in Major Californian Cities Using a Geographic Information System [Article]. *Isprs International Journal of Geo-Information*, *13*(5), 22, Article 157. https://doi.org/10.3390/ijgi13050157

Azami, H., Jamasbi, M. M., Bayati, M. M., Bakhtiari, Z., Bayati, S. M., & Bonyad, S. A. (2020). Epidemiological Study of Mortality Caused by Road Accidents in the Intensive Care Unit of Besat Educational-Medical Hospital in Hamadan [Article]. *Journal of Biostatistics and Epidemiology*, *6*(3), 197-206. https://doi.org/10.18502/jbe.v6i3.5104

Berhanu, Y., Schroeder, D., Teklu, B., & Alemayehu, E. (2023). Spatial analysis of road traffic accidents: Identifying hotspots for improved road safety in Addis Ababa, Ethiopia [Article]. *Cogent Engineering*, *10*(2), 23, Article 2269655. https://doi.org/10.1080/23311916.2023.2269655

Blazquez, C. A., Picarte, B., Calderón, J. F., & Losada, F. (2018). Spatial autocorrelation analysis of cargo trucks on highway crashes in Chile [Article .[*Accident Analysis and Prevention*, *120*, 195-210. https://doi.org/10.1016/j.aap.2018.08.022

Butt, A., Ahmad, S. S., Shabbir, R., & Erum, S. (2017). GIS based surveillance of road traffic accidents (RTA) risk for Rawalpindi city: a geo-statistical approach [Article]. *Kuwait Journal of Science*, *44*(4), 129-134. <Go to ISI>://WOS:000417985800013

Daranjani, A. R., & Rezaeizadeh, M. (2020). A Comparison of Nowruz 2016 and Nowruz 2017 Accidents Data in Iran [Article]. *Health in Emergencies and Disasters Quarterly*, *5*(2), 71-78. https://doi.org/10.32598/hdq.5.2.305.2

Getis, A., & Ord, J. K. (1992). The Analysis of Spatial Association by Use of Distance Statistics. *Geographical Analysis*, *24*(3), 189-206. https://doi.org/https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Habib, M. F., Bridgelall, R., Motuba, D., & Rahman, B. (2023). Exploring the Robustness of Alternative Cluster Detection and the Threshold Distance Method for Crash Hot Spot Analysis: A Study on Vulnerable Road Users [Article]. *Safety*, *9*(3), 21 ,Article 57. https://doi.org/10.3390/safety9030057

Hazaymeh, K., Almagbile, A., & Alomari, A. H. (2022). Spatiotemporal Analysis of Traffic Accidents Hotspots Based on Geospatial Techniques [Article]. *Isprs International Journal of Geo-Information*, *11* ,18 ,(4)Article 260. https://doi.org/10.3390/ijgi11040260

Hovenden, E., & Liu, G. J. (2020). Use of Spatial Analysis Techniques to Identify Statistically Significant Crash Hot Spots in Metropolitan Melbourne [Article]. *Journal of Road Safety-Jrs*, *31*(4), 36-> .58Go to ISI>://WOS:000590865100004

Kavousi, A., Moradi, A., Soori, H., & Rahmani, K. (2020). Environmental factors influencing the distribution of pedestrian traffic accidents in Iran [Article]. *Archives of Trauma Research*, *9*(1), 8-15. https://doi.org/10.4103/atr.atr_76_19

Khatun, M. S., Hossain, M. A., Kabir, M. A., & Rahman, M. A. (2024). Identification and analysis of accident black spots using Geographic Information System (GIS): A study on Kushtia-Jhenaidah national highway (N704), Bangladesh] Article]. *Heliyon*, *10*(3), 16, Article e25952. https://doi.org/10.1016/j.heliyon.2024.e25952

Mekonnen, A. A., Sipos, T., & Krizsik, N. (2023). Identifying Hazardous Crash Locations Using Empirical Bayes and Spatial Autocorrelation [Article]. *Isprs International Journal of Geo-Information*, *12*(3), 17, Article 85. https://doi.org/10.3390/ijgi12030085

Mesquitela, J., Elvas, L. B., Ferreira, J. C., & Nunes, L. (2022). Data Analytics Process over Road Accidents Data-A Case Study of Lisbon City [Article]. *Isprs International Journal of Geo-Information*, *11*(2), 18, Article 143. https://doi.org/10.3390/ijgi11020143

Mohaymany, A. S., Shahri, M., & Mirbagheri, B. (2013). GIS-based method for detecting high-crash-risk road segments using network kernel density estimation [Article]. *Geo-Spatial Information Science*, *16*(2), 113-119. https://doi.org/10.1080/10095020.2013.766396

Moran, P. A. P. (1948). The Interpretation of Statistical Maps. *Journal of the Royal Statistical Society. Series B (Methodological)*, *10*(2), 243 .251-http://www.jstor.org/stable/2983777

Obaid, L., Alechleh, H., Hamad, K., & Al-Ruzouq, R. (2024). Spatiotemporal Analysis of Property Damage-only Accident Hotspots Using GIS in Sharjah, UAE [Article]. *Jordan Journal of Civil Engineering*, *18*(2), 322-3> .33Go to ISI>://WOS:001222543900004

Qalb, A., Arshad, H. S. H., Nawaz, M. S., & Hafeez, A. (2023). Risk reduction via spatial and temporal visualization of road accidents: a way forward for emergency response optimization in developing countries [Article]. *International Journal of Injury Control and Safety Promotion*, *30*(2), 310-320. https://doi.org/10.1080/17457300.2022.2164312

Qian, K. J., & Li, Y. J. (2023). Safer Traffic Recovery from the Pandemic in London - Spatiotemporal Data Mining of Car Crashes. *Applied Spatial Analysis and Policy*. https://doi.org/10.1007/s12061-023-09533-y

Rad, F. M., & El-Basyouny, K. (2024). How COVID-19 impacted the temporal and spatial distribution of collision hotspots [Article]. *CANADIAN JOURNAL OF CIVIL ENGINEERING* .616-639 ,(6)51 , https://doi.org/10.1139/cjce-2023-0258

Sababhi, S., Aldala'in, S., Al Taani, A., Al Rawashdeh, S., Al Barari, T., Aladwan, Z., & Manan, T. (2024). Safety on Jordan's highways: A GIS-Based approach to identifying road accident hotspots [Article]. *Geojournal*, *89*(3), 19, Article 105. https://doi.org/10.1007/s10708-024-11115-5

Song, L., Fan, W., Li, Y., & Wu, P. J. (2021). Exploring pedestrian injury severities at pedestrian-vehicle crash hotspots with an annual upward trend: A spatiotemporal analysis with latent class random parameter approach [Article]. *Journal of Safety Research*, *76*, 184-196. https://doi.org/10.1016/j.jsr.2020.12.008

Telima, M., El Esawey, M., El-Basyouny, K., & Osama, A. (2023). The use of crowdsourcing data for analyzing pedestrian safety in urban areas [Article]. *Ain Shams Engineering Journal*, *14*(6), 10, Article 102140. https://doi.org/10.1016/j.asej.2023.102140

Truong, L. T., & Somenahalli, S. V. C. (2011). Using GIS to Identify Pedestrian-Vehicle Crash Hot Spots and Unsafe Bus Stops [Article]. *Journal of Public Transportation*, *14*(1), 99-114. https://doi.org/10.5038/2375-0901.14.1.6

Vaz, E., Tehranchi, S., & Cusimano, M. (2017). Spatial assessment of road traffic injuries in the greater toronto area (GTA): spatial analysis framework. *Journal of Tourism, Sustainability and Well-being*, *5*(1), 37-55 .

Watson, R. B., & Ryan, P. J. (2024). Geospatial Factors Applied to Road Accidents: A Review [Article]. *Journal of Advances in Information Technology*, *15*(3), 451-457. https://doi.org/10.12720/jait.15.3.451-457

WHO. (2023). *Global status report on road safety 2023: summary*. World Health Organization. https://books.google.de/books?id=a6YOEQAAQBAJ

Wikipedia. (2025). *Geography of Iran*. https://en.wikipedia.org/wiki/Geography_of_Iran

Woolson, R. F. (2005). Wilcoxon signed-rank test. *Encyclopedia of Biostatistics*, *8* .

Yasin, Y. J., Grivna, M., & Abu-Zidan, F. M. (2021). Global impact of COVID-19 pandemic on road traffic collisions. *World Journal of Emergency Surgery*, *16*(1), 51 .https://doi.org/10.1186/s13017-021-00395-8

Yuan, R. T., Ding, S. X., Fang, Z. H., Gu, X., & Xiang, Q. J. (2023). Investigating the spatial heterogeneity of factors influencing speeding-related crash severities using correlated random parameter order models with heterogeneity-in-means [Article; Early Access]. *Transportation Letters-the International Journal of Transportation Research*, 13. https://doi.org/10.1080/19427867.2023.2262201

Zandi, K., Kashani, A. T., & Okabe, A. (2023). Influence of Traffic Parameters on the Spatial Distribution of Crashes on a Freeway to Increase Safety [Article]. *Sustainability*, *15*(1), 20, Article 493. https://doi.org/10.3390/su15010493

Zhang, H., Ci, Y., Huang, Y., & Wu, L. (2024). The Effect of the COVID-19 Pandemic on the Distribution of Traffic Accident Hotspots in New York City. *Sustainability*, *16*(8), 3440 .

Zhuang, Y., Dong, C. J., Li, P. H., & Xu, B. (2024). Identifying spatio-temporal pattern of electric vehicles involved traffic accidents [Article; Early Access] .*Journal of Transportation Safety & Security*, 21. https://doi.org/10.1080/19439962.2024.2342478

.