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Spatiotemporal analysis of traffic accidents in Kuwait (2023-2024) using geographic information systems (GIS)

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Abstract

Objectives: The main objective of this study is to investigate the spatiotemporal distribution of traffic accidents in Kuwait relying on the quantitative approach represented by spatial analysis. **Method:** The study relied on the statistical approach for traffic accidents, where the data were analyzed using a variety of GIS statistical tools including Global Moran's I to detect spatial autocorrelation and Kernel Density Estimation to identify hot spots. **Results:** The results were that accidents are concentrated in certain districts, such as Al-Ahmadi and Al-Jahra. Also, the frequency of accidents was higher during the afternoon period during the study area. Further studies should contemplate correlation analysis between rates and counts of accidents with road features as well as age as a factor in the causation of these accidents. **Conclusion:** It is expected that this study will help decision-makers to improve road safety and attempt to develop modern traffic strategies that reduce the number of traffic accidents in areas with high concentration.

Keywords: traffic accidents, Kuwait, GIS, spatial autocorrelation, kernel density estimation

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التحليل الزماني والمكاني لحوادث المرور في دولة الكويت (2023-2024) باستخدام نظم المعلومات الجغرافية

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ملخص

الأهداف: ترمي هذه الدراسة إلى تعرّف التوزيع الزماني والمكاني لحوادث المرور في دولة الكويت باستخدام نظم المعلومات الجغرافية. **المنهج:** اعتمدت الدراسة على المنهج الإحصائي لدراسة التوزيع الجغرافي لها، وحلّلت البيانات باستخدام مجموعة متنوعة من الأدوات الإحصائية لنظم المعلومات الجغرافية، بما في ذلك مؤشر موران العالمي (Global Moran's I) للكشف عن الترابط المكاني، وطريقة تقدير الكثافة النووية (Kernel Density Estimation) لتحديد النقاط الساخنة. **النتائج:** أظهرت النتائج أن الحوادث تتركز في مناطق معينة؛ مثل الأحمدي، والجهراء، كما أن معدل الحوادث كان أعلى خلال فترة بعد الظهر ضمن منطقة الدراسة. وتقترح الدراسة إجراء دراسات مستقبلية تأخذ في الاعتبار تحليل الارتباط بين معدلات الحوادث وعددها وخصائص الطرق، بالإضافة إلى عامل العمر كعنصر متسبب في هذه الحوادث. **الخاتمة:** تُسهم النتائج التي تم التوصل إليها في الارتقاء بسلامة الطرق وحركة المرور في منطقة الدراسة، فنتائج هذه الدراسة يمكن أن تساعد صُنّاع القرار على تحسين السلامة المرورية، والسعي إلى تطوير إستراتيجيات مرورية حديثة، تُقلل من عدد الحوادث في المناطق ذات التركيز العالي.

الكلمات المفتاحية: حوادث المرور، الكويت، نظم المعلومات الجغرافية، الارتباط الذاتي المكاني، تقدير الكثافة النووية

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Introduction

Traffic accidents are considered a public health issue as they cause millions of deaths and injuries annually across the world. According to the World Health Organization (WHO) (2023), more than 800 billion dollars are spent annually worldwide in the development of safer road infrastructure by both the public and private sectors to reduce the number of injuries and victims caused by car accidents. Regardless of the level of development of the country in question, efforts are made to minimize the negative impact of traffic accidents necessitating, for example, improving signaling, widening hard shoulders, maintaining roads, imposing speed limits, and monitoring driving behavior depending on the local weather and an understanding of the level of education and lifestyle of the population, such as nocturnal entertainment lifestyle. These can have a significant impact on the reduction of deaths (Calvo-Poyo et al., 2020).

Most of the studies seeking to understand the spatiotemporal distribution of road accidents have been carried out using Geographic Information Systems (GIS). This is because it is a powerful field to visualize spatial patterns. GIS provides insights into the factors that contribute to the formation of clusters and the identification of underlying causes behind these patterns. Most of these studies have used a set of data over a long period of time (e.g., Khatun et al., 2024; Mohammed et al., 2023), which makes their prediction very reliable. This information is crucial for policymakers who can then design targeted interventions and public awareness campaigns in areas with higher accident rates.

Kuwait is a rich oil country with a high percentage of cars; hence, no surprise that one of the main causes of death at the national level is due to car accidents (WHO, 2024); however, where and when these car accidents occur are still not clear. The main objective of this research is to study the spatiotemporal distribution of traffic accidents in Kuwait during a period of 12 months relying on the quantitative approach represented by spatial analysis. It is proposed that this distribution of accidents and their frequency is not random and follows a pattern of distribution in the urban areas, which can be visualized as hot spots. Understanding the spatiotemporal variation of this phenomenon will help policymakers make more effective decisions to reduce the number of car accidents.

Previous Studies

The use of long period of data coupled with GIS statistical tools can provide important features associated with traffic accidents that are unique to the location of the study. For example, Khatun et al. (2024), in Bangladesh, used a dataset from 2017 to 2021 combined with clustering analysis and Kernel Density Estimation (KDE) to generate a heat map of the variation in the range of traffic accidents and hot spots analysis. These identified trucks as the primary factor involved in accidents, and the reason was attributed to driving inexperience, use of mobile phones, speeding, and environmental factors such as seasonality and land use. The study detected specific locations where road accidents were statistically more frequent.

Spatial autocorrelation and GIS spatial tools such as KDE, which were applied and integrated in GIS, were used to identify clusters and hot spot of car incidences in several places of the world (Anderson, 2009; Bíl et al., 2013; Flahaut et al., 2003; Gedamu et al., 2024; Le et al., 2022; Thakali et al., 2015). For example, Al-Aamari et al. (2020) used KDE, Network-based Nearest Neighborhood Distance (Net-NND), and other spatial analysis tools and found that, in Muscat, Oman, road traffic accidents were significantly demarcated by intersections and roundabouts. These results suggest and confirm that traffic accidents tend to cluster spatially and temporally in specific locations, particularly on long roads with high–traffic intersections.

Spatial autocorrelation coupled with local Moran's I, which is a statistical tool to assess significance in spatial clustering, was used by Gedamu et al. (2024) to compare two cities with large socioeconomic differences, Berlin in Germany and Addis Ababa in Ethiopia. This study used a dataset of three years and found that there is a significant difference in spatial cluster of road traffic crashes, with a strong clustering towards injury in crashes rather than fatal accidents. However, in Berlin, the clustering of fatal accidents was considerably weaker. The authors suggest that socioeconomic factors, road user behavior, and roadway factors contributed to the differences.

Other studies have investigated the frequency of accidents by GIS means. For example, Wang et al. (2024) used a Geographically Weighted Regression (GWR) method to analyze variations in the frequency of car accidents in cities of the United States associated with influencing factors such as characteristics of the road network, socioeconomic attributes, and land use. The study showed that there exists a spatial distinctive effect of factors on car accidents. For instance, the number of intersections is particularly important in the southern and northeastern areas. Roadwork networks were relevant across the whole area of study, but socioeconomic factors had a moderate impact and land use had almost no relevance. These results underscore the need to account for spatial variability when analyzing traffic safety, as local characteristics can significantly influence the effectiveness of interventions and policymakers' decisions.

Recently, a study was conducted by Mohammed et al. (2023), also using spatial autocorrelations coupled with three-dimensional representation of spatiotemporal data (time-space cube) and regression analysis (GWR), to identify accident hot spots in Qatar. The study found that most of the car accidents were concentrated in the central eastern region of Qatar, particularly in Doha, where most of the population lives. The study also found that temporal variations in car accidents during weekdays in 2019 were more strongly clustered than those in 2015, which might indicate systematic causes. The study highlights the importance of GIS to visualize and identify car accident hot spots as this information provides guidelines for policymakers, for the design of campaigns to change drivers' behavior and for more effective use of the police to reduce car accidents.

A space-time analysis of accident frequency was conducted by Soltani and Qadikolaei (2024) in Melbourne, Australia. This study used a dataset of 15 years (2006–2020), which was analyzed using different approaches including spatiotemporal techniques integrated in GIS. This study revealed that people between 25 and 29 years and 60 and 65 years present an increased incidence of accidents, which might be related to a tendency to speed for young people and a decline of mental and physical attitudes for elderly. Also, a positive correlation was found between job density and road accidents, perhaps as a consequence of increased traffic congestion in those areas. Further positive correlations were found between traffic volume; road features such as cycle lanes; and proximity to Central Business District (CBD) and green areas with the frequency of accidents.

Further to this, weather factors, such as the effect of hot days on the incidence of accidents, were investigated by Gu et al. (2024) in Florida. In their study, several GIS tools were used to identify the correlation between hot days and car accidents, such as hot spot analysis and Moran's I test. Interestingly, this study found that accidents during extreme hot days showed significant spatial clustering, particularly in areas where the temperature is cooler. This result suggests that there is a spatial spillover effect of traffic. There is an increase in traffic towards certain colder areas, as people might be seeking shelter against extreme heat, therefore, there is an increase in traffic volume in areas typically with a lower density of cars. These results are relevant as extreme heat events are expected to increase, which confirms the urgent need for integrating resilience into urban planning.

Spatiotemporal evolution of hot spot car accidents was also investigated by Al Hamami and Matisziw (2021) in Columbia, USA. This study used a combination of GIS approaches, including autocorrelation for different periods of time, and spatial statistical tools, such as Getis, Moran's I, and three-dimensional representation, to assess the spatial coverage of road accidents clustering during that period of time. Their results found that the temporal and spatial patterns show a variation in accident clustering. In addition, the study found that car accident clusters tend to be located near major intersections with smaller clusters close to minor intersections. The study concluded that GIS tools helped provide a better understanding of where car accidents tend to occur.

In Kuwait, where this study is carried out, the information regarding road accidents is limited as pointed out by AlSaeid et al. (2015). These authors made a survey, and the results showed that socioeconomic factors and attitudes, such as speeding, illegal driving, and work commitments were factors that contributed to the behavior of drivers. The study concluded that there is a need for research regarding the analysis and modelling of these factors and road accidents frequency. Alnasrallah and Almatar (2024) were the first to use GIS to identify spatial patterns of the distribution of road accidents in Kuwait. This study used a database of one year, which was analyzed by average nearest neighbor, point density, and hot spot analysis. The study revealed a significant difference between rural and urban areas in the recurrence of accidents as well as a seasonal disparity. However, it is not clear whether there is a consistent frequency of accidents in specific spots.

Due to the unique social structure of Kuwait where, almost 70% of the population are migrants (PACI, 2024), there is a rising concern for road safety as these new members of the society might not understand the road rules, due to language barriers, lack of driving education, or lesser driving skills. These questions have been addressed in some Australian studies where the number of migrants overwhelms the citizens. One of them, conducted in the city of Adelaide, found that recently arrived road users were more likely to be at-fault for their crashes. However, these results were conditioned by their age and their unfamiliarity with the road environment or the specific road rules of the area (Thompson et al., 2023). Another study, carried out in the state of New South Wales, investigated whether migrants had higher rates of death in car accidents than local ones. This study found no evidence for this claim; however, pedestrian migrants, especially older foreigners, experienced higher rates of death and hospitalization due to road accidents (Dobson et al., 2004). This suggests that road signaling and traffic norms can indirectly impact the lives of new migrants.

Furthermore, Kuwait is a rich country, which makes the purchase of cars more accessible than in other nations. According to Al-Dabbous et al. (2025), in Kuwait, car ownership is one of the highest at the global scale, with 445 passenger cars per 1,000 people in 2019. The main use of cars is to get to work (AlAttar and AL-Mutairi, 2019); however, the large proportion of Kuwaitis are below 35 years (WHO, 2024) and have the tendency to display risky driving habits and are thus most likely to be involved in car accidents

(Alsaleh, 2006). Also, other factors besides age, such as gender and annual driving distance, can induce improper driving behaviors that violate traffic regulations, which might increase the likelihood of car accidents in Kuwait (Al-Rukaibi et al., 2006; Shebab and Alkandari, 2021). For all these reasons, Kuwait has the highest death toll due to car accidents among the Gulf Cooperation Council Nations (Alnasrallah and Almatar, 2024), but what is most remarkable is that car accidents are also among the main causes of death for the country (WHO, 2024).

Previous studies had provided helpful facts about the spatial and temporal patterns of traffic accidents, and the application of GIS tools in traffic accidents studies. However, few research studies have focused on Kuwait using those GIS techniques. Therefore, the information gained from a locality with a large population of cars, with potential incidents due to their socioeconomic characteristics, is important as this information can provide guidelines for policymakers or for the development of an educational driving campaign.

Data and Methodology

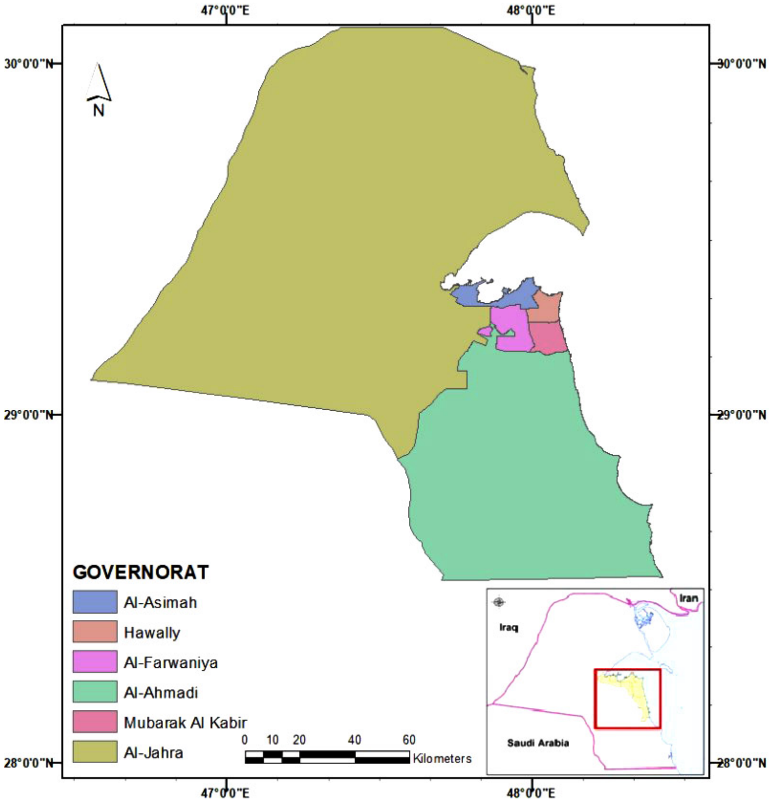
Study Area

The study was conducted in the State of Kuwait, located in the northwestern zone of the Arabian Gulf, with a total area of about 17,818 km². The country's total population is around 4.8 million in 2024, with 2.42 million vehicles registered in 2022. Kuwait has a road network of 5,749 km, with 85% being paved. This network is situated across the six governorates that exist in Kuwait (Figure 1).

The data about traffic accidents by location was obtained from Kuwait Police, which is under the control of the Ministry of Interior. The data covered one year from 2023 to 2024. The total number of records was 4,361 road accidents. These records were classified based on the time of the day: the morning period (between 12:00 a.m. and 12:00 p.m.); the afternoon period (between 12:00 p.m. and 12:00 a.m.); and the total period from 00:00 to 23:59.

Figure 1

Study Area



Data Processing

This study used ArcMap 10.8.2 GIS software to understand the spatial distribution of traffic accidents in Kuwait. The data about traffic accidents was imported into ArcMap 10.8.2 to create a geodatabase for the three groups of accidents (traffic accidents (TC) from 12:00 a.m. to 12:00 p.m., TC from 12:00 p.m. to 12:00 a.m., and TC over 24 hours). Traffic accident rates were calculated for every district in Kuwait (number of accidents per population of that district) where the output maps displayed how many traffic accidents occurred in each district for every 100,000 individuals.

Further comparative analyses were also based on the absolute number of traffic accidents. This was decided because some districts presented a high rate, not because they were intrinsically more dangerous, but because they had a smaller population, such as rural farms or industrial areas. Therefore, a few accidents in those low-populated areas would appear far worse than in densely populated areas. Using absolute numbers of traffic accidents (frequency) then provides a clearer picture of where road accidents were more frequent regardless of the population size of the district.

Spatial Autocorrelation and Statistical Analysis

Spatial autocorrelation and Kernel Density Estimation analyses were employed to identify clusters and hot spots of traffic incidences. Spatial autocorrelation helps to comprehend the geographic distribution of traffic accidents. It is based on the principle of a systematic pattern of distribution. This means that if nearby or neighboring areas are more likely to be similar than areas further away, then the pattern is positively spatially autocorrelated (Burt et al., 2009). In the context of this study, if the results of the model are positive, then it would indicate a positive autocorrelation among traffic accidents in the study area. However, a negative spatial autocorrelation is used to describe patterns from differing surrounding areas, and no spatial autocorrelation presents as zero to identify random patterns (Griffith and Arbia, 2010). Moreover, global spatial autocorrelation tests are statistical tools that investigate the spatial dataset of a study area for relationships between the variables. Global Moran's I is one of the most popular tests implemented in GIS software. This study utilized the Global Moran's I tool in ArcMap 10.8.2 to detect the spatial autocorrelation of traffic in three temporal groups (TC from 12:00 a.m. to 12:00 p.m., TC from 12:00 p.m. to 12:00 a.m., and TC over 24 hours).

Density distribution of traffic accidents was also calculated and mapped using a choropleth map for the three time periods, that is, morning, afternoon, and total. The traffic density was measured by the number of traffic accidents per the size of the district. This calculation was performed to find out the relationship between the size of a district and the number of accidents occurring there.

Kernel Density Estimation (KDE) is a well-known point pattern analysis. Point pattern analysis is one type of spatial analysis that aims to analyze the geometric structure of patterns in one, two, and three dimensions, which are formed by objects distributed randomly in space (Illian et al., 2008). The analysis of spatial point patterns became one of the subfields of geography in the late 1950s when spatial statistical analysis became relatively well known within the discipline (Gatrell et al., 1995). Kernel Density Estimation (KDE) is widely used in geography to understand the spatial distribution of traffic accidents hot spots (Benedek et al., 2016; Ouni and Belloumi, 2018). The output of this test helps recognize the nature of traffic accidents in space, by identifying the hot spots in dense colors, which provide a simple visualization of the distribution of the risk of an accident (Anderson, 2009). Another advantage is that it provides a smooth and continuous estimate of the probability density function when the data distribution is not clearly defined (Kaygisiz et al., 2015).

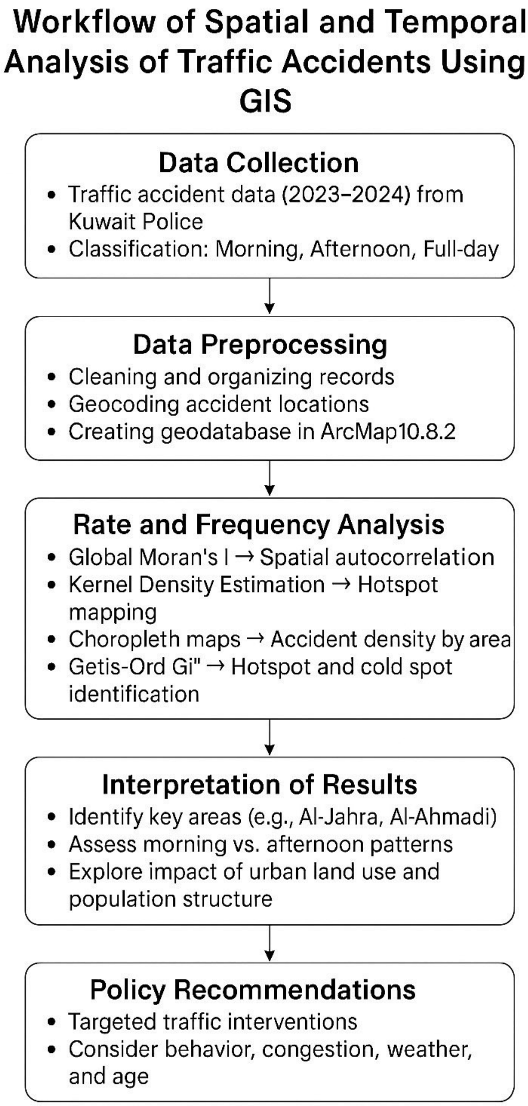
For all of these reasons, this research employed KDE testing, which is embedded in ArcMap to project the density of traffic accidents for the three groups.

Hot spot analysis of traffic accidents was performed using the same study period criteria of morning, afternoon, and a whole day. This analysis highlighted the spatial variation in accident density. The calculation was based on Getis-Ord Gi statistics, which evaluate each point with regard to its surroundings. P-values and z-scores are measured for each point or location, indicating significant clustering either with high or low values. Those red-colored areas indicate a statistically significant clustering of high accident frequencies (hot spots), whereas the blue areas indicate locations with statistically significant lower accident densities (cold spots). Variation in red or blue indicated the level of confidence; dark red or blue represented 99% confidence; medium red or blue indicated 95% confidence; and light red or blue indicated 90% confidence. Grey areas represented locations with no significant clustering of accidents.

Figure 2 illustrates the methodological framework employed in this study. It outlines the sequence from data collection and preprocessing, through spatial and statistical analyses, to interpretation and policy recommendations. This flowchart highlights how GIS techniques, such as Global Moran's I and Kernel Density Estimation, were integrated to analyze the spatiotemporal distribution of traffic accidents in Kuwait.

Figure 2

Methodological Workflow for the Spatial and Temporal Analysis of Traffic Accidents Using GIS in Kuwait

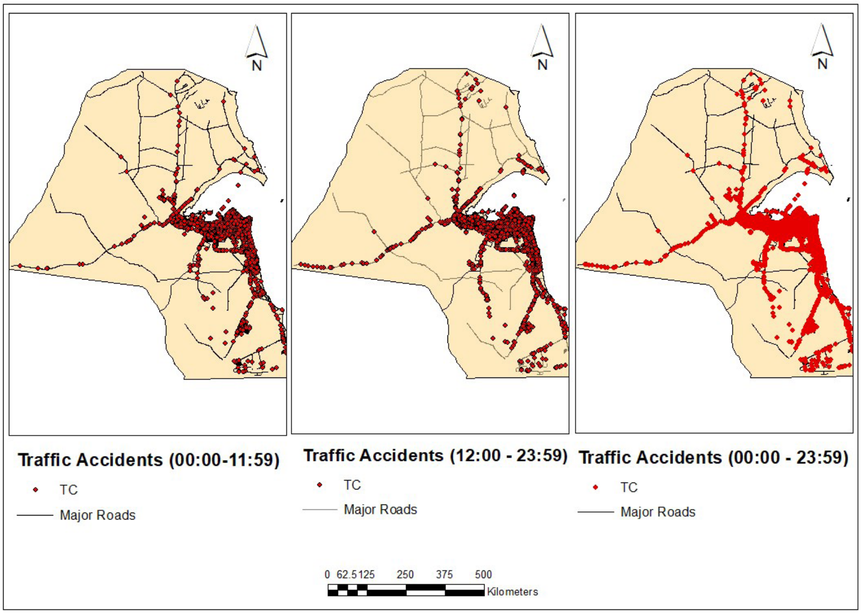


Results and Discussion

The spatial distribution of traffic accidents was concentrated along major road networks, where the northern coastal region of the country has the highest concentration of incidents. These results were consistent in the morning, afternoon, and, therefore, throughout the whole day (Figure 3). There were, though, more accidents reported in the afternoon than those reported during the morning.

Figure 3

Spatial Distribution of Traffic Accident



Most car accidents were reported within the urban area of Kuwait, which might be related to the nature of the land use in the country, where only 10% of the nation is urbanized and the rest is just desert. Surprisingly, areas with high density were not identified as hot spots by analyses carried out either by rates of traffic accidents or merely by their frequency (Table 1). This result suggests that heavy traffic observed in the afternoon slows down the motion of the commuter and, therefore, reduces the chances of impact between two cars. Another possible reason behind the low rates and number of traffic accidents in these highly populated areas is the heavy police presence, speed cameras, and cameras on traffic lights. For instance, Al-Farwaniya and Al-Ahmadi have the highest population and a low rate of traffic accidents, where the number of cameras is three times more common than in low-populated districts such as Shamiya. These results were consistent with the findings of Wang et al. (2024) who highlighted the need to consider local characteristics, such as the presence of road intersections and the relevance of traffic features specific to an area for the effectiveness of road safety.

During the morning period, Al-Ahmadi presented the highest number of traffic accidents (357 accidents), followed by Al-Jahra (339 accidents), while the lowest was in Mubarak Al-Kabir (147 accidents). These differences can be attributed to the land-use type. Mubarak Al Kabir has mixed-use land, including residential, recreational, commercial, and governmental areas, in contrast to Al-Ahmadi, which is mainly a residential area. Population may also be one of the reasons for the differences reported in traffic accidents. Mubarak Al Kabir has a population of 306,208, while Al-Ahmadi has 1,111,135 and Al-Jahra has 607,549. For the same period, the highest rate was that of Al-Jahra with 56 per 10,000, while the lowest was that of Al-Farwaniya with a rate of 21 per 10,000, which supports the idea of busy roads tending to present fewer traffic accidents. The fact that congestion reduces the frequency of accidents is important to test as other studies (e.g., Dobson et al., 2004; Soltani and Qadikolaei, 2024; Zheng et al., 2020) have shown a completely different trend. On the other hand, study by Phan and Truong (2024) found that congestion indeed reduces the number of fatal incidents. Therefore, it is important for further studies to analyze the number of accidents in relation to the amount of congestion and the severity of an accident.

Another possible reason is the population composition in these districts. In Al-Jahra governorate, Kuwaitis are predominant, which suggests a substantial difference in income and, therefore, in the possession of cars. Migrants predominantly live in Al-Farwaniya, and these possibly use public transport more often to travel to their jobs, for example. Further studies should contemplate the relative effect of migrants on car accidents and the severity of accidents, which has been suggested by the studies conducted in Australia by Dobson et al. (2004) and Thompson et al. (2023).

The afternoon period followed a similar trend to that in the morning. Al-Jahra had the highest number of car accidents (574), followed by Al-Ahmadi with 555 car accidents, while the lowest number was also observed in Mubarak Al-Kabir with 279 accidents (Table 1). As the trend is strikingly similar between both periods of the day, the frequency of accidents in these locations could be attributed to the population size, number of cars per capita, presence of police, and speed cameras. However, the number of traffic accidents increased in residential areas in afternoon periods and decreased in mixed-use districts.

For the afternoon and night periods, the highest rate was that of Al-Jahra with 94 per 10,000, while the lowest was that of Al-Farwaniya with 35 per 10,000. For overall traffic accidents, the highest number of accidents was in Al-Jahra (913 accidents), while the lowest was in Mubarak Al-Kabir (426 accidents). For the traffic accident rate, the highest rate was that of Al-Jahra with 140 per 10,000, while the lowest was that of Al-Farwaniya with 56 per 10,000. In terms of time periods, traffic accidents tend to be high during the afternoon and night, with 36.09% occurring during the morning in comparison to 63.9%, which is almost double. This large percentage difference can perhaps be explained by human behavior. Car drivers are fatigued and perhaps pay less attention to road rules. This is a factor highly recognized as one of the most important causes in car crashes (e.g., Morrison et al., 2012; Saleem, 2022). Another possible explanation is the weather. In hot weather countries, such as Kuwait, people tend to go out after sunset, when it is cooler; hence, the chances of car accidents increase. Future studies should correlate hot days with the frequency and clustering of accidents, as this might support the results given by Gu et al. (2024) for certain localities in the United States.

Table 1

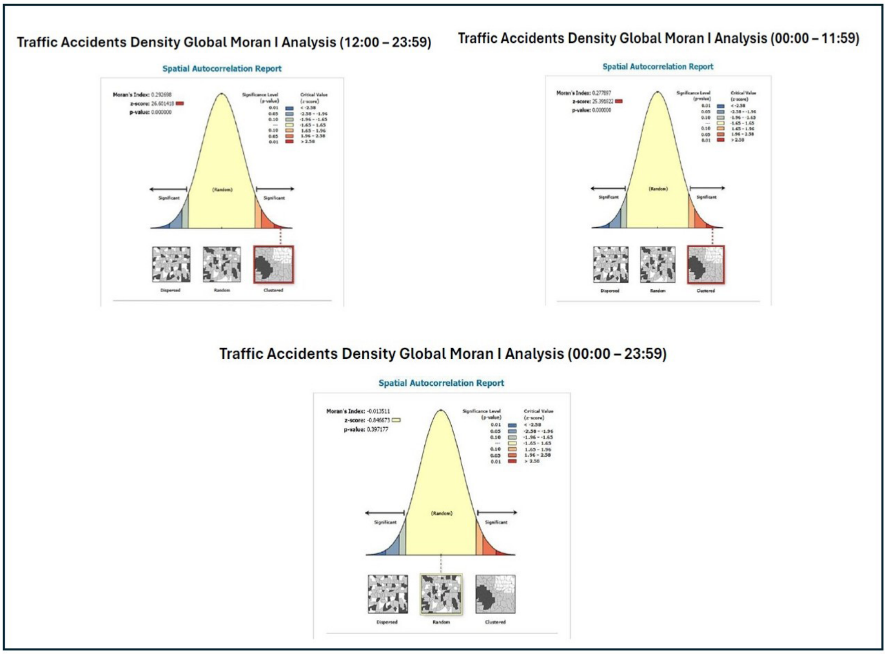
Traffic Accidents by Governorates

Governorate	Traffic Accidents 00:00 – 11:59		Traffic Accidents 12:00 – 23:59		Traffic Accidents 00:00 – 23:59		Population
	Count	Rate	Count	Rate	Count	Rate	
Al-Asimah	255	41	477	76	732	117	625,208
Hawally	226	23	487	49	713	72	989,042
Mubarak Al-Kabir	147	48	279	91	426	139	306,208
Al-Ahmadi	357	32	555	50	912	82	1,111,135
Al-Farwaniya	250	21	415	35	665	56	1,191,141
Al-Jahra	339	56	574	94	913	140	607,549
Total	1,574	33	2,787	58	4,361	90	4,830,283

The Global Moran's I analysis of traffic accidents revealed significant clustering during both periods under study, with a z-score = 25 in the morning and a z-score = 26 for the afternoon period. These results suggest that traffic accidents in Kuwait are clustered in their geographical location. This means that there were certain locations more likely to have road accidents by chance– either during the morning or during the afternoon. The z-scores and p-values confirmed significant statistical evidence of spatial clustering, where the afternoon period had stronger clustering than the morning period. The test confirms that traffic accidents are not randomly distributed in Kuwait's urban area by period of the day. The three groups of datasets show a bell-shaped distribution with a positive value of spatial autocorrelation. These results are consistent with previous studies showing that urban accidents are not random and follow certain spatial patterns (e.g., Gedamu et al., 2024; Mohammed et al., 2023; Shafabakhsh et al., 2017). However, when traffic accidents are considered, overall, the distribution appears random (Figure 4). The overall traffic accident autocorrelation suggested that traffic accidents were random, and there were no locations that had more accidents than others. This provided another dimension to understand traffic accident distribution in the study area. Therefore, the temporal split of traffic accidents into two groups (morning and afternoon) might help decision–makers in Kuwait establish better measures, patrols, and traffic rules at these points.

Figure 4

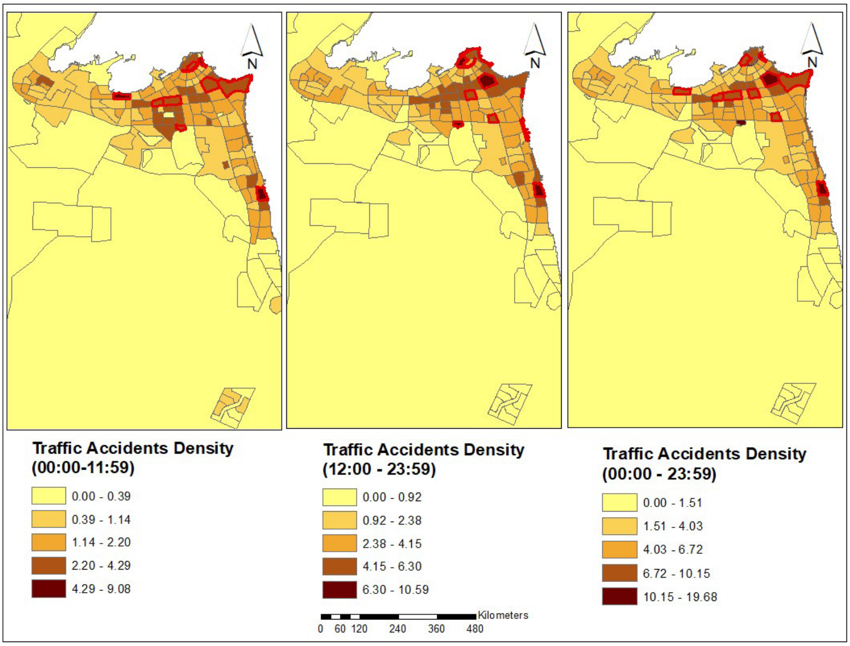
Results of the Global Moran's I Analysis for Traffic Accidents



The results obtained by the spatial density distribution of traffic accidents during the morning, afternoon, and nighttime across all time periods revealed that these were predominantly concentrated in the northern part of the urban area. The values given by the choropleth map ranged from 0.00 to 9.06 during the morning period, from 0.00 to 10.59 for the afternoon period, and from 0.00 to 19.68 for the full day (Figure 5), which suggested a high clustering of accidents during the afternoon and nighttime, distributed in the northern part of the urban area. These results were not surprising as this section comprises the CBD, ministries, and government buildings, as well as populated districts such as Salimya, which makes the traffic volume significantly higher than in other regions of the country. Although the road accidents followed similar spatial patterns to those that occurred in the afternoon and nighttime, they also exhibited a notable increase in density within the western districts of the urban area, including residential districts such as Abdullah Al-Mubarak. These results were consistent with the previous calculations based on absolute values and rates, as this district reflects a high standard of economic situation, which might increase the use of cars during the evening for pleasure or recreational activities, and therefore, there is a higher chance of experiencing car accidents. Another possibility is that young people tend to go out more often during the evening. According to AlSaeid et al. (2015), in Kuwait, most teenagers tend to drive before they obtain their driver's licenses, and Shehab and Alkandari (2021) found that young Kuwaitis tend to violate traffic rules significantly more than adults. It is remarkably important to correlate this cluster with the age structure, as the causes behind many accidents could be caused by young people.

Figure 5

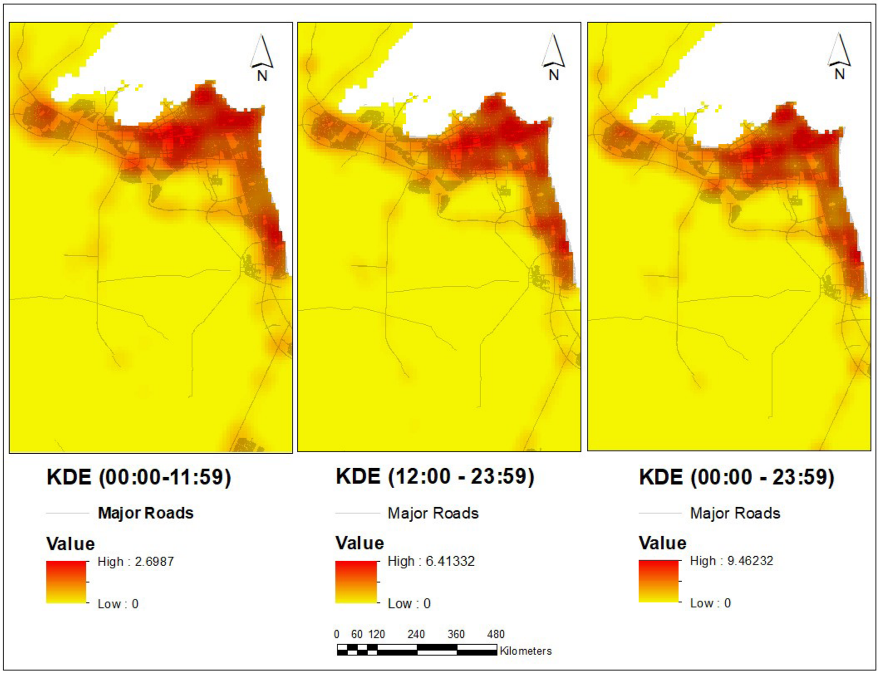
Spatial Distribution of Traffic Accidents Density



The results obtained by the Kernel Density Estimation (KDE) on traffic accidents across the three periods were 2.6987 during the morning period, 6.41332 for the afternoon period, and 9.46232 for the whole day (Figure 6). These values were consistent with those of a previous analysis that showed that, during the morning, the density cluster of accidents is significantly lower (approximately 2.4 times lower) than that of the afternoon period. The analysis showed an expansion in the spatial density of car accidents, with a higher concentration during the morning in the northern districts, of the urban area. However, as the day continues, the spatial density of accidents spreads out towards the northeastern districts covering areas nearby the capital and along the roads around governmental land use districts. The results of KDE for both time periods showed that traffic accidents were clustered in dwelling districts, more than in commercial land–use districts with a higher density in the northern urban area. This result is also consistent with those of previous studies such as Al-Aamari et al. (2020) in Oman, where accidents cluster on specific roads. Overall, this analysis showed that, during the afternoon and nighttime, accidents were more frequent and spatially concentrated. This supports previous analyses about frequency and spatial density of car accidents during the evening and night, when there is an increase in car usage.

Figure 6

Results of Kernal Density of Car Accidents



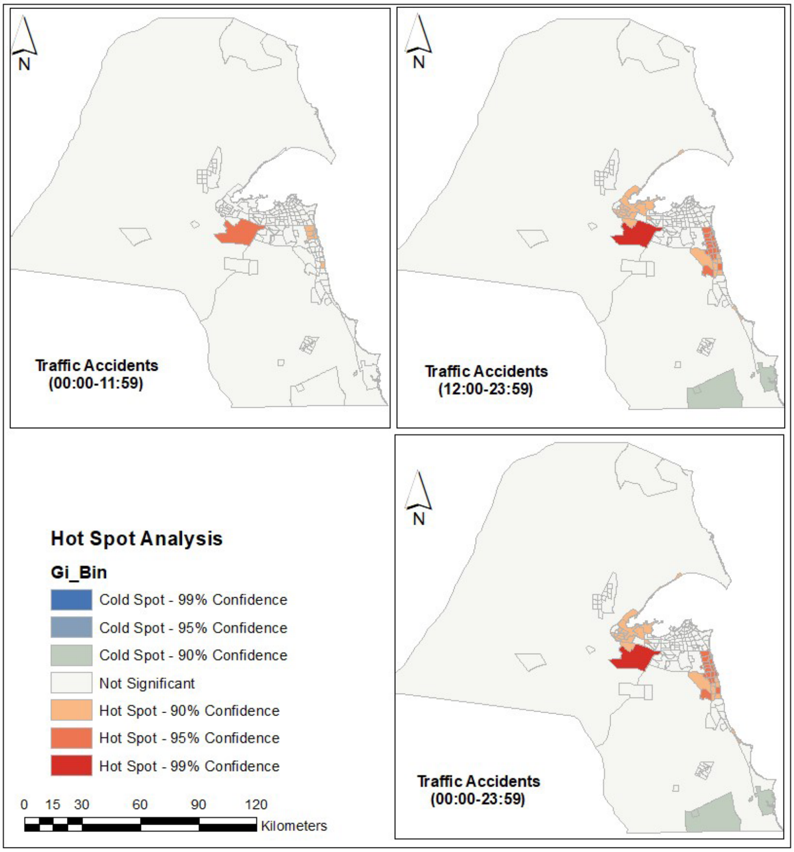
The hot spot analysis showed that, during the morning period, the intensity of hot spots is relatively lower compared to that of the afternoon and nighttime periods in which the concentration of hot spots emerged. During the morning period, the concentration of traffic accidents occurred in the central urban area, with the afternoon period and full–day incidents being concentrated in southern urban areas (Figure 7).

As the day progressed, the number of hot spots also increased, clearly visible during the afternoon period in the western and eastern areas of urban Kuwait. This outcome is interesting as these districts were not identified in previous analyses as areas of high concentration or frequency of road accidents. This phenomenon can be attributed to the concentration factor, as the hot spot analysis does not examine concentration and spread; instead, it focuses on identifying areas where values are either high or low compared to neighboring districts. Thus, a hot spot area is considered significantly different when the surrounding areas present low values and vice versa. The analysis highlights areas where values were higher than those adjacent to them, or lower than those adjacent to them.

During the whole day period, the hot spots persisted, showing that some district areas had a high number of traffic accidents and were surrounded by low-value districts. These results suggest that there were districts that either had no accidents with regard to their immediate neighborhood or presented a completely opposite trend. Further studies are required to establish what makes these points stand out as hot spots.

Figure 7

Results of Hot Spot Analysis for Different Time Periods



Conclusion

The spatial pattern suggests that accident occurrences are not uniformly distributed throughout the city of Kuwait as all analyses identified the districts located in the northern coastal urban area (Kuwait City metropolitan area) as the places with significantly higher occurrence of accidents. In terms of counts of accidents, districts

Al-Ahmadi and Al-Farwaniya presented the highest number of accidents. However, Al-Jahra had the highest rate of accidents per inhabitant. Although this study does not seek for the reasons behind the spatial distribution of car accidents, it is proposed that the accident counts can be attributed to differences in land use and districts inhabited by citizens versus migrants. Perhaps the differences found between the rates and counts are due to specific road features such as intersections or peak traffic congestion, which might contribute to the elevated rates in areas with a low density of inhabitants. However, these are potential explanations, which must be properly tested. Hence, a plethora of studies is envisaged to emerge from this baseline study.

The temporal distribution of accidents throughout the study period was consistent. Regardless of the analyses conducted, all of them pointed out that, during the afternoon period (12:00 p.m. to 11:59 p.m.), the number of accidents was significantly higher, with a significantly greater clustering and a larger intensity of hot spots. A plausible explanation of this strong and consistent temporal pattern of distribution for road accidents is human behavior, such as an increase in driving during hours after sunset. Further studies should contemplate if there is a correlation between periods of the day and the fatality rates. Also, it is necessary to test if age factors correlate with the frequency of accidents and severity. This is remarkably important as one of the leading causes of death in Kuwait is car accidents.

Overall, all the maps generated by GIS provided a clear distinction in the occurrence of accidents within high-density urban areas. These occurrences were also correlated with major road networks, main intersections, and, more importantly, highways. These outcomes are not surprising as they follow the same pattern of any modernized and developed city in the world where the volume of traffic increases at certain times and on specific roads.

The use of GIS and the spatial statistical and analytical tools, such as Moran's I, hot spot analysis, and Kernel Density Estimation, provided a comprehensive understanding of the spatial-temporal pattern of distribution of road accidents in the Kuwait area. This information should be taken into consideration for policymakers and authorities for the improvement of road safety.

The future direction of this research may be built upon the present study by incorporating additional variables such as weather conditions, traffic volume, and locations of speed and law–enforcement cameras, and machine learning to gain comprehensive understanding of the factors contributing to traffic accidents. Collaborative efforts with governmental sectors need to be done to access more detailed datasets to study such an important phenomenon to reduce traffic accidents and support traffic safety policy in Kuwait.

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