Saudi Journal of Emergency Medicine

ORIGINAL ARTICLE

Exploring the spatio-temporal patterns of road traffic accidents in Saudi Arabia

Faisal Alhusain[1,2*], Mohammad Alghafees[2,3], Ahmed Rezk[4,5], Saud Alwatban[2,3], Faisal Almoaiqel[2,3], Majid Alsalamah[1,2]

ABSTRACT

Background: Road traffic accidents (RTAs) are a leading cause of mortality and morbidity in the young population and are a growing problem worldwide. This study is a comprehensive analysis of the spatiotemporal patterns of 352,464 RTAs in Saudi Arabia from 2017 to 2018.

Methods: This study consists of three principal phases of analysis (exploratory data analysis of the RTA dataset by analyzing population involvement in RTAs and mortality or morbidity, we examined the geographic and temporal distribution of RTA, and we performed a spatial hotspot analysis per region on a monthly basis using local Moran's *I* hotspot clustering). This study presented the monthly spatiotemporal patterns of RTAs in Saudi Arabia in 1439 Hijri and data were obtained from the Saudi Open Data Portal for all.

Results: Four cities, Ar Riyad, Ash Sharqiyah, Makkah, and Jeddah, were in the top 25% of RTA involvement, mortality, and morbidity in Saudi Arabia. Four cities, Ar Riyad, Ash Sharqiyah, Makkah, and Jeddah, were in the top 25% of RTA involvement, mortality, and morbidity in Saudi Arabia. There were 11 injuries and 2 deaths per 100 accidents during the study period. More than 84% and 88% of those who were injured and killed in RTAs were male, respectively. There was a significant decrease in the number of RTAs in the last months of the year (Hajj month in the Hijri calendar) compared to other months in the Makkah region and the Eastern Province. In addition, no significant temporal patterns in daily occurrence rates at the national level. Similarly, there was no significant difference between RTA incidence on weekdays and weekends. Differences between daytime and nighttime were significant, with more accidents occurring during the day. The number of injuries per 1,000 population is the same throughout the year in the provinces of the country.

Conclusion: This study identified areas in Saudi Arabia where further investigation is needed to analyze the points that lead to more RTAs and consequently more disabilities and mortalities.

Keywords: Accident hotspots, Moran's *I*, motor vehicle accidents, Saudi Arabia, spatial statistics.

Introduction

Every day, more than 3,000 people die as a result of RTAs for a total of nearly 1.3 million deaths per year worldwide [1,2]. RTAs cause severe and debilitating injuries. These injuries have been neglected on the global health agenda for many years. In response to this emergent issue, the World Health Organization (WHO) released the Global Plan for the Decade of Action for Road Safety 2011-2020. This plan aims to reduce the predicted incidence of RTAs [2]. Road traffic injuries are expected to continue to rise relative to other causes of death. By 2030, RTAs are projected to be the seventh leading cause of death. This raises concern considering the high mortality rate, economic losses, and long-term impact on human life and society. RTAs are a leading cause of mortality and morbidity in the young population and are a growing problem worldwide [1,2]. In Saudi Arabia, the number of injuries caused by RTAs is highest among young people aged 20-24 years. The number of people injured by RTAs in Saudi Arabia is 677 cases per 100,000 population [3]. Local data on RTAs has prompted Saudi Vision 2030 to address its urgency. The vision aims to reduce RTAs and their consequences through road safety measures

Correspondence to: Faisal Alhusain
*Department of Emergency Medicine, Ministry of National Guard - Health Affairs, Riyadh, Saudi Arabia.
Email: Faisalaalhusain@gmail.com
Full list of author information is available at the end of the article.
Received: 24 November 2022 | **Accepted:** 08 April 2023

[4]. According to WHO, the number of traffic fatalities in Saudi Arabia in 2013 was 27.4 deaths per 100,000 population [5].

The public health burden of RTAs is not limited to physical injuries and losses but is much broader [6-8]. RTAs cause financial losses and impose a significant economic burden on society and the government [6,7]. The financial burden of RTAs was estimated to exceed $1.797 trillion from 2015 to 2030. Some of the individuals involved in RTAs develop psychological symptoms [8]. The most severe form is post-traumatic stress disorder, which can strongly affect the quality of life [8,9].

This study presents the monthly spatiotemporal patterns of RTAs in Saudi Arabia in 1439 Hijri (corresponding to 11 Gregorian months and 19 days from September 20, 2017, to August 9, 2018). We examined the geographic distribution of the incidence rate of RTAs, as well as the morbidity and mortality. The analysis is based on both absolute road traffic accident (RTA) occurrence rate and RTA occurrence per capita. A spatial hotspot analysis was conducted to define the extent of the issue and to determine the most and least vulnerable locations. Currently, there is little literature addressing RTAs and their spatial analysis in Saudi Arabia. The objective of this study is to provide the theoretical evidence to improve existing preparedness and response practices, policies, and plans within various authorities in Saudi Arabia and Vision 2030.

Materials and Methods

Data availability

We obtained the RTA dataset from the Saudi Open Data Portal (https://data.gov.sa/en/home). The dataset was time-tagged and aggregated according to the Hijri calendar, as it is the official calendar system in Saudi Arabia. The data was cleaned and translated into English by the authors for analysis. Additional datasets on administrative boundaries and population count were obtained from the Saudi Arabia Digital Data project at King Saud University [10] and Saudi Annual Statistical Report for 2018 [11].

Study design

This study consists of three principal phases of analysis. First, we conducted an exploratory data analysis of the RTA dataset to understand key demographic indicators and trends in the field. We analyzed population involvement in RTAs and mortality or morbidity by gender, marital status, age group, and context (urban or suburban). Second, we examined the geographic and temporal distribution of RTA. Charts were developed to compare the causes and temporal density of RTAs per region. Finally, we performed a spatial hotspot analysis per region on a monthly basis using local Moran's *I* hotspot clustering. We used this method to demonstrate the potential change in accident occurrence due to external events, such as the pilgrimage season. We conducted most of our analysis by the absolute number of each attribute (occurrence, injuries, mortalities, etc.) and attribute per 1,000 or 10,000 population to determine if the attribute reflected an actual societal issue or was due to population concentration.

Study area and context

Saudi Arabia is the largest Arab country in West Asia, with a land area of 2,149,690 km [10]. The country is classified as a high-income country and is part of the "Group of Twenty". The latest census from 2016 shows a population growth of almost 32 million. The population of Kingdom of Saudi Arabia (KSA) is distributed among 13 administrative regions [12]. In the current study, the administrative regions were divided into 16 regions instead of 13 regions based on the division made by the Ministry of Interior. The division into 16 regions is done for logistical reasons. The 16 regions are Riyadh, Makkah, Jeddah, Eastern Region, Aseer, Al-Madina, Jazan, Al-Qaseem, the Northern Borders Region, Tabouk, Hail, Al-Qurayyat, Al-Jouf, Najran, Al-Baha, and Al-Taif. Data were originally collected by the Ministry of Interior (MOI) and made available through the Saudi Open Data Portal. The use of the 16-region distribution was more appropriate. Makkah is the area with the highest population density. More than 2.5 million visitors come to the area annually during the pilgrimage season and an undetermined number of visitors throughout the year [12,13]. This increment in population leads to increased transportation needs. However, there is no good public transportation in the country, so the population relies on their own cars. More than 9,584,414 people in KSA own a car, and 1,804,375 families own a car [12]. The regions with the most RTAs are Riyadh, Jeddah, Makkah, Madinah, and Qassim [14].

Population involvement in RTA

To understand the population's involvement in RTAs, exploratory data analysis was conducted to determine the population's gender, marital status, and literacy status. An additional exploratory analysis was conducted to explore the demographic indicators of the population impacted by an RTA. For this step, the data were aggregated at the national level. Python Pandas and the Matplotlib library were the primary tools used to transform the data and create the graphs.

Analysis of RTA spatial patterns

Geographic maps and graphs were used to understand RTA trends in different regions in KSA. Using Python Geopandas and Matplotlib, we first visualized the spatial distribution of accidents, injuries, and mortalities. The RTAs were spatially represented according to the implications, and we could understand the number and percentage of accidents in each region that resulted in mortalities, injuries, and damages. We classified these attributes using the Jenks Natural Breaks classification method [15] and plotted them on choropleth maps to visually examine the geographic distribution of each attribute. Prior to this step, the same attributes were classified using a four-quantile classification (25%) and plotted on bar charts to visually capture the overall trend of each attribute and the performance of each region.

With a view to better use of health care resources, an additional analysis was conducted to understand the nature of the accidents in each region. First, we visualized the causes of the accidents in each region and compared them with the national average to demonstrate whether healthcare response and preparedness measures should follow global or local measures. We then examined the existing hypotheses linking RTA in KSA to younger age groups. At last, we visualized the age group distribution per region for RTA mortality, injury, and involvement. Regional mean age was superimposed on the distribution to illustrate areas where mortality, injury, and involvement are unequally distributed.

Analysis of the RTA temporal patterns

The available dataset contained 192 temporal data points (16 regions × 12 months). Each point included the RTA incidence per weekday and per day/night. Two new time units were formed to represent weekends (Fridays and Saturdays) and workdays (Sundays through Thursdays). Weekends and workdays exhibit different road traffic patterns. To compare the occurrence rates and distribution patterns of the different time units, we visualized the temporal data using a swarm plot distribution from the Python Seaborn Library [16]. Swarm plots are statistical plots where each observation is plotted as a point within a confined symmetrical histogram-like space. The swarm plots were a useful tool in our case because they allowed us to look at the actual temporal density of the observations and the overall trend within a limited space, which allowed for comprehensive comparisons between RTA occurrences in different time units. Similar to our analysis of spatial data, the mean and median values for each time unit were overlaid on the graphs to highlight the differences between occurrence rates at different time units.

Analysis of RTA space-time relations

The two most important results of the space-time analysis are the regional differences in occurrence times and the temporal changes in spatial patterns of occurrence. To compare temporal patterns of occurrence between regions, we selected two main variables to measure: 1) day/night occurrence and 2) weekday/weekend occurrence. Both variables were represented by the total number of incidences, as well as the per capita number.

To analyze temporal changes in spatial patterns of occurrence, we compared the spatial distribution of monthly RTA occurrences and the number of injuries and deaths. To examine the spatial patterns, we selected Anselin's hotspot and outlier analysis [17,18]. This analysis, also known as Local Moran's *I* clustering, is one of the most reliable and is frequently used for spatial autocorrelation and clustering methods [19]. The Local Moran's $I_i I_i$ is a local indicator of spatial autocorrelation (LISA) statistic, developed by Anselin [17] to measure the extent of significant clustering of similar values around an observation [20]. In this sense, the Local Moran statistic is defined as:

$$I_i = \frac{\gamma_i - \overline{\gamma}}{m_2} \sum_j w_{ij} (\gamma_i - \overline{\gamma}) \ldots$$

$$m_2 = N^{-1} \sum_i (\gamma_i - \overline{\gamma})^2$$

$\gamma_i \gamma_j$, and $\overline{\gamma}$ are the values of the studied attribute (e.g., RTA injuries) at observation *i*, *j* and its mean, while W_{ij} is the spatial weight defined for each neighboring observation *j* of *i* under a set definition of neighborhood.

According to the geographic nature of KSA and the existing administrative borders, we used an adaptive Gaussian kernel to develop the spatial weights matrix defining the neighborhood relationship between the regions. The kernel bandwidth h_i at each region was defined by the k-nearest neighbors function as: $h_i = dKnn_i$ where $dKnn_i$ is the distance to kth nearest neighbor for each observation [21]. In that sense, the Gaussian kernel is defined as:

$$K \frac{d_{i,j}}{h_i} = (2\pi)^{\frac{-1}{2}} exp \frac{- \frac{d_{i,j}}{h_i}^{2}}{2}$$

Local Moran's *I* clustering assigns each geographic unit (region) into one of four categories; 1) HH: a hot spot, which is an area of high incidences surrounded by other areas with high incidences, 2) LL: a coldspot, which is an area with low incidences surrounded by areas with low incidences, 3) LH: a low outlier or a low-high area, which is an area with low incidences surrounded by areas with high incidences, 4) HL: a high outlier or a high-low area, which is an area with a high incidence surrounded by areas with a low incidence. We conducted this analysis using the Python spatial analysis library (PySAL). The statistical significance of these clusters is tested in PySAL using randomly generated spatial permutations of the observed attribute values. The clustering is conducted on each permutation (999 permutations by default) and compared with the actual distribution to generate a pseudo-*p*-value that can be used to accept or reject spatial randomness [21].

Results

Demographic indicators

In 1439 Hijri (from September 20, 2017, to August 9, 2018), there were 638,208 people involved in at least one traffic accident in KSA. This number presents about 2% of the total population. With more than 350,000 traffic accidents in that year, there were about 11 injuries and 2 deaths in 100 accidents. However, the consequences were not evenly distributed among the different population groups (Table 1). More than 84% and 88% of those injured and killed in RTAs were male. Other indicators such as nationality, marital status, and literacy showed a consistent imbalance in favor of Saudis, married, and educated. The location of the accident, however, showed different patterns. The younger age group (under 30 years) showed a consistent rate of approximately 45% for all the previous attributes. This rate corresponds to

Table 1. Full descriptive statistics of the dataset.

Attribute	Indicator	Value	*N*	Mean	Percentage
RTA occurance	Number of accidents		352,464	1,836	100
	Location	Urban	255,254	1,329	72
		Suburban	97,210	506	28
Population involvement in RTA	Number of people involved in an accident		638,208	3,324	100
	Age group	0-18	69,729	363	11
		18-30	226,258	1,178	35
		30-40	178,479	930	28
		40-50	106,059	552	17
		50 +	53,843	280	8
	Age group	0-30	295,987	771	46
		30 +	338,381	587	54
	Nationality	Saudi	404,970	2,109	63
		Foreign	229,398	1,195	36
	Marital status	Married	385,513	2,008	60
		Single	248,855	1,296	40
	Literacy	Litarate	617,549	3,216	97
		Illiterate	16,819	88	3
RTA injuries	Number of injuries due to involvement in RTA		30,217	157	100
	Sex	Male	25,314	132	84
		Female	4,903	26	16
	Location	Urban	14,977	78	50
		Suburban	15,240	79	50
	Age group	0-18	4,339	23	14
		18-30	9,312	49	31
		30-40	8,001	42	26
		40-50	5,234	27	17
		50+	3,331	17	11
	Age group	0-30	13,651	36	45
		30+	16,566	29	55
	Nationality	Saudi	19,739	103	65
		Foreign	10,478	55	35
RTA mortalities	Number of mortalities due to involvment in RTA		6,025	31	100
	Sex	Male	5,295	28	88
		Female	730	4	12
	Location	Urban	1,959	10	33
		Suburban	4,066	21	67
	Age group	0-18	841	4	14
		18-30	1,958	10	32
		30-40	1,448	8	24
		40-50	827	4	14
		50+	951	5	16
	Age group	0-30	2,799	7	46
		30 +	3,226	6	54
	Nationality	Saudi	3,678	19	61
		Foreign	2,347	12	39

its 57% share in the total population [11], considering that this category includes infants and primary school students. Despite the unbalanced incidence rate between urban (72%) and suburban areas (28%), injuries were evenly distributed. In contrast, more than 67% of all-cause RTA mortality occurred in suburban areas.

Spatio-demographic dimensions of RTA

As shown in Table 2, the spatial distribution of demographic indicators was rather trivial. RTA involvement, mortality, and morbidity varied across the regions. Ar Riyad, Ash Sharqiyah, Makkah, and

Table 2. Spatial distribution of RTA attributes.

Region	Number of accidents (%)	Number of injuries (%)	Number of mortalities (%)	number of intact individuals (%)	Number of indiviuals involved in rta (%)
Ar Riyad	79,884 (22.7)	4,554 (15.1)	1,091 (18.1)	157,527 (26.2)	163,172 (25.6)
Ash Sharqiyah	45,077 (12.8)	2,969 (9.8)	661 (11.0)	91,365 (15.2)	94,995 (14.9)
Makkah	44,915 (12.7)	3,400 (11.3)	609 (10.1)	84,463 (14.0)	88,472 (13.9)
Jeddah	40,759 (11.6)	2,965 (9.8)	337 (5.6)	73,236 (12.2)	76,538 (12.0)
Aseer	25,964 (7.4)	2,192 (7.3)	696 (11.6)	47,197 (7.8)	50,085 (7.8)
Madinah	20,547 (5.8)	2,666 (8.8)	483 (8.0)	4,715 (0.8)	7,864 (1.2)
Jazan	19,572 (5.6)	2,112 (7.0)	563 (9.3)	30,593 (5.1)	33,268 (5.2)
At-Taif	18,299 (5.2)	3,566 (11.8)	355 (5.9)	24,196 (4.0)	28,117 (4.4)
Qaseem	17,510 (5.0)	1,269 (4.2)	225 (3.7)	31,672 (5.3)	33,166 (5.2)
Northern Region	10,705 (3.0)	428 (1.4)	75 (1.2)	19,771 (3.3)	20,274 (3.2)
Tabouk	10,034 (2.8)	977 (3.2)	293 (4.9)	8,635 (1.4)	9905 (1.6)
Hail	6,955 (2.0)	912 (3.0)	193 (3.2)	9,416 (1.6)	10,521 (1.6)
Al-Qurayyat	3,703 (1.1)	304 (1.0)	55 (0.9)	7,120 (1.2)	7,479 (1.2)
Al-Jouf	3,652 (1.0)	314 (1.0)	102 (1.7)	6,470 (1.1)	6,886 (1.1)
Najran	3,124 (0.9)	654 (2.2)	176 (2.9)	2,718 (0.5)	3,548 (0.6)
Al-Baha	1,764 (0.5)	935 (3.1)	111 (1.8)	2,872 (0.5)	3,918 (0.6)
Total	352,464	30,217	6,025	601,966	638,208

Jeddah were among the top 25%, which scored high in all attributes of the study, except mortality, where Jeddah scored higher than average. In contrast, Al-Baha, Al-Jouf, and Najran were consistently in the lowest 25% percentile.

These patterns became redundant when regional RTA numbers per capita were calculated. RTA incidence and involvement per capita in Ar Riyad and Ash Sharqiyah were below average and in the bottom 25% of regions with injuries and deaths per capita. Similarly, Al-Qurayyat, Northern Region, and Al-Taif, which performed well in absolute values, had significantly high involvement, injury, and mortality per capita. Jazan and Aseer scored above average in all cases, and Makkah was the only region that was in the top 25% of regions in terms of occurrence and involvement as absolute values and per capita. The full comparison between absolute RTA rates and RTA rates per capita is shown in Figures 1-4.

The distribution of age groups was significantly homogenous in all regions. In terms of involvement in RTAs, all regions had a similar distribution to the national average, except Al-Qurayyat, where almost 80% of the involved population was younger than 30 years. The Northern Region and Tabouk also had a much higher proportion of the young population (60%). A similar pattern emerged for injuries: In Al-Qurayyat, the younger population accounted for 70% of the injuries, followed by Asser, Al-Baha, and the Northern Region with 60% in the younger generation. RTA mortality was the only attribute with an opposite tendency for the older generation who had a higher representation. Although the senior age groups (50+ years old) were more represented on this attribute in all regions, the average age at death due to RTA in the Makkah region was 43 years. The older generation, 30 years and older, accounted for 70% of mortality in Makkah. An opposite trend was observed in Al-Qurayyat and Al-Jouf regions: The mortality rate in the younger population was just below 60%. The regional distribution of age groups is shown in Figures 5-7.

Another critical dimension related to space is the causes of the RTA (Figure 8). Nationally, only 35% of accidents were due to a violation. The remaining accidents were attributed to "pedestrian and infrastructure-related causes" (40%) and speeding (25%). In 50% of regions, the cause of most crashes was originally reported as "other," defined by the data source as pedestrian and infrastructure-related. In these regions, Al-Baha, Al-Jouf, Ash Sharqiyah, Al-Taif, Jeddah, Makkah, Northern Region, and Tabouk, more than 60% of all accidents occurred due to other causes. A small number of accidents in these regions were attributed to violations (less than 5%) and speeding, ranging from 8% to 30%. In Hail, Aseer, and Jazan regions, the main cause of accidents was excessive speed. In two regions (Ar Riyad and Qassim), the trend was different from the other regions and the national average. In these two regions, most of the accidents were due to traffic violations.

RTA spatiotemporal patterns and trends

Table 3 shows that there were no significant temporal patterns in daily occurrence rates at the national level. Similarly, there was no significant difference between RTA incidence on weekdays and weekends. Differences between daytime and nighttime were significant, with more accidents occurring during the day. The national temporal patterns are displayed in Figure 9. At the regional level, the difference between the occurrence of RTA on weekends and weekdays, varied between 17% and 20%, except for Al-Qurayyat, where there were 27% fewer accidents on weekends, and Aseer, where the number of accidents increased by 50% on weekends. In terms of the day/night difference, most regions showed a significant decrease in accidents at night, ranging from -12% in Ar Riyad to -55% and -82% in Aseer and Jeddah,

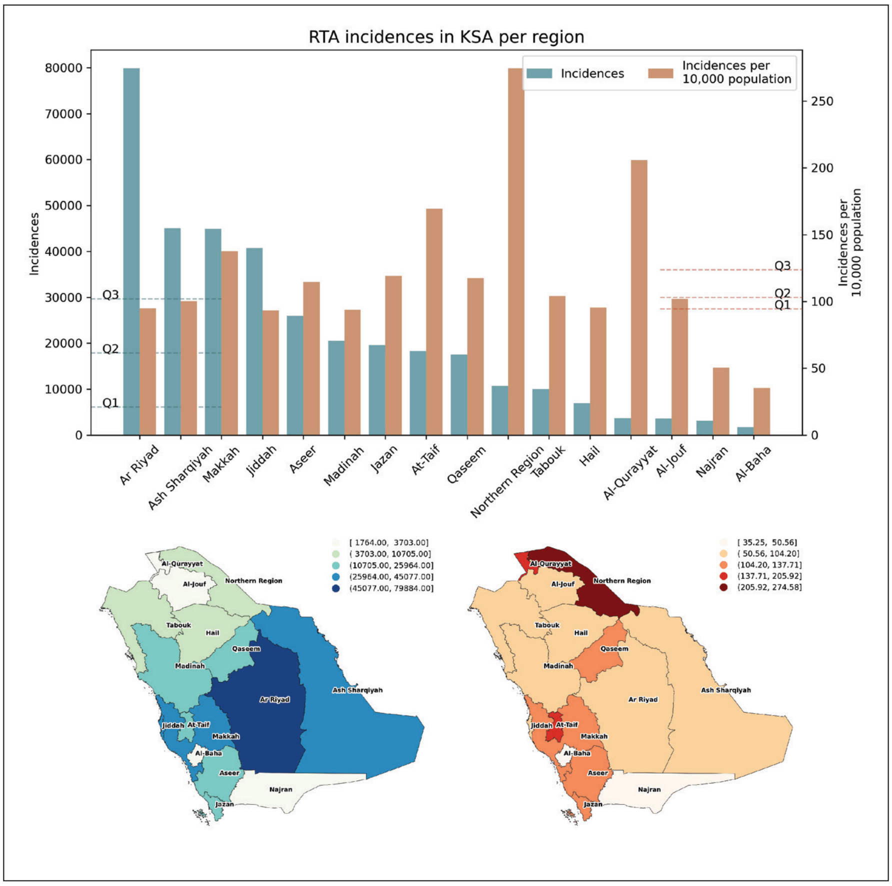

Figure 1. RTA incidences in KSA.

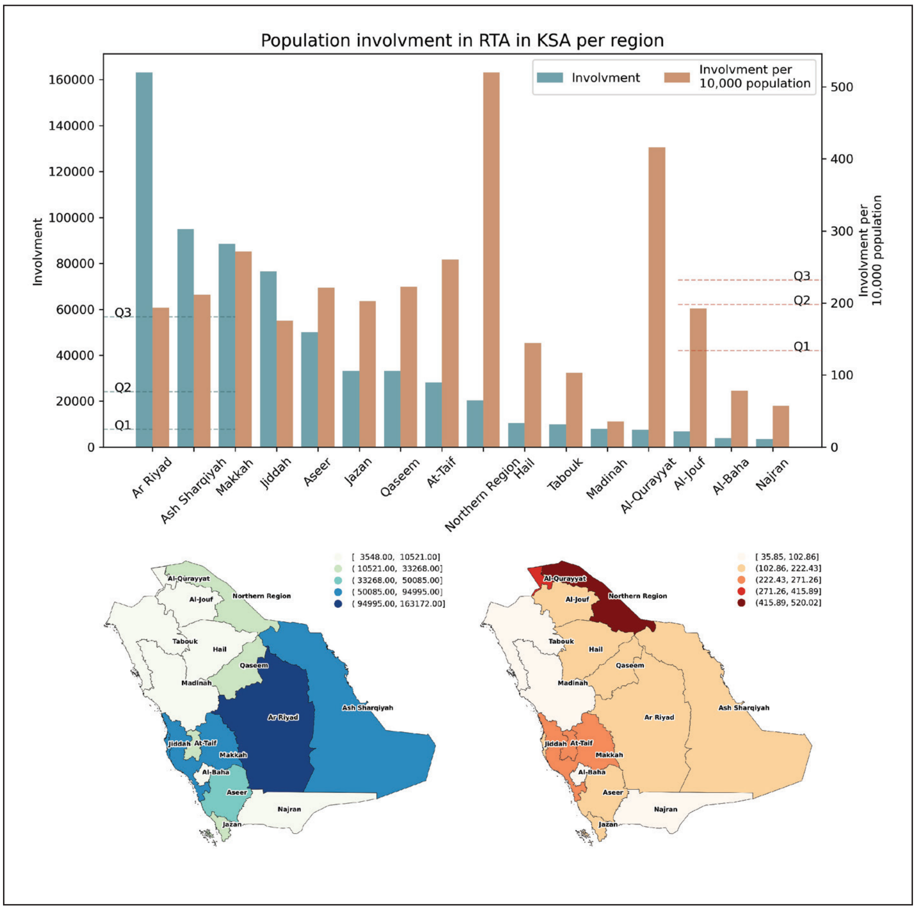

Figure 2. *Population involvement in RTA in KSA.*

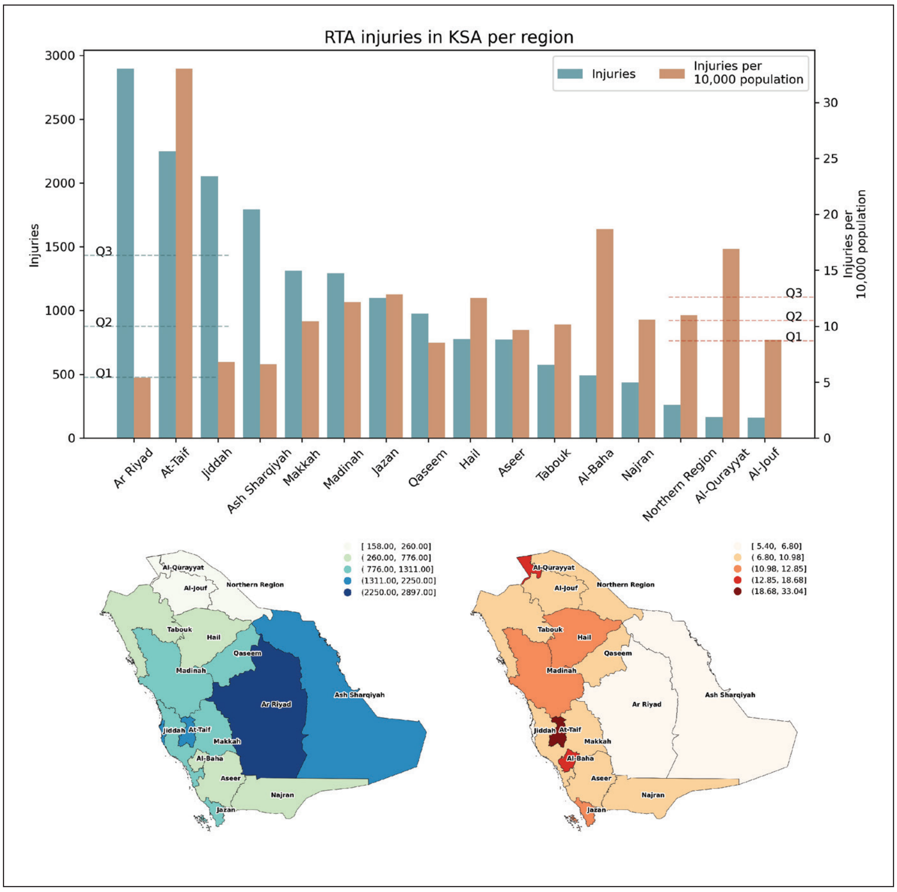

Figure 3. RTA injuries in KSA.

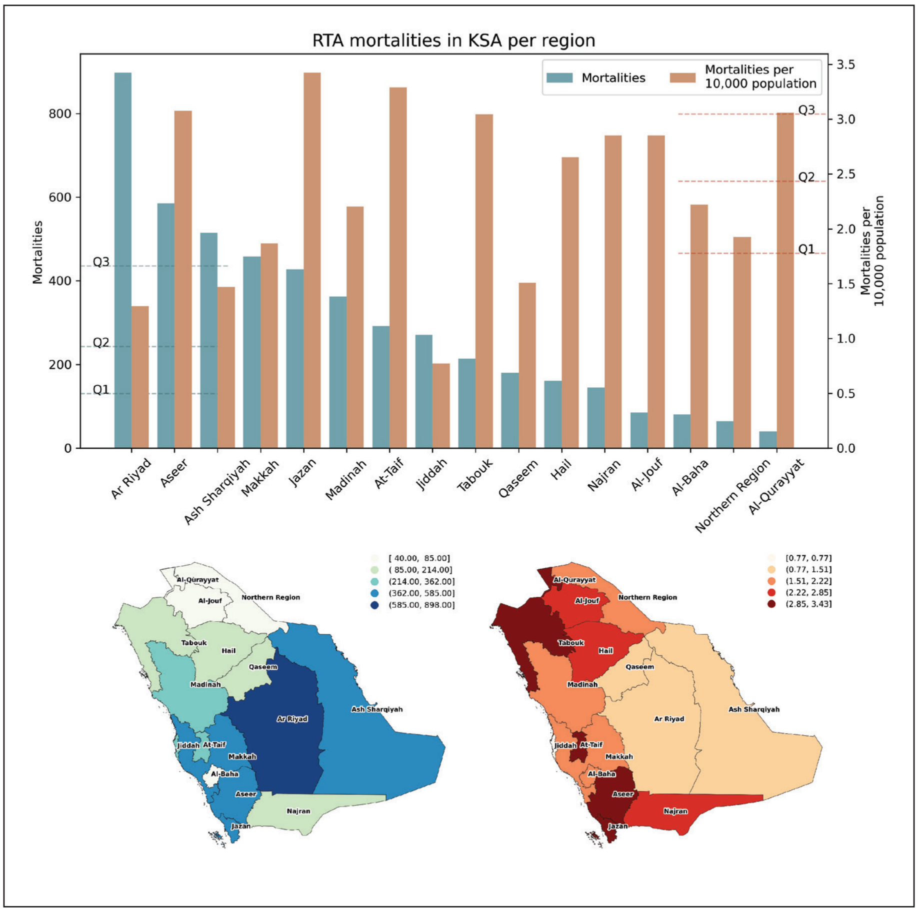

***Figure 4.** RTA mortality in KSA.*

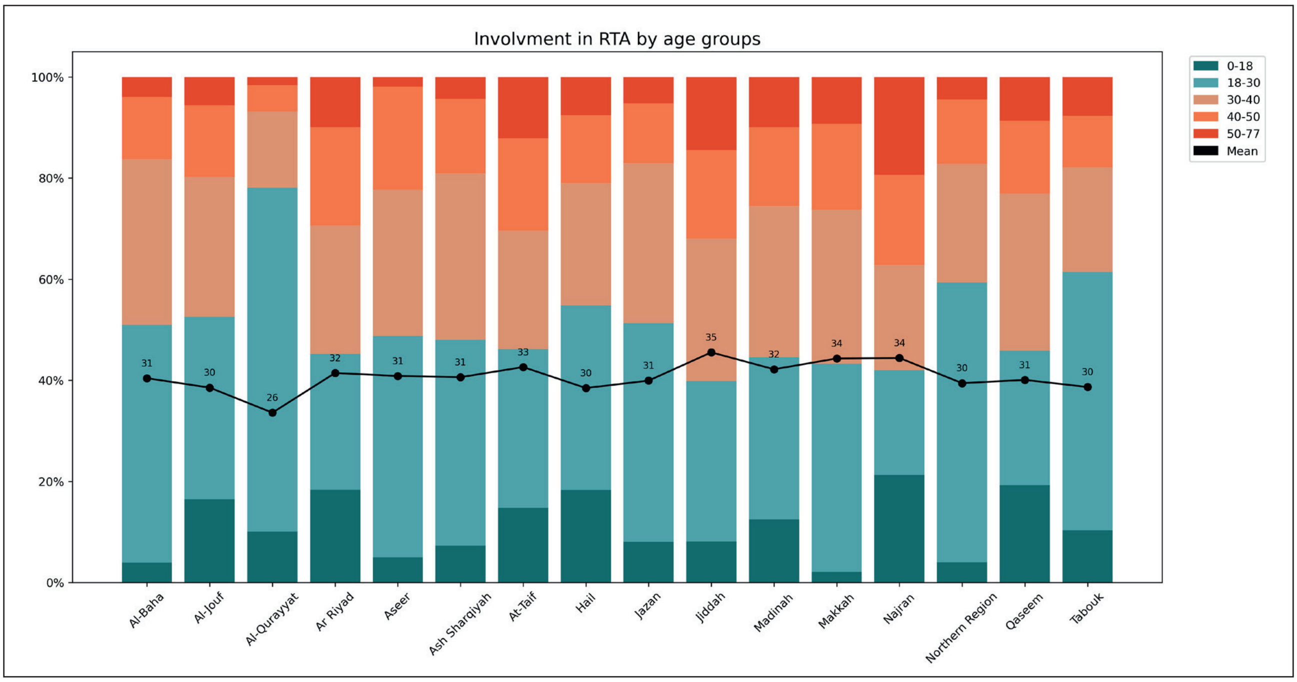

Figure 5. *Regional population involvement in RTA by age group.*

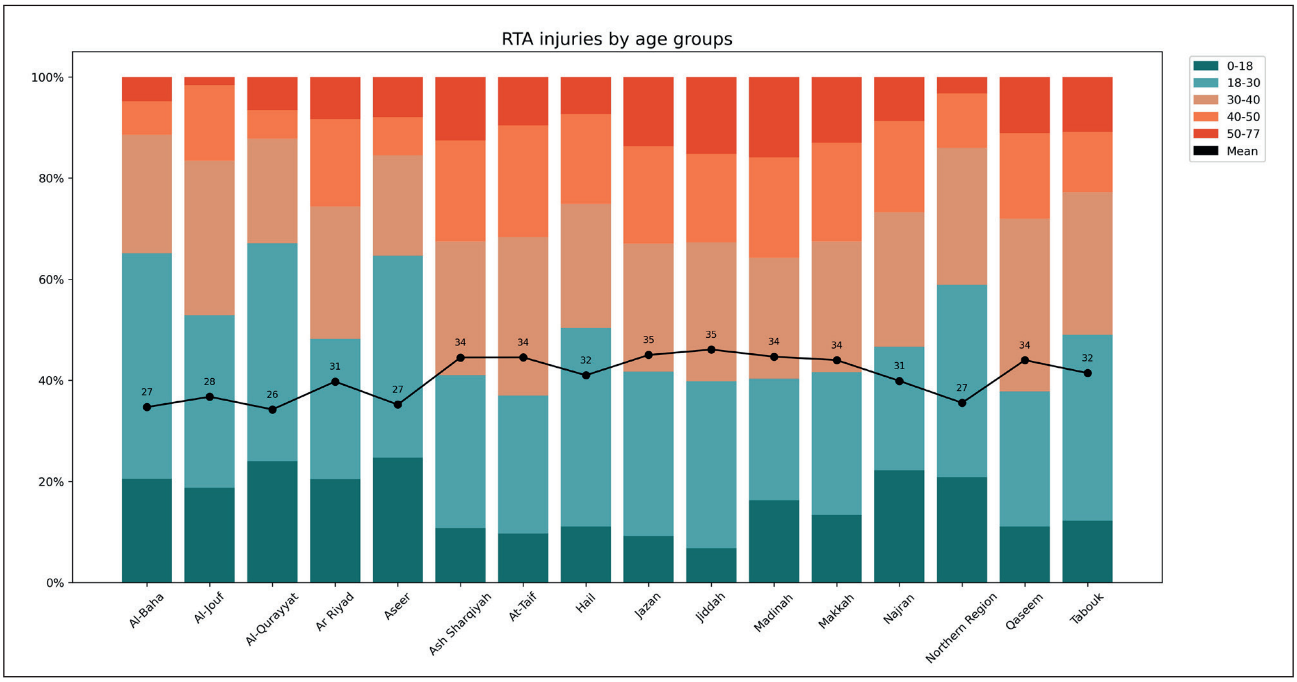

Figure 6. *Regional RTA injuries by age group.*

respectively. Only three regions recorded an increase in accidents during the night. Madinah and the Northern Region recorded a 12% and a 15% increase in evening accidents, respectively. In Al-Qurayyat, the number of nighttime traffic accidents increased by as much as 253%. Figures 10 and 11 show a comparison between regional accident occurrence per day/night and weekday/weekend.

LISA clustering and hotspot analysis results

Local Moran's *I* clustering revealed limited, but statistically significant (at the 95% level), RTA hotspots and coldspots for all months of the year (Figures 12-14). Ar Riyad was the only permanent hotspot for all attributes. In addition to Ar Riyad, Ash Sharqiyah was a hotspot for RTA occurrences during the first 5 months of the year and a consistent hotspot for RTA deaths for 11 months. Al-Hijaz province (Makkah, Al-Taif, Jeddah, Al-Baha) was a hotspot for RTA injuries in the second half of the year, except for the month of Shaban, when only Jeddah and At-Taif were hotspots. The Northern Desert Province (Northern Region, Al-Qurayyat, Al-Jouf, and Tabouk) was a constant

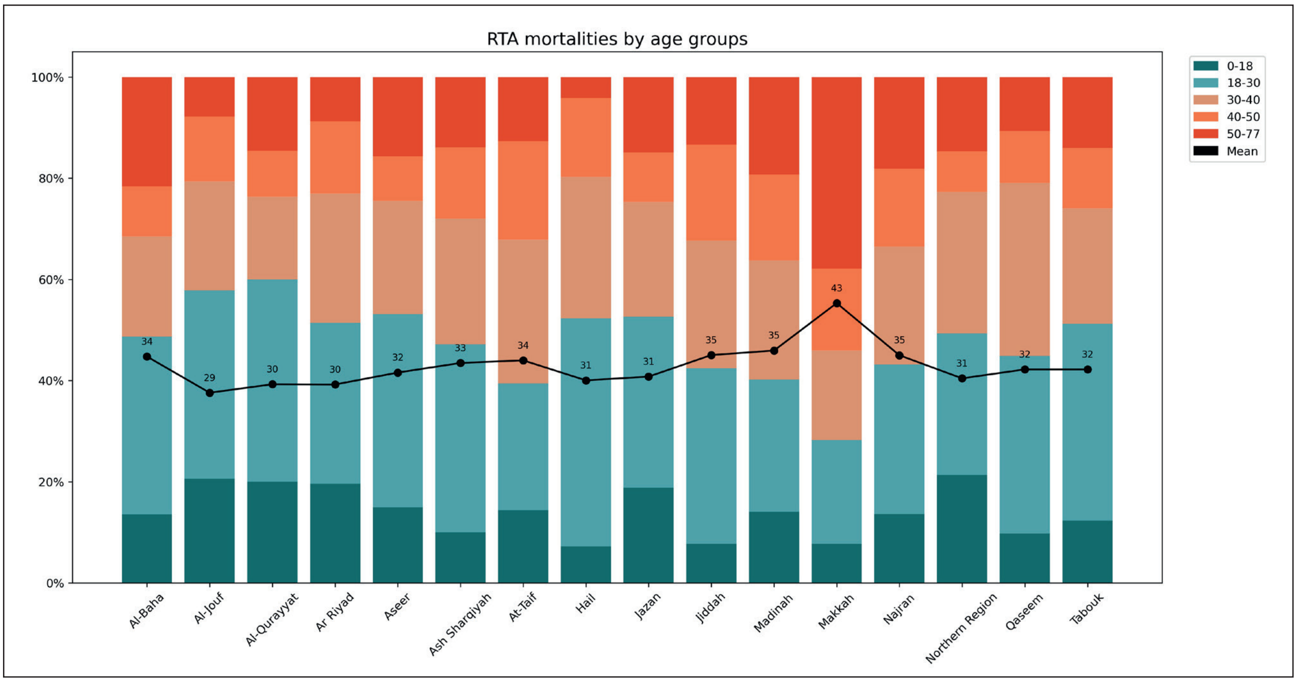

Figure 7. *Regional RTA mortalities by age group.*

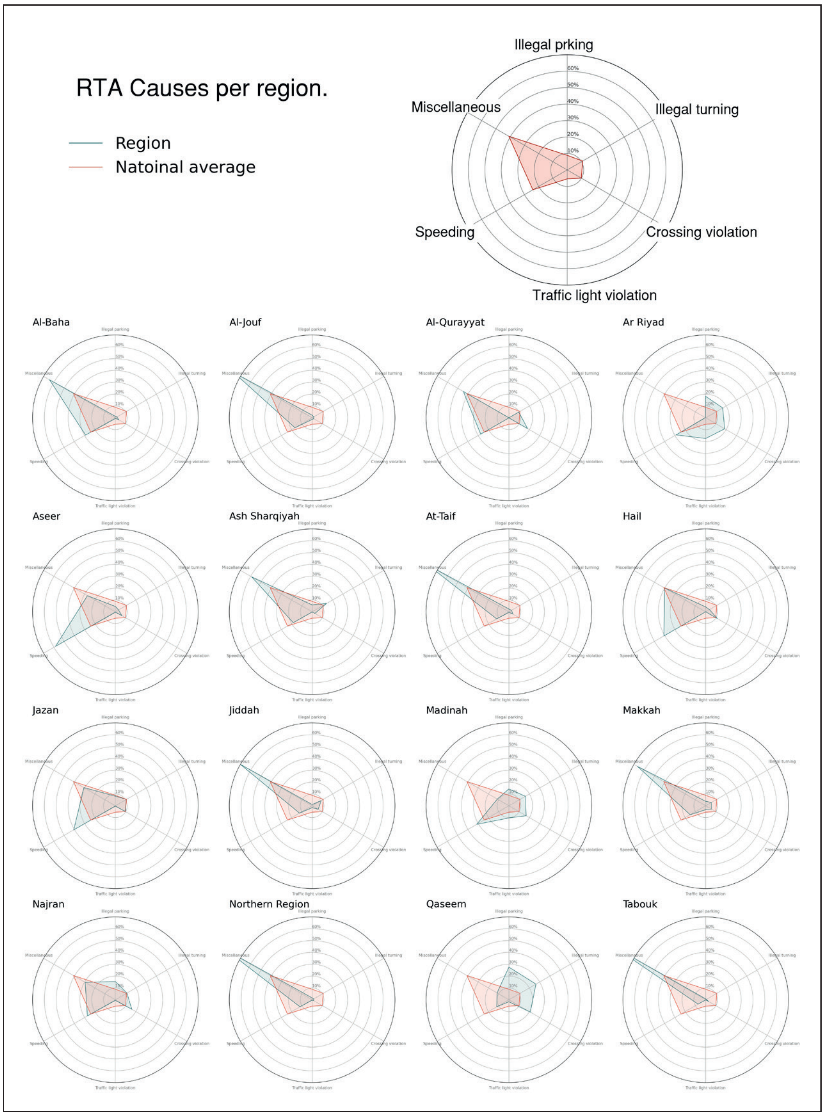

Figure 8. *Regional causes of RTA in KSA.*

Table 3. Summary statistics of RTA occurrence in the analyzed time units for each observation.

Time unit	Count	Mean	Std	Minutes	25%	50%	75%	Max	Sum
Day	192	1134.57	1231.46	54	216	758	1312.5	4896	217,838
Night	192	701.18	803.22	19	229.5	473	721	3920	134,626
Workdays	768	258.38	268.66	0	56	181.5	294.25	1434	198,438
Weekends	384	265.47	295.99	9	51.5	177	317	1481	101,941
Sunday	192	271.28	302.65	11	68	175	285.75	1436	52,085
Monday	192	264.88	279.8	0	58.75	184.5	301	1434	50,856
Tuesday	192	251.47	262.68	9	59.75	176	280.5	1122	48,283
Wednesday	192	250.43	261.11	7	52	177	288.5	1140	48,082
Thursday	192	266.76	273.01	0	52	199	318.25	1139	51,217
Friday	192	257.14	280.93	10	44.75	179.5	313.5	1481	49,370
Saturday	192	273.81	311.59	9	56.5	174	310	1427	52,571

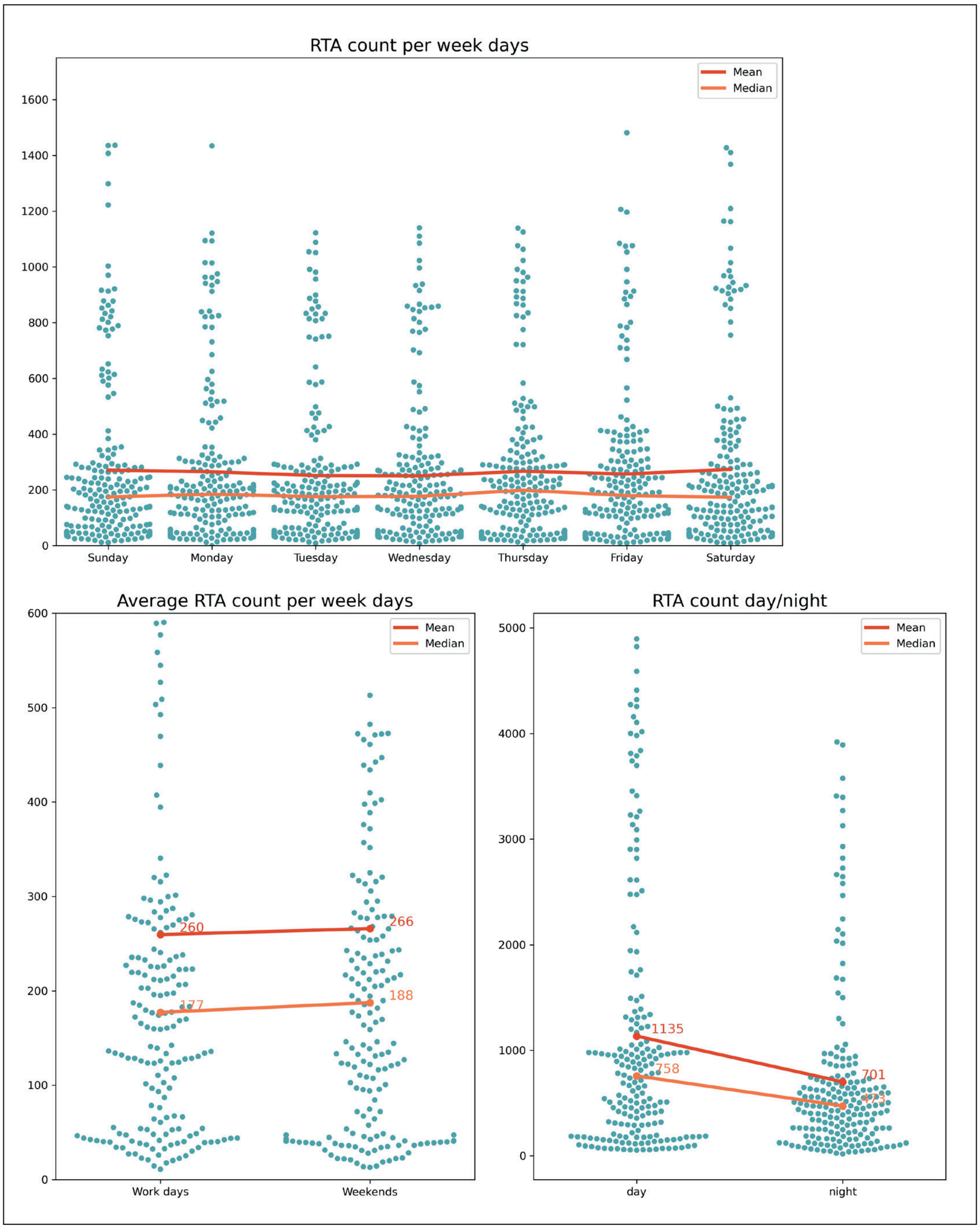

Figure 9. Temporal patterns of RTA in KSA.

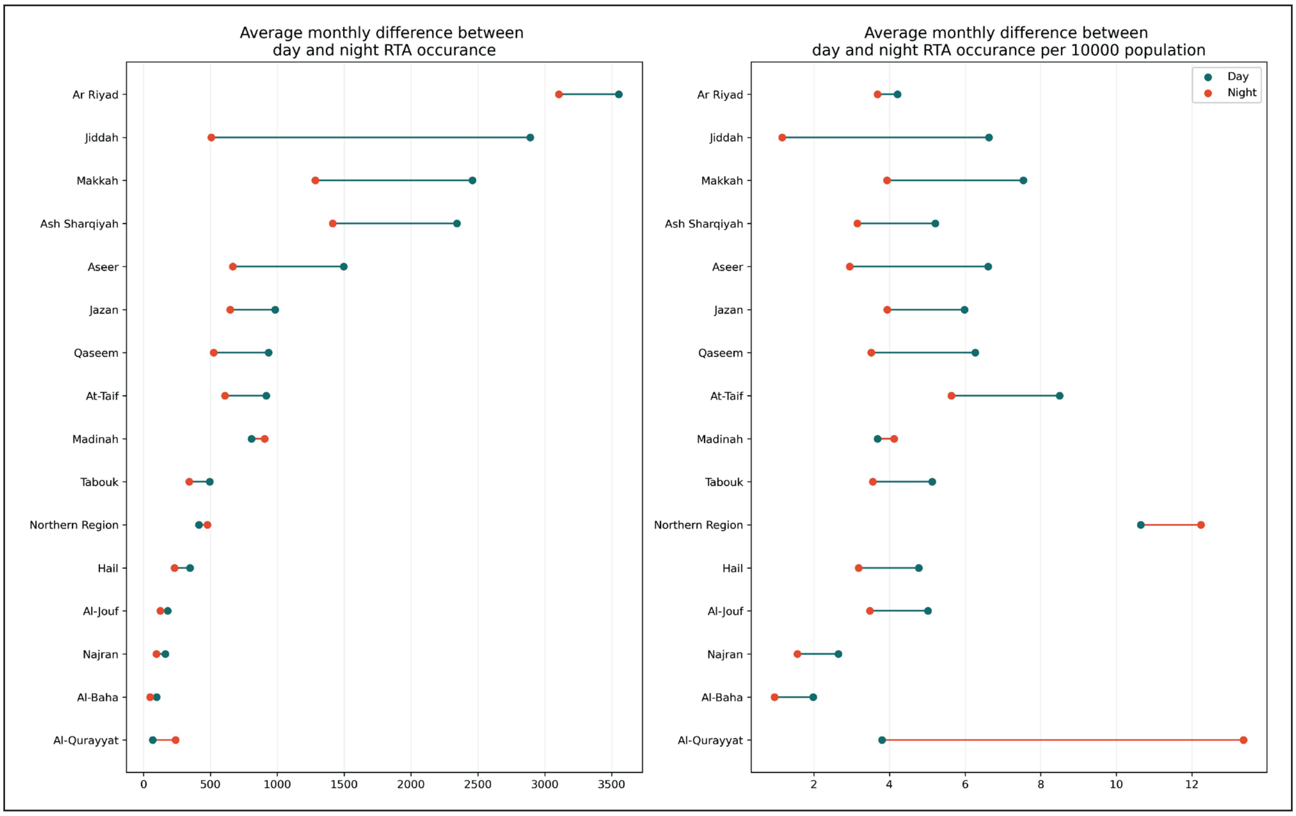

Figure 10. *Difference between average monthly regional RTA occurrence during day and night.*

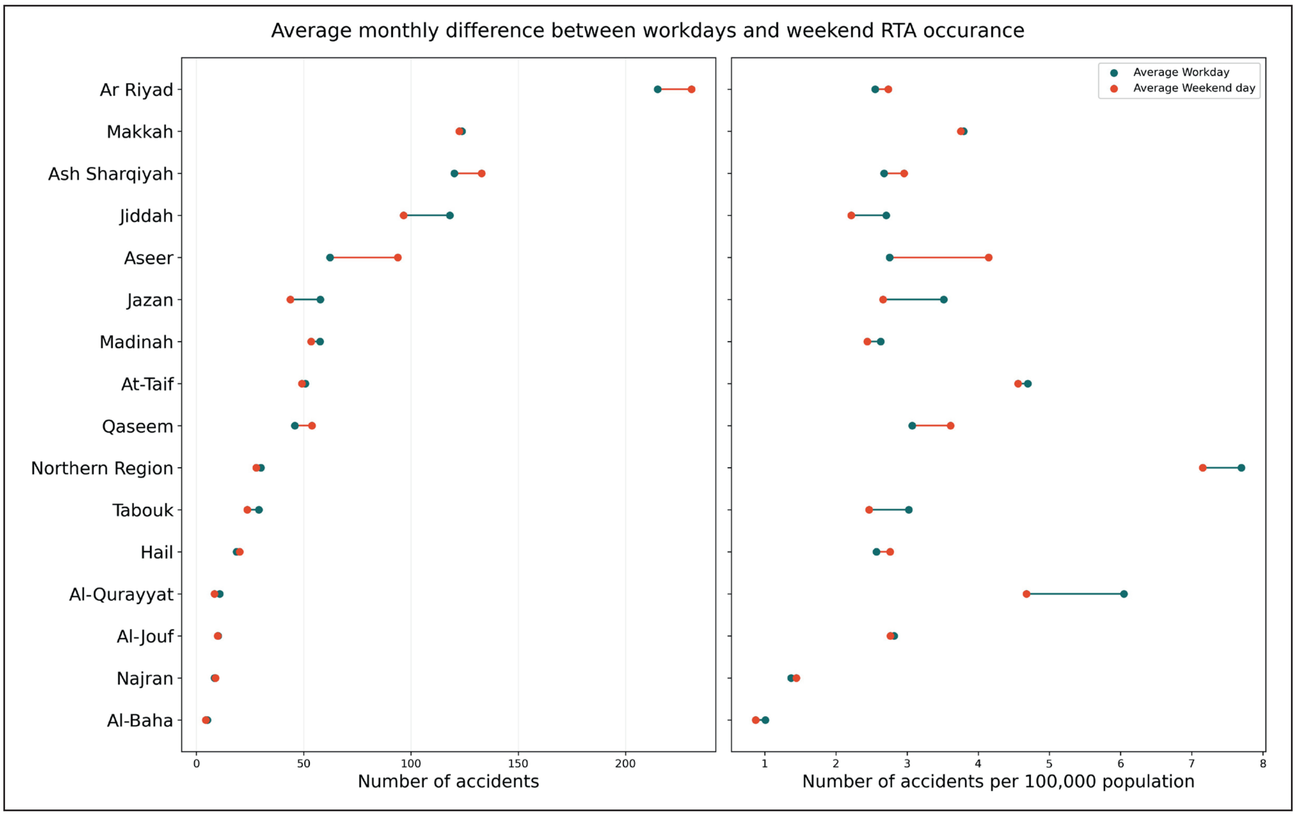

Figure 11. *Difference between average monthly regional RTA occurrence during workdays and weekends.*

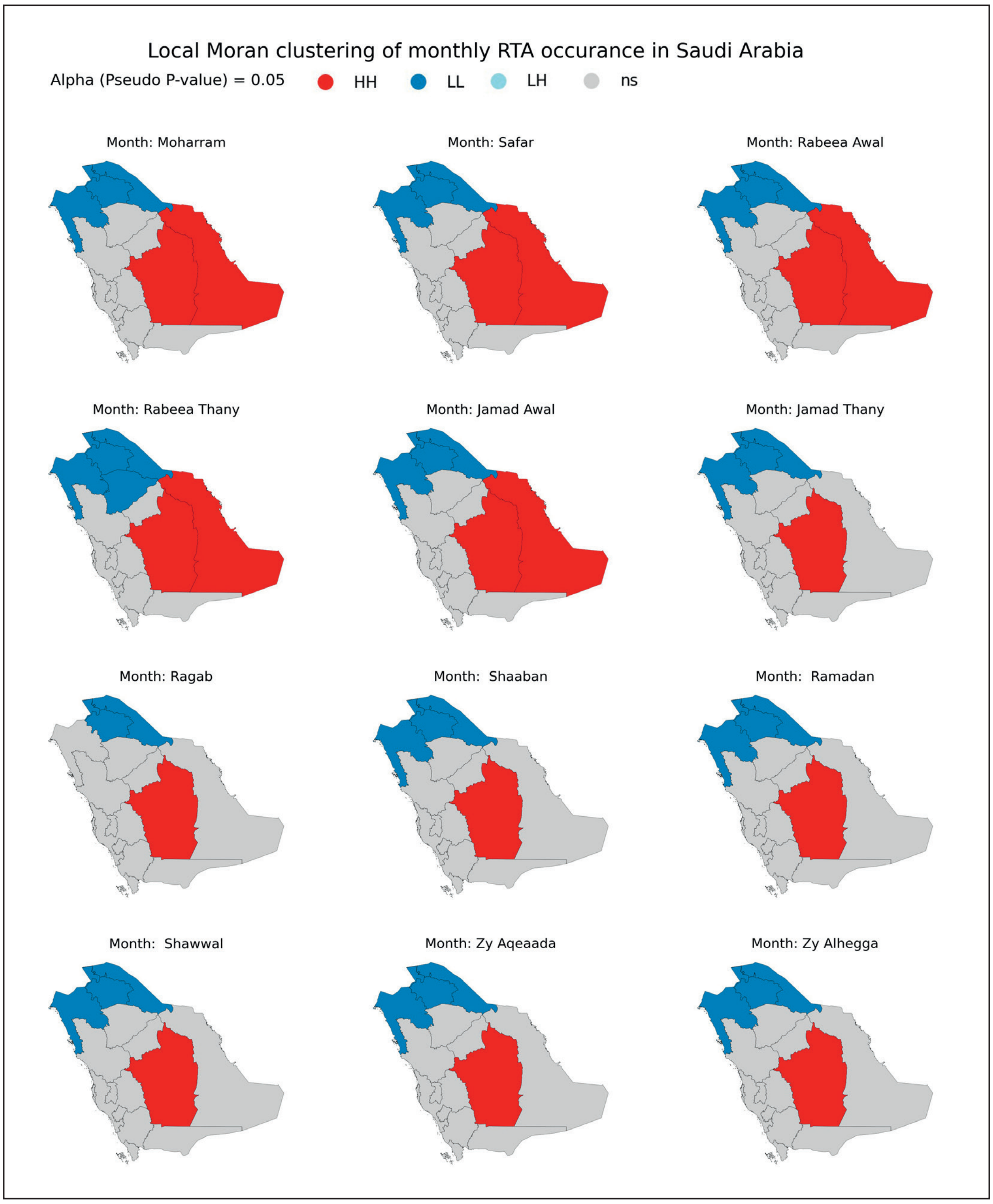

Figure 12. *LISA clustering for monthly RTA occurrence.*

coldspot for RTA occurrences, injuries, and deaths throughout the year.

Clustering results were more implicit and contradictory when each attribute was presented per capita (Figures 15-17). The Northern Region and Al-Qurayyat were both permanent hotspots in terms of RTA occurrence per capita. The Najran region was a coldspot for RTAs in the first 6 months of the year, and the Ash Sharqiyah region was a coldspot in only two individual months. Al Taif region remained a hotspot in terms of RTA injuries throughout the year, and Al-Hijaz province was a hotspot in Zy Alhegga month. In contrast, the Ar Riyad and Ash Sharqiyah regions were permanent RTA injury coldspots, and the Makkah region was a low-high spot in two different months. Finally, per capita mortality was inconsistent across the RTAs. The Ar Riyad and Jeddah regions were coldspots for five and three separate months, respectively. Al Qurayyat region was a hotspot for 5 months, and Tabouk, Jazan, and Aseer regions were hotspots for 3 months each. The Northern Region and Al-Qurayyat were coldspots for only 1 month.

Discussion

This study investigated the geographic distribution of the incidence rate of RTAs and morbidity and mortality in Saudi Arabia. The significant decrease in the incidence of RTAs in the Makkah region during the last 6 months of the year may be related to traffic congestion in the city during Ramadan, a holy month for Muslims, and the "Hajj" (pilgrimage) season. During these religious events, more than 2 million pilgrims from all over the world come to the Makkah region every year. In addition, vehicles are normally prohibited from entering the Holy

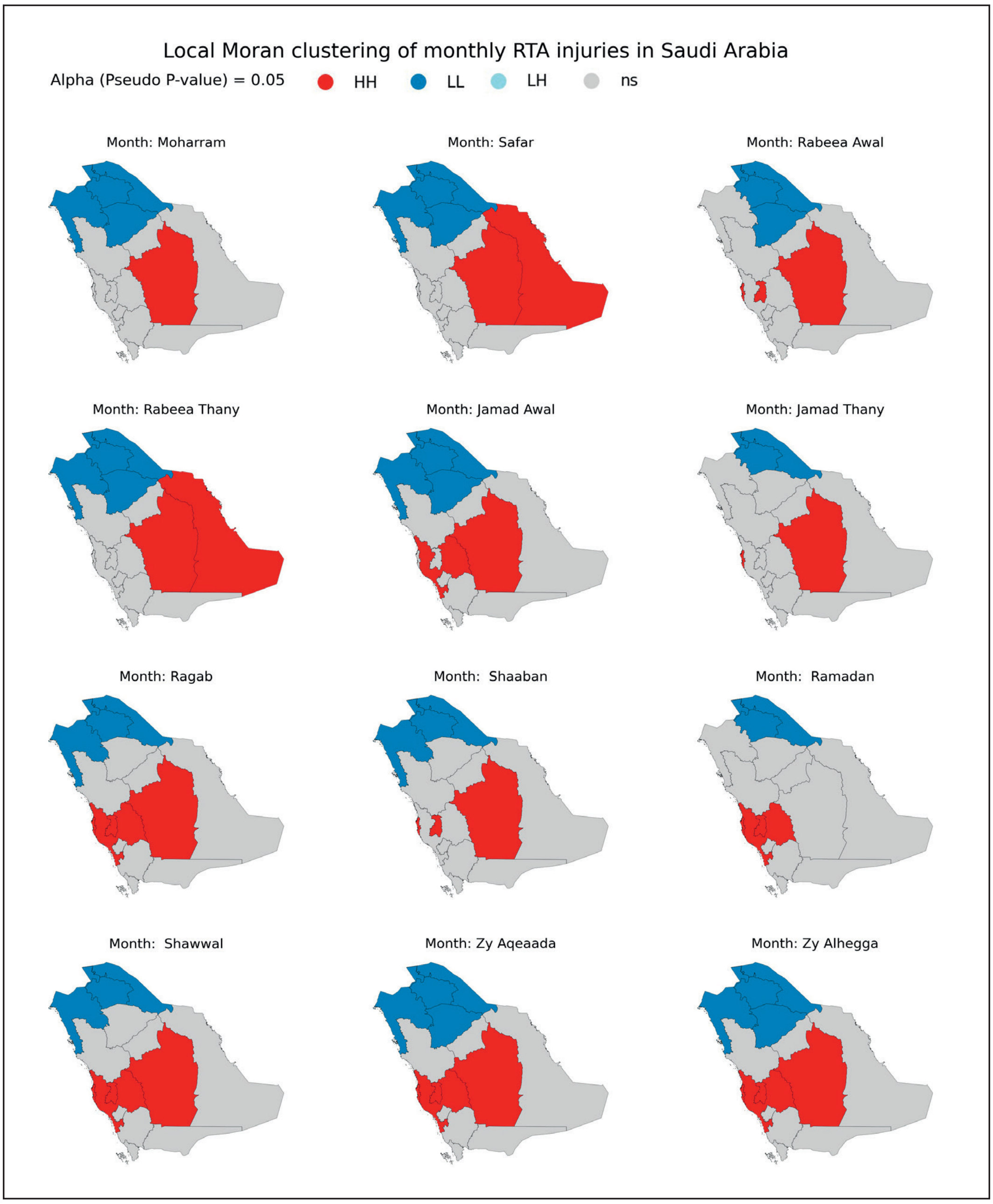

Figure 13. *LISA clustering for monthly RTA injuries.*

City to relieve traffic during the Hajj season and the last holy days of Ramadan. The decrease in RTAs may be due to the extensive planning process that the Saudi government conducts each year during Ramadan and the Hajj season in Makkah to ensure the safety of pilgrims and visitors, with more than 350,000 workers employed in the pilgrimage service [22]. In the Eastern Region, more RTAs were observed during the first 6 months, which are the peak tourist seasons (winter, spring, and early summer), resulting in a large influx of visitors [23].

Almost two-thirds of the accidents in Saudi Arabia involved age groups between 18 and 40. This trend could be related to the relatively young Saudi population, according to a Saudi Statistics Authority report, as well as the risky behaviors of young adults, who do not wear seatbelts and disregard traffic rules. The population of Makkah is relatively older than that of other areas in Saudi Arabia [24], which is reflected in the results of the median age of RTA mortalities in the Makkah region. Al-Qurayyat, the Northern Region, Tabouk, Asser, and Al-Baha had much higher involvement and injury rates in the young population. One possible reason is the tendency of the population living in these areas to drive at a younger age and before officially obtaining a driver's license. More motor vehicle accidents occurred in urban areas of Saudi Arabia. However, fatality statistics showed that urban areas were not statistically more dangerous than suburban areas. There were more injuries and deaths in the suburban areas. Although there are fewer cars in these areas, there may be different driving behaviors, high-speed roads, more large trucks on the road, underdeveloped infrastructure, less stringent regulations, and limited access to medical care. In Al-Qurayyat and the Northern Region, there were inconsistent patterns in

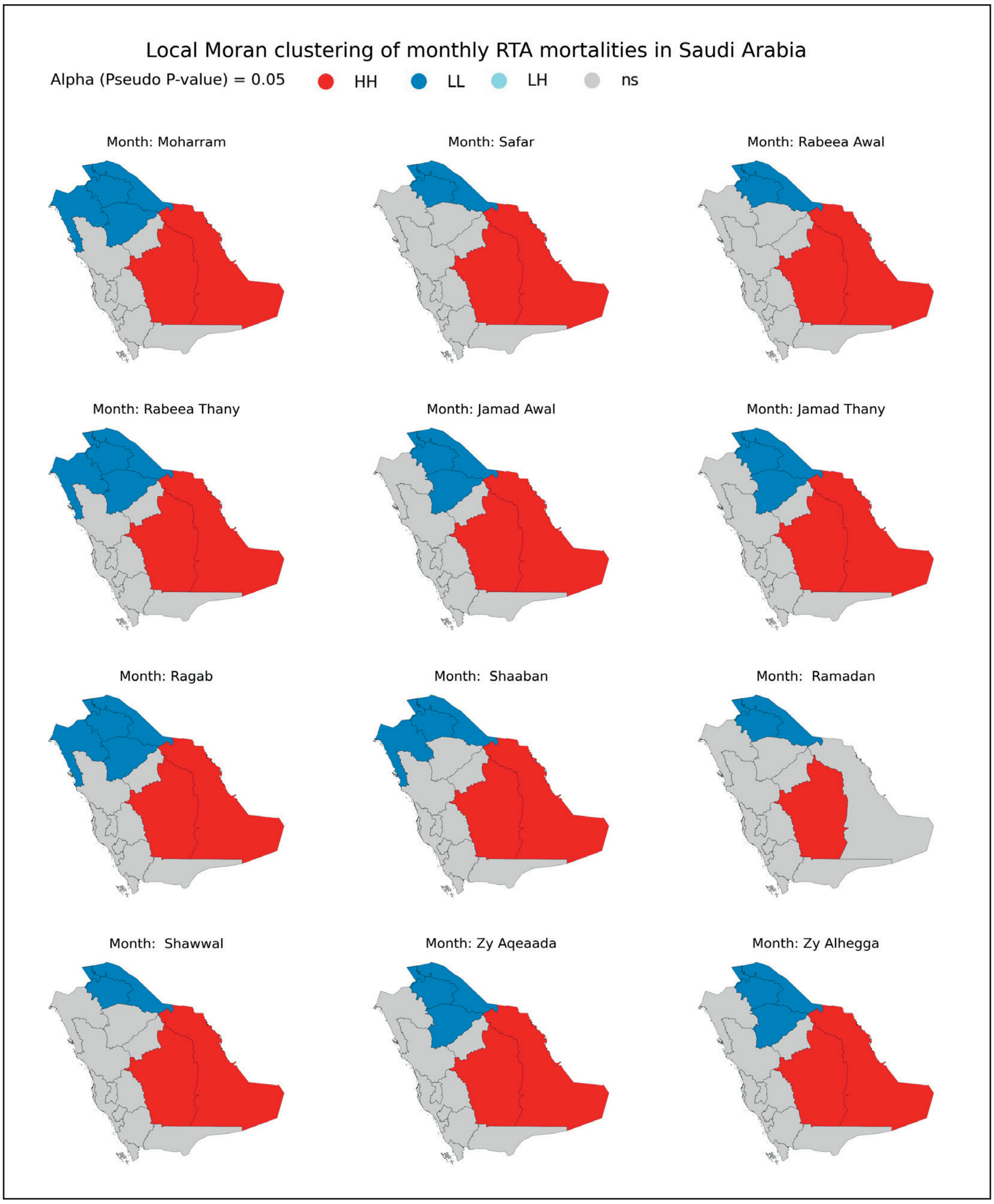

Figure 14. *LISA clustering for monthly RTA mortalities.*

several areas compared to the other areas for unknown reasons. These areas also reported higher injuries and deaths, involvement of a younger population in RTAs, more injuries and mortalities in the younger groups, and more accidents at night. This could also be related to infrastructure and less access to advanced health services in these areas.

Almost 12% of mortality in Saudi Arabia is caused by RTA [25], and it is the second leading cause of death in the country [26]. RTA patients occupy one-third of the beds in Saudi hospitals [27]. However, there are insufficient data on RTAs because there is no literature on the epidemiology of RTAs showing the distribution and causes of accidents in the country. This study shows that Riyad, Ash Sharqiyah, Makkah, and Jeddah are among the 25% of regions with the highest RTA scores, which is in line with a systematic review by Mansuri et al. [26] on RTAs in Saudi Arabia. Their study concluded that Riyadh, Jeddah, Makkah, Madinah, and Qassim are the top regions in the country in terms of RTAs. The LISA clustering for the monthly occurrence of RTA in this study showed that more RTAs occurred in Al Sharqiyah in Jumad Thany than in other months. Similarly, a study conducted in AlAhsa, the largest city in Al Sharqiyah, reported that 13.7% of accidents occurred during Jumad Thany [28].

According to our study, two-thirds of RTAs were caused by the 18-40-year-old-age group 18-40 years. This finding corresponds to a study of trauma patients arriving at a large tertiary center in Riyadh, according to which 64% were between 20 and 39 years old [29]. In the Saudi Arabian literature, the most common injuries in RTAs occurred in patients in their second and third decades [26,30]. The mean age of RTA patients was 29

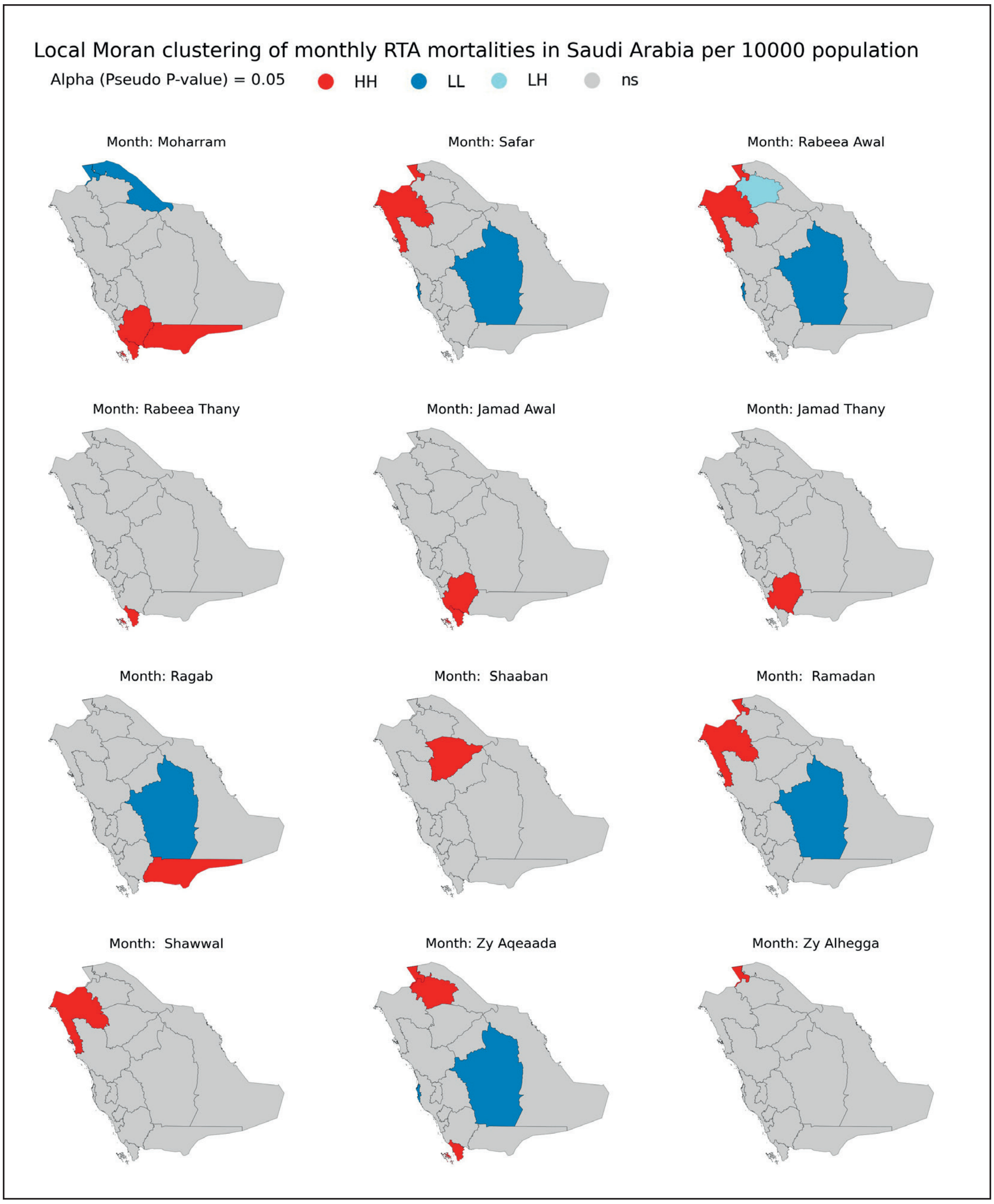

Figure 15. *LISA clustering for monthly RTA occurrence per capita.*

± 2 years in studies conducted in Riyadh [29], Aseer [31], Najran [32], Hail [33], Eastern Province [34], and Tabuk [35]. The studies are consistent with the average age group in this study. In line with a study by [36] on the prevalence of risky driving habits in Riyadh, both studies showed that violation of traffic regulations in the city was the main reason for RTAs. The difference between the average monthly occurrence of daytime and nighttime RTA in Alqurayyat and the Northern Region was similar to other areas. In these areas, RTAs occurred more frequently at night. Similarly, a study conducted in a hospital in the Northern Region, reported most of the RTAs occurred in the early morning hours, after midnight [37]. The same study concluded that speeding was the most common cause of an RTA in the Northern Region, which is inconsistent with the finding of this study that the most common cause of an RTA was related to pedestrians and infrastructure.

International literature with similar objectives to the current study is available. Mahata et al. [38] analyzed the trends and patterns of RTAs in India between 2000 and 2015, as well as the specific RTA patterns in 2015 in cities with populations over 2 million. The results showed an upward trend in the exponential growth curve of RTA incidence between 2000 and 2015; however, the spatiotemporal analysis of the RTA severity did not reveal a direct relationship between the number of accidents and the severity. However, the citywide analysis of the RTAs yielded similar results to our study. First, discrepancies in mortality by RTAs were evident, with the highest incidence in Delhi, followed by Chennai. However, this study found that although the incidence of RTAs was highest in Mumbai, the severity of RTAs was negligible, as only 2.6% of these accidents were severe. In Surat and Nagpur, although the frequency of RTAs is much lower than in other cities, the severity of accidents and the

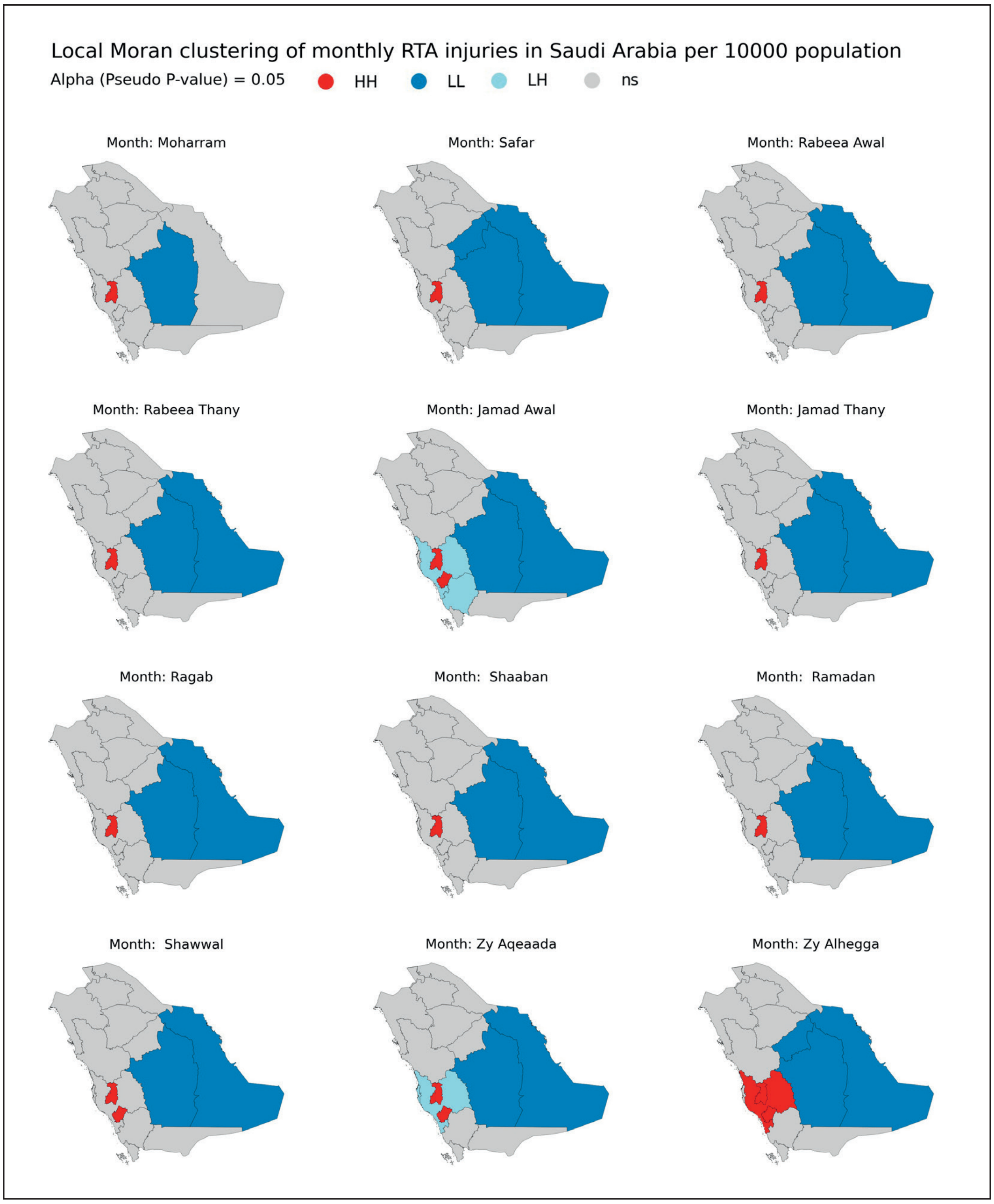

Figure 16. *LISA clustering for monthly RTA injuries per capita.*

number of fatalities are higher. The results regarding the individuals involved in RTAs confirm the results of our study. We found that the average age groups were lower in the areas with high mortality and injury frequency. Mahata et al. [38] found that the proportion of individuals involved in RTAs was primarily concentrated in the broad age group of 14-45 years in all cities examined in this study.

The findings of our study in terms of average age groups involved in RTAs are also corroborated by the WHO 2013 Global Burden of Disease study. This study found that more than half of all RTA mortality occurs in the 15-44-year-old age group [39]. Le et al. [40] also examined the incidence of RTAs using a spatiotemporal analysis in Hanoi, Vietnam. Due to the drastic change of seasons in Vietnam, the study divided the analysis into the four seasons of weather conditions in Hanoi, in addition to different time intervals, including daytime, nighttime, and peak hours. The first notable finding, confirmed by our findings, is the severity of RTAs as a function of time of day, with Le et al. [40] recording a high severity index during the night (6:00 to 11:59 pm), compared to the daytime. The seasonal factor contributed directly to the accident severity index, with a high severity index being more prevalent in the winter months. The reverse was true in the summer months. This analysis also identified several hotspots, which were primarily concentrated in the intersections in the center of Hanoi and also near illegal crossroads and railroad stations. The current literature also highlights that the frequency of RTAs during rush hour, particularly in the UK, is decreasing due to increasing traffic congestion. Wang et al. [41] provide evidence to support this hypothesis that increased traffic density may have a positive impact on road safety,

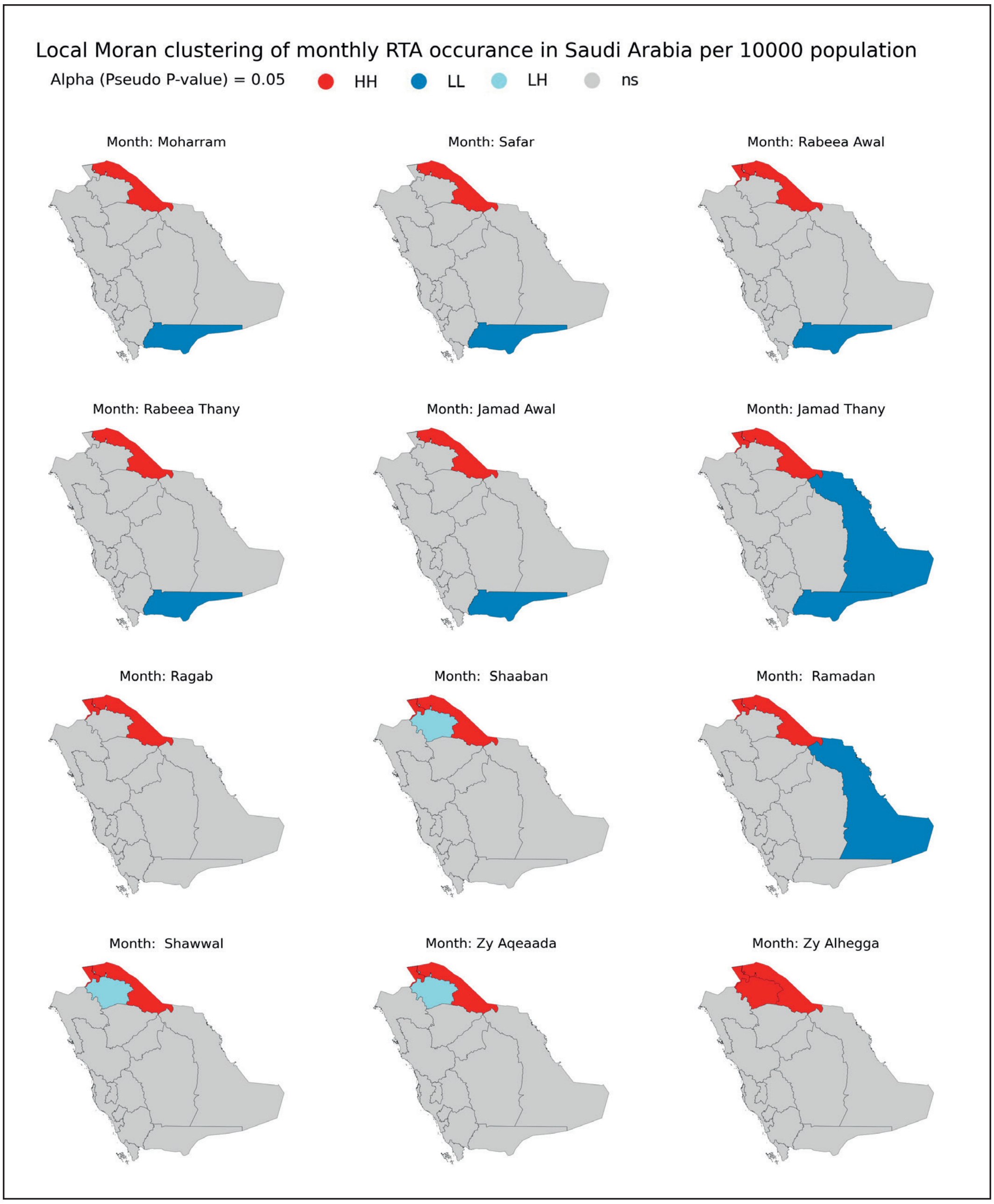

Figure 17. *LISA clustering for monthly RTA mortalities per capita.*

as the incidence of mortality and morbidity resulting from RTAs would be lower due to the low average speed during congestion.

Several studies have reported reasons for differences in the frequency and severity of RTAs. First, in industrialized countries, the incidence of RTAs and resulting mortality have declined dramatically since the mid-1900s, due to seat belt safety laws, enforcement of speed limits, and safer design and use of both roads and vehicles. Kopits and Cropper [42] presented statistical evidence that RTA mortality decreased by 27% in the United States and 63% in Canada between 1975 and 1988; however, in developing countries, RTA mortality increased during the same period, by 44% in Malaysia and by 243% in China. From the results of this study and the current literature, it is evident that variations in the frequency and severity of RTAs are present. This is to be expected since each country has different traffic patterns depending on working hours, population size, and different landscapes.

The present study has some limitations. First, due to the retrospective nature of the study, the research team had to rely on external sources to obtain accurate and reliable records, and the data may be incomplete or there may be an underreporting issue. In addition, because this is an ecological study, data on confounding factors are lacking and there is a possibility that provinces differ systematically in how they measure, record, report, and classify exposure. The classification of RTA mortality did not follow the internationally recommended definition of a fatal RTA which includes a 30-day follow-up period. The main limitation of the analysis was the spatial and temporal resolution of the data aggregation. Data were spatially aggregated at the regional level, treating regions such as Ar Riyad and Ash Sharqiyah, which are larger than Germany and France, as individual units. The higher temporal resolution would have yielded more accurate results on patterns of RTA occurrence and the putative impact of religious events on the issue.

This review and epidemiological study of all aspects related to reported RTAs highlights neglected areas in the prevention of RTAs, including solving young driver behavior, focusing on post-accident care, including pre-hospital and in-hospital care, following up on the consequences of RTAs, improving infrastructure in areas where the causes of RTAs are related to infrastructure, availability of more detailed open data from government agencies, and producing more literature on RTAs in the country. Saudi Vision 2030 was presented in response to the urgent need to pave the way for Saudi Arabia's future. One of the pillars is to create a vibrant society with a fulfilling life. To achieve this, it was necessary to ensure road safety by supporting efforts to reduce traffic accidents and their severity. Vision 2030 led to an increase in gasoline prices and the implementation of a value-added tax. The increase in gasoline prices contributed to a short-term decrease in RTAs, injuries, and fatalities by 22.4%, 21.9%, and 14.1%, respectively [43]. A 2018 study indicated that despite all measures reduce RTAs, such as the enforcement of traffic laws, RTAs may increase in Saudi Arabia and become the first cause of death in the country.

List of Abbreviations

RTA Road traffic accident
WHO World Health Organization

Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this article.

Funding

None.

Consent to participate

Not applicable.

Ethical approval

Ethical approval was granted by Institutional Review Board King Abdullah International Medical Research Centre via reference number NRC21R-311-08, dated: 11 August 2021.

Author details

Faisal Alhusain[1,2], Mohammad Alghafees[2,3], Ahmed Rezk[4,5], Saud Alwatban[2,3], Faisal Almoaiqel[2,3], Majid Alsalamah[1,2]

1. Department of Emergency Medicine, Ministry of National Guard - Health Affairs, Riyadh, Saudi Arabia
2. King Abdullah International Medical Research Center, Riyadh, Saudi Arabia
3. College of Medicine, King Saud Bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia
4. TU-Dortmund, Dortmund, Germany
5. Ardhi University, Dar es Salaam, Tanzania

References

1. WHO. Global plan for the decade of action for road safety 2011-2020. Geneva, Switzerland: WHO; 2011. p 25.
2. WHO. Injuries violence the facts, the magnitude and causes of injuries. Geneva, Switzerland: World Health Organization; 2014. 20 p.
3. Household Health Survey. Saudi Arabia: Household Health Survey, General Authority for Statistics 2017. Available from: https://www.stats.gov.sa/en/6047
4. Government of Saudi Arabia. Vision 2030 Kingdom of Saudi Arabia. 2020. pp 1–85. https://doi.org/10.4324/9781351040020-1
5. WHO. Global status report on road safety 2015. Geneva, Switzerland: WHO; 2015.
6. Chen S, Kuhn M, Prettner K, Bloom DE. The global macroeconomic burden of road injuries: estimates and projections for 166 countries. Lancet Planet Health. 2019;3(9):e390–8. https://doi.org/10.1016/S2542-5196(19)30170-6
7. Alotaibi MM. Impact of traffic accidents in the Saudi Arabia. Glob Sci Res Environ Sci. 2021;1(3):1–6. https://doi.org/10.53902/GSRES.2021.01.000515
8. European Transport Safety Council. Social and economic consequences of road traffic injury in Europe. European Transport Safety Council; 2007. Available from: https://etsc.eu/wp-content/uploads/Social-and-economic-consequences-of-road-traffic-injury-in-Europe.pdf
9. Fekadu W, Mekonen T, Belete H, Belete A, Yohannes K. Incidence of post-traumatic stress disorder after road traffic accident. Front Psychiatry. 2019;10:519. https://doi.org/10.3389/fpsyt.2019.00519
10. Almutlaq F. Digital Saudi Data | KSU faculty. [cited 2021 July 19]. Available from: https://faculty.ksu.edu.sa/falmutlaq/page/226516
11. GASTAT. Annual statistical report (No. 2018-1439-1440). GASTAT; 2018. p 422. Available from: https://www.stats.gov.sa/en/46
12. Hajj Statistics Report. Hajj Statistics 1435H-2014G. 42. Hajj Statistics; 2014. Available from: https://www.stats.gov.sa/en/28
13. Bastawesy ME, Harbi KA, Habeebullah T, Abdelkarim A, Ahmed FD, Gaber MH, et al. Demography survey 2016. J Geogr Inf Syst. 2019;9(9):1–9.
14. Al-Naami MY, Arafah MA, Al-Ibrahim FS. Trauma care systems in Saudi Arabia: an agenda for action. Ann Saudi Med. 2010;30(1):50–8. https://doi.org/10.5144/0256-4947.59374
15. Jenks GF. The data model concept in statistical mapping. Int J Cartogr. 1967;7:186–90.
16. Waskom ML. Seaborn: statistical data visualization. J Open Source Softw. 2021;6(60):3021. https://doi.org/10.21105/joss.03021
17. Anselin L. Local indicators of spatial association-LISA. Geogr Anal. 1995;27(2):93–115. https://doi.org/10.1111/j.1538-4632.1995.tb00338.x
18. Anselin L. Local indicators of spatial association-LISA. Geographical Analysis; 2003. Available from: https://asu.pure.elsevier.com/en/publications/local-indicators-of-spatial-associationlisa
19. O'Sullivan D, Unwin D. Geographic information analysis. John Wiley & Sons Wiley; 2014. Available from: https://www.wiley.com/en-sg/Geographic+Information+Analysis,+2nd+Edition-p-9780470288573
20. Yamagata Y, Seya H, editors. Spatial analysis using big data: methods and urban applications. London, UK: Academic Press; 2019.
21. Rey SJ, Anselin L. PySAL: a Python library of spatial analytical methods. Handbook of applied spatial analysis. Berlin, Heidelberg: Springer; 2010. 175–93 pp. https://doi.org/10.1007/978-3-642-03647-7_11

22. Statistics H. General authority for statistics. Kingdom of Saudi Arabia; 2019. Available from: https://www.stats.gov.sa/en
23. The Supreme Commission for Tourism. National tourism development project in the Kingdom of Saudi Arabia. Tourism Development Fund; 2020. Available from: https://www.tdf.gov.sa/content/TDF/TDF/en/AboutUs.html
24. General Authority for Statistics. Saudi youth in numbers. A report for International youth day. 2020. Available from: https://www.stats.gov.sa/sites/default/files/saudi_youth_in_numbers_report_2020en.pdf
25. Memish ZA, Jaber S, Mokdad AH, AlMazroa MA, Murray CJ, Al Rabeeah AA, et al. Burden of disease, injuries, and risk factors in the Kingdom of Saudi Arabia, 1990-2010. Prev Chronic Dis. 2014;11:E169. https://doi.org/10.5888/pcd11.140176
26. Mansuri FA, Al-Zalabani AH, Zalat MM, Qabshawi RI. Road safety and road traffic accidents in Saudi Arabia. A systematic review of existing evidence. Saudi Med J. 2015;36(4):418–24. https://doi.org/10.15537/smj.2015.4.10003
27. Ansari S, Akhdar F, Mandoorah M, Moutaery K. Causes and effects of road traffic accidents in Saudi Arabia. Public Health. 2000;114(1):37–9. https://doi.org/10.1016/S0033-3506(00)00306-1
28. Qayed MH. Epidemiology of road traffic accidents in Al-Ahssaa governorate, Saudi Arabia. East Mediterr Health J. 1998;4(3):513–9. https://doi.org/10.26719/1998.4.3.513
29. Alghnam S, Alkelya M, Aldahnim M, Aljerian N, Albabtain I, Alsayari A, et al. Healthcare costs of road injuries in Saudi Arabia: a quantile regression analysis. Accid Anal Prev. 2021;159:106266. https://doi.org/10.1016/j.aap.2021.106266
30. Bakhsh A, Aljuzair AH, Eldawoody H. An epidemiological overview of spinal trauma in the kingdom of Saudi Arabia. Spine Surg Relat Res. 2020;4(4):300–4. https://doi.org/10.22603/ssrr.2019-0118
31. Alotaibi F, Alqahtani AH, Alwadei A, Al-Raeh HM, Abusaq I, Mufrrih SA, et al. Pattern of orthopedic injuries among Victims of Road Traffic Accidents in Aseer region, Saudi Arabia. Ann Med Surg (Lond). 2021;67:102509. https://doi.org/10.1016/j.amsu.2021.102509
32. Al-Zamanan MY, Al-Yami AS, Al-Najrani AA, Al-Asmari MY, Manaa AA, Al-Qahtani AM, et al. Injury pattern among road traffic accidents' victims in Najran city, Saudi Arabia. Int J Clin Med. 2018;9(04):270–80. https://doi.org/10.4236/ijcm.2018.94024
33. Ahmed S, Mahmood M, Rizvi SA, Siddiqui AA, Shahid N, Akram WA, et al. Frequency and nature of road traffic injuries: data of more than 10,000 patients from Ha'il, Saudi Arabia. Cureus. 2019;11(1):e3830. https://doi.org/10.7759/cureus.3830
34. Jamal A, Rahman MT, Al-Ahmadi HM, Mansoor U. The dilemma of road safety in the eastern province of Saudi Arabia: consequences and prevention strategies. Int J Environ Res Public Health. 2019;17(1):157. https://doi.org/10.3390/ijerph17010157
35. Yagoub U, Saiyed NS, Rahim BE, Musawa N, Al Zahrani AM. Road traffic injuries and related safety measures: a multicentre analysis at military hospitals in Tabuk, Saudi Arabia. Emerg Med Int. 2021;2021(1):6617381. https://doi.org/10.1155/2021/6617381
36. Al-Wathinani AM, Schwebel DC, Al-Nasser AH, Alrugaib AK, Al-Suwaidan HI, Al-Rowais SS, et al. The prevalence of risky driving habits in Riyadh, Saudi Arabia. Sustainability (Basel). 2021;13(13):7338. https://doi.org/10.3390/su13137338
37. Mehmood Y, Shafiq P. Pattern of injuries in road traffic accidents in Ar'ar Central Hospital. Pak J Med Health Sci. 2019;13(4):1149–52.
38. Mahata D, Narzary PK, Govil D. Spatio-temporal analysis of road traffic accidents in Indian large cities. Clin Epidemiol Glob Health. 2019;7(4):586–91. https://doi.org/10.1016/j.cegh.2019.01.005
39. Haagsma JA, Graetz N, Bolliger I, Naghavi M, Higashi H, Mullany EC, et al. The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the global burden of disease study 2013. Inj Prev. 2016;22(1):3–18.
40. Le KG, Liu P, Lin LT. Determining the road traffic accident hotspots using GIS-based temporal-spatial statistical analytic techniques in Hanoi, Vietnam. Geo Spat Inf Sci. 2020;23(2):153–64. https://doi.org/10.1080/10095020.2019.1683437
41. Wang C, Quddus M, Ison S. A spatio-temporal analysis of the impact of congestion on traffic safety on major roads in the UK. Transp A Transp Sci. 2013;9(2):124–48. https://doi.org/10.1080/18128602.2010.538871
42. Kopits E, Cropper M. Traffic fatalities and economic growth: world bank policy research working paper (No. 3035). Washington, DC: World Bank. 2003. https://doi.org/10.1596/1813-9450-3035
43. Dahim MA. Impact of vision 2030 on traffic safety in Saudi Arabia. Int J Pediatr Adolesc Med. 2018;5(3):103–9. https://doi.org/10.1016/j.ijpam.2018.08.002