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ANALYSIS OF ACCIDENT-PRONE LOCATIONS AND ROAD SAFETY INSPECTIONS IN YOGYAKARTA CITY

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ABSTRACT
The growth in the number of motor vehicles and community activities in Yogyakarta City put great pressure on the transportation system, which has an impact on the increasing number of traffic accidents. The high accident rate shows the need to identify vulnerable locations as a basis for the preparation of prevention strategies. This study aims to identify accident-prone locations in the city of Yogyakarta through a spatial approach and formulate handling recommendations based on the results of road safety inspections. The methods used include spatial analysis using the ArcMap software-based Geographic Information System (GIS), with three main approaches, namely spatial autocorrelation analysis (Moran's I), hotspot analysis (Getis-Ord Gi), and density estimation (Kernel Density Estimation). Accident data was obtained from the Yogyakarta City Resort Police and weighted using the Equivalent Accident Number (EAN) method. The results of the analysis identified 16 hotspot points with a 99% confidence level, as well as four priority locations that require immediate handling, namely Jalan Kyai Mojo, Jalan Menteri Supeno, Jalan P. Diponegoro, and Jalan Brigjen Katamso. The results of road safety inspections show that there are problems such as damage to the road surface, markings that are not clearly visible, lack of traffic signs, and misuse of sidewalks. Handling recommendations include repairing road infrastructure, repainting markings, adding signs and crossing facilities, and restoring sidewalk functions for pedestrians. It is hoped that the implementation of this recommendation can reduce the accident rate and significantly improve traffic safety in the city of Yogyakarta.
Keywords: Traffic Accidents, Accident-Prone Locations, Road Safety Inspection, GIS, GIS

INTRODUCTION

The growth of motor vehicles and the increase in community activities in urban areas have put great pressure on the transportation system, including in the city of Yogyakarta. The consequence of this dynamic is an increasing number of traffic accidents that not only threaten the safety of road users, but also cause significant social and economic losses (WHO, 2023). Based on data from the Central Statistics Agency of Yogyakarta City (2024), the number of traffic accidents shows an increasing trend every year, so appropriate handling strategies are needed to reduce the risk of accidents.

Research on the identification of accident-prone locations has been carried out using a spatial approach. Pratama and Mahmudah (2024) applied spatial analysis in Kulon Progo Regency to determine black spot areas with results that showed the effectiveness of *the Geographic Information System* (GIS) method. Similar studies were also conducted by Al-Aamri et al. (2021) in the Sultanate of Oman and Rabbani (2019) in Pakistan, which utilized techniques such as *Kernel Density Estimation* (KDE), *Getis-Ord Gi**, and *Moran's I* in identifying priority accident sites. Research in Indonesia has also adopted similar methods, such as those conducted by Saputri and Indrianawati (2021) in Sleman Regency, as well as Emiliyanta, Mulyono, and Utomo (2022) in Sleman, which emphasize the importance of integration between spatial analysis and road safety inspection.

In the context of handling accidents, road safety inspections are one of the widely used preventive approaches. Setiawan, Rezki, and Mahmudah (2018), as well as Syarifuddin, Hadi, and Marwanto (2024), show that visual inspection of geometric elements, traffic signs, road markings, and the condition of pedestrian facilities can reveal the dominant cause of accidents in a location. Similar evaluations were conducted by Respati (2023) and Khomeini and Taufik (2017), who recommended geometric improvements and the addition of safety facilities to reduce the risk of accidents. A study by Azizah, Lesmana, and Fitrianingsih (2017) on the Ngawi-Mantingan section also emphasizes the importance of road safety audits as a form of continuous improvement efforts. Although there have been many studies that discuss the identification of accident-prone locations and road safety inspections, there is still a gap in the integration of the two approaches in an integrated manner for the City of Yogyakarta. Several previous studies, such as by Mahmudah, Reswara, and Al-Haji (2023) and Hermanto, Mulyono, and Suparma (2021), provide a strong methodological basis, but have not yet accommodated the potential for spatial-statistical merging and technical audits in a single complete analytical framework. Hadi et al. (2025) also conveyed the need for integration between topographic and spatial terrain of accidents, especially in complex urban areas such as Yogyakarta.

This study aims to identify locations prone to traffic accidents in Yogyakarta City using a GIS-based spatial approach and provide handling recommendations based on the results of road safety inspections. The analysis methods used included Global *Moran's I* spatial autocorrelation analysis, *Getis-Ord Gi* hotspot* analysis, and KDE, followed by field inspections to assess physical conditions and safety equipment at priority locations. This research is expected to contribute to formulating a strategy to improve road safety based on spatial data and comprehensive field observation.

The scope of this research is focused on the administrative area of Yogyakarta City using traffic accident data obtained from the local police. The main emphasis is directed at a combination of quantitative and qualitative analysis to identify and recommend handling at priority accident sites. The study also adopts findings and approaches from previous research (Afolayan et al., 2022; Hazaymeh, Almagbile, & Alomari, 2022; Alam & Tabassum, 2023; Mohammed et al., 2019; Efendi, Hijar, & Hadjia, 2023; Anafi & PJNNR, 2024; Mulyono, Kushari, & Gunawan, 2009), as the basis for methodology and validation of the results obtained.

LITERATURE REVIEW

1. Spatial Analysis in Accident-Prone Location Identification (Blackspot Analysis)

Accident-prone location identification (LRK) is an important element in traffic engineering to prioritize safety handling. A spatial approach based on *Geographic Information System* (GIS) has proven to be effective in uncovering the geographical patterns of accidents that are not visible through conventional analysis. Several spatial statistical methods such as Global Moran's I, Getis-Ord Gi*, and Kernel Density Estimation (KDE) are often used to detect *crash clustering* patterns as well as map high-risk zones.

Previous studies, such as Pratama and Mahmudah (2024), Al-Aamri et al. (2021), and Rabbani (2019), show that a combination of several spatial statistical methods can provide more accurate results in identifying accident *hotspots*. This approach is in line with the findings of this article which uses these three techniques to identify *hotspots* in the city of Yogyakarta.

2. Equivalent Accident Number (EAN) in Weighting Accident Severity

The Equivalent Accident Number (EAN) method is used to give quantitative weight to the severity of the victim, so that the location with the fatal accident has a higher priority. Weighting is commonly used in LRK analysis techniques to equalize different levels of severity into a single comparable value. This article applies the EAN method with a weight of M:B:R:K = 12:3:3:1, which as used in various other road safety studies in Indonesia, makes the identification results more representative of the actual risks in the field.

3. Road Safety Inspection as a Risk Evaluation Stage

Road Safety Inspection (RSI) is a visual evaluation technique used to identify technical risks on roads. In the context of civil engineering, this inspection examines elements such as:

- the condition of the pavement surface,
- visibility of markings and signs,
- geometric design,

- pedestrian facilities,
- the existence of *road furniture*,
- and sidewalk functions.

Research by Setiawan et al. (2018) and Syarifuddin et al. (2024) shows that safety inspections can reveal the causes of accidents that cannot be seen from statistical data alone. The article you uploaded corroborates this by finding pavement damage, fading markings, lack of signage, and sidewalk abuse in the four priority locations identified through spatial analysis.

4. Spatial Analysis and Safety Audit Integration

The latest literature emphasizes the need for integration between spatial quantitative analysis and technical audits of road safety, especially in complex urban conditions. Studies by Hazaymeh et al. (2022), Alam & Tabassum (2023), and Mahmudah et al. (2023) show that spatial analysis can identify cluster patterns of accidents, while safety inspections can uncover the physical factors that cause accidents at that point. This article is one of the studies that applies this integration directly: spatial analysis to identify hotspots, then safety audits to determine the causes and technical solutions, so as to produce more comprehensive and accurate recommendations for road safety improvements.

5. Infrastructure Factors as the Dominant Cause of Accidents

Many studies state that infrastructure factors such as inadequate road design, faded markings, lack of lighting, and malfunctioning pedestrian facilities are significant causes of accidents. This is reinforced by the studies of Mulyono et al. (2009), Hermanto et al. (2021), and Efendi et al. (2023). This article finds a similar problem in the city of Yogyakarta, which shows that infrastructure problems are still a key factor in the high number of accidents in urban Indonesia.

RESEARCH METHODOLOGY

This research was conducted in the administrative area of Yogyakarta City which includes all road sections categorized as primary arterial roads, secondary arteries, secondary collectors, secondary locals, and secondary environments. The classification refers to the Yogyakarta City Regional Regulation Number 2 of 2021 concerning the Yogyakarta City Regional Spatial Plan. The selection of this location is based on the number of cases of traffic accidents recorded in recent years, so it is relevant to map and analyze the spatial analysis of accident-prone locations.

The data used in this study consisted of primary data and secondary data. Secondary data includes traffic accident data obtained from the Yogyakarta City Resort Police, including information on the location of coordinates, the number of victims based on severity (minor injuries, serious injuries, and deaths), the type of accident, and the time of the incident. In addition, spatial data in the form of a map of the road network of Yogyakarta City in shapefile format (.shp) obtained from relevant government agencies was also used. Meanwhile, primary data was obtained through road safety inspection activities carried out directly in the field, especially in locations with the highest accident rates that had been identified through previous spatial analysis. The stages of data processing include:

1. Accident Rate ClassificationData processing begins by classifying the severity of accident victims into four categories:
   - die
   - severe wounds,
   - minor injuries, and
   - material loss.
2. Application of Weighting Equivalent Accident Number (EAN)To give weight to the severity of the accident, the EAN method is used with a weighting ratio:
   M:B:R:K = 12 : 3 : 3 : 1 (M = death, B = serious injury, R = minor injury, K = material loss).

3. Spatial Analysis Using ArcMap GIS Accident data is then analyzed using ArcMap Geographic Information System (GIS) software to identify the pattern of accident distribution in the study area.
4. Spatial Autocorrelation Analysis (Global Moran's I)This stage is performed to determine whether the accident distribution has a pattern:
   - clustered,
   - random, or
   - dispersed. Moran's I value is calculated based on the deviation of each feature's attribute to the average value and spatial weight between features, thus illustrating the statistical relationship between accident sites.
5. Hotspot Analysis Using Getis-Ord Gi*This analysis aims to identify areas with high concentrations of accidents (*hotspots*) and low (*cold* spots). This technique evaluates the spatial significance of accident values based on attributes at the location and its neighbors within a given radius, resulting in a priority map of the accident site.
6. KDE's Kernel Density Estimation (KDE) analysis is used to estimate the density of accident points non-parametrically, generating a heatmap that visually depicts the intensity of an accident. This method is very effective for detecting high-risk areas.
7. Road Safety InspectionAfter the priority location is obtained, a field inspection is carried out using a checklist based on:
   - Road Traffic and Transportation Safety Inspection Guidelines
   - Road Safety Audit Guidelines Number 03/P/BM/2024The aspects examined include the physical condition of the road, markings, signs, geometry, and the behavior of road users. The inspection findings are used to identify the dominant factors causing accidents and develop technical handling recommendations.

ANALYSIS AND DISCUSSION

According to data obtained from the Yogyakarta City Resort Police, during the period from 2021 to 2024, there have been 2,813 traffic accidents. Details of the number of incidents and traffic accident victims are presented in Table 1, which shows the details of deaths, serious injuries, and minor injuries in each observation year.

Table 1 shows that the number of accident incidents increased significantly from 2021 to 2023. 2023 was the peak of incidents with a total of 831 accident cases, while 2021 was the year with the lowest number of incidents, namely 466 cases. Although there was a slight decrease in 2024 to 824 incidents, the general upward trend still shows the need to evaluate locations that have a high concentration of incidents.

Table 1. Data on the Number of Incidents and Accident Victims in 2021 - 2024

Year	Number of Events	Types of Victims		
		Die	Severe Injuries	Minor Wounds
2021	466	36	4	648
2022	692	41	0	994
2023	831	29	1	995
2024	824	33	2	959
Sum	2.813	139	7	3.596

Spatial Analysis of Traffic Accident Locations

To identify the spatial distribution pattern of traffic accidents, a global autocorrelation analysis was performed using *Moran's I* method. Based on the results of the analysis, *Moran's I* value was 0.022 with an Expected Index of -0.000374. This value indicates that the spatial pattern of accident distribution in Yogyakarta City tends to be random and does not show significant grouping. This is reinforced by a *z-score* of 1.154 and *a p-value* of 0.248, indicating that there is no significant spatial relationship at the 95% confidence level. The results of the analysis visualization are shown in Figure 1.

Furthermore, to detect the spatial concentration of accidents with a local statistical approach, hotspot analysis was carried out using *the Getis-Ord Gi** method. Based on the mapping results, 16 location points with a 99% confidence level were identified as *hotspot* areas, which were spread across several main roads in Yogyakarta City. Areas with high *z-scores* were marked as priority areas of intervention because they showed a concentration of spatially significant accidents. The visualization of the results of *the hotspot* analysis is shown in Figure 2.

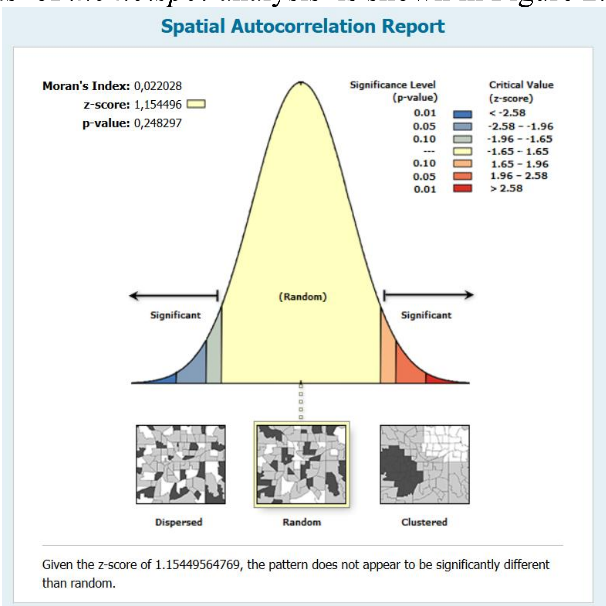

Figure 1. Spatial Autocorrelation Analysis Results Using *Moran's I*

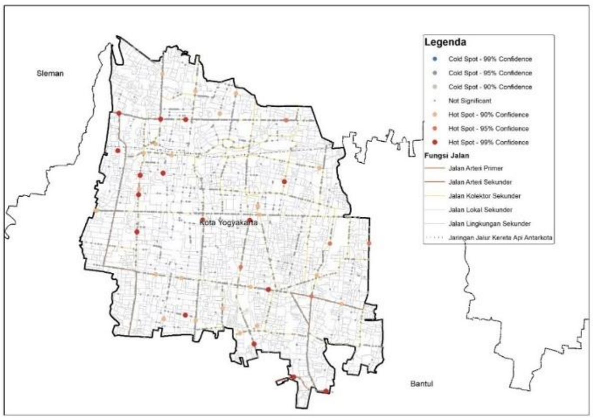

Figure 2. Hotspot Analysis Results Using *Getis-Ord Gi**

In addition, an analysis of Accident Density was also carried out using *the Kernel Density Estimation* (KDE) approach. With a search radius of 300 meters, a map surface was obtained that showed the highest concentration of accidents along the Secondary Artery Road and the Secondary Collector Road. This technique allows the identification of the spatial distribution pattern of accident events in more detail and comprehensively. The results of the KDE analysis are shown in Figure 3.

Ranking of Accident-Prone Locations

Based on the results of *the Getis-Ord Gi** and Kernel Density analysis, the process of ranking accident-prone locations was carried out to determine handling priorities in accordance with the

Guidelines for Handling Traffic Accident-Prone Locations (Department of Settlements and Regional Infrastructure, 2004). Of the 16 *hotspots* identified, four priority locations were determined for intervention, namely Jalan Kyai Mojo, Jalan Menteri Supeno, Jalan P. Diponegoro, and Jalan Brigjen Katamso. The process of integrating the spatial analysis results is shown in Figure 4 which combines *the Getis-Ord Gi** and Kernel Density results.

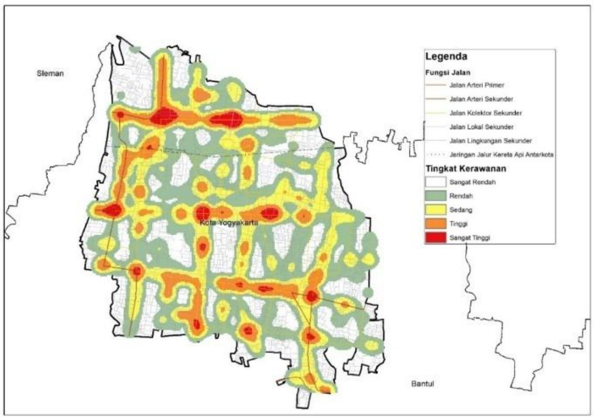

Figure 3. Kernel *Density Estimation Analysis Results*

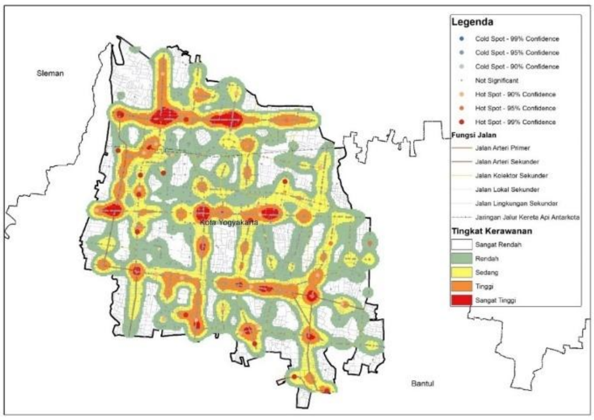

Figure 4. Combined *Getis-Ord Gi** and *Kernel Density Estimation Results*

Road Safety Inspection

To strengthen the results of spatial identification, road safety inspections were carried out at the four priority locations. This inspection aims to directly review the physical condition of road infrastructure, the completeness of signs and markings, road geometry, and the behavior of road users. Based on field observations, several dominant problems were found that contributed to the high risk of accidents. Among them are damage to the road surface, road markings that are not clearly visible, lack of traffic signs, and the existence of unsignaled intersections without adequate arrangements. In addition, the use of sidewalks by street vendors and illegal parking poses a serious threat to pedestrian safety. These findings show that infrastructure and road completeness factors play a significant role in the high accident rate.

Handling Recommendations

Based on the results of the field inspection, the following are the technical handling recommendations for each location:

1. Kyai Mojo Street
   It is necessary to repair faded road markings, reinstall traffic signs that meet standards, and repair drainage systems to avoid waterlogging.
2. Jalan Minister Supeno

It is recommended to carry out road reconstruction, repair longitudinal and transverse markings, and add crossing facilities for pedestrians.

3. Jalan P. Diponegoro
   It is necessary to repair the road surface from damage such as cracks and potholes, restore the function of the sidewalks that are now used for parking and trading, as well as repainting the markings of lane dividers, stop lines, and zebra crosses.
4. Jalan Brigjen Katamso
   It is necessary to repair road markings, especially at crossing facilities, adjust the intersection design to make it safer, and add public street lighting (PJU) to increase night visibility.

A series of spatial analyses equipped with road safety inspections provide a comprehensive overview of priority locations and intervention strategies that can be applied appropriately in an effort to reduce the number of traffic accidents in Yogyakarta City.

The technical recommendations provided have referred to the regulations and road safety standards that apply nationally, namely:

1. Law No. 22 of 2009 (Road Traffic and Transportation)
   - Regulating the obligation of road operators to maintain safe road conditions.
   - Requires signs, markings, and sidewalks to function according to their designation.
2. Government Regulation No. 34 of 2006 (Road)
   - Stipulates that road maintenance includes repairing damages, updating markings, and providing road equipment.
3. Permenhub No. 13 of 2014 (Traffic Signs)
   - It is the basis for adding and improving signs at all inspection sites.
4. Permenhub No. 34 of 2014 (Road Markings)
   - Setting up markings repainting guidelines, including standard zebra crosses and stop lines.
5. Permenhub No. 82 of 2018 (Traffic Management & Engineering)
   - It is a reference in identifying accident-prone locations (blackspots) and improving intersection designs.
6. Regulation of the Minister of Public Works and Public Works No. 19/2011 (Road Technical Requirements)
   - Contains standards for road geometry, pedestrian space, transverse slope, as well as sidewalk and intersection provisions.
7. Road Safety Audit Guidelines 03/P/BM/2024
   - It is used as the basis for physical inspection techniques and the identification of safety risk factors.
8. SNI 8153:2015 (Road Equipment)
   - Provide the technical basis for installing PJU, signs, markings, guardrails, and other safety equipment.

CONCLUSION

Based on the results of spatial analysis and road safety inspections, it can be concluded that the incidence of traffic accidents in Yogyakarta City tends to increase in recent years, with a significant concentration of incidents on certain road sections. Spatial analysis using *Moran's I* method showed a random accident distribution pattern, but through the *Getis-Ord Gi** approach and *Kernel Density Estimation*, 16 locations classified as accident *hotspots* were identified with a 99% confidence level. From these locations, four priority points were set as the focus of handling, namely Jalan Kyai Mojo, Jalan Menteri Supeno, Jalan P. Diponegoro, and Jalan Brigadier General Katamso.

The results of the road safety inspection revealed various infrastructure problems that contributed to the high risk of accidents, including damage to the road surface, markings that were not clearly visible, lack of traffic signs, and the use of sidewalks that were not in accordance with their function. Based on these findings, a number of technical actions are recommended such as road rehabilitation, repainting of markings, adding signs and crossing facilities, and regulating the use of sidewalks.

An integrated approach that combines GIS-based spatial analysis and road safety inspection has proven effective in accurately identifying accident-prone locations and developing targeted handling recommendations. The implementation of the results of this study is expected to support efforts to improve transportation safety in urban areas, especially in the city of Yogyakarta, as well as become a model for accident risk management for other cities in Indonesia.

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