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Spatial Distribution Patterns of Vehicle-Etching Cases in Johor Bahru, Malaysia

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Abstract – Geographic Information Systems (GIS) are increasingly recognized across industries, with growing demand for system development in various sectors such as logistics, transportation, utilities, and government, particularly in crime mapping. However, crime databases in Malaysia currently lack spatial integration, especially in forensic applications. This study analyses the spatial distribution patterns of vehicle-etching cases in Johor Bahru District, Malaysia. The study has three main objectives: (1) to identify challenges in managing databases and information related to vehicle etching cases, (2) to develop a geospatial database integrating spatial data with existing crime records, and (3) to analyse the spatial distribution of etching cases within Johor Bahru District. The research methodology is divided into three phases: formulating the research background, data pre-processing and database design, and spatial distribution analysis. This study focuses on vehicle-etching cases within the jurisdiction of the Johor State Police Headquarters (IPK Johor). The results consist of non-spatial and spatial analyses. The non-spatial analysis examines case distributions based on vehicle type, colour, model, and quarterly trends. The spatial analysis includes five key components: heatmap and hotspot analysis, mean centre analysis, and spatial distribution pattern analysis. Findings indicate that the Pandan-Larkin and Kota Masai areas are the main hotspots for vehicle-etching cases. At the same time, mean centre analysis highlights the Bakar Batu-Tebrau area as a key location. Nearest Neighbour Analysis and Spatial Autocorrelation reveal an overall clustered distribution pattern. However, when analysed by Parliamentary boundaries, distribution patterns vary, exhibiting random, clustered, and dispersed patterns. This study underscores the importance of integrating spatial data into crime databases for improved forensic analysis and crime prevention strategies.

Keywords *– Geographic Information System (GIS), Spatial Analysis, Crime Mapping, Vehicle Etching Cases, Vehicle etching*

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1.0 Introduction

The Royal Malaysia Police D10 Forensic Division, also known as Polis Diraja Malaysia (PDRM) D10 Forensik, operates under the Crime Investigation Department (CID) of PDRM. The D10 Forensic Division is vital in criminal investigations, including crime scene reconstruction, information gathering, and evidence analysis. They are typically involved in investigating crimes such as etching, housebreaking, murder, etc. With the evolution of technology and the increasing number of cases over time, compelling case and evidence management and the analysis of crime patterns have become crucial for ensuring efficient information storage and retrieval (Almuhanna et al., 2021; Ashby, 2019). This also aids the police in making informed decisions to prevent crime through analysis (Elias et al., 2022).

In modern law enforcement, Geographic Information Systems (GIS) offer capabilities that cannot be ignored or underestimated (Ahmad et al., 2024; Sheikh et al., 2017). Geospatial technology provides valuable insights into crime investigations, crime scene reconstruction, and the analysis of crime trends and patterns (Ahmad et al., 2024a; Ahmad et al., 2024b; Anumba et al., 2018; Deshmukh et al., 2020; Fardani et al., 2021; Onyewuchi & Eke, 2015; Othman & Baharin, 2007; Shankar et al., 2022; Sheikh et al., 2017; Zahra, 2018). Besides that, other challenges include the lack of technology to link or visualize cases with geographical locations, the inability to display multiple cases on a single page, and limited accessibility to critical information (Othman & Baharin, 2007; Phiri & Phiri, 2019; Shankar et al., 2022).

PDRM faces inefficiencies and challenges in retrieving case data from its current management system in Malaysia. Othman et al. (2007) noted that the current system cannot track all case details, such as information from report forms, complainants, suspects, and investigating officers. PDRM still relies on traditional record-keeping methods, which are mostly paper-based. Additionally, the database requires users to query data one by one, making it impossible to display multiple cases and information simultaneously, which results in increased time consumption. The data are not centralized, leading to further delays and an inability to perform analyses because the data are stored in different databases. Moreover, the inability to link and visualize cases with geographical locations is another issue PDRM faces. Consequently, spatial analysis of crime cases cannot be performed due to the lack of spatial data and elements in the database.

This study aims to analyse the spatial distribution patterns of vehicle etching cases in the Johor Bahru district for the D10 Forensic Division, IPK Johor, PDRM, and to support decisionmaking and crime prevention efforts. To achieve this aim, three main objectives have been identified: (1) to identify the issues and limitations in managing databases and information regarding vehicle etching cases, (2) to develop a geospatial database that integrates spatial data with current crime databases, and (3) to analyse the spatial distribution of etching cases in the Johor Bahru District.

2.0 Literature Review

According to Jin (2012), a vehicle's engine and chassis numbers are the most crucial identifying markers, as they are challenging to remove and can be restored to their original form after being obscured. Etching is a technique used to recover vehicle identification numbers that have been obliterated.

Several issues have been raised in previous studies. Almuhanna et al. (2021) highlighted the significant need and demand for enhanced GIS to improve crime detection and better protect communities. Additionally, the growing rate of criminal activities necessitates investigating the latest methods for managing criminal information (Zahra, 2018). Zahra (2018) also mentioned that characteristic records are critical for maintaining spatial records and that honour crime records are mapped through geocoding. Despite advancements in technology, outdated methods are still being used for mapping and tracking crime in society.

Elias et al. (2022) noted that the crime rate can also be attributed to the lack of continuous monitoring of crime-prone and potential crime locations (PCL), ineffective community policing of activities that could breed crimes, and inconclusive investigation and/or prosecution of criminal cases. They suggested the adoption of GIS to understand, map, and analyse spatial phenomena such as crimes at a given time. Elias et al. (2022) also stated that monitoring PCLs is crucial to curbing or drastically reducing crime, as criminals shift their operational bases once these areas become known to the public and security operatives.

Meanwhile, Sheikh et al. (2017) noted that crime mapping and spatial analysis play a crucial role in representing and visualizing new forms of crime activity, and are essential for effectively addressing criminality. To further investigate the implementation of GIS and spatial analysis in crime information, Table 1 below summarises the insights and findings from previous research.

Table 1. Insight and findings from previous studies.

Authors	**Insight**	**Findings**
Onyewuchi & Eke (2015)	The paper discusses the development of a crime analysis information system using GIS, which includes creating a crime-geospatial database.	• Crime hotspots are far from police stations. • The prevalence of assault, rape, and robbery in the city is attributed to factors such as unemployment, poverty, and drug use.
Almuhanna et al. (2021)	Predict Spatio-temporal criminal patterns within the New York City neighbourhoods using a dataset from 2006 until 2019 with 2.2M criminal records for 25 different crime types.	• XGboost has predicted the highest number of correct classifications out of 25 crime types and has accurately predicted 22 cases. In contrast, Random Forest predicted 21 crime cases accurately, and SVM predicted 17 types of crimes with the lowest accuracy.
Zahra (2018)	The paper discusses the use of GIS in crime mapping and analysis.	• Hotspot mapping in GIS is effective for crime analysis. The analysis helps understand how crimes are spread evenly over a zone and provides a basis for advanced forms of crime representation and visualization. • Crime mapping can aid in the development of policing strategies.
Elias et al.(2022)	The paper discusses the use of Geographic Information Science (GIS) to identify potential crime locations (PCLs) in the College of Medicine University of Lagos (CMUL) neighbourhood. It analyses human activities and spatial features that influence crime and recommends surveillance and regular patrols by security agents.	• Five of the nine high potential crime locations (PCLs) are within 500m of the College of Medicine University of Lagos (CMUL). • Fifteen of the forty-two high PCLs are within a 500m buffer.
Sheikh et al. (2017)	The paper discusses the use of GIS in crime mapping and analysis, including identifying hotspots and using spatial analysis methods.	• Forecasting crime is challenging, but GIS helps. • Maps improve understanding and fight against crime.
Fardani et al.(2021)	This research aims to develop a geospatial database using an open-source GIS program related to tourism activities in Bekasi Regency, Indonesia.	• The culinary sub-sector is the most dominant in the Bekasi Regency. • The Cikarang subdistrict has the most creative economic potential among the other subdistricts.
Anbaroğlu et al. (2020)	The paper discusses the development of a geospatial database using QGIS and other open-source technologies for mobile spatial data collection.	• Developed educational material for mobile spatial data collection. • Evaluated effectiveness through feedback from undergraduate students.

Ashby (2019)	The paper discusses the creation of the Crime Open Database, a database containing crime data from 10 United States cities.	• The Crime Open Database (code) was introduced; this allows researchers to examine the spatiotemporal patterns of crime in various US cities.
Anumba et al.(2018)	The GIS approach is to develop a comprehensive crime database and perform spatial analysis to map crime activities in the urban area of Enugu State, Nigeria.	• Nineteen different types of crimes were mapped in the Enugu urban area. • Five hotspots with concentrated crime activities were identified.
Ahmad, Masron, Junaini, et al. (2024)	Use comprehensive spatial-temporal analysis of property crime, linking crime patterns to urban development.	• Need for policies aimed at enhancing urban safety and mitigating property crime.
Ahmad, Masron, Jubit, et al., (2024)	This study provides a comprehensive framework for crime prevention by incorporating spatial-temporal data and land use into crime analysis.	• Suggest that evening hours exhibit the largest spread of violent crime, and key urban centres in Kuala Lumpur and Selangor remain high-risk areas.
Fedchak et al. (2024)	Exploration of crime mapping techniques and police interventions tailored to different crime clusters.	• A structured and logical approach is necessary to analyse hot spots while cautioning against reliance on subjective analysis or automated algorithms that may misidentify crime clusters.

Based on previous studies, most studies utilize open-source tools to develop spatial databases. While there's a focus on general spatial databases, research on crime-related geospatial databases is less prevalent. Common techniques involve using PostgreSQL with PostGIS for integrating shapefiles or Microsoft Excel for storing non-spatial data, followed by importing the data into a GIS environment. The findings suggest that creating a geospatial database is a valuable preliminary step for spatial analysis.

Many studies have employed GIS for crime analysis and mapping. Hotspot analysis is a widely used technique, although other spatial distribution analyses, such as analysing distribution patterns, are underrepresented. Besides that, GIS has proven invaluable for crime analysis, enabling people to map, analyse, and understand crime patterns effectively. The creation of a comprehensive crime database is essential for conducting in-depth spatial analyses. Open-source technologies, such as QGIS, have gained popularity due to their accessibility and affordability. Various spatial analysis techniques, including hotspot and spatial distribution analyses, are employed to identify crime trends and patterns. Studies have consistently shown that high-crime areas are often associated with socioeconomic factors like poverty, unemployment, and drug use. Using GIS-based crime analysis, law enforcement agencies can develop more informed, targeted crime prevention and response strategies.

3.0 Methodology

The methodology is structured into three phases (Figure 1). Phase 1 involves identifying issues and limitations, developing aims and objectives, and data collection. Phase 2 focuses on data processing, database design, and development. Lastly, Phase 3 involves database testing and data analysis.

Phase 1 focuses on identifying problems and collecting data. A literature review was conducted to understand challenges in forensic GIS applications, particularly in crime mapping and vehicle etching cases. At the same time, early discussions helped define research gaps and refine the scope of the study. The research objectives were formulated based on the identified issues to address the gaps in forensic GIS database integration. The primary dataset consisted of forensic cases related to vehicle etching incidents obtained from relevant agencies and formatted for spatial processing.

Phase 2 focuses on data processing and database development. Geocoding techniques were employed to convert case addresses into spatial data, while filtering techniques were applied to clean and refine the dataset for accuracy. A structured database model was then developed through three design levels: conceptual design, logical design for defining data relationships and schema, and physical design for implementation in a spatial database environment. The conceptual database design is shown in Figure 2. The database was built using PostgreSQL, PostGIS, QGIS, and ArcGIS to efficiently integrate and manage geospatial data.

Phase 3 involves database testing and data analysis. Query operations were conducted to validate data integrity and ensure accurate retrieval of forensic cases. Spatial analyses were then performed, including hotspot analysis to identify high-crime density areas, point pattern analysis using Kernel Density Estimation, Nearest Neighbour Analysis, and Moran's I to detect spatial trends, and spatial distribution analysis to determine whether crime patterns are random, dispersed, or clustered.

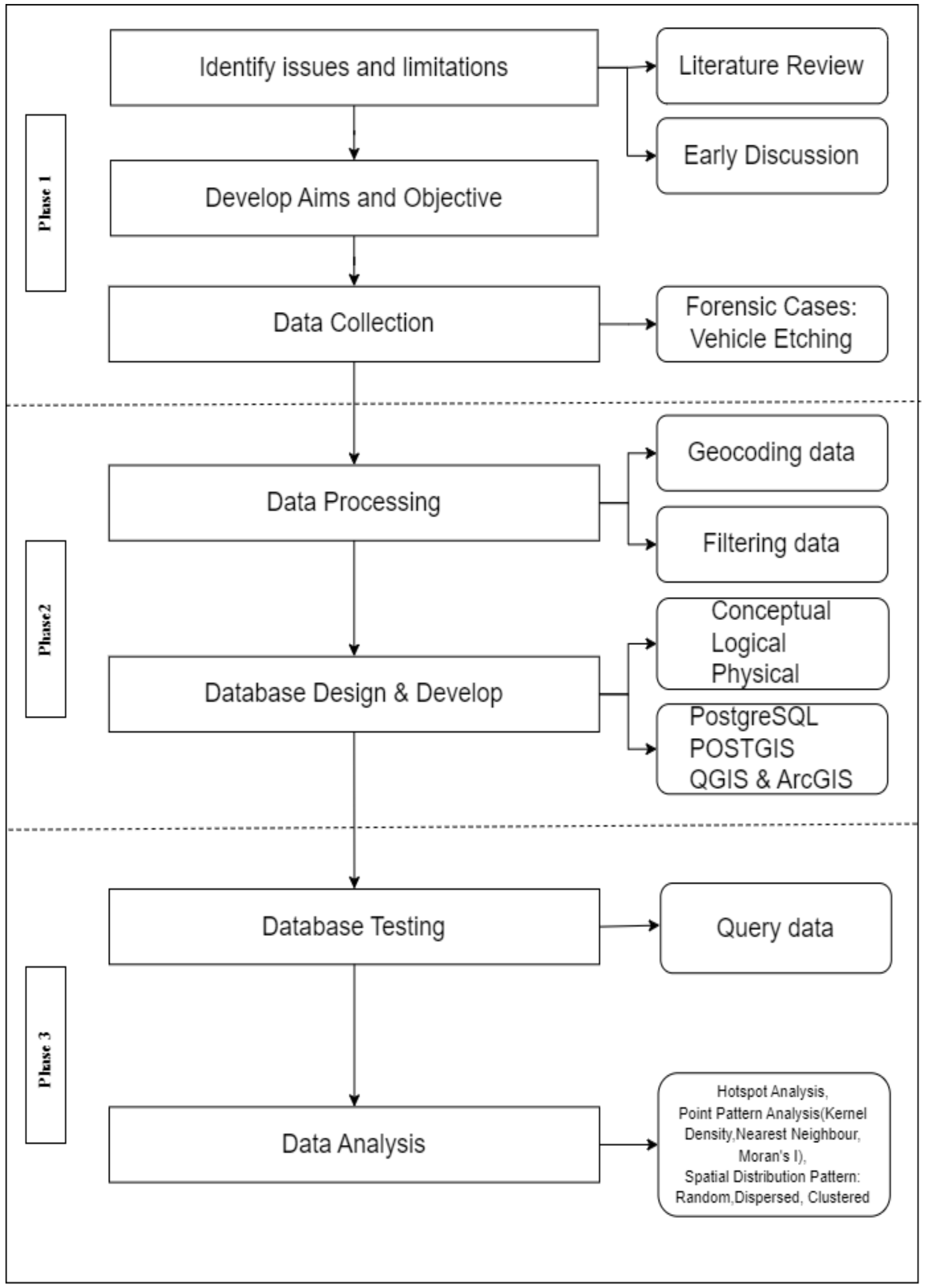

Figure 1. Steps used in this study

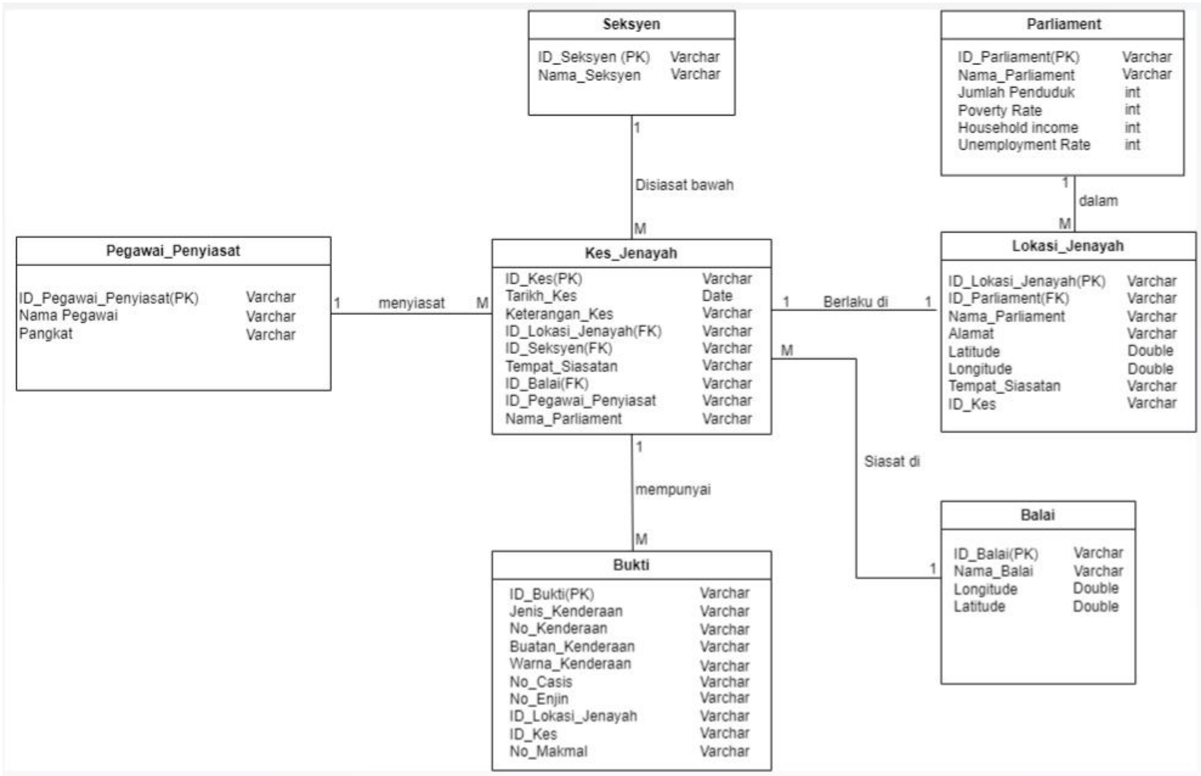

Figure 2. Conceptual design of the database

4.0 Results

The results of this study are divided into two primary analyses: non-spatial analysis and spatial analysis. The non-spatial analysis includes the type of vehicle involved in etching cases, vehicle colour, vehicle model, and the total number of etching cases per quarter. The spatial analysis comprises a heatmap analysis, point pattern analysis using nearest neighbour analysis, spatial autocorrelation analysis using Moran's I index.

4.1 Non-Spatial Analysis

The non-spatial analysis examines the attribute information. This analysis presents four main results: the number of cases categorized by vehicle type, vehicle colour, vehicle model, and the number of cases per quarter.

4.1.1 Type of Vehicle Involved in The Etching Cases

The results show that motorcycles are the most common vehicles involved in etching cases, accounting for 62 cases (Figure 3). Motorcycle frames account for 15 cases, and private cars account for 13 cases.

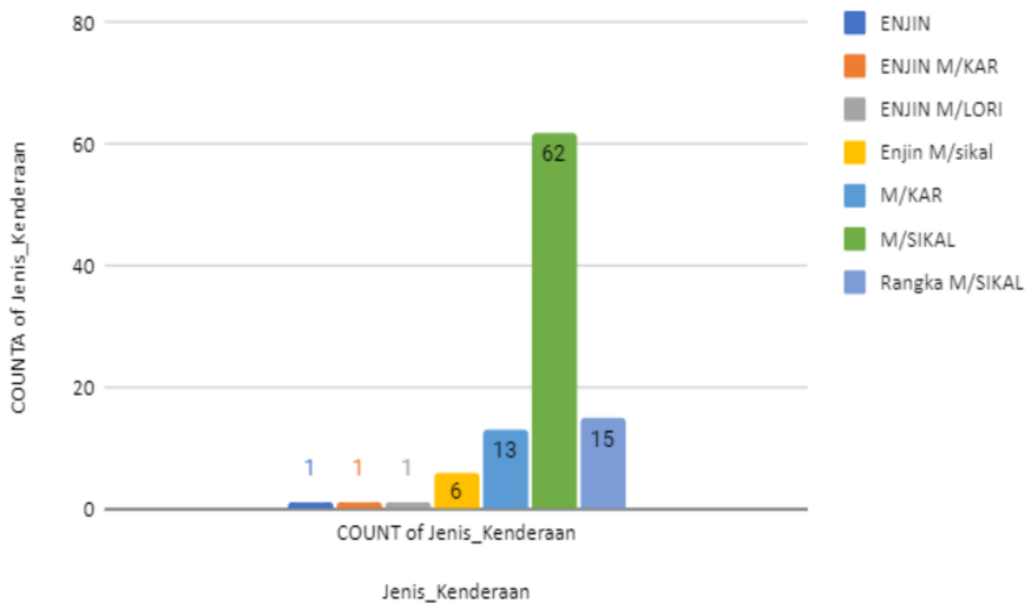

Figure 3. Type of vehicle involved in vehicle etching cases

4.1.2 Vehicle Colour Involves in Etching Cases

The results indicate that black, red, and blue vehicles are the most frequently involved in etching cases. Specifically, black cars are involved in 34 cases, red in 13 cases, and blue in 10 cases.

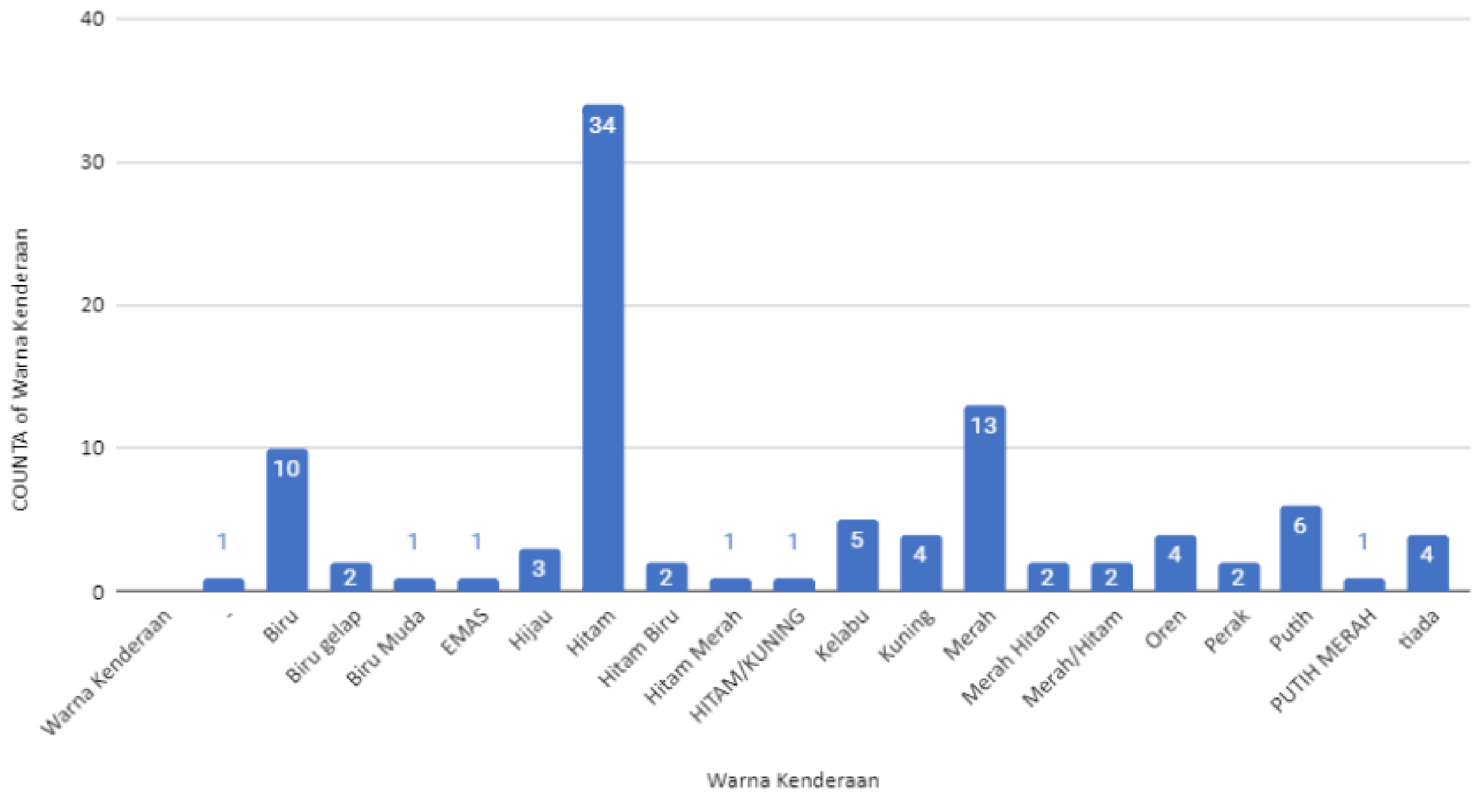

Figure 4. Vehicle color involved in vehicle etching cases

4.1.3 Vehicle Model Involved in Etching Cases

For motorcycles, the Honda EX5, Yamaha 135LC, and Honda Wave 125 are the most frequently involved in etching cases, with 18, 11, and 6 cases, respectively (Figure 5). For private cars, the Toyota Vellfire is engaged in 2 etching cases. For vehicle parts, motorcycle frames are involved in 19 cases, and motorcycle engines are involved in 7 cases. Compared to data from VRTEC (Figure 6), our results align closely with the top 10 most stolen motorcycles in Malaysia for 2020, where the Honda EX5, Yamaha LC 135, and Honda Wave are listed.

4.1.4 Total of Etching Cases vs Quarters

Quarters 2 and 3 had the highest etching cases in 2020 (Figure 7). Quarter 3 recorded the most cases, with 35, followed by Quarter 2 with 32 cases. This suggests that the cases tend to increase from April to October.

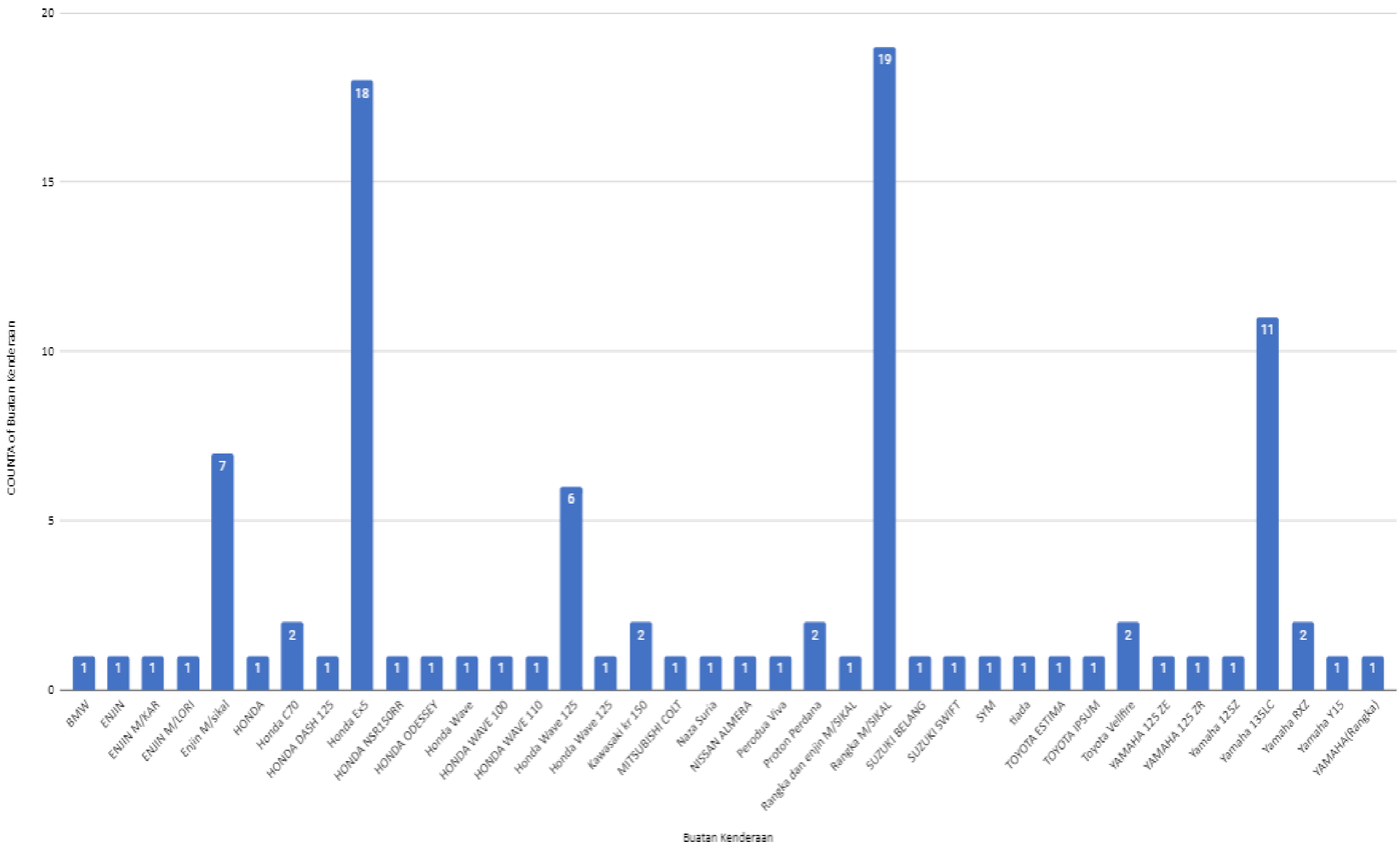

Figure 5. Vehicle models involved in vehicle etching cases

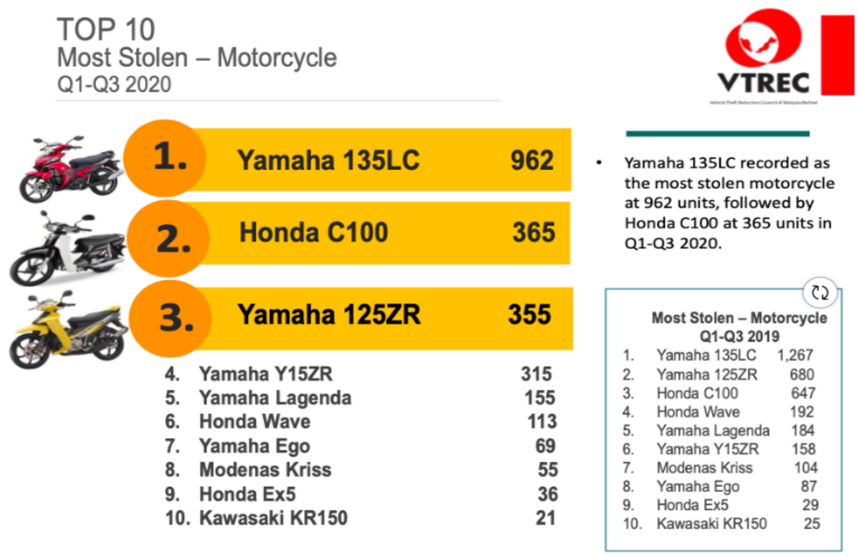

Figure 6. Top 10 most stolen motorcycles from Q1 to Q3 2020 in Malaysia

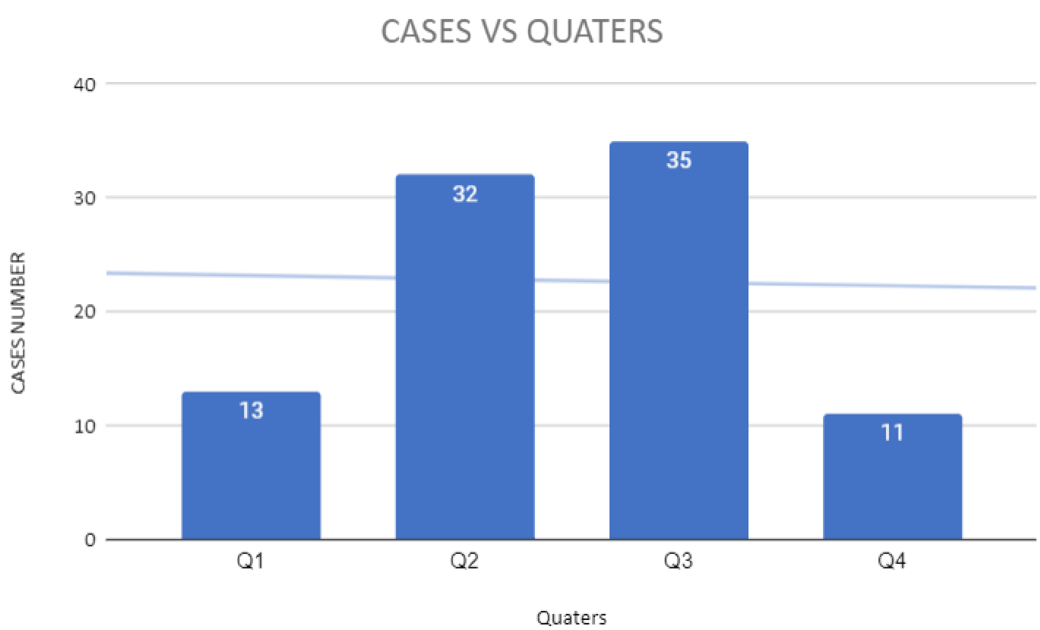

Figure 7. Vehicle etching cases in 2020 vs Quarters

4.2 Spatial Analysis

Spatial analysis involves using spatial information to analyse data, visualize it on a map, and discover hidden patterns that are not immediately visible to the naked eye. The spatial analysis results in this study are divided into four primary analyses: Heatmap Analysis, Point Pattern Analysis, and Spatial Autocorrelation.

4.2.1 Heatmap Analysis

Heatmap analysis was conducted to identify hotspot areas for etching cases in the Johor Bahru District. The study utilized the Kernel Density Estimation method. This approach helps PDRM identify hotspot areas based on reported cases. The results from the heatmap indicate that the main areas for vehicle etching cases are the Pandan-Larkin and Kota Masai areas. The Mean Centre analysis shows a concentration of cases in the Bakar Batu-Tebrau area (Figure 8). Figure 9 shows the map density of the cases in 2020.

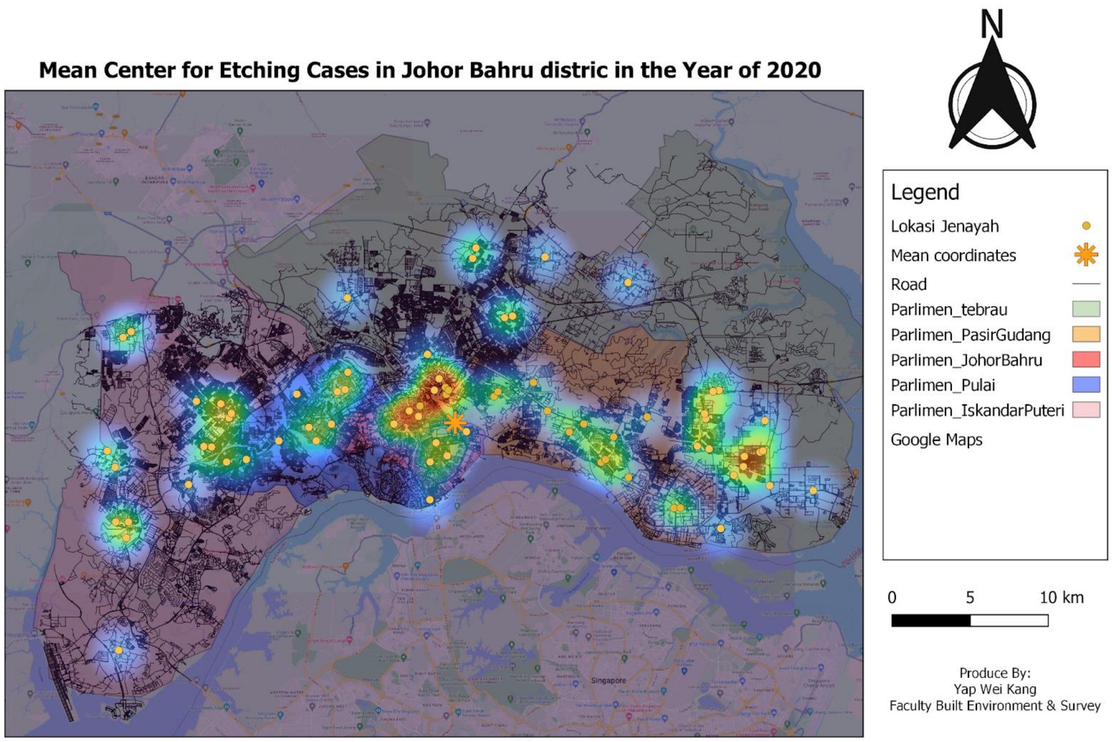

Figure 8. Map of the mean center for vehicle etching cases

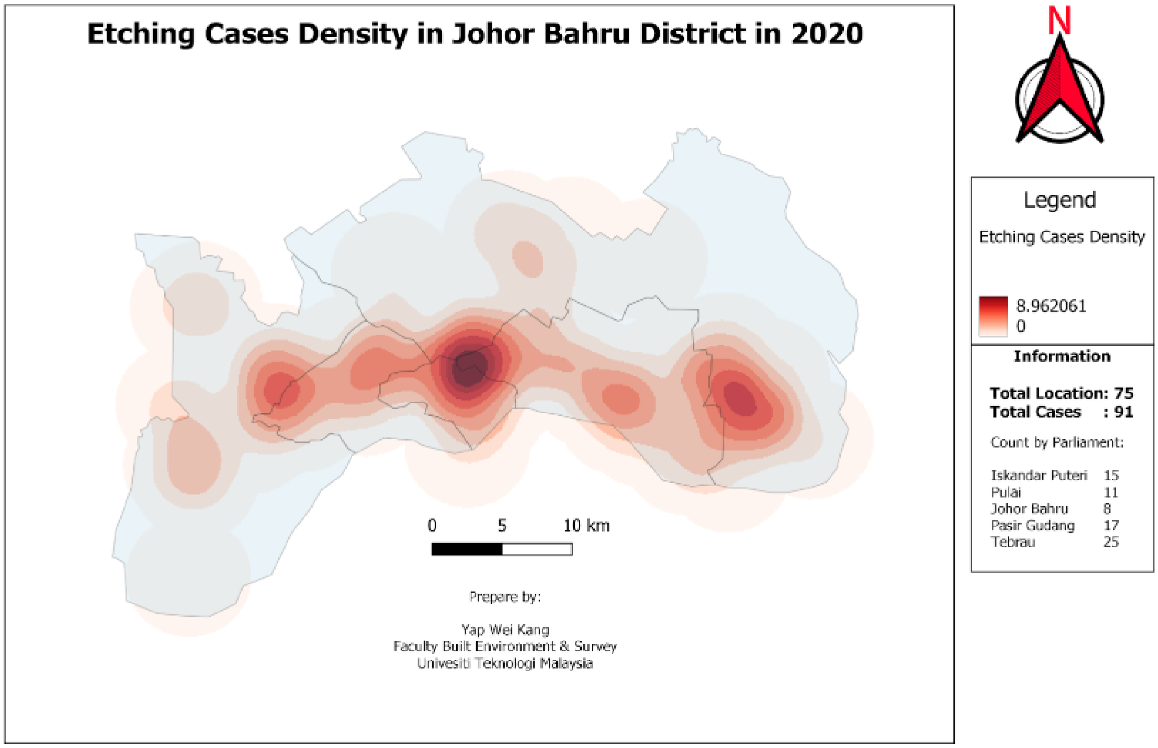

Figure 9. Results of heatmap analysis of etching cases density in Johor Bahru

4.2.2 Point Pattern Analysis

Point pattern analysis is used to identify the distribution pattern of the reported etching cases. This analysis helps determine whether the spatial distribution of the cases is clustered, random, or dispersed. Figure 10 and Table 2 shows the results of the point pattern analysis. Based on the nearest neighbour analysis, the results indicate that the etching cases in the Johor Bahru District follow a clustered pattern. This suggests that many cases are concentrated in certain areas, which may indicate a relationship or common factors contributing to their occurrence in these locations.

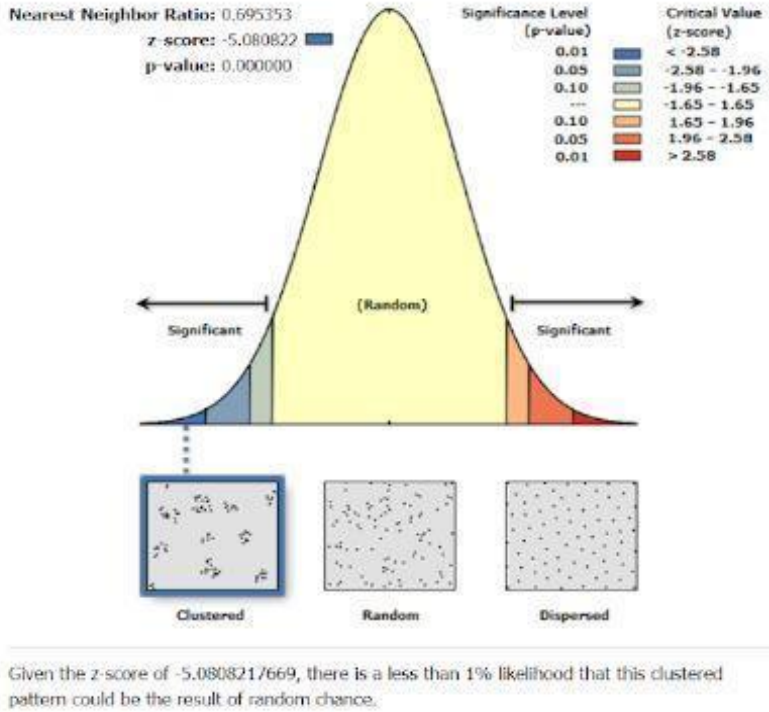

Figure 10. Results of point pattern analysis

Table 2. Result of nearest neighbour analysis for Johor Bahru district

	Observed Mean Distance	Expected Mean Distance	Nearest Neighbour Ratio	Observed Point	z-score	p-value
Johor Bahru District	0.0110 Meters	0.0159 Meters	0.69535	76	-5.080822	0.00000

4.2.3 Point Pattern by Parliamentary Boundaries

The point pattern analysis reveals that the distribution of etching cases in the Iskandar Puteri and Pasir Gudang parliamentary areas is random. This suggests that the cases in these areas are less likely to be related to each other and occur randomly. In contrast, two areas within the Johor Bahru district—Parliament Pulai and Parliament Johor Bahru—exhibit a dispersed distribution (Figure 11 and Table 3). Compared to a random pattern, this indicates that the cases are more evenly spaced and less likely to occur close to one another, potentially implying the influence of underlying factors on their distribution. Finally, a clustered distribution pattern was observed in Parliament Tebrau.

According to the Nearest Neighbour Index (NNI), this clustering suggests that the cases are closely related and may have strong connections.

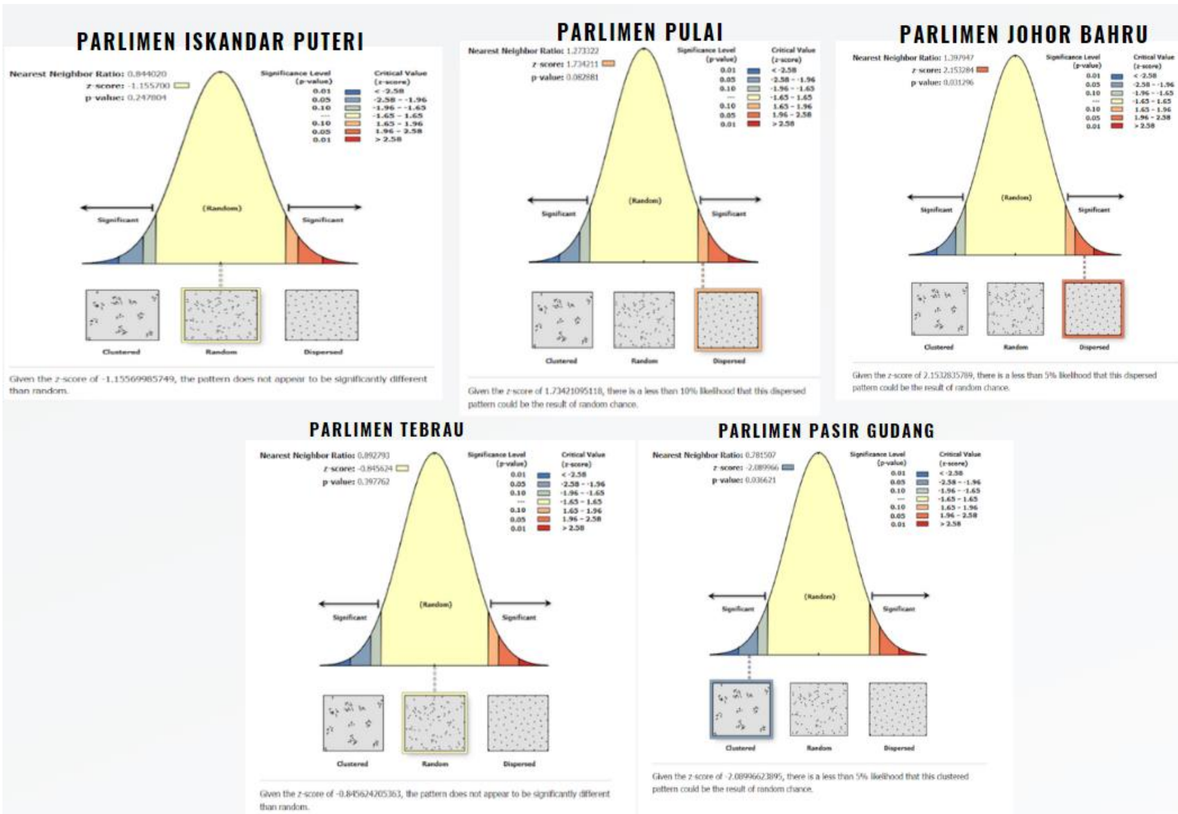

Figure 11. Result of point pattern analysis by parliamentary boundaries in Johor Bahru.

Table 3. Result of nearest neighbour analysis by Parliamentary Boundaries in Johor Bahru

	Observed Mean Distance	Expected Mean Distance	Nearest Neighbour Ratio	Observed Point	z-score	p-value
Iskandar Puteri	0.0121 m	0.0144 m	0.844020	15	-1.155700	0.247804
Pulai	0.0167 m	0.0131 m	1.273322	11	1.734211	0.082881
Johor Bahru	0.0076 m	0.0054 m	1.397947	8	2.153284	0.031296
Pasir Gudang	0.0090 m	0.0101 m	0.892793	17	-0.845624	0.397762
Tebrau	0.0136 m	0.0174 m	0.781507	25	2.089966	0.036621

m = meters

4.2.4 Spatial Autocorrelation

The following analysis is the spatial autocorrelation analysis. The result of spatial autocorrelation for the Johor Bahru District is a clustered distribution pattern (Figure 12 and Table 4). The presence of clusters suggests that underlying factors could influence the spatial distribution of these incidents. Socioeconomic conditions, such as high unemployment rates or low-income neighbourhoods, may make people more vulnerable to criminal activity.

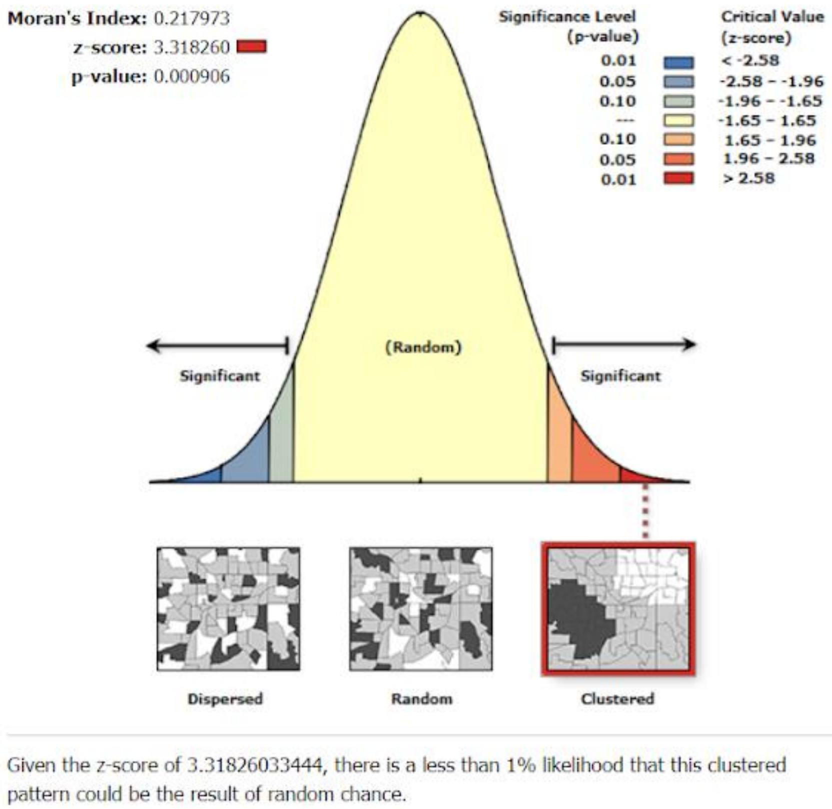

Figure 12. Result of spatial autocorrelation for Johor Bahru District

Table 4. Result of Moran's I index for Johor Bahru District

	Moran's Index	Expected Index	Variance	z-score	p-value
Johor Bahru District	0.217973	-0.004464	0.004494	3.318260	0.000906

4.2.5 Spatial Autocorrelation by Parliamentary Boundaries

The results of spatial autocorrelation by parliamentary boundaries are divided into five areas: Iskandar Puteri, Pulai, Johor Bahru, Pasir Gudang, and Tebrau. The spatial autocorrelation results indicate a clustered pattern in Iskandar Puteri, Pulai, and Tebrau. In contrast, Johor Bahru and Pasir Gudang exhibit a random spatial autocorrelation pattern (Figure 13 and Table 5).

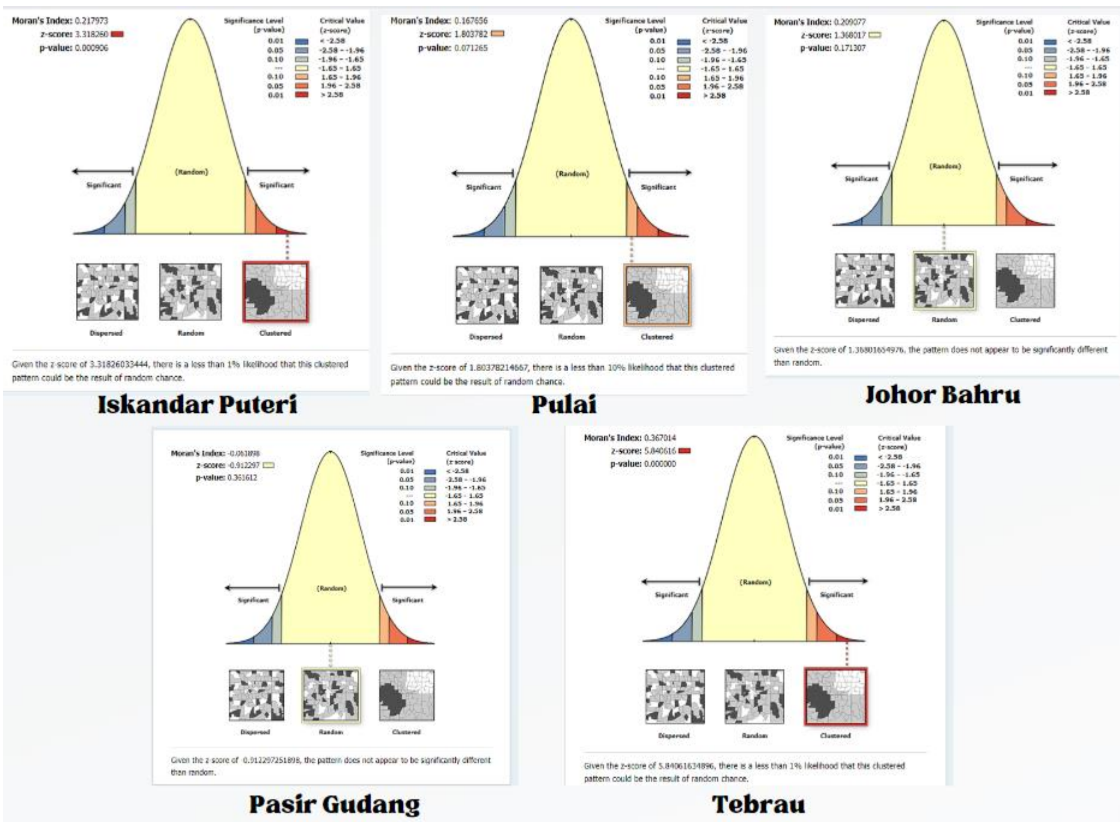

Figure 13. Result of spatial autocorrelation by Parliamentary Boundaries in Johor Bahru

Table 5. Result of Moran's I index by Parliamentary Boundaries in Johor Bahru

	Moran's Index	Expected Index	Variance	z-score	p-value
Iskandar Puteri	0.217973	-0.004464	0.004494	3.318260	0.000906
Pulai	0.167656	-0.010101	0.009711	1.803782	0.071265
Johor Bahru	0.209077	-0.041667	0.033595	1.368017	0.171307
Pasir Gudang	-0.061898	-0.004464	0.003963	-0.912297	0.361612
Tebrau	0.367014	-0.004464	0.004045	5.840616	0.000000

5.0 Discussion

This project conducted both non-spatial and spatial analyses to examine vehicle etching cases. The non-spatial analysis involving descriptive statistics aimed to provide insights into key factors such as vehicle type, colour, and model. The results indicate that motorcycles account for the highest etching cases, with black being the most targeted vehicle colour. Additionally, Quarter 3 recorded the highest number of incidents. However, due to data limitations, a direct correlation between the non-spatial and spatial analyses could not be established. The spatial analysis used in this study includes hotspot analysis, mean centre, Point Density Analysis using Kernel Density Estimation, point pattern analysis using Nearest Neighbour Analysis, and Spatial Autocorrelation using Moran's I index.

Hotspot analysis revealed that Taman Molek and Taman Kota Masai are among the hotspots for vehicle etching cases. Similarly, point density analysis yielded similar results. Furthermore, both nearest neighbours' analysis and Moran's I index indicated a clustered distribution pattern for vehicle etching cases in Johor Bahru districts. However, the point pattern for parliament in Johor Bahru district differed between the two methods due to varying parameters.

Based on these comprehensive analyses, the Royal Malaysia Police (PDRM) can implement targeted strategies to mitigate vehicle etching cases in Johor Bahru. Non-spatial analysis identifies the specific types, colours, and models of vehicles most frequently targeted. Consequently, PDRM can increase patrols around these vehicles, especially in high-risk areas, and launch community awareness programs to educate the public on preventive measures. Collaborating with car manufacturers to explore potential design modifications can make vehicles less vulnerable.

Spatial analysis, including hotspots, point density, and point pattern analysis, highlights areas such as the Pandan-Larkin area and Taman Kota Masai as significant hotspots for etching incidents. These areas should receive increased law enforcement presence and enhanced surveillance measures, such as the installation of CCTV cameras. The clustered distribution pattern identified through point pattern analysis suggests that resources should be focused on these clusters for preventive actions. Utilizing advanced GIS tools and predictive policing techniques can further enhance real-time monitoring and crime prevention efforts. Engaging the community through neighbourhood watch programs and developing policies for better lighting and security in parking areas can reduce vehicle etching incidents.

6.0 Conclusion

The study reveals that vehicle etching cases in the Johor Bahru district fluctuate quarterly and are concentrated in specific areas, as identified by heatmap and hotspot analyses, which highlight Pandan-Larkin and Kota Masai as primary hotspots. The mean centre analysis pinpoints the central location of incidents around Bakar Batu and Tebrau. Using Nearest Neighbour and Spatial Autocorrelation, spatial distribution pattern analysis indicates an overall clustered distribution, although parliamentary boundaries exhibit mixed patterns of random, clustered, and dispersed distributions. Additionally, a higher incidence of vehicle etching correlates with higher poverty rates, except within the Johor Bahru parliamentary boundaries, which, despite having high poverty rates, report fewer cases of vehicle etching. This suggests the need for targeted interventions and further investigation into the socioeconomic factors that influence these patterns.

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The authors would like to express their gratitude to the Royal Malaysian Police (PDRM), particularly the D10 Forensic Department at the Johor State Police Headquarters (IPK JOHOR), for providing the data and the opportunity to conduct this study on vehicle etching cases. Additionally, the authors would like to thank the Geospatial Forensics Satellite Laboratory-UTM-PDRM for their valuable suggestions and guidance throughout the project.

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