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SPATIAL ANALYSIS OF ROAD TRAFFIC ACCIDENT HOTSPOTS AND PATTERNS IN MUSCAT, OMAN: AN EXPLORATORY RISK MANAGEMENT ASSESSMENT

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Abstract

Oman is grappling with a significant challenge posed by road accidents, with approximately 1,539 accidents recorded in 2021. To tackle this issue, this study showcases the potential of Geographical Information Systems (GIS) technology in mapping and analysing road accident hotspots and distribution patterns in Muscat, Oman. The data (from 2019 to 2021) was gathered from the Omani Royal Police Department, with ArcGIS Pro serving as the geographical representation and analysis platform. The study identified high-risk locations for road accidents in specific areas of Mutrah, Bawshar, and Al-Amerat, which were attributed to densely populated areas and heavy traffic flow. The spatial pattern of accidents appeared dispersed, with Fridays and Mondays recording the highest number of accidents due to increased traffic associated with social gatherings and commuting to work or school after the weekend. Qualitative effect analysis revealed that factors such as roadway characteristics, environmental conditions, traffic volume, driver behaviour, and vulnerable road users may influence local accident hotspots. These GIS-based road accident analyses can enhance road accident guidelines and traffic prevention strategies in the Muscat region.

Keywords: GIS, Hotspots, Muscat Oman, Road Traffic Accidents, Spatial Pattern

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INTRODUCTION

Transportation is crucial for economic success and quality of life in urban and rural areas. However, population growth, increased private car usage, and longer travel distances can lead to air pollution, noise pollution, traffic congestion, and road accidents (Mounce et al., 2019). These accidents occur during sudden collisions between vehicles. Many countries worldwide face transportation challenges due to factors such as drivers, roads, and surrounding areas. Researchers are exploring methods to mitigate this harm, as road accidents are the most common cause of death and severe injury globally. These accidents consume significant human resources and energy, resulting in substantial loss of life and property.

Controlling road accidents in Oman is challenging (Belwal et al., 2015). Statistics from the Omani Royal Police indicate a steady increase in traffic accidents, which have resulted in far-reaching social and economic effects. This problem deserves investigation to reduce road accidents and daily deaths. There is a need to identify road locations where road accidents occur frequently before proceeding to clarify underlying issues and develop preventive measures. Hotspots are simply groups that present high-risk accident areas and are used to identify accident-prone sites in urban settings. In this study, the numerical results obtained from the Omani Royal Police in Muscat using traffic accidents between 2019 and 2021 are examined spatially.

Oman is intensively preparing for a modern road network comparable to many countries worldwide. Many roads have been upgraded over the past few years, alongside the construction of bridges and tunnels. As a result, the roads connecting the Sultanate's regions are enhanced, and ongoing development of services and traffic safety measures are visible. To analyse the network, fundamental knowledge of road accident hotspots is required. Due to numerous problems and limitations, collecting accurate and timely statistics on the volume of road accidents is challenging. The issue is the increasing number of traffic accidents in the Sultanate of Oman and the resulting negative consequences. This research aims to understand the current state of road accidents in Muscat by analysing the sites where accidents are increasing and exacerbating this problem.

The Sultanate of Oman aims to comprehend the geographic distribution of traffic accidents and implement the necessary measures to alleviate this significant issue that Omani society faces. Extensive research has been conducted to study road accidents in Oman and globally (Ramana et al., 2018). However, accidents should be spatially studied in GIS with their occurrence coordinates, type, effects, and frequency to devise preventive measures (Mansour, 2016). Identifying hotspot areas is essential for road safety activities as it allows for a more efficient distribution of sources through prioritising safety measures and infrastructure evaluations (Alam & Tabssum, 2023; Aldala'in et al., 2023;

Hazaymeh et al., 2022; Pleerux, 2019; Manap et al., 2019). The research focuses on discovering and detecting the spatial distribution of the accident location. Additionally, spatial features with high spatial accuracy and GIS software are needed to approach accidents systematically and scientifically on the road network. The main objective of this study is to locate and analyse the road accident hotspots and their possible factors in Muscat.

A REVIEW OF GIS ANALYSIS OF ROAD TRAFFIC ACCIDENTS IN OMAN

Traffic accidents and deaths are increasing in Oman, requiring policymakers' urgent attention and action. In Oman, roads are the primary means of transportation for people and goods. Unlike other countries with options like railways, Oman relies solely on roads for transportation (Al-Hasani et al., 2019). The number of traffic accidents in Oman is steadily increasing, and certain regions like Al Batinah, Muscat, Ash-Sharqiyah, and Adh-Dhahirah are particularly prone to accidents (Belwal, 2015).

According to official reports from the Ministry of Health in Oman, highway and road accidents are a significant concern as they cause many premature deaths and disabilities (Ramana et al., 2018). The reasons behind these accidents are complex and involve a variety of factors. These include human-related factors, such as driver behaviour, vehicle-related factors, and the conditions of the roads (Ramana et al., 2018). According to the National Centre for Statistics (2019), the traffic accident rate in the Sultanate of Oman, with a population of 4,527,446, has reached 1,539 in 2021. In Muscat, with a population of 1,310, approximately 371 accidents have occurred, including 78 deaths and 349 injuries. From 2011 to 2013, 2,726 traffic accidents were recorded, and the Muscat Governorate is ranked first in the Sultanate of Oman for the number of traffic accidents (Al-Jubouri, 2015).

Many factors contribute to road accidents in Oman, including reliance on vehicles for transportation, the rise in car demand, and industrial growth and development. These factors have attracted people, including expatriates and locals, to areas of Oman where activities and services are abundant (Belwal, 2015). Consequently, traffic on particular road axes for work and the pressures of commercial activities have increased the likelihood of road accidents. For instance, a study by Ramana et al. (2018) identified Muscat's riskiest areas as at-grade intersections and Y-junctions, where regular roads intersect with the main express highway. Common issues involve rear-end collisions caused by driver errors. To address road accidents, the government has taken stricter measures to enhance rules for obtaining a driving license, including age requirements, driving test appointments, and higher fees for driving schools. Despite these efforts, the number of accidents and injuries continues to rise, with the younger generation

driving without a license. Proper training and knowledge of traffic rules are crucial for those under 25, as the lack of training can lead to reckless driving and speeding, the leading causes of fatal road accidents in Oman.

Over the years, Oman has managed to control the frequency of road traffic accidents (RTAs), but concerns persist regarding the increasing number of injuries and fatalities (Belwal, 2015). While respondents generally comply with road safety measures, the rising toll of injuries and deaths underscores the need for further action. These actions may include integrating various public transportation options into urban planning and offering proactive and reactive treatment for accident victims (Belwal, 2015).

Identifying RTAs in urban areas with GIS is another alternative to prevent local accidents. Hotspot analysis entails spatial analysis and mapping techniques that focus on pinpointing clusters of spatial phenomena represented as points on a map, indicating event or object locations. Under a random distribution of events, a hotspot is an area with a higher concentration of 12 events than expected. Hotspot detection has evolved from studying point distributions or spatial arrangements in a given space (Chakravorty, 1995). Geoinformation technology aids in understanding the localisation and distribution of hotspots in transportation networks, highlighting the impact of spatial and temporal factors (Prasannakumara et al., 2011). This analysis assists in identifying areas with high accident concentrations, determining the main reasons behind the increased accidents, and finding solutions to address the issue.

Traffic engineers and city officials can improve road safety by identifying potential accidents, enabling the modification of signs and roads, and enhancing the efficiency of traffic enforcement agents (Romano, 2017). GIS is a crucial tool for studying road accidents, analysing their location on maps, identifying patterns and hotspots, and determining their distribution in areas with a facility accessibility system (Zain Rashid et al., 2019; Jalil et al., 2018; Rasam et al., 2018; Lokhman et al., 2012). With GIS, researchers can understand how accidents are connected to factors like the local economy, land use, and people's travel. There are different ways to analyse accident data using GIS. One popular method is called Kernel Density Estimation (KDE), which helps us understand the distribution and hotspots of accidents. Other methods, such as Average Nearest Neighbour (ANN) and Getis-Ord Gi*, have also been used to study the spatial pattern of accidents (Alam & Tabssum, 2023; Aldala'in et al., 2023; Hazaymeh et al., 2022; Pleerux, 2019; Manap et al., 2019).

The hotspots analysis tool uses the Getis-Ord Gi* statistic to find patterns in a dataset. The Z score shows how close high and low values are to each other (Alam & Tabssum, 2023; Alkaabi et al., 2023; Hazaymeh et al., 2022; Pleerux, 2019). KDE is another method for identifying road accident patterns and creating a map without strict assumptions. The size and distance of the shapes

impact the map's detail, while the "average nearest neighbour" method measures proximity to each other. The ratio of distances to the nearest neighbouring item's centre point determines the average nearest-neighbour ratio, indicating a clustered pattern or a trend towards dispersion or spreading out (Yue, 2018).

These GIS-based methods can be further improved using more complex analytical methods and risk factors to find meaningful insights. These methods include geospatial artificial intelligence (GeoAI), open GIS-cartographic sources, multi-criteria decision analysis (MCDA), visualisation, and others. Scholars such as Alam and Tabssum (2023), Lin et al. (2023), Adnan et al. (2023), Abdul Rasam et al. (2023), Ramli et al. (2022), Omar et al. (2021), Sha'aban et al. (2021), and Azewan et al. (2020) have contributed to this progress.

RESEARCH METHODOLOGY

This study consists of several vital steps to achieve its goal (Figure 1). The steps include project planning, data acquisition, data processing, data analysis, and results. Through careful project planning and applying advanced spatial analysis tools, project planning identifies areas with a high frequency of accidents, analyses contributing factors, and selects appropriate sites for targeted interventions. Project planning is the first step, and the original plan is discussed. Planning involves creating a calendar as a Gantt diagram, typically completed in the initial phase as a table containing dates and times.

For data acquisition, this study utilises secondary data on accidents in Muscat from 2019 to 2021 obtained from the Royal Police of Muscat. Data was collected in an Excel file containing details about the accidents' locations. The data was organised based on the type of accidents, number of people affected, time of the accident, and type of roads involved. The boundaries of Oman were used as a base map to show the accidents' location on a map. A layer that displays the primary and secondary roads in Muscat Governorate was used to identify where the accidents occurred. The researcher created a location-based system using this descriptive information. This process is called geocoding, which involves converting the accident descriptions into geographic coordinates (latitude and longitude) to pinpoint the positions on a map.

During data processing, this study engaged in activities such as modifying, transforming, and effectively managing the existing data to ensure a seamless workflow throughout the project. This study relied heavily on two primary tools: spatial analysis and spatial statistics tools in ArcGIS. These tools played a pivotal role in creating distinct types of hotspot maps. A comprehensive breakdown of the data processing steps is provided in a dedicated section within the study.

The data analysis involved two types: accident hotspots and correlation analysis. The study began by analysing the location and pattern of accident

hotspots using an initial Excel format (.csv). Then, the data is converted into a feature class before creating heat maps and hotspot maps. Next, the Average Nearest Neighbour (ANN) tools are used to identify the spatial pattern, either clustered, random, or dispersed, depending on the radius between the set of point features. A nonparametric density can be applied to KDE. The authors were assessing technology within GIS. Like a standard SIG algorithm, KDE may create a density map based on car crash hotspots to show density.

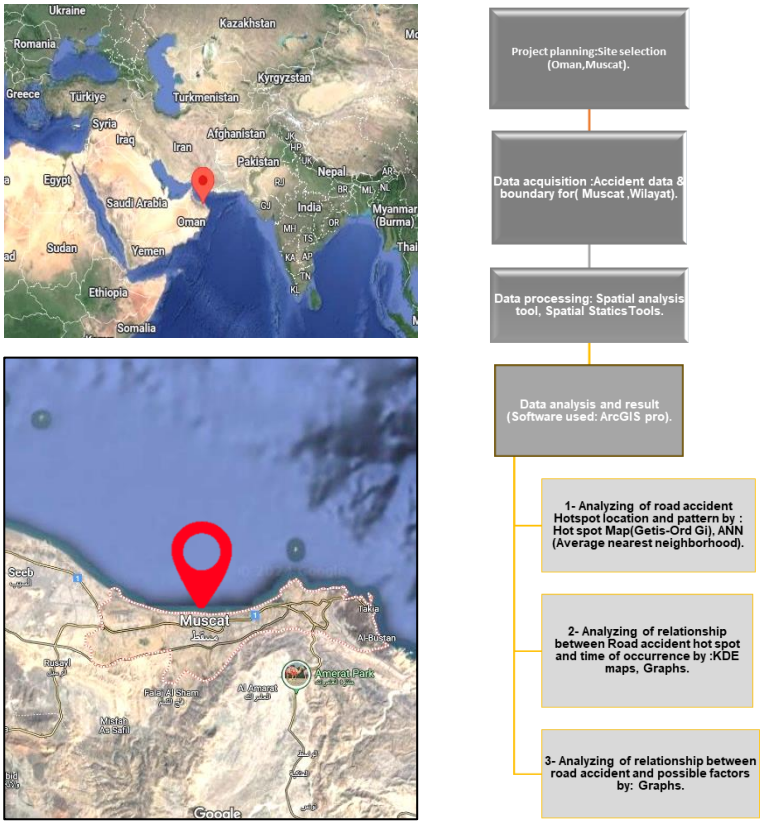

Figure 1: Study Area and Research Methodology
Source: Authors (2024)

For analysing the relationship between road accident hotspots and the time of occurrence, the temporal distribution of car accidents during the three years is measured annually, daily, and in a timely fashion using a graph that shows temporal distributions of road accidents. This identifies the maximum number of road traffic accidents by year, day, and hour. Creating a KDE map can demonstrate the relationship between road accident hotspots and possible

variables and provide valuable insights into the spatial distribution and correlation between accidents and various factors. KDE maps are practical visual tools that help identify high-risk areas, understand underlying patterns, and guide interventions to improve road safety.

ANALYSIS AND DISCUSSION

The Road Accident Hotspots and Patterns

A hotspot map was created to identify areas with higher or lower concentrations of road accidents in the Muscat Governorate (Figure 2).

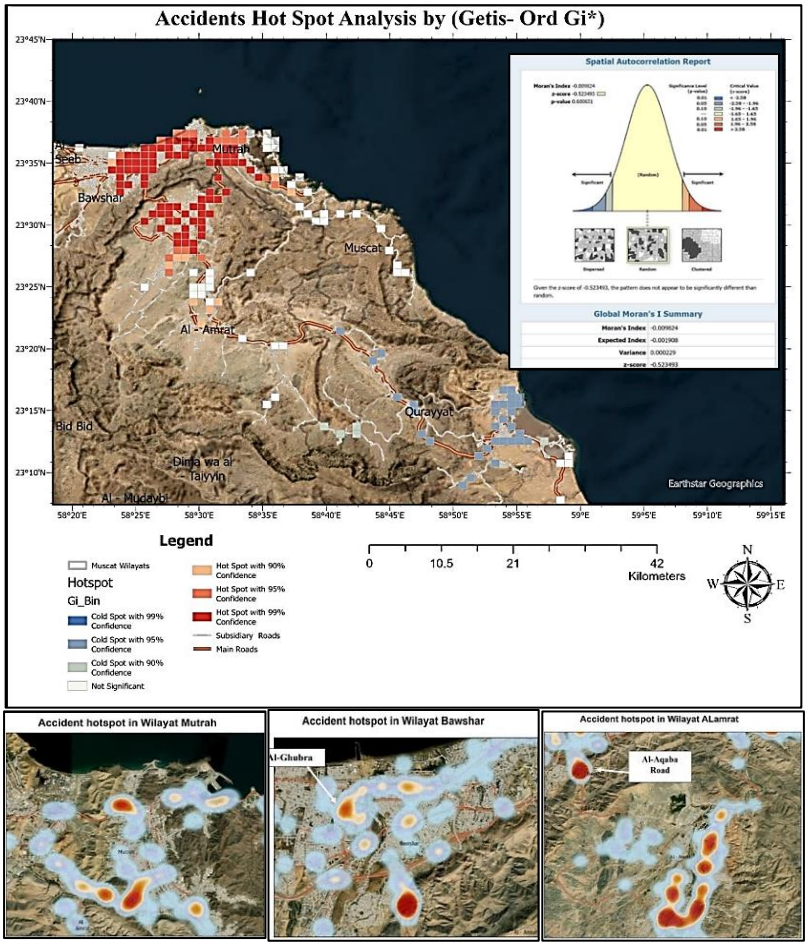

Figure 2: Accident Hotspots and Spatial Pattern in Muscat, Oman
Source: Authors (2024)

The map, created using accident data from 2019 to 2021, uses colour gradients to represent accident intensity. High-risk areas are highlighted in red, while fewer areas are shown in blue. The map was generated using a tool based on hotspot analysis (Getis-Ord Gi*). It shows red hotspots in Wilayat Mutrah, Bawshar, and Alamrat and a blue cold spot in Wilayat Qurayyat.

ArcGIS Pro's ANN analysis is a spatial statistical technique used to assess the dispersion or clustering of a dataset pattern. It compares the observed pattern of accidents to complete spatial randomness, providing three key results: the nearest neighbour ratio, the z-score, and the p-value. The analysis shows that the spatial pattern of accidents, evaluated using ArcMap's Average Nearest Neighbor analysis, is significantly dispersed. This suggests that accidents are not clustered but exhibit a dispersed spatial pattern, possibly occurring more scattered across the study area. The analysis is conducted on maps of Muscat's wilayat, Mutrah, Bawshar, and Al Amarat.

Mutrah is a popular tourist destination with high pedestrian traffic due to its traditional markets and tourist attractions (Al-Shakri, 2009). The reliance on private vehicles due to limited public transportation options can contribute to higher traffic congestion, increasing the likelihood of accidents as more vehicles compete for limited road space. There are areas with frequent accidents.

One of these areas is Darsait Street, which gets crowded and allows cars to go very fast, even though the road is curved. Another hotspot is Ruwi Street, an integral part of Muscat city. Ruwi is a busy neighbourhood with many shops, businesses, and government offices. It is also a central hub for public transportation, with buses going to different parts of the city. Figure 2 shows a map of accident hotspots in Muscat. Thirty-three cities, including Dubai, are included. Many government agencies have offices in Ruwi. Inadequate pedestrian facilities, such as poorly marked crossings and insufficient sidewalks, coupled with drivers' disregard for pedestrian safety, also contribute to pedestrian accidents (Maouli, 2014).

Al-Ghubra in Wilayat Bawshar is a vital business area with numerous shops, malls, and hotels. It is also a hotspot for accidents in Mutrah 34. Al-Jabal Street, particularly Al-Aqaba Road, connects Al Amerat with Bawsher, allowing access to Muscat and other governorates. However, expanding residential and commercial areas without improvements in road infrastructure has resulted in congested and poorly designed networks. Bawshar's limited public transportation options have caused an increased reliance on private vehicles, leading to traffic congestion and more accidents during peak hours. Effective enforcement of traffic laws may be necessary in Bawshar. Al-Amerat's growing population and influx of residents have also heightened traffic congestion and accidents, putting pressure on the existing transportation infrastructure. The rising number of

vehicles on the roads in Al-Amerat highlights the need for improved traffic laws and regulations.

Several actions were taken to tackle these issues. The construction of the Wadi Adai Bridge Road and Al Jabal Street, also known as the Aqabat Al-Amerat-Bawshar, has significantly facilitated transportation and enhanced social connections between Al Amerat and other regions and governorates. The Wadi Uday Bridge Road spans 14 kilometres and has contributed to improved mobility and connectivity. Additionally, the Quriyat-Tur dual road construction has contributed to improved traffic flow, ease of movement for vehicles and cargo, and the development of residential and industrial areas along the route. The convergence of a burgeoning population in the Al-Amerat region, combined with the implementation of new thoroughfares and bridges to facilitate transportation between Muscat and other governorates via Al-Amerat, has significantly contributed to a marked rise in the occurrence of accidents on the roads of Al-Amerat (Fadha et al., 2018).

The Road Accident Hotspots by Accident Time of Occurrence

Road traffic accidents (RTAs) can occur at any time of the day, but specific periods tend to have higher accident rates than others. Understanding the timing of road accidents is critical for developing effective strategies to improve road safety and allocate resources appropriately. Muscat's Traffic Police have consistently reported high traffic-related fatalities and injuries within the city. The graph in Figure 3 presents the number of road traffic accidents between 2019 and 2021 in Muscat.

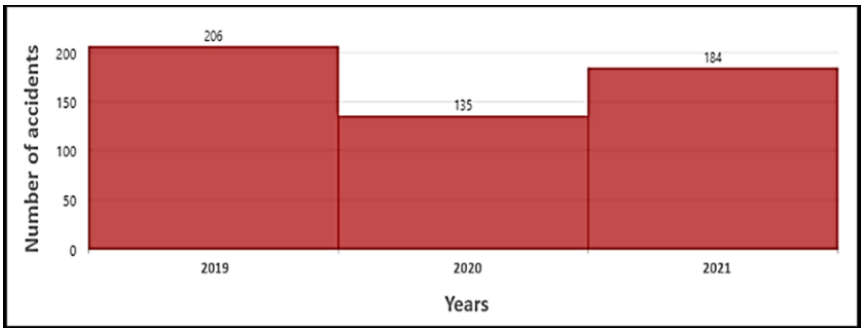

Figure 3: Road Traffic Accidents between 2019 and 20201in Muscat
Source: Authors (2024)

In 2019, Oman also experienced 24 deaths and 338 injuries due to accidents. The number of deaths decreased by eight from the previous year, while the number of injuries also decreased by 171. Although deaths and injuries decreased, the number of injuries remained high, indicating the severity and

impact of accidents on individuals and society. Moving on to 2020, a further decrease in deaths and injuries is recorded. The number of deaths dropped to 16, showing a decrease of 8 compared to the previous year. The number of injuries decreased to 167, indicating a decline in cases compared to the previous year. This decline suggests that efforts to enhance road safety and accident prevention measures may have a positive impact. However, the data for 2021 shows a slight increase in deaths and injuries compared to the previous year. There were 26 deaths recorded, indicating a rise of 10, whereas the number of injuries increased to 226, representing an increase of 59. Although the overall trend of accidents has improved in previous years, the slight increase in 2021 suggests that continuous efforts are needed to maintain and further improve road safety in Oman. KDE maps are also produced to represent such data by creating a continuous surface that estimates the density of accidents across a geographical area and analyses the number of injuries and fatalities resulting from accidents.

In the weekly analysis of accident situations, accidents are highest on Fridays and Mondays, with 86 incidents, as shown in Figure 4. These accidents could be attributed to various factors. On Fridays, people commonly gather with family and friends, leading to increased traffic as they head to various destinations for social gatherings, shopping, or recreational activities.

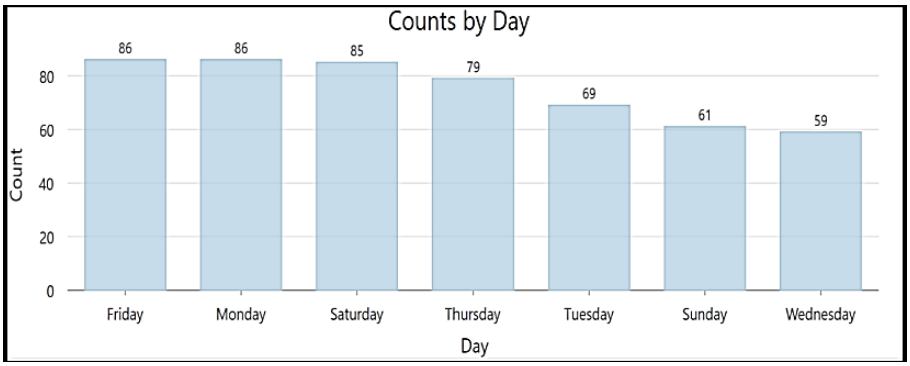

Figure 4: Graph of Accidents per Weekday
Source: Authors (2024)

Saturday has the second-highest number of accidents, with 85 recorded incidents. This could be due to people returning to work or school after the weekend, while Monday mornings can be hectic, leading to a higher risk of accidents. Sundays saw a decline, with 61 accidents. Disciplined driving and fewer distractions may contribute to fewer accidents on Sundays. Authorities can improve road safety by implementing targeted awareness campaigns, increasing traffic law enforcement during peak hours, and promoting responsible driving

behaviour. Encouraging public transportation or carpooling on weekends can also help alleviate traffic congestion.

According to the daily analysis shown in Figure 5, accidents in Al Amerat, Oman, tend to increase throughout the week, with Saturdays and Thursdays experiencing the highest number of incidents. Thursdays mark the end of the work week. The accidents occurred over the weekend, resulting in increased movement of residents from Muscat, the business centre, to their respective areas. A rise in accidents on Saturdays is recorded as people return from their localities to Muscat for work. Figure 6 also displays an hourly analysis of accidents recorded. It shows a relatively low number of accidents during the early morning hours, from 4:00 AM until around 8:00 AM. Accident numbers rise gradually from 8:00 AM until 9:00 AM, indicating increased traffic volume during rush hour.

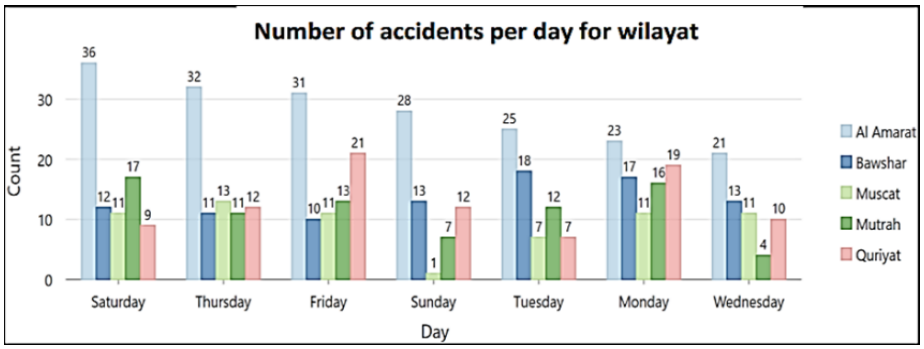

Figure 5: Graph of the Number of Accidents for the Wilayat
Source: Authors (2024)

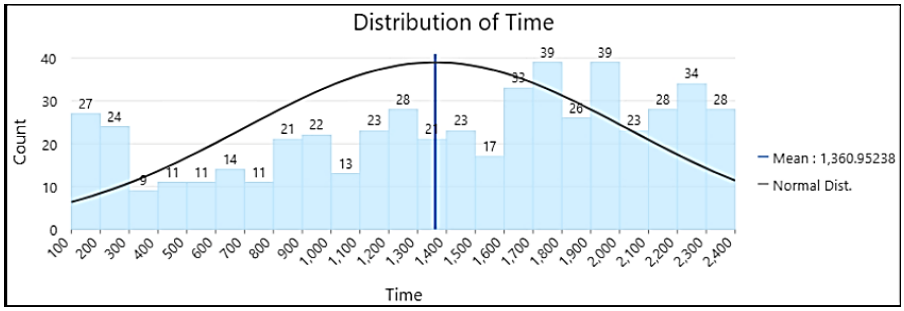

Figure 6: Graph of the Number of Accidents Per Day by Hour
Source: Authors (2024)

The accident count in the Wilayat area fluctuates between mid-morning and early afternoon hours with moderate traffic flow. However, it increases significantly from 4:00 PM to 5:00 PM, reaching its peak in the evening. The

highest accident count occurs between 5:00 PM and 05:00 AM. This surge in accidents during the evening hours is attributed to increased traffic congestion during the evening rush hour, shorter reaction times, and more aggressive driving behaviour. The graph shows the daily number of accidents for each Wilayat.

After a long day, drivers may experience fatigue or become distracted, potentially impairing their ability to maintain focus on the road. This factor, along with the use of mobile devices while driving, can significantly increase the risk of accidents. During the evening hours, natural light diminishes, and visibility decreases. Reduced visibility can make detecting potential road hazards more challenging, increasing the likelihood of accidents. Driving during the evening hours requires different skills compared to daylight driving. Factors such as oncoming headlight glare, increased difficulty judging distances, and impaired depth perception can pose challenges for drivers, leading to accidents.

The Possible Relationship between Hotspots and Possible Factors of Road Accidents: A Qualitative Approach

Understanding the relationship between hotspots, defined as areas with a high concentration of road accidents, and the potential factors contributing to these accidents is crucial for effective accident prevention and road safety measures. By identifying and analysing the factors associated with accident hotspots, authorities, policymakers, and traffic safety experts can develop targeted interventions and strategies to reduce the frequency and severity of accidents in these areas.

The factors influencing accident hotspots include roadway characteristics, environmental conditions, traffic volume, and driver behaviour. Environmental conditions, such as adverse weather conditions, can significantly impact driver visibility, vehicle handling, and braking capabilities. Identifying areas prone to flooding or poor drainage can prioritise safety measures. Driver behaviour, including speeding, aggressive driving, distracted driving, impaired driving, and non-compliance with traffic rules, contributes to accident-prone areas.

As indicated in Figure 7, this study reveals that speed is the primary cause of accidents, with 264 reported incidents. Speeding increases the likelihood and severity of accidents due to reduced control, longer stopping distances, and decreased reaction times. Driver error or negligence, such as running red lights or ignoring traffic rules, contributes significantly to road incidents. Careless driving accounts for 71 accidents, indicating a lack of attention, failure to anticipate hazards, or insufficient safety distance, including distractions like texting or eating while driving.

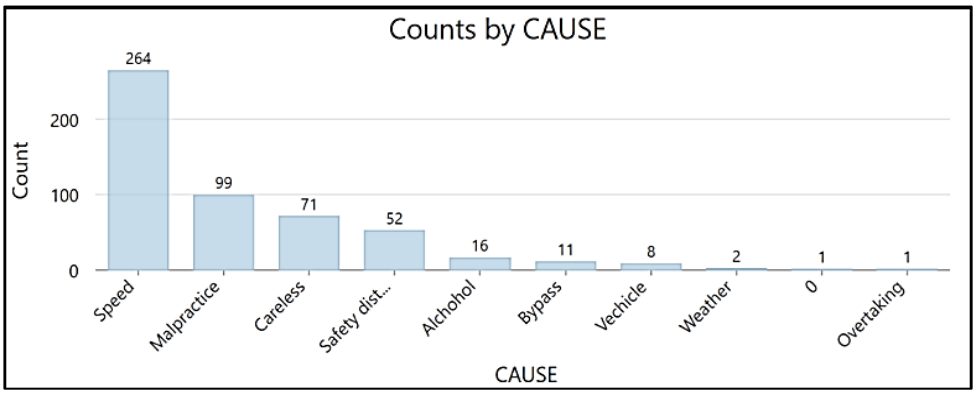

Figure 7: Graph of the Number of Accidents by Cause
Source: Authors (2024)

Maintaining a safe distance between vehicles is crucial for preventing accidents. Alcohol-related accidents account for 16 incidents while driving under the influence increases the risk. Bypass, vehicle-related issues, weather conditions, and overtaking cause fewer accidents but still warrant attention and potential interventions. These factors should be addressed to prevent accidents. The graph analysis also shows that speed, malpractice, and careless driving are the leading causes of accidents, with speed being the most common. Addressing these factors is crucial for improving road safety. Measures include enforcing speed limits, educating drivers on responsible driving, promoting safe distances, and implementing policies to discourage alcohol-impaired driving. These targeted interventions can reduce accident rates, mitigate consequences, and enhance road safety.

CONCLUSION

Road traffic accidents in Oman, particularly in the Muscat Governorate, have significant social and economic impacts. Innovative approaches to processing spatial data are crucial to addressing this issue. GIS and spatial analysis are valuable techniques for mapping and analysing road accidents, providing insights into distribution patterns. This study identified the high-risk locations in the Muscat Governorate from 2019 to 2021 due to densely populated areas and heavy traffic flow. The spatial pattern of accidents was dispersed, indicating the need for a thorough investigation of this critical scenario. Qualitative effect analysis between hotspots and road accidents revealed potential risk factors such as roadway characteristics, environmental conditions, traffic volume, driver behaviour, and vulnerable road users. Speeding, malpractice, careless driving, and safety significantly impact the accident hotspots, providing valuable insights for prioritising safety measures, evaluating infrastructure, and implementing

targeted interventions. Improving road infrastructure, promoting responsible driving behaviour, and enhancing overall safety are essential to reducing accidents in the governorate. Future research will integrate geospatial data sources such as road networks, demographics, human behaviour, and land use data to understand the factors influencing accident hotspots empirically.

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REFERENCES

Adnan, N. A., Mahadzir, Z. 'Aqilah, Hashim, H., Mohd Yusoff, Z., Abdul Rasam, A. R., & Mokhtar, E. S. (2023). Road Accessibility and Safety Analysis In Gated And Non-Gated Housing Communities. *Planning Malaysia, 21*(28). https://doi.org/10.21837/pm.v21i28.1318

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

Abdul Rasam, A. R., Taileh, V., Lin, S., Adnan, N. A., & Ghazali, R. (2023). Integrating spatial cost path and multi-criteria analysis for finding alternative routes during flooding. *Planning Malaysia*, 21. https://doi:10.21837/pm.v21i26.1264

Aldala'in, S. A., Abdul Sukor, N. S., Obaidat, M. T., & Abd Manan, T. S. (2023). Road accident hotspots on Jordan's highway based on geometric designs using structural equation modelling. *Applied Sciences, 13*(14), 8095. https://doi.org/10.3390/app13148095

Al-Hasani, G., Asaduzzaman, M., & Soliman, A. (2019). Comparison of Spatial Regression Models with Road Traffic Accidents Data. In *Proceedings of the International Conference on Statistic: Theory and Applications (ICSTA'19)*, Lisbon, Portugal - August 13 - 14, 2019 (Paper No. 31, pp. DOI: 10.11159/icsta19.31). Retrieved from https://doi.org/10.11159/icsta19.31

Al-Jubouri, S. N. J. (2015). The Spatial Analysis of Traffic Accidents in the Sultanate of Oman (A Study in Transportation Geography). *Journal of Adab*, (Issue 114), University of Baghdad, College of Arts, Department of Geography.

Alkaabi, K. (2023). Identifying hotspot areas for traffic accidents and analysing drivers' behaviours and road accidents. Transportation *Research Interdisciplinary Perspectives*, p. 22, 100929. https://doi.org/10.1016/j.trip.2023.100929

Al-Shukri, M. B. (2009). The market of the authenticity of the past and the spirit of modernity. Education Message, 24, 166-173. Content Type: Research and Articles. Peer-Reviewed: Yes. Country: Oman. Gregorian Date: 2009. Hijri Date: 1430. Month: Rajab - June.

Azewan, M. D., & Abdul Rasam, A. R. (2020). Disease mapping and health analysis using free and open source software for geospatial (FOSS4G): An exploratory qualitative study of tuberculosis. Charting the Sustainable Future of ASEAN in

Science and Technology, 495–506. doi:10.1007/978-981-15-3434-8_43

Belwal, R., Belwal, S., & Al Quraini, A. (2015). Road Traffic Accidents (RTAs) and road safety in Oman: an analysis of people's perception towards the causes. Advances in *Transportation Studies: An International Journal*, Section B, 105–118.

Chakravorty, S. (1995). Identifying crime clusters: The spatial principles. Middle States Geographer, pp. 28, 53–58.

Fadha, I. H. R., Al-Abriyyah, F. B. B. M., Al-Ma'mariyah, J. K., & Al-Wahibiyyah, H. S. (2022, August). The Impact of Urban Expansion on Infrastructure Services in the Neighborhoods of the Wilayat Al Amerat in the Sultanate of Oman. *Al-Adab Journal of Social Sciences, 13*(3), 65-80.

Hazaymeh, K., Almagbile, A., & Alomari, A. H. (2022). Spatiotemporal analysis of traffic accident hotspots based on geospatial techniques. *ISPRS International Journal of Geo-Information, 11*(4), 260. https://doi.org/10.3390/ijgi11040260

Jalil, I. A., Rasam, A. R., Adnan, N. A., Saraf, N. M., & Idris, A. N. (2018). Geospatial network analysis for Healthcare Facilities Accessibility in semi-urban areas. 2018 IEEE 14th International Colloquium on Signal Processing & Its Applications (CSPA). https://doi.org/10.1109/cspa.2018.8368722

Lin, S., Mathew, S., & Abdul Rasam, A. R. (2023). Transmission Suitability Route Map Using the Least Cost Path Analysis (LCPA). *Planning Malaysia, 21*(26). https://doi.org/10.21837/pm.v21i26.1267

Lokhman, M. T., Abdul Rasam, A. R., & Mohd Noor, A. M. (2012). Reforming Health Care Facility Using Geographical Information System. *2012 IEEE Control and System Graduate Research Colloquium*. https://doi.org/10.1109/icsgrc.2012.6287174

Manap, N., Borhan, M. N., Yazid, M. R. M., Hambali, M. K. A., & Rohan, A. (2019). Determining Spatial Patterns of Road Accidents at Expressway by Applying Getis-Ord Gi* Spatial Statistic. *International Journal of Recent Technology and Engineering (IJRTE), 8*(3S3), 123-128.

Mansour, S. (2016). Spatial analysis of public health facilities in Riyadh Governorate, Saudi Arabia: a GIS-based study to assess geographic variations of service provision and accessibility. *Geospatial Information Science, 19*(1), 26–38.

Maouli, S. (2014, July 27). Traffic Congestion: A Crisis That Can Only End with a Change in Consumer Culture. *Fada'at*. Retrieved July 30, 2023, from https://www.atheer.om/archives/6776/

Mounce, R., & Nelson, J. D. (2019). On the potential for one-way electric vehicle car-sharing in future mobility systems. *Transportation Research*. Part a, Policy and Practice, pp. 120, 17–30. https://doi.org/10.1016/j.tra.2018.12.003

National Center for Statistics & Information. (2022). Population Statistics 2021: Sultanate of Oman. Retrieved from portal.ecensus.gov.om

Omar, M. B., Mamat, R. C., Rasam, A. R., Ramli, A., & Samad, A. M. (2021). Artificial intelligence application for predicting slope stability on soft ground: A comparative study. *International Journal of Advanced Technology and Engineering Exploration, 8*(75), 362–370. https://doi.org/10.19101/ijatee.2020.762139

Pleerux, N. (November 2019). Geographic Information System-based Analysis to Identify the Spatiotemporal Patterns of Road Accidents in Sri Racha, Chon Buri.

CAST: *Civil Engineering Journal*, 1477.6.

Prasannakumar, V., Vijith, H., Charutha, R., & Geetha, N. (2011). SpatioTemporal Clustering of Road Accidents: GIS-Based Analysis and Assessment. *Procedia - Social and Behavioral Sciences*, pp. 21, 317–325.

Ramana, G. V., Nallamilli, S. R., & Praneeth, D. M. V. (2018). Analysis on traffic safety and road accidents: A case study on selected roads in Muscat, Oman. *International Journal of Civil Engineering and Technology, 9*(2), 417–427.

Ramli, M. N., Abdul Rasam, A. R., & Rosly, M. A. (2022). Cartography and mapping for Precision Health: Review of essential elements for disease mapping. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVI-4/W3-2021, 273–280. https://doi.org/10.5194/isprs-archives-xlvi-4-w3-2021-273-2022

Romano, B., & Jiang, Z. (2017). Visualising Traffic Accident Hotspots Based on Spatial-Temporal Network Kernel Density Estimation. In SIGSPATIAL '17: Proceedings of the 25th ACM SIGSPATIAL *International Conference on Advances in Geographic Information Systems* (pp. 1–4). Article No.: 98.56

Sha'aban, S. N., Abdul Rasam, A. R., & Asmat, A. (2021). A 3D GIS mapping for Landscape Geovisualisation and park management: A case study in Kuala Keniam Station, Taman Negara Malaysia. *IOP Conference Series: Earth and Environmental Science, 685*(1), 012010. https://doi.org/10.1088/1755-1315/685/1/012010

Yue, Y., Sun, J., Liu, X., Ren, D., Liu, Q., Xiao, X., & Lu, L. (2018). Spatial analysis of dengue fever and exploration of its environmental and socio-economic risk factors using ordinary least squares: A case study in five districts of Guangzhou City, China, 2014. *International Journal of Infectious Diseases*, pp. 75, 39-48.

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