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GIS-BASED IDENTIFICATION AND ANALYSIS OF TRAFFIC ACCIDENT-PRONE ROAD SEGMENTS IN PALU CITY, INDONESIA

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Abstract

Traffic accidents remain a critical public safety and urban mobility concern in rapidly developing cities in Indonesia. This study aims to identify, analyze, and spatially classify traffic accident-prone road segments in Palu City, Central Sulawesi, using a Geographic Information System (GIS)-based approach. Secondary data on traffic accidents recorded from 2018 to 2021 were obtained from the Palu City Regional Police (POLRESTA Palu) and covered all arterial and collector roads within the city. The Upper Control Limit (UCL) method was applied to determine accident weighting scores (Accident Point Weightage/APW) and to rank road segments by their relative hazard levels. Spatial databases were constructed and visualized using ArcGIS 10.8 software. Results indicate that three national primary arterial roads — Jl. Trans Sulawesi (APW = 167; UCL = 30.689), Jl. RE Martadinata (APW = 60; UCL = 24.675), and Jl. Yos Sudarso (APW = 56; UCL = 24.389) — represent the highest accident risk corridors. GIS-based hazard mapping further classified road segments into three levels: high (APW > 35), moderate (APW 10–34), and low (APW < 10). The dominant contributing factors include speeding, non-compliance with traffic regulations, poor road surface conditions, and inadequate road safety infrastructure. Recommended mitigation strategies include immediate road repairs, installation of traffic signal systems and warning signs, and structured road safety education campaigns targeting vulnerable road users, particularly students.

Keywords: *traffic accidents; accident-prone roads; GIS; Upper Control Limit (UCL); road safety; Palu City*

1. Introduction

Traffic accidents constitute one of the most pervasive public health challenges globally, resulting in millions of fatalities and injuries annually. According to the World Health Organization (WHO), approximately 1.19 million people die each year as a result of road traffic crashes, with low- and middle-income countries bearing a disproportionate burden (Ahmed et al., 2023). In the Indonesian context, the rapid growth of private vehicle ownership, insufficient road safety enforcement, and expanding urban road networks have collectively contributed to sustained high rates of road traffic accidents.

Palu City, the provincial capital of Central Sulawesi, has experienced considerable urbanization over recent decades, driving an increase in motor vehicle density. Data from the Palu City Regional Police (POLRESTA Palu) reveal that between 2018 and 2021, a total of 451 traffic accident events were recorded, resulting in 148 fatalities, 155 serious injuries, and 609 minor injuries, with an estimated cumulative material loss of IDR 1,490,850,000. Despite the substantial human and economic toll, the systematic spatial identification of

accident-prone locations has historically been limited, with accident records maintained primarily as non-spatial administrative documents.

The identification and spatial analysis of accident-prone road segments, commonly referred to as Black Spots or Black Sites, is an established practice in road safety management worldwide (Vitianingsih et al., 2021). Geographic Information Systems (GIS) offer a powerful analytical framework for integrating spatial and attribute data to visualize, quantify, and rank road hazard levels, enabling evidence-based decision-making by urban planners and traffic authorities (Albert et al., 2000; Rebolj & Sturm, 1999). GIS-based accident mapping has been successfully applied in various contexts to improve the precision and efficiency of safety interventions (Olusina & Ajanaku, 2017; Sari et al., 2018).

The Upper Control Limit (UCL) method, derived from statistical quality control principles, has been widely adopted in Indonesian road safety guidelines (Pd.T-09-2004-B) as a standardized approach to identifying road segments where accident severity exceeds statistically expected levels. By computing the Accident Point Weightage (APW) — a weighted score accounting for fatality severity — and comparing it against the UCL threshold for each road segment, this method provides an objective, replicable criterion for hazard classification (Ye et al., 2023; Kristianto et al., 2024).

Despite the practical and policy relevance of this issue, published research systematically combining the UCL method with GIS visualization for road safety mapping in Sulawesi is limited. This study therefore aims to: (1) identify road segments in Palu City that are statistically prone to traffic accidents; (2) analyze and rank those segments using the UCL and APW methods integrated with ArcGIS 10.8; and (3) develop practical recommendations for road safety interventions based on field observations and GIS-based hazard classification.

2. Literature Review

2.1 Traffic Accidents and Causative Factors

Under Article 1 of Indonesian Law No. 22 of 2009, a traffic accident is defined as an unexpected and unintentional road event involving vehicles, with or without other road users, resulting in human casualties and/or material damage. Traffic accidents are typically attributed to a combination of human factors, vehicle conditions, and road and environmental factors (Kumar Sharma & Kumar, 2023). Human factors — including speeding, driving under the influence of alcohol, fatigue, and non-compliance with traffic regulations — are consistently identified as the dominant causative category (Zegeer & Deen, 1994; Jovanis & Delleur, 1985). Vehicle-related factors encompass inadequate maintenance of safety-critical components such as mirrors, brakes, and lighting systems, while road and environmental factors include pavement deterioration, inadequate road markings, absence of pedestrian infrastructure, and poor illumination (Marselus, 2018).

2.2 Identification of Accident-Prone Locations

The identification of hazardous road locations generally follows a two-stage process: (1) a macro-level review of historical accident records to screen candidate locations, and (2) a micro-level detailed analysis of selected sites to guide targeted interventions (Vitianingsih et al., 2021). Hazardous locations are classified into three types: hazardous sites (Black Spots — discrete high-risk points), hazardous routes (Black Sites — extended high-risk corridors), and hazardous areas

(broader zones with elevated accident density). Road safety literature extensively employs statistical control chart methods, Kernel Density Estimation (KDE), and weighted severity indices (WSI) for the identification and ranking of such locations (Olusina & Ajanaku, 2017; Ye et al., 2023).

2.3 Geographic Information Systems in Road Safety Analysis

A Geographic Information System (GIS) is an integrated information system designed to collect, store, manage, and analyze spatially referenced data. In the domain of road safety, GIS enables the overlay of accident event data with road network layers, land use maps, and traffic volume data, facilitating multi-dimensional spatial analysis (Albert et al., 2000; Malczewski, 2004). The application of mobile and desktop GIS platforms has substantially improved the efficiency and accuracy of accident database management in developing country contexts (Bârliba et al., n.d.; Rebolj & Sturm, 1999). ArcGIS, as a leading commercial GIS platform, provides robust tools for spatial querying, thematic mapping, and location-based analysis applicable to urban road safety assessments (Bolla, 2017).

3. Materials and Methods

3.1 Study Area

The study area encompasses the road network of Palu City (0°54'S, 119°52'E), the provincial capital of Central Sulawesi, Indonesia. Palu City is located in a narrow valley along the shores of Palu Bay and is traversed by an extensive road hierarchy comprising national arterial roads, provincial collector roads, city local roads, and secondary collector roads. The study focused on roads classified as arterial (primary and secondary) and collector (primary and secondary) roads, totalling more than 80 named road segments. These road categories are of primary interest from a traffic safety perspective due to their higher traffic volumes and design speeds relative to local roads.

3.2 Data Sources

The study relied primarily on secondary data comprising official traffic accident records for the period 2018–2021, obtained from the Palu City Regional Police (POLRESTA Palu). For each recorded accident event, the dataset included the location (road segment name and general position), accident type (collision mode), number and type of casualties (fatality, serious injury, minor injury), and estimated material loss. In total, 451 accident events were recorded over the four-year study period. Spatial data on the road network were sourced from the Palu City Public Works Department (Dinas Pekerjaan Umum Kota Palu). Software tools employed included ArcGIS 10.8 for spatial database construction and GIS mapping, AutoCAD for geometric road data processing, and Microsoft Office for tabular data management.

3.3 Accident Weighting and APW Calculation

To compute the relative severity of accidents on each road segment, a weighting scheme was applied to each type of casualty according to the operational guidelines of the Traffic Accident Research Unit (Accident Blackspot Investigation Unit/ABIU, also referred to as Unit Penelitian Kecelakaan/UPK, 2007). The severity weights are defined as follows: fatality (Meninggal Dunia, MD) = 6; serious injury (Luka Berat, LB) = 3; and minor injury (Luka Ringan, LR) = 0.8. The Accident Point Weightage (APW) for each road segment was then calculated as:

$$APW = (MD \times 6) + (LB \times 3) + (LR \times 0.8)$$

This formulation is consistent with the weighting ratios specified in the Indonesian guideline for the management of accident-prone locations (Pd.T-09-2004-B), which prescribes a severity equivalence of MD : LB : LR : K (property damage only) = 12:3:3:1.

3.4 Upper Control Limit (UCL) Method

The Upper Control Limit (UCL) method, adapted from statistical process control theory, was applied to establish a threshold value for each road segment above which the segment is classified as accident-prone (Black Site). The UCL is calculated using the following formula as specified in Pd.T-09-2004-B:

$$UCL = \lambda + \Psi \times \lambda m + 0.829m + (1/(2m))$$

where λ is the mean accident weighting value (APW mean) across all analyzed road segments, Ψ is a standard normal deviate at a specified confidence level (typically 2.576 for a 99% confidence level), and m is the number of accidents recorded on a given road segment. A road segment is classified as accident-prone (Black Site) when its APW value exceeds its corresponding UCL value. The mean APW across all analyzed arterial and collector segments was calculated at 15.64.

3.5 GIS Database Development and Spatial Mapping

A spatial database of traffic accidents was developed using ArcGIS 10.8. Accident records were geocoded to the corresponding road segment features within the Palu City road network shapefile. Each road segment feature was attributed with its APW value, UCL threshold, road classification (function and administrative status), and hazard level category. Thematic maps were produced to visualize the spatial distribution of accident-prone roads classified by hazard level (high, moderate, low), enabling rapid visual communication of priority intervention zones to stakeholders. The analytical workflow consisted of five sequential stages: (1) data collection and database preparation; (2) APW computation; (3) UCL threshold calculation; (4) road segment hazard classification; and (5) GIS-based mapping and output generation.

4. Results and Discussion

4.1 Temporal Trends in Traffic Accidents (2018–2021)

Traffic accident data recorded by POLRESTA Palu from 2018 to 2021 revealed a non-monotonic temporal trend (Table 1). The annual frequency of accidents declined from 124 events in 2018 to 112 in 2019 and further to 98 in 2020 — a reduction attributable in part to reduced road mobility during the COVID-19 pandemic period. However, 2021 witnessed a rebound to 117 accident events, indicating that accident rates cannot be assumed to have structurally improved. The total casualty count over the four-year period reached 451 events, with 148 fatalities, 155 serious injuries, and 609 minor injuries.

Table 1. Annual Traffic Accident Statistics in Palu City (2018–2021)

Year	Total Accidents	Fatalities (MD)	Serious Injuries (LB)	Minor Injuries (LR)	Material Loss (IDR)
2018	124	44	42	168	471,150,000
2019	112	36	38	151	388,200,000
2020	98	29	31	132	315,500,000
2021	117	39	44	158	316,000,000
Total	451	148	155	609	1,490,850,000

Source: POLRESTA Palu (2022), processed by authors.

The ratio of fatalities to total casualties (approximately 32.8%) is notably high, suggesting that high-speed crashes dominate the accident profile. This is consistent with the predominance of high-speed national arterial roads in the study area. The estimated material loss of IDR 1,490,850,000 over the study period, while likely underestimating true economic costs, underscores the substantial socioeconomic burden of traffic accidents in the city.

4.2 Characteristics of Accident Victims by Occupation

Analysis of the demographic profile of accident victims revealed that students (pelajar) constituted the single largest group involved in traffic accidents, accounting for 320 out of the total recorded victims across all four years (Table 2). This finding is consistent with observations from other Indonesian cities, where young and unlicensed riders represent a disproportionate share of accident victims (Kumar Sharma & Kumar, 2023). Contributing factors include operating vehicles without a valid driving license, non-use of helmets, and poor risk perception. Private-sector employees and traders also constituted significant proportions of those involved in accidents.

Table 2. Accident Victims by Occupation in Palu City (2018–2021)

Occupation	2018	2019	2020	2021
Student	94	82	68	76
Private Employee	61	58	47	54
Civil Servant (PNS)	28	22	19	24
Self-employed / Trader	33	29	24	31
Other / Unrecorded	28	23	20	25

Source: POLRESTA Palu (2022), processed by authors.

4.3 UCL-Based Identification of Accident-Prone Road Segments

The UCL analysis was applied to all arterial and collector road segments within Palu City, yielding individual APW and UCL values for each segment. The global mean APW across all analyzed segments was 15.64, with a total cumulative APW of 641.2. Road segments with APW values exceeding their respective UCL thresholds were classified as accident-prone (Black Sites). Table 3 presents the five highest-ranked accident-prone segments.

Table 3. Top Five Accident-Prone Road Segments by UCL Analysis

Rank	Road Name	Road Function	Status	APW	UCL	Category
1	Jl. Trans Sulawesi	Primary Arterial	National	167	30.689	High
2	Jl. RE Martadinata	Primary Arterial	National	60	24.675	High
3	Jl. Yos Sudarso	Primary Arterial	National	56	24.389	High
4	Jl. Soekarno Hatta	Primary Collector	City	54	24.219	High
5	Jl. Malonda	Primary Collector	National	37	22.781	High

Note: APW = Accident Point Weightage; UCL = Upper Control Limit. Source: Authors' analysis.

Jl. Trans Sulawesi emerged as the most accident-prone corridor by a substantial margin, with an APW of 167 against a UCL of 30.689. This primary national arterial road, serving as the main intercity highway through Palu, carries high volumes of both through-traffic and intra-urban traffic, and its accident profile reflects the compounding effects of high vehicle speed, heavy goods vehicles, mixed traffic compositions, and limited grade-separated intersections. The second and third-ranked corridors — Jl. RE Martadinata and Jl. Yos Sudarso — are also national primary arterials, further reinforcing the pattern that high-speed, high-volume national roads generate the most severe accident concentrations.

These findings are broadly consistent with the international literature, which identifies primary arterial roads in developing cities as disproportionate contributors to accident severity due to the combination of high design speeds, inadequate pedestrian separation, and mixed use of roadway space (Vitianingsih et al., 2021; Ye et al., 2023). The inclusion of Jl. Soekarno Hatta (city primary collector; APW = 54) and Jl. Malonda (national primary collector; APW = 37) in the top five further highlights the role of roads serving commercial and mixed-use urban corridors.

4.4 GIS-Based Spatial Hazard Classification

The integration of UCL analysis outputs into ArcGIS 10.8 enabled the construction of a thematic accident hazard map for Palu City, classifying all analyzed road segments into three hazard levels based on APW thresholds (Table 4). This spatial visualization provides

planners and traffic authorities with a rapid-assessment tool for prioritizing safety investments and enforcement activities.

Table 4. GIS-Based Hazard Classification of Road Segments in Palu City

Hazard Level	APW Range	Representative Roads
High	APW > 35	Jl. Malonda, Jl. RE Martadinata, Jl. Soekarno Hatta, Jl. Trans Sulawesi, Jl. Yos Sudarso
Moderate	APW 10–34	Jl. Basuki Rahmat, Jl. Emy Saelan, Jl. Maleo, Jl. Toli-toli–Palu, Jl. Towua, Jl. Zebra
Low	APW < 10	Jl. Dewi Sartika, Jl. Dr. Wahidin, Jl. Gajah Mada, Jl. Garuda, Jl. Gatot Subroto, and others

Source: Authors' GIS analysis based on POLRESTA Palu data (2022).

High-hazard segments (APW > 35) are concentrated on primary arterial and primary collector roads, which carry the highest traffic loads and design speeds. Moderate-hazard segments (APW 10–34) predominantly correspond to secondary arterial and secondary collector roads with intermediate traffic volumes. Low-hazard segments (APW < 10) are largely confined to secondary collector and environmental (residential) roads with lower speeds and volumes. This three-tier classification is operationally consistent with GIS-based road safety classification frameworks used in comparable studies in Southeast Asian contexts (Vitianingsih et al., 2021; Sari et al., 2018).

4.5 Causal Factors and Field Observations

Field observations at the identified Black Site locations corroborated the statistical findings and provided contextual insight into site-specific causal factors. Three dominant causal categories were identified:

- Human/behavioral factors: Speeding, aggressive overtaking, disregard for traffic signals and lane markings, and operation of vehicles without valid licenses — particularly prevalent among the student age group — were the most frequently observed behavioral risk factors.
- Vehicle factors: Defective lighting systems, malfunctioning side mirrors, and brake failures were noted as contributing factors, particularly for commercial and aged vehicles.
- Road and infrastructure factors: Pavement deterioration including potholes (notably at Jl. Soekarno-Hatta in front of Gardu Induk Talise and PT. Kuliner Nusantara Tondo), absence of traffic signal systems at key intersections (e.g., Jl. RE Martadinata at the Jl. Pendidikan junction), insufficient road markings and warning signage, and inadequate street lighting were identified at multiple high-risk locations.

These findings align with the multi-causal model of traffic accidents described by Kumar Sharma and Kumar (2023), confirming that the highest-risk locations are typically characterized by the simultaneous convergence of behavioral, vehicular, and infrastructure

deficiencies. The absence of traffic signals at high-volume intersections on national arterial roads, in particular, represents a readily addressable infrastructure gap.

4.6 Recommended Mitigation Strategies

Based on the UCL analysis, GIS hazard mapping, and field observations, a set of differentiated mitigation strategies is recommended, organized by intervention type:

- Infrastructure engineering interventions: Priority installation of traffic signal systems at unsignalized high-volume intersections (notably Jl. RE Martadinata at Jl. Pendidikan junction); immediate resurfacing and pothole repair on Jl. Soekarno-Hatta; enhancement of horizontal road markings and vertical warning signage on all high-hazard corridors; and improvement of street lighting on unlit sections of Jl. Trans Sulawesi.
- Enforcement interventions: Targeted speed enforcement operations on Jl. Trans Sulawesi, Jl. RE Martadinata, and Jl. Yos Sudarso using speed cameras and patrol operations, with particular focus on heavy goods vehicles and student road users.
- Education and awareness campaigns: Structured road safety education programs targeting secondary school students across Palu City, with emphasis on helmet use, traffic sign compliance, and the legal requirements for vehicle operation. Community-level awareness campaigns at high-hazard corridors should complement enforcement activities.

These recommendations are consistent with the "Safe System" approach advocated by the United Nations Global Plan for Road Safety and align with best practices for road safety management in developing country urban contexts (Ahmed et al., 2023; Kumar Sharma & Kumar, 2023). The GIS-based spatial database developed in this study provides a foundational tool for ongoing monitoring of road safety trends and for evaluating the effectiveness of implemented interventions.

5. Conclusion

This study successfully applied a GIS-based analytical framework, integrating the Upper Control Limit (UCL) method with ArcGIS 10.8 spatial visualization, to identify, classify, and map traffic accident-prone road segments in Palu City, Indonesia, using accident data from 2018 to 2021.

The analysis identified Jl. Trans Sulawesi (APW = 167; UCL = 30.689) as the highest-risk corridor, followed by Jl. RE Martadinata (APW = 60; UCL = 24.675) and Jl. Yos Sudarso (APW = 56; UCL = 24.389) — all classified as national primary arterial roads. GIS-based thematic mapping further classified all analyzed road segments into three hazard levels (high, moderate, and low), providing a spatial decision-support tool for traffic authorities and urban planners.

Causal analysis identified human behavior (speeding, license non-compliance), vehicle condition deficiencies, and road infrastructure inadequacies (potholes, absent signals and signage) as the principal contributing factors. Mitigation strategies encompassing targeted infrastructure engineering, traffic enforcement, and road safety education are recommended, with priority actions focused on the five highest-ranked road segments.

The GIS-based accident database developed in this study represents a significant methodological advancement over the prior paper-based record management system in Palu City and provides a replicable model for traffic safety management in comparable Indonesian cities. Future research should incorporate traffic volume data for exposure-adjusted accident rate calculations and should employ time-series analysis to assess whether the 2021 accident rebound reflects a structural trend or a post-pandemic anomaly.

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