

OPTIMIZING ROAD SAFETY THROUGH GEOSPATIAL ANALYSIS OF ACCIDENT HOTSPOT CHARACTERISTICS AND VULNERABILITY LEVELS IN KARANGASEM REGENCY

GIS-Based Mapping and Analysis for Road Accident Prevention in Karangasem Regency

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ABSTRACT

According to data published by the World Health Organization (WHO, 2018), approximately 1.35 million people die annually due to road traffic accidents. This equates to one life lost every 25 seconds. In addition to the loss of life, road traffic accidents also cause profound psychological trauma for victims and families who lose loved ones. This research aims to identify road vulnerabilities and characterize traffic accident incidents in Karangasem Regency while addressing the research gap through a geospatial-based accident hotspot analysis using QGIS. This approach has not been comprehensively conducted in previous studies to support the development of more targeted and effective road safety policies in line with SDG 9. The primary data for this research involved geospatial analysis of high-risk locations, including the Tebola, Budakeling, and Tulamben highways, as well as other road sections. Furthermore, geoinformatics analysis using a quantum geographic information system (QGIS) was conducted to map the distribution of incidents and identify accident-prone areas as secondary data. The evaluation showed that the severity of road accidents is closely related to driver behavior and the physical condition of the road. From 2018 to 2022, 1,613 traffic accidents were recorded, with motorcycles accounting for the largest proportion, at 80.47%. Side-impact collisions were the most common type, with 384 reported. Mondays saw the highest number of accidents, with 222 incidents. In total, there were 1,648 injuries and 168 deaths. Evaluations show that the severity of traffic accidents is closely related to driver behavior and road conditions.

Keywords: Driver behavior, Geo-informatics, Geospatial analysis, Road safety, Vulnerability assessment.

ABSTRAK

Menurut data yang diterbitkan oleh Organisasi Kesehatan Dunia (WHO, 2018), sekitar 1,35 juta orang meninggal setiap tahun akibat kecelakaan lalu lintas. Ini setara dengan satu nyawa hilang setiap 25 detik. Selain kehilangan nyawa, kecelakaan lalu lintas juga menyebabkan trauma psikologis yang mendalam bagi korban dan keluarga yang kehilangan orang yang dicintai. Penelitian ini bertujuan untuk mengidentifikasi kerentanan jalan dan mengkarakterisasi kejadian kecelakaan lalu lintas di Kabupaten Karangasem sekaligus mengatasi kesenjangan penelitian melalui analisis titik rawan kecelakaan berbasis geospasial menggunakan QGIS, suatu pendekatan yang belum dilakukan secara komprehensif dalam penelitian sebelumnya, untuk mendukung pengembangan kebijakan keselamatan jalan yang lebih tepat sasaran dan efektif sesuai dengan SDG 9. Data primer untuk penelitian ini melibatkan analisis geospasial lokasi berisiko tinggi, seperti jalan raya Tebola, Budakeling, Tulamben, dan ruas jalan lainnya. Selanjutnya, analisis geoinformatika menggunakan sistem informasi geografis kuantum (QGIS) dilakukan untuk memetakan distribusi kejadian dan mengidentifikasi daerah rawan kecelakaan sebagai data sekunder. Evaluasi menunjukkan bahwa tingkat keparahan kecelakaan lalu lintas sangat berkaitan dengan perilaku pengemudi dan kondisi fisik jalan. Dari tahun 2018 hingga 2022, tercatat 1.613 kecelakaan lalu lintas, dengan sepeda motor menyumbang proporsi terbesar, yaitu 80,47%. Tabrakan samping merupakan jenis yang paling umum, dengan 384 kasus dilaporkan. Hari Senin mencatat jumlah kecelakaan tertinggi, dengan 222 insiden. Secara total, terdapat 1.648 korban

luka dan 168 korban meninggal. Evaluasi menunjukkan bahwa tingkat keparahan kecelakaan lalu lintas sangat berkaitan dengan perilaku pengemudi dan kondisi jalan.

Kata kunci: Perilaku Pengemudi, Geoinformatika, Analisis Geospasial, Keselamatan Jalan, Penilaian Kerentanan.

1. INTRODUCTION

Transportation is one of the main components that support the smooth functioning of community activities and economic growth in a region. Well-developed transportation infrastructure allows for the efficient distribution of goods and human mobility, thereby improving people's quality of life. However, alongside these benefits, transportation also presents serious challenges, one of which is the high rate of traffic accidents, which is still one of the leading causes of unnatural death in many countries. According to a report by the WHO, approximately 1.35 million people die each year due to road traffic accidents, equivalent to roughly one life lost every 25 seconds (WHO, 2018). In addition to fatalities, traffic accidents also cause deep psychological trauma for survivors and for the families of those who have lost loved ones (Bhateja et al., 2025).

In Indonesia, traffic accidents are widespread across many regions, including areas with moderate population density and diverse geographical conditions. One of the regions of particular concern in this study is Karangasem Regency, located in the eastern part of Bali Island. This region features complex geographical characteristics, such as hilly topography, narrow roads, and uneven infrastructure development. Based on data from the Karangasem County police, approximately 1,613 traffic accident cases were recorded between 2018 and 2022, with motorcycles being the most dominant contributors, accounting for 80.47% of total incidents (Suthanaya, 2015). The most common type of accident was side swipe collisions, totalling 384 cases, while Monday was reported as the day with the highest number of accidents, at 222 incidents. During this period, the number of injuries reached 1,648 people, with 168 fatalities (Chaudhuri et al., 2023).

Based on the results of observations at the research location, the problem of traffic accidents in Karangasem is closely related to several causal factors, both technical and behavioral factors. Driver behaviour is a significant factor, such as lack of concentration while driving, the use of mobile phones, traffic violations, and low awareness of traffic safety. Road conditions also play a significant role, including poor lighting, damaged or missing traffic signs, and road geometry that does not meet technical standards (Suthanaya, 2015). The complexity of these causes indicates that addressing traffic accidents requires a more systematic and data-driven approach.

With the rapid development of information technology, geospatial approaches have increasingly been applied in transportation safety studies, particularly for identifying accident-prone areas (accident hotspots) and evaluating their spatial distribution. Previous studies have demonstrated that Geographic Information Systems (GIS) are effective tools for analyzing the spatial patterns of traffic accidents. For instance, research conducted by Pleerux (2020) shows that GIS-based spatial analysis can reveal clusters of accident locations and support the identification of high-risk road segments (Shahid et al., 2015).

Among various GIS platforms, QGIS offers several advantages, including its open-source accessibility, flexibility in spatial data processing, compatibility with various geospatial data formats, and the availability of advanced spatial analysis tools for mapping accident distributions and identifying hotspot areas (Shariff et al., 2018). These capabilities allow researchers to visualize spatial patterns of traffic accidents and support data-driven decision-making in transportation safety management.

However, comprehensive geospatial analyses of traffic accident hotspots at the regional level remain limited, particularly in Karangasem Regency. Previous studies have generally focused on broader national or urban contexts, leaving a lack of spatially detailed investigations in this region. Therefore, the novelty of this research lies in the application of a QGIS-based geospatial hotspot analysis specifically in Karangasem Regency, which has not been comprehensively conducted in previous studies. This approach is expected to provide a clearer spatial understanding of accident-prone locations and support more targeted road safety policies.

However, research integrating geospatial approaches with in-depth analysis of Karangasem's

accident characteristics and vulnerability levels is still minimal. This region has unique geographical and social conditions that require more specific and locally informed approaches.

Therefore, the objectives of this research are:

1. To identify the characteristics of traffic accidents in Karangasem Regency based on the type of collision, time of occurrence, vehicle type, and victim age;
2. To conduct geospatial mapping of accident-prone points using QGIS software.

Through this approach, the research is expected to make a meaningful contribution to the formulation of more targeted traffic safety policies and to support the development of a more inclusive and sustainable transportation infrastructure that is truly oriented toward public safety in Karangasem.

2. LITERATURE REVIEW

2.1 Traffic accident

Traffic accidents are unexpected incidents involving vehicles or road users, often resulting in fatalities or material losses. This issue remains a central concern in transportation safety planning due to its significant social and economic implications. Based on official traffic accident records obtained from the Karangasem County police, data from 2018 to 2022 recorded 1,613 traffic accident cases, with the highest number occurring in 2019 (405 cases). Motorcycles were the most frequently involved vehicle type, accounting for 1,298 units or 80.47% of all accidents. The most common type of collision occurred during lane changing (384 cases), with Mondays being the most accident-prone day (222 cases). The impact on victims included 1,648 minor injuries, 33 serious injuries, and 168 fatalities. Most accidents occurred between 12:00 p.m. and 6:00 p.m., indicating peak traffic volume during these hours. Material losses over the five years totaled approximately IDR 1.98 billion, averaging IDR 396 million annually. The high frequency and severity of these incidents highlight the need for data-driven approaches, such as geospatial analysis, to identify high-risk locations (black spots and black sites). Implementing such methods is expected to enhance traffic safety policymaking and promote the use of safer and more sustainable construction materials (Shad et al., 2017).

2.2 Characteristics and risk factors

Understanding the characteristics of traffic accidents, including vehicle types, time of occurrence, collision types, and victim demographics (age and gender), is essential. This information provides a solid foundation for spatial analysis and identifying accident-prone areas, particularly in Karangasem Regency. Based on traffic accident records obtained from the Karangasem County police, motorcycles are the most frequently involved vehicles in accidents, accounting for 1,298 units or 80.47% of all cases, followed by light vehicles (7.56%) and heavy vehicles (11.97%). In terms of collision types, overtaking-related crashes dominate with 384 cases, followed by head-on collisions (160 cases) and hit-and-run incidents (137 cases). The most common time frame for accidents is between 12:00 p.m. and 6:00 p.m., totaling 417 cases, coinciding with peak traffic hours. Most accident victims fall within the 16 to 30-year-old age group, with 642 individuals affected. This highlights the high vulnerability of the productive age group, in line with Elvik (2024), who stated that young drivers face a 2 to 3 times higher risk of being involved in accidents compared to other age groups (Elvik, 2024). Additionally, male victims significantly outnumber females, 1,279 compared to 569, reflecting the dominance of male road users in the region. These characteristics form a crucial basis for mapping vulnerability and developing more targeted and effective traffic safety strategies (Elvik et al., 2024).

2.3 Geospatial analysis and hotspot detection

Geospatial analysis is utilized to identify patterns in the distribution of traffic accident locations based on coordinate data. In this study, accident-prone areas (black sites) were identified using the Z-score method, which calculates the deviation of accident frequency from the overall mean to

determine hazardous road segments (Ghadi et al., 2019). The analysis revealed that the Kubu-Tejakula Road and Abang Main Road are the areas with the highest accident rates. Previous studies have also shown that a relatively small portion of total road length often contributes disproportionately to the number of traffic accidents. Additionally, the NKDE (Network Kernel Density Estimation) method has proven more precise at identifying locations with a high risk of fatal accidents. Thus, geospatial approaches have demonstrated their effectiveness in risk mapping and serve as valuable tools for prioritizing efforts to enhance traffic safety (Karatzoglou, 2022).

2.4 QGIS as an analysis and visualization tool

QGIS is an open-source software used in Geographic Information Systems (GIS) for mapping and analyzing spatial data. In this study, QGIS was utilized to visualize the distribution of traffic accident points in Karangasem Regency based on road segment coordinate data. Through processes such as base map digitization, layer processing, and attribute overlay of accident characteristics, QGIS assisted in identifying road segments with high accident rates. Previous studies have demonstrated that QGIS can effectively support the mapping of accident zones, especially when combined with features such as heatmaps and clustering. These tools are highly useful for developing accident-prone area maps. Thus, QGIS serves not only as a visualization tool but also as a decision-support system for spatially based traffic safety planning (Parmar et al., 2018).

3. METHOD

3.1 Research location

Figure 1 shows the location of the study conducted in Karangasem Regency, located in the eastern part of Bali Province, Indonesia.

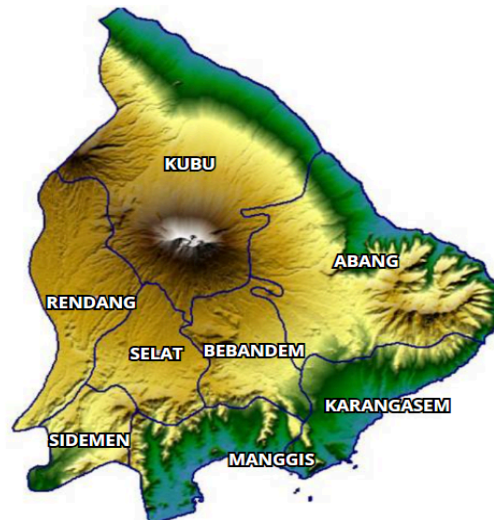


Figure 1. Map of Karangasem Regency.
(Source: Adapted from Yudiantara (2011).)

Complex topographical conditions, including winding roads, hills, and non-uniform infrastructure, characterise the region. These factors contribute to the road network's vulnerability to traffic accidents, making it a suitable area for geospatial accident risk analysis and hotspot detection.

3.2 Tools and materials used

The study employed various tools and data sources to conduct both spatial and statistical analyses, as detailed below.

1. QGIS 3.30: For spatial mapping and hotspot analysis using shapefile-based layers.
2. Microsoft Excel: For tabulation, Z-score calculation, and descriptive statistical analysis.
3. Shapefiles: Including administrative boundaries and road network maps of Karangasem.
4. Accident Records: Compiled from 2018 to 2022, sourced from police reports and academic

archives.

5. Literature Support: Including works by Hazaymeh et al. (2022); Shariff et al. (2018); and Suthanaya (2015).

3.3 Data sources

The data used in this study were obtained from both primary and secondary sources, including.

1. Official traffic accident reports collected by the Karangasem County police Department.
2. Coordinate data from STA references converted into GIS-compatible formats.
3. Secondary sources, such as research theses and journal articles, provide contextual and comparative insights.
4. Karangasem Regency spatial data, including road segment maps and population density overlays.

3.4 Data analysis

The Z-score method is employed to statistically identify accident-prone areas (black sites) by analyzing the deviation of accident frequency in each subdistrict from the overall mean. Z-Score Formula:

$$Z_i = \frac{X_i - \mu_i}{\sigma}$$

(1)

Where: Z_i = Z-score value of subdistrict III

X_i = Number of accidents in subdistrict III

μ = Mean of accident occurrences across all subdistricts

σ = Standard deviation of accident occurrences

Criteria for Z-Score Classification:

$Z > 1.0$: High-risk area (Black Site)

$-1.0 \leq Z \leq 1.0$: Moderate-risk

$Z < -1.0$: Low-risk area

Table 1 below presents the Z-score results for each subdistrict (2018–2022), showing accident frequency, calculated deviations from the mean, and corresponding risk classifications.

Table 1. Z-Score Calculation Example (2018–2022)

Subdistrict	Accident Count (Xi)	Z-Score (Zi)	Risk Category
Karangasem	58	+1.52	High
Abang	35	-0.42	Moderate
Manggis	49	+0.73	Moderate
Rendang	22	-1.36	Low
Selat	30	-0.79	Moderate
Sidemen	28	-0.95	Moderate

Note: Mean (μ)=37, Standard Deviation (σ)=13.81 from the complete district dataset.

Figure 2 below illustrates the spatial distribution of these accident risk categories across the district.

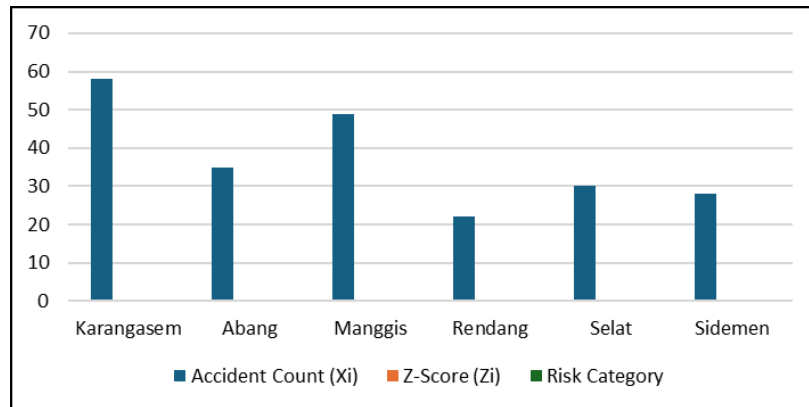


Figure 2. Bar chart of Z-score by subdistrict

3.5 Spatial mapping using QGIS

Accident coordinates, after conversion from STA references, were georeferenced and input into QGIS to produce thematic maps. The following steps were undertaken.

1. Data Preprocessing: Coordinate cleaning and integration with shapefile road layers.
2. Heatmap Generation: To highlight the density of accident clusters.
3. Buffer Analysis: 100 m-500 m buffers were applied around hotspots for vulnerability zone assessment.
4. Layer Overlay: Combining base maps, accident points, subdistrict boundaries, and demographic data.

This technique follows the spatial methodology applied by Shafabakhsh et al. (2017) and Hazaymeh et al., (2022), enabling clearer visual recognition of crash clusters and spatial risk intensity.

3.6 Descriptive analysis of accident characteristics

A descriptive statistical analysis was conducted on four primary accident parameters: collision type, vehicle type, age group, and victim gender (2018–2022).

Table 2 shows that most accidents fall under other types (39.7%), followed by side-swipe and rear-end collisions.

Table 2. Collision Type Distribution

Collision Type	Number of Cases	Percentage
Side-swipe	384	23.8%
Head-on	160	9.9%
Hit-and-run	137	8.5%
Rear-end	291	18.0%
Other types	641	39.7%

Table 3 indicates that victims are predominantly aged 18–30 years.

Table 3. Victim Demographics by Age

Age Group	Number of Victims	Percentage
< 17 years	88	5.3%
18–30 years	642	38.7%
31–50 years	525	31.8%
> 50 years	393	24.2%

Table 4 shows that most victims are male.

Table 4. Gender Distribution

Gender	Number of Victims	Percentage
Male	1,279	69.8%
Female	569	30.2%

3.7 Research procedure

The methodological steps followed in this study are as follows:

1. Data Collection: Accident reports and coordinate references from police and academic sources (2018–2022).
2. Data Preprocessing: Formatting and cleaning accident data in Excel and QGIS-compatible formats.
3. Z-Score Calculation: Statistical processing to identify subdistricts with significantly above-average accident rates.
4. Spatial Analysis with QGIS: Mapping accident points, applying heatmaps, and identifying spatial black sites.
5. Descriptive Analysis: Categorising accident records based on collision type, vehicle type, victim age, and gender.
6. Interpretation and Validation: Cross-referencing results with existing literature and local road safety conditions.

4. RESULT AND DISCUSSION

The Z-score analysis method was employed to identify subdistricts in Karangasem Regency that have a significantly higher incidence of traffic accidents compared to the average. This method uses statistical normalisation to measure how far a particular data point deviates from the mean, making it a powerful tool in identifying "black spots" or high-risk zones that require immediate attention. The traffic accident data analysed spans the period from 2018 to 2022, providing a comprehensive view of accident distribution across the region.

Based on the analysis, the average number of traffic accidents across all subdistricts (μ) was calculated to be 37.33 cases, while the standard deviation (σ) was 13.81. These values were then applied to the Z-score formula as in formula number one.

Where X represents the number of accidents in a specific subdistrict, μ is the average number of accidents, and σ is the standard deviation. The resulting Z-score indicates how many standard deviations a particular subdistrict's accident count deviates from the mean.

For instance, the Karangasem and Kubu subdistricts, both of which recorded 58 accidents over the five years, yielded a Z-score of approximately +1.50. This value clearly indicates that these subdistricts are 1.5 standard deviations above the mean accident rate, categorising them as high-risk or blackspot areas. In contrast, subdistricts such as Bebandem and Rendang showed Z-scores below -1.0, placing them in the low-risk category. The rest of the subdistricts, including Manggis, Abang, Selat, and Sidemen, had Z-scores that ranged between -1.0 and +1.0, indicating a medium risk level.

The detailed breakdown of Z-scores and associated risk levels allows for better prioritization of traffic safety measures. High-risk areas like Karangasem and Kubu should be the primary focus of intervention strategies. These could include improved road signage, installation of traffic calming measures, enhanced road lighting, regular maintenance, and stricter enforcement of traffic laws. Such targeted interventions have the potential to significantly reduce the accident rate in these blackspot zones.

This analytical approach is supported by previous research findings. Satria et al., (2020) & Zhang et al., (2023) emphasized that a relatively small proportion of road segments often accounts for the

majority of traffic accidents. This observation is consistent with the "Pareto Principle," which states that roughly 80% of consequences come from 20% of the causes. Applying this principle to road safety suggests that concentrating resources on a few high-risk areas can yield substantial improvements in overall road safety.

In summary, Z-score analysis proves to be an effective statistical method for identifying accident-prone zones. It enables policymakers and transportation authorities to focus their attention and resources on the most problematic areas, ensuring that interventions are data-driven and targeted. Such an evidence-based approach not only enhances traffic safety but also ensures efficient use of public resources.

4.1 Statistical parameters used

4.1.1 Mean (μ)

$$\mu = \frac{1}{n} \sum_{i=1}^n X_i \quad (2)$$

Where n is the number of subdistricts, and X_i is the number of accidents in subdistrict i .

4.1.2 Standard deviation (σ)

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (X_i - \mu)^2} \quad (3)$$

4.1.3 Example of Z-Score calculation

For the Karangasem subdistrict, which recorded 58 accident cases, the Z-score can be calculated as follows:

$$Z_i = \frac{X_i - \mu_i}{\sigma} \leftrightarrow Z = \frac{58 - 37,33}{13,81} \leftrightarrow Z = 1,496 \leftrightarrow Z \approx 1,50$$

A Z-score of +1.50 indicates that the number of accidents in Karangasem is 1.5 standard deviations above the mean, which classifies it as a high-risk (black site) location.

Table 5 shows that Karangasem and Kubu are classified as high-risk (black site) subdistricts due to Z-scores above +1.0, indicating accident frequencies significantly higher than the district mean and requiring priority safety interventions.

Table 5. Z-Score Values and Risk Categories by Subdistrict

Subdistrict	Accident Cases (2018–2022)	Z-Score	Risk Category
Karangasem	58	+1.50	High
Manggis	49	+0.84	Medium
Abang	35	-0.17	Medium
Selat	30	-0.53	Medium
Sidemen	28	-0.68	Medium
Bebandem	21	-1.18	Low
Rendang	22	-1.11	Low
Kubu	58	+1.50	High

From the table, it can be concluded that Karangasem and Kubu subdistricts are identified as black sites due to their Z-scores exceeding +1.0. These areas should be prioritised for traffic safety interventions such as enhanced signage, road maintenance, and enforcement.

This finding aligns with Satria et al., (2020) & Zhang et al., (2023), who emphasise that a small percentage of road segments often account for the majority of crashes, a principle consistent with the "Pareto Principle" in road safety.

4.2 Geospatial visualization using QGIS

Figure 3 illustrates the distribution and intensity of traffic accidents in the Karangasem Regency (Bali, Indonesia) using QGIS software

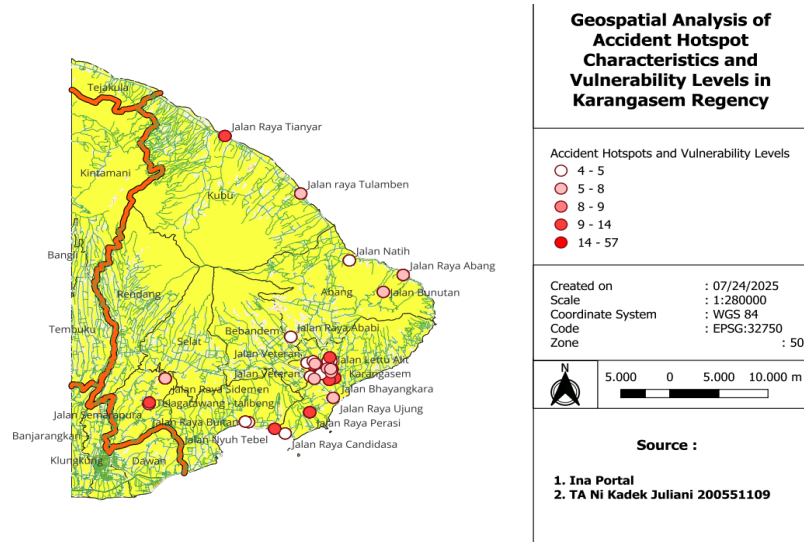


Figure 3. Geospatial Analysis of Accident Hotspot Characteristics and Vulnerability Levels in Karangasem Regency

The displayed map presents a spatial visualization of accident rates in Karangasem Regency based on traffic incident data from 2022. The color indicators represent different levels of accident vulnerability, ranging from very low to very high. Areas marked with darker red colors indicate districts with higher accident vulnerability levels. As presented in Table 6, below, the color indicators are used to classify the levels of accident vulnerability across districts in Karangasem Regency.

Table 6. Classification of Accident Vulnerability Levels Based on Color Indicators






Color Indicator	Range	Vulnerability Level
	4 - 5	Very Low
	5 - 8	Low
	8 - 9	Moderate
	9 - 14	High
	14 - 57	Very High

Table 6 shows the classification of accident vulnerability levels using color indicators and accident value ranges. The vulnerability levels are categorized into five classes, ranging from very low (4-5)

to very high (14–57). The spatial visualization was generated using QGIS by converting accident point data from STA (Stationing) references into geographic coordinates and integrating them with the Karangasem road network in shapefile format. Spatial analyses such as heatmap visualization and buffer zone analysis (100–500 meters) were applied to identify areas with high accident density and potential risk zones. The results reveal that the highest concentration of accidents occurs in the southern part of Karangasem Regency, particularly around Amlapura and along major road corridors such as Karangasem Amlapura, Tulamben Abang, and Kubu Tianyar. These areas exhibit clear clusters of accidents, indicating accident hotspots and higher vulnerability levels that require priority attention in road safety planning and infrastructure improvement. Figure 4 shows the condition of road segments and traffic signage:



Figure 4. a) The Kubu Tejakula road segment. b) damaged traffic signs

Based on the analysis, the Kubu Tejakula Highway at Sta 4 Sta 5 (which refers to the road kilometer markers between km 4 and km 5 from the starting point of measurement) is identified as an accident-prone location (black spot) on this road section. Therefore, it is necessary to study the characteristics of accidents that occur at this location to provide alternative solutions. Observations also show that traffic signs in the Tejakula area are damaged, making it difficult for drivers to recognize road conditions. One improvement effort that can be made is the installation of traffic signs at accident-prone locations, such as Sta 4-Sta 5, to encourage drivers to be more cautious when passing through this road section. In accordance with the regulations, accident-prone signs must be installed at least 50 meters before the accident-prone location to ensure that the warning function can work optimally. Figure 5 shows the malfunctioning street lighting system:



Figure 5. Street lights are obstructed by vegetation.

The improvement of street lighting on several segments of Jalan Raya Kubu – Jalan Tejakula is necessary, since side-swipe collisions frequently occur, particularly at night when the street lights are not functioning properly, thereby reducing drivers' visibility and increasing the risk of accidents. Proper and consistent maintenance of street lighting is therefore essential to enhance safety and minimize potential traffic hazards along this road section. Figure 6 shows the location and condition of the road:



Figure 6. Potholes and uneven road surface

Road repairs along Jalan Raya Abang need to be carried out by the government or relevant agencies, as the existing conditions are one of the main factors causing traffic accidents. The most frequent type of accident is Out of Control (OC), which occurs when drivers lose control due to damaged road surfaces. If not addressed promptly, such road damage will not only reduce driving comfort but also increase the risk of fatal accidents, particularly for motorcycle riders who are more vulnerable to poor road conditions.

Observations and visualization results indicate that urban areas in Karangasem, as well as coastal access roads in Kubu and Tulamben, have a high accident intensity. These areas are generally characterized by narrow road geometry, heavy tourism traffic flow, and a significant amount of damaged infrastructure. These findings are consistent with (Hazaymeh et al., 2022), which highlights the effectiveness of geospatial tools such as QGIS and Kernel Density Estimation in identifying traffic accident hotspots.

4.3 Descriptive analysis of accident characteristics

4.3.1 Collision type

From 2018 to 2022, side-swipe collisions dominated the incident types, accounting for 384 cases (23.8%). Other frequent types included rear-end collisions (18%) and head-on collisions (9.9%).

As can be seen in the distribution of accidents and their types in Table 7 below, there were a total of 1,613 recorded cases between 2018 and 2022.

Table 7. Distribution of Collision Types

Collision Type	Cases	Percentage
Side-swipe	384	23.8%
Rear-end	291	18.0%
Head-on	160	9.9%
Hit-and-run	137	8.5%
Others	641	39.7%

This is consistent with Suthanaya (2015) , who noted that overtaking on narrow roads in Karangasem significantly contributes to side-swipe and rear-end collisions.

4.3.2 Vehicle Type

Motorcycles were the most involved vehicle type, contributing to 1,298 out of 1,613 total cases (80.47%). This reflects the heavy dependence on two-wheelers in rural and peri-urban Balinese communities.

4.3.3 Victim Age and Gender

The 18–30 age group accounted for the highest number of victims (642 individuals or 39%), followed by the 31–50 age group (32%). Men accounted for 69.8% of victims, reinforcing the high-risk behavior trend among young male motorcyclists.

Table 8 shows the demographic breakdown of accident victims:

Table 8. Victim Demographics

Age Group	Victims	Percentage
<17 years	88	5.3%
18–30	642	39.0%
31–50	525	32.5%
>50	393	23.2%
Gender	Victims	Percentage
Male	1,279	69.8%
Female	569	30.2%

These findings are in agreement with Elvik, (2024) and Shariff et al., (2018), who highlight that young male drivers in developing regions are disproportionately involved in accidents due to risky driving behaviours and a lack of enforcement.

5. CONCLUSION

This study applied a combination of statistical and geospatial analysis to evaluate road safety risks in Karangasem Regency based on traffic accident data from 2018 to 2022. A total of 1,613 traffic accidents occurred during this period, with motorcycles accounting for the largest share at 80.47%. The most common collision type was a side-swipe, and the highest number of accidents occurred on Mondays, particularly during 12:00–18:00 peak hours. The most affected demographic was young adults aged 18–30 years, especially male motorcyclists, who constituted nearly 70% of the total victims, confirming their higher vulnerability in road traffic incidents. Using the Z-score method, Karangasem and Kubu subdistricts were identified as high-risk areas (black sites), requiring immediate intervention. QGIS-based spatial analysis revealed that accident hotspots are concentrated along main urban corridors and coastal tourism routes, including Jalan Raya Kubu–Tianyar, Jalan Raya Karangasem Amlapura, and Tulamben–Abang. The integration of Z-score statistical models with GIS visualization proved effective in identifying accident-prone zones and supports more targeted, data-driven road safety planning. These findings collectively highlight the need for improved, reliable, and inclusive infrastructure development, contributing to the achievement of SDG 9, which promotes resilient and sustainable infrastructure through innovation and strategic management.

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