ZULFAQAR Journal of Defence Science, Engineering & Technology
e-ISSN: 2773-5281
Vol. 9, Issue 1 (2026)
DOI: https://doi.org/10.58247/jdset-2026-0901-03
Journal homepage: https://zulfaqarjdset.upnm.edu.my

KUALA LUMPUR'S ROAD NETWORK'S RISK TO FLASH FLOODS

Muhamad Faisharulfaizi Mohd Rofi[a], Choy Peng Ng[a, *], Teik Hua Law[b], Neza Ismail[a]

[a] Department of Civil Engineering, Faculty of Engineering, National Defence University of Malaysia, Sg. Besi Camp, 57000 Kuala Lumpur, Malaysia
[b] Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

ARTICLE INFO

ARTICLE HISTORY
Received: 01-07-2025
Revised: 10-09-2025
Accepted: 10-01-2026
Published: 30-05-2026

KEYWORDS
Flash floods
Road
Risk
Vulnerability
Urban

ABSTRACT

Well-maintained roads are crucial to modern society, especially in urban areas. Flash floods can expose urban road networks' vulnerabilities and degrade their performance. Inadequate or poorly maintained drainage systems make roads the alternative flooding routes, causing delays and traffic disruptions. Thus, identifying susceptible road network segments disrupted by prior floods is vital for investigating and analysing the risks associated with such incidents. Vulnerability analysis contributes to risk management by providing information for better mitigation strategies and decisions. The objective of this research is to evaluate Kuala Lumpur's road network vulnerability based on flash flood frequency and ten road geometric factors. This study covered 349 flash flood incidents that occurred from 2015 to 2022. The vulnerability analysis revealed that Kuala Lumpur's central region is most vulnerable to flash floods. Jalan Gurney Kiri, Jalan Tun Razak, Jalan Raja Chulan, and Jalan Cheras have the highest vulnerability index scores due to frequent flash flood events and road conditions that exacerbate their effects. The study's results were used to create a risk map for flash floods, which may be used by local authorities to develop action plans and strategies for managing flash floods in the city.

1.0 INTRODUCTION

Flash flooding is a common phenomenon in Kuala Lumpur, the capital of Malaysia, primarily due to its location in a valley between the river basins of the Klang and Gombak Rivers. The city's topography, coupled with inadequate drainage systems, results in frequent flash floods, especially during the monsoon season when clogged drainage systems fail to channel water flow effectively. Urban flash floods have been shown to cause significant damage and loss of life, with their frequency and impact increasing dramatically over the past decade [1-4]. Kuala Lumpur is particularly susceptible to such events, given its propensity for flooding during the monsoon season [5]. Road transportation, a critical infrastructure component, is often severely impacted when flash floods occur, turning city streets into water channels and causing significant traffic congestion and delays [6]. The vulnerability of urban road networks is further highlighted by these events, which underscore the impact of rapid urbanization and development on flood risk [7]. Rapid urbanization has often led to the replacement of natural landscapes with impervious surfaces, which exacerbates runoff generation and flood risk by diminishing the soil's ability to absorb precipitation [8]. Consequently, frequent flash flooding occurs in low-lying areas due to clogged drains and river overflow [9]. Additionally, it is estimated that climate factors contribute to up to 80% of pavement deterioration [10].

Urban flooding occurs when the capacity of both natural and drainage systems is insufficient to handle the volume of precipitation and runoff discharge within an urbanized area. The high surface runoff discharge resulting from heavy rainfall, impervious surfaces, and high building densities further escalates. the risk of urban flooding [11-12]. Although urban flooding is commonly associated with short-duration,

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

high-intensity precipitation, it has also been documented following prolonged moderate rainfall [13-14]. Flash floods are specifically characterized by high precipitation over a short duration, typically less than six hours [15]. Literature distinguishes between natural and man-made disasters, with flash floods, landslides, and fires being common in Kuala Lumpur. An event is classified as a disaster when it causes significant disruption to the functioning of a community [16-17]. Kuala Lumpur's road networks are essential infrastructure that facilitates mobility and accessibility for populations, goods, and services, forming the backbone of the city's transportation system. However, these networks are vulnerable to various risks, including natural disasters and infrastructure failures, which can severely impact their functionality and reliability [18]. Past studies have focused on assessing road network vulnerabilities, particularly concerning natural disasters like flooding and landslides [19-20]. These investigations emphasize the necessity for effective risk analysis to protect road infrastructure and mitigate property loss.

Despite the insights gained from previous research, gaps remain in comprehensively assessing vulnerability indicators. Many studies have concentrated on limited factors such as road surface conditions and drainage capacity [21]. This study aims to address these gaps by incorporating a broader set of ten vulnerability indicators, including road type, lane configurations, median characteristics, and roadside parking types. By expanding the scope of assessment, this research seeks to provide a more detailed understanding of road network risks in Kuala Lumpur. Maps are valuable tools for visualizing flood risks and identifying vulnerable areas [22-23]. This study evaluates the vulnerability of Kuala Lumpur's road network to flash floods from 2015 to 2022 based on historical flood data and physical road characteristics. The resulting vulnerability map will assist local authorities in developing effective evacuation plans during flash flood events.

2.0 STUDY LOCATION CHRACTERISTICS

Kuala Lumpur, Malaysia's capital, has a population of 1.9 million as of 2020, projected to rise to 2.35 million by 2040 [24-25]. The city is one of Southeast Asia's fastest-growing metropolitan regions, facing significant challenges due to its two major rivers, the Klang and Gombak, which have become sediment choked from upstream development and soil erosion. Flash floods frequently occur in low-lying areas due to heavy rainfall exceeding 60 mm within 2 to 4 hours, often exacerbated by rapid urban development that clogs drainage systems [9]. Monsoon rains can bring intense precipitation, sometimes exceeding several hundred mm in a single day [26].

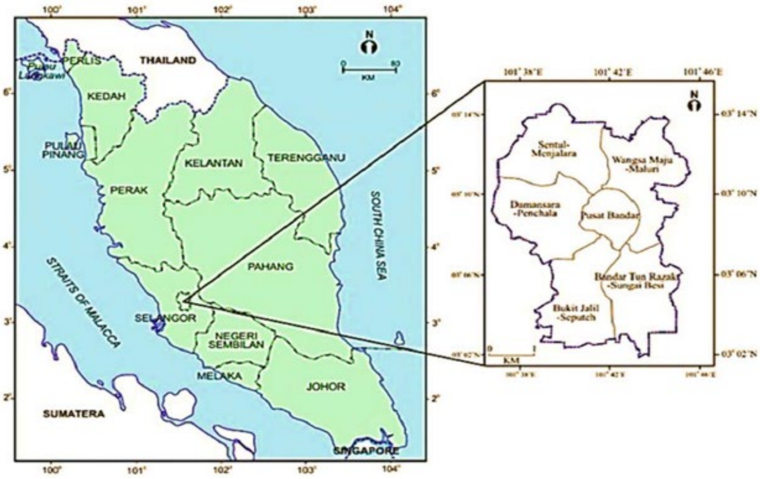


Figure 1. Map of the study area

On average, Kuala Lumpur experiences flash floods four times a year, affecting around 30 roads annually between 2015 and 2022. These floods typically happen two to three hours after heavy rainfalland are most prevalent in flood-prone areas such as Jalan Gurney Kiri and Jalan Tun Razak. Theinadequate drainage systems and river overflow significantly contribute to these flash floods, leading tosevere road congestion as streets become channels for water dispersion. Addressing these vulnerabilitiesis crucial for enhancing the resilience of Kuala Lumpur's road network against flash floods.

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

3.0 METHODOLOGY

The section outlines the research methodology used to identify the vulnerability of roads in Kuala Lumpur and develop risk maps. Figure 2 entails the methods employed to ensure a systematic approach to collecting data and analysing results.

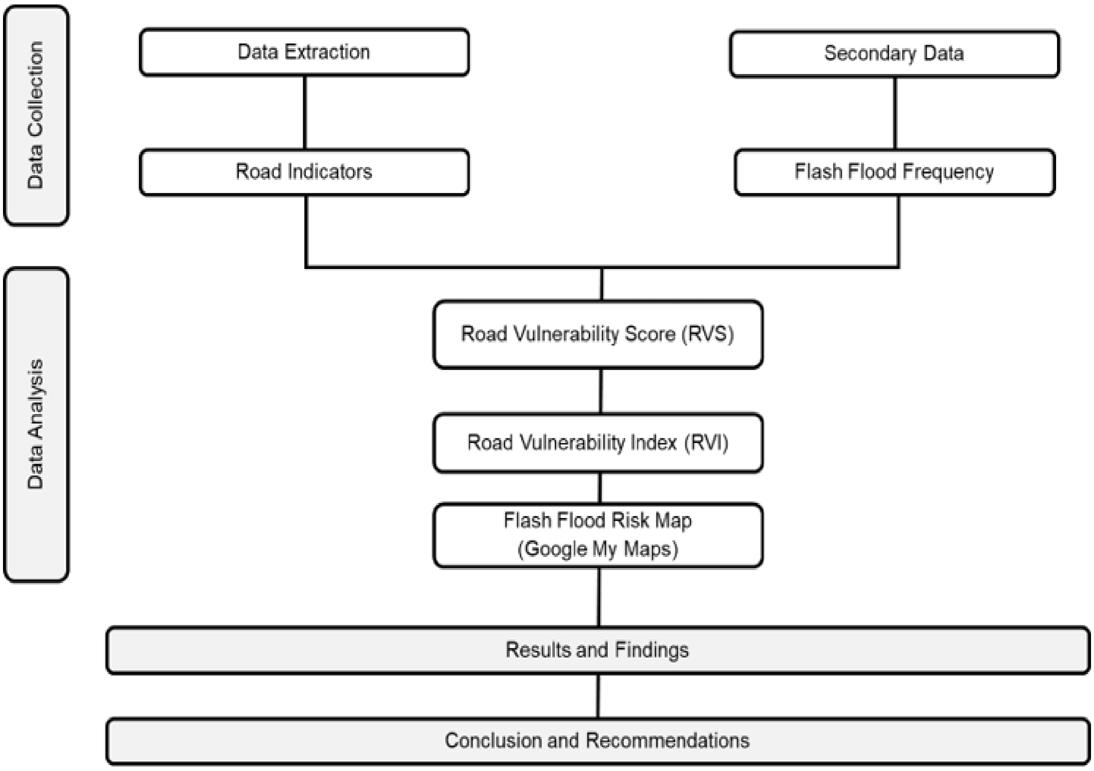


Figure 2. Flowchart of the research methodology

3.1 Data Collection

The section outlines the data collection process undertaken to support the development of the Road Vulnerability Indicator (RVI) and the assessment of flash flood impacts on Kuala Lumpur's road network. Multiple data sources were integrated, including primary road geometry information, historical flash flood records, and rainfall data. These datasets were systematically compiled to construct a comprehensive database of flash flood incidents and affected road segments between 2015 and 2022. The collected data formed the basis for developing a risk map for flash floods and for analysing the vulnerability of the road network based on flood frequency and road's physical characteristics.

3.1.1 Extraction Data

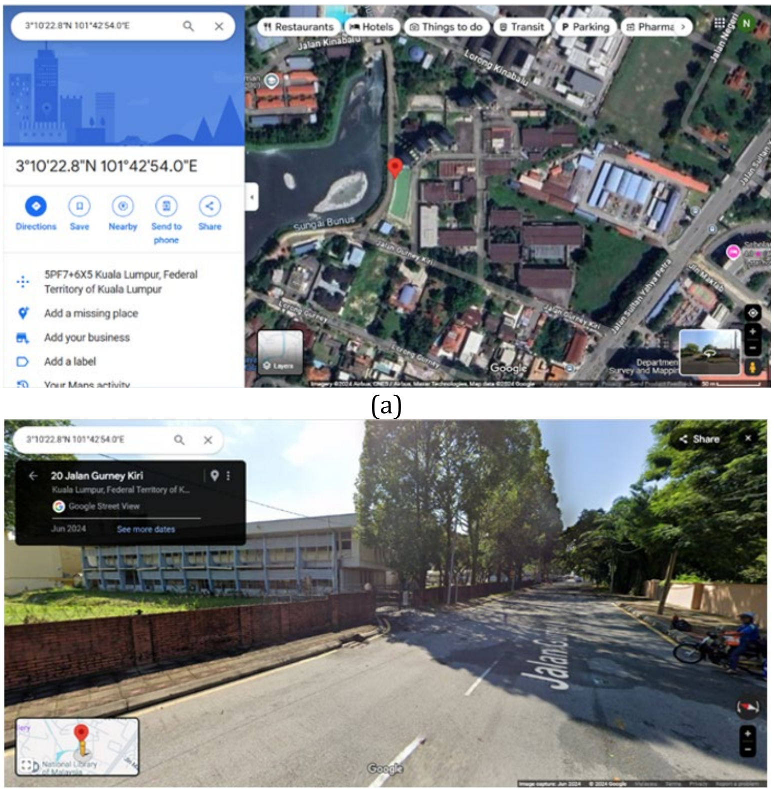
Firstly, data on road geometry information was extracted to develop the Road Vulnerability Indicator (RVI) score. Thus, several road indicators were extracted for the selected roads affected by flash floods in Kuala Lumpur. The following road indicators were used to identify the vulnerability of each road:

(a) Road type (minor or major) – Major roads typically accommodate higher traffic volumes and serve as primary routes for emergency access and evacuation. Flooding a major road can significantly disrupt transportation networks and emergency response. Minor roads, though less trafficked, may lack sufficient drainage infrastructure, increasing vulnerability to flooding.
(b) Number of ways for the road (one-way or two-way) – Two-way roads may experience greater disruption during floods, as traffic flow is affected in both directions. Moreover, the need to manage bi-directional movement may complicate emergency response during a flood event.
(c) Number of lanes per direction for the road – More lanes may suggest a higher-capacity road, but they also increase the surface area exposed to rainwater accumulation.

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

(d) Presence of a median (yes or no) – A median can act as a barrier that prevents water from flowing across lanes, potentially worsening pooling on one side of the road. However, it may also prevent vehicles from maneuvering around flooded areas, restricting escape or redirection options.
(e) Height of the median – A low median is a cheaper option but at higher risk during flash floods because it allows some degree of water overflow, impacting both directions of the traffic.
(f) Width of the median (small or big, with a small median with a width below 1.5 m) – Wider medians may provide space for water collection or landscaping that can aid drainage. Conversely, narrow medians have minimal impact on water management and may contribute to inefficient drainage, increasing road vulnerability.
(g) Presence of roadside parking (yes or no) – Roadside parking can obstruct water flow and drainage, especially if vehicles block storm drains or gutters. It also reduces maneuvering space during emergencies, increasing risk for road users.
(h) Type of roadside parking (car parking or motorcycle parking) – Car parking occupies more space and poses greater obstruction to water flow compared to motorcycle parking. The type of vehicle parked also determines the degree of damage or blockage during a flood event.
(i) Presence of a road shoulder (yes or no) – Road shoulders can serve as temporary refuge areas for vehicles during flooding. Their absence may leave vehicles with no safe space to move aside or park during heavy rain, increasing traffic congestion and hazards.
(j) Road shoulder type (paved or unpaved) – Paved shoulders are more resistant to erosion and waterlogging, offering safer conditions during floods. Unpaved shoulders may quickly degrade or become muddy and unusable, further limiting road usability during and after a flood event.

These indicators collectively provide insights into the structural features and drainage capabilities of a road, both of which are critical in determining how vulnerable a road is during flash flood events. By assessing these characteristics, it becomes possible to estimate the degree of hazard to road users, prioritize infrastructure improvements, and guide flood mitigation strategies. Google Maps was utilized using the "street view" option to obtain information about the road (see Figure 3). For each indicator, values are assigned to each factor to classify the magnitude of the indicator, such as those conducted in the previous study, whereby a higher value suggests a larger contribution to flash flood occurrence. This study assigned values ranging from 0 to 1 or 1 to 2 if the mentioned factor contributes to vulnerability in flash floods. Table 1 below enlists the indicators and their guide to assigning values.



(a)

(b)

Figure 3. Example of using street view in Google Maps to identify the road indicators

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

Table 1. Summary of the 10 road indicators and value assignment guide

Indicators	Symbols	Values
Road tupe	RT	1 – Minor roads, 2 – Major roads
Number of ways	W	1 – 1-way road, 2 – 2-way road
Number of lanes (per way)	L	Lane count (e.g. 2 inidcates 2 lanes)
Median	M	0 – No median, 1 – With a median
Height of median	M_H	1 – high (>=300 mm), 2 – low (<300 mm)
Width of median	M_W	1 – small (<1.5m), 2 – big (>=1.5m)
Roadside parking	RP	0 – None, 1 – With roadside parking
Type of roadside parking	RP_T	1 – Car, 2 – Motorcycle parking
Road shoulder	S	0 – No road shoulder, 1 – Yes, with road shoulder
Type of shoulder	S_T	1 – Paved, 2 – Unpaved

3.1.2. Secondary Data

The second type of data includes the identification of secondary data on flash flood incidents from the Department of Irrigation and Drainage of Malaysia's Annual Flood Report and news articles. The Department of Irrigation and Drainage also provided the rainfall data in Kuala Lumpur. The study involves the collection of data on flash flood incidents that happened between 2015 and 2022. The Annual Flood Reports published between 2015 and 2022 (see Figure 4) were reviewed to extract information regarding roads affected by flash floods, including the frequency and depth of flooding events. Based on the data presented in these reports, a total of 144 roads across Selangor were identified as having experienced flash flood incidents during the specified period.

Figure 4. The annual flood reports prepared by the Department of Irrigation and Drainage

3.2 Data Analysis

A database was created to record all the flash flood incidents that occurred in Kuala Lumpur as well as the routes that were affected during the flash flood catastrophe. A risk map for flash floods was then generated using the created database. To analyse the vulnerability of Kuala Lumpur's road network, a road vulnerability index was developed based on the frequency and physical road characteristics that were affected by flash floods. The first method of risk assessment developed in this study is the Road Vulnerability Index (RVI). Prior to developing the RVI, the study required to determining the indicator-

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

based scoring that generates quantitative scores to determine the roads' vulnerability to flash floods for road users, called the Road Vulnerability Scores (RVS). The vulnerability assessment framework was adapted from previous works on infrastructure vulnerability indices. Ten road-related indicators were assigned values, based on the assumed degree of vulnerability to surface flooding, and were summed to derive the Road Vulnerability Score (RVS) in Equation (1), where a higher score reflects greater potential susceptibility of road infrastructure to flood-related hazards.

To incorporate the role of flood hazard intensity, the frequency of flash flood events in each unit was added to the RVS, yielding the Road Vulnerability Index (RVI) in Equation (2). This composite index therefore integrates both intrinsic road characteristics and external flood hazard conditions, providing a comprehensive measure of road vulnerability. The equations are as follows:

$$RVS = RT + (W \times L) + M + (MH \times MW) + RP + RPT + RS + RST, \quad (1)$$

where,

RVS	=	the Road Vulnerability Index.
RT	=	road type.
W	=	the number of ways.
L	=	the number of lanes per way.
M	=	the presence of median.
M_H	=	the median height.
M_W	=	the median width.
RP	=	the roadside parking.
RP_T	=	the roadside parking type.
S	=	the road shoulder.
S_T	=	the types of road shoulder.

$$RVI = RVS + \text{total frequency of flash flood incidents} \quad (2)$$

Following the calculation of the RVI, a flash flood risk map for the flash floods of the roads involved was developed. This was done by referring the index scores to determine the categories of risks in the following order: blue (RVI scores of 9 and below), green (RVI scores of 10 to 14), yellow (RVI scores of 15 to 19), and red (RVI scores of 20 and above. To do so, Google Maps was utilised to pin the locations, which allowed the visualization of affected roads in Kuala Lumpur.

4.0 RESULTS AND DISCUSSIONS

There are several study scopes for analysing road vulnerabilities associated with flash flood incidents in Kuala Lumpur.

4.1 Frequency of Flash Flood Incidents

Appendix A-2 included the summary of the overall frequency of flash flood occurrences along the relevant roads from 2015 to 2022. A total of 144 roads in the city of Kuala Lumpur were identified as susceptible to flash flood incidents. In a span of 8 years, a total of 349 flood occurrences were recorded. 55.6% (n = 80 out of 144) of the roads had at least one recorded flash flood event, followed by 19.4% (n = 28 out of 144) and 8.3% (n = 12 out of 144) of the roads with a total frequency of 2 and 3 flood incidents, respectively, within the same timeline. The frequency of flood occurrences for the remaining roads ranged from 4 to 22 recorded incidents. Between 2015 and 2022, Jalan Gurney Kiri (n = 22). Jalan Raja Chulan (n = 13), Jalan Tun Razak (n = 12) and Jalan Cheras (n = 10) are the top four roads vulnerable to flash flood incidents. On top of that, the year with the most cases of flash floods recorded was in 2020, with 76 occurrences in total. Moreover, the result also indicated that floods were most likely to happen in the central region of Kuala Lumpur.

4.2 Road Vulnerability Scores

This section reports the findings of the Road Vulnerability Score (RVS) analysis. The highest RVS values were observed on Jalan Segambut, Jalan Langkawi, Jalan Cheras, and Jalan Ampang, with scores ranging

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

from 14 to 15. Roads that recorded moderate RVS values (approximately 8) included Jalan Maarof, Jalan Ampang, Jalan Chan Sow Lin–Terowong, and Jalan Tiong Nam. In contrast, the lowest RVS values (score of 4) were identified on Lorong Raja Mahadi, Jalan Segambut Dalam, Jalan Kampung Pasir Baru, and Lorong Kiri 15. Road segments with elevated RVS values generally exhibited similar structural and functional characteristics. These roads are predominantly major arterial routes featuring two-way traffic, multiple lanes in each direction, central medians, and paved shoulders. Such attributes contribute to increased exposure and vulnerability among road users during flash flood events. Conversely, roads with lower RVS values were typically minor, characterised by two-way traffic with a single lane in each direction, the absence of a central median, and either roadside parking or no defined road shoulder, resulting in comparatively lower vulnerability.

4.3 Road Vulnerability Index

Subsequently, the RVS values were integrated with the frequency of recorded flash flood events between 2015 and 2022 to derive the Road Vulnerability Index (RVI). The RVI serves as an indicator of overall road user vulnerability, whereby higher RVI values correspond to greater potential risk during flash flood occurrences. In total, 144 road segments within Kuala Lumpur were identified as being susceptible to flash flood events. Jalan Gurney Kiri recorded the highest RVI score of 28, followed by Jalan Tun Razak and Jalan Raja Chulan, both with scores of 26. Jalan Cheras and Jalan Kuching recorded RVI values of 24 and 22, respectively. These roads experienced between 8 and 22 flash flood incidents over the study period. The nine roads with the highest RVI values are Jalan Gurney Kiri (RVI = 28), Jalan Tun Razak (RVI = 26), Jalan Raja Chulan (RVI = 26), Jalan Cheras (RVI = 24), Jalan Kuching (RVI = 22), Jalan Ampang (RVI = 20), Jalan Pahang (RVI = 20), Jalan Segambut (RVI = 20), and Jalan Tuanku Abdul Halim (RVI = 20); all are major arterial routes providing key access to the city centre. Jalan Gurney Kiri, which exhibited the highest RVI score, is particularly susceptible due to its proximity to areas frequently affected by waterlogging during heavy rainfall. As a critical urban connector, flooding along this road poses substantial risks to daily commuters and may hinder emergency response operations. The recurrence of flash flood incidents, ranging from one to seven occurrences during the study period highlights the persistent flood vulnerability of this location. Jalan Tun Razak (RVI = 26), a segment of Kuala Lumpur Middle Ring Road 1, functions as a major link between the north-western and south-eastern parts of the city, spanning approximately 6.3 km.

Flash flood events along this corridor predominantly occur during weekday evening peak hours following intense rainfall, often coinciding with elevated water levels in the Gombak River. These events have resulted in stranded vehicles and severe traffic congestion and, in some cases, necessitated rescue operations by fire and emergency services. Similarly, Jalan Raja Chulan, with an RVI score of 26, represents a vital access route to the city centre, accommodating substantial commercial and residential traffic. Recurrent flash flooding along this road disrupts traffic flow and adversely affects surrounding economic activities and daily mobility. Given its strategic location within the urban road network, flooding on Jalan Raja Chulan can generate cascading impacts, including prolonged delays and diversions that affect many road users.

Table 2. Road vulnerability index

No	Road	RVS	Freq	RVI
1	Jalan Gurney Kiri	6	22	28
2	Jalan Tun Razak	14	12	26
3	Jalan Raja Chulan	13	13	26
4	Jalan Cheras	14	10	24
5	Jalan Kuching	14	8	22
6	Jalan Ampang	14	6	20
7	Jalan Pahang	14	6	20
8	Jalan Segambut	15	5	20
9	Jalan Tuanku Abdul Halim	14	6	20
10	Jalan Pudu	14	5	19
11	Jalan Rahmat	9	10	19
12	Jalan Sultan Azlan Shah	12	7	19
13	Jalan Sultan Ismail	14	4	18
14	Jalan Batu Bata	8	10	18
15	Jalan Dang Wangi	14	3	17
16	Jalan Maharajalela	14	3	17

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

No	Road	RVS	Freq	RVI
17	Jalan Parlimen	13	4	17
18	Jalan Genting Kelang	13	3	16
19	Jalan Langkawi	15	1	16
20	Jalan Loke Yew	14	2	16
21	Jalan Sri Permaisuri	15	1	16
22	Lebuhraya Baru Pantai	15	1	16
23	Besraya Expressway	14	1	15
24	Jalan Bangsar	13	2	15
25	Jalan Damansara	14	1	15
26	Jalan Sultan Salahuddin	12	3	15
27	Jalan Tun Perak	13	2	15
28	Kampung Pandan (Jalan Kampung Pandan)	14	1	15
29	Main Street (Balai Polis Salak Selatan)	14	1	15
30	Bulatan Dato Onn	11	4	15
31	Lebuhraya Sultan Iskandar	13	2	15
32	Jalan Syed Putra	14	1	15
33	Jalan Travers	14	1	15
34	Lebuhraya Persekutuan	13	1	14
35	Jalan Dutamas	13	1	14
36	Jalan Kepong	13	1	14
37	Jalan Khidmat Usaha/Jalan Sultan Haji Ahmad Shah	13	1	14
38	Jalan Lingkaran Tengah 2	13	1	14
39	Jalan Melaka	8	6	14
40	Jalan Pantai Baharu	13	1	14
41	Jalan Raja	13	1	14
42	Jalan Yaacob Latif	12	2	14
43	Lorong Delapan	13	1	14
44	Lebuhraya Kesas -Tol Awan Besar	13	1	14
45	Lebuhraya Kl - Seremban	13	1	14
46	Jalan 46/10	12	1	13
47	Jalan Bukit Setiawangsa	12	1	13
48	Jalan Sentul Manis	9	4	13
49	Jalan Sultan Hishamuddin	12	1	13
50	Jalan Tasik Permaisuri 3	12	1	13
51	Kepong Baru (Jalan Kepong)	12	1	13
52	Ppr Batu Muda (Jln 1/12 Ppr Batu Muda)	12	1	13
53	Taman Sri Rampai (Jalan 34/26)	12	1	13
54	Lebuh Ampang	8	5	13
55	Batu Muda Tambahan (Jalan Sentul Pasar)	11	1	12
56	Bulatan Kampung Pandan	11	1	12
57	Jalan Kelapa Muda	7	5	12
58	Jalan Pekeliling (Lama)	10	2	12
59	Jalan Raja Laut	9	3	12
60	Jalan Segambut Dalam	4	8	12
61	Lorong Kampung Periok	4	8	12
62	Jalan 1/96a (Hos Pantai Cheras)	8	3	11
63	Jalan Hang Lekiu	10	1	11
64	Jalan Kolam Air	9	2	11
65	Jalan Larut	6	5	11
66	Jalan Raja Alang	8	3	11
67	Jalan Tun H S Lee	9	2	11
68	Jalan Union 2	7	4	11
69	Blok 83 Bandar Baru Sentul	9	1	10
70	Jalan Ampang Hilir	7	3	10
71	Jalan Chow Kit Kiri	7	3	10
72	Jalan Dutamas raya	9	1	10
73	Jalan ipoh kecil	7	3	10
74	Jalan Kaskas	9	1	10

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

No	Road	RVS	Freq	RVI
75	Jalan kemuja	9	1	10
76	Jalan lai tet loke	8	2	10
77	Jalan permaisuri	8	2	10
78	Jalan pudu perdana	8	2	10
79	Jalan tiong nam	8	2	10
80	Kampung Chubadak	7	3	10
81	Lorong Lobak	9	1	10
82	Segambut Bahagia Tambahan	7	3	10
83	Jalan 4/108a (RC Residence Sales Gallery)	8	1	9
84	Jalan Bunga Kantan	8	1	9
85	Jalan Datuk Keramat	7	2	9
86	Jalan Dewan Sultan Sulaiman	7	2	9
87	Jalan Kenanga	8	1	9
88	Jalan Kia Peng	7	2	9
89	Jalan Maarof	8	1	9
90	Jalan masjid india	7	2	9
91	Jalan Merlimau	8	1	9
92	Jalan Pudu Ulu	8	1	9
93	Jalan Thamboosamy	8	1	9
94	Jalan Tun Ismail	7	2	9
95	Kampung Sungai Penchala	7	2	9
96	PPR Beringin (Surau Jumaat Al Hikmah, Jalan Miri)	8	1	9
97	Jalan Ayer Panas	7	2	9
98	Jalan Lingkungan Budi	7	2	9
99	Kampung Kasipillay (Jalan Kasipillay)	7	2	9
100	Jalan Chan Sow Lin - Terowong	8	1	9
101	Flat Sungai Baru (Jalan Sungai Baru)	7	1	8
102	Jalan Gurney	6	2	8
103	Jalan Jambu Laut	7	1	8
104	Jalan Kampar	7	1	8
105	Jalan Kampung Pandan	7	1	8
106	Jalan Kiara 3	7	1	8
107	Jalan Mangga	7	1	8
108	Jalan Munshi Abdullah	7	1	8
109	Jalan P Ramlee	7	1	8
110	Jalan Penchala Hilir	7	1	8
111	Jalan Raja Ali	6	2	8
112	Jalan Selvadurai	7	1	8
113	Jalan Sentul	7	1	8
114	Jalan Sentul Bahagia 2	7	1	8
115	Jalan Serkut 1	7	1	8
116	Jalan Taman Batu Muda	7	1	8
117	Jalan Taman Desa Aman	7	1	8
118	Kampung Bandar Dalam (Lorong Balai Raya)	7	1	8
119	Lorong Kampung Padang Balang	7	1	8
120	Lorong Tiong Nam 5	6	2	8
121	Ppr Hiliran Ampang (Jalan Putra Sulaiman)	7	1	8
122	Jalan Hang Tuah 4	7	1	8
123	Taman Sri Petaling	7	1	8
124	Jalan Batu 2 1/2 Cheras	7	1	8
125	Lorong Balai Putra	7	1	8
126	Jalan 9 (Kampung Cheras Baru)	6	1	7
127	Jalan Bukit Keramat	6	1	7
128	Jalan Hassan Salleh	6	1	7
129	Jalan Lemak	6	1	7
130	Jalan Melayu	5	2	7
131	Jalan San Ah Wing	6	1	7
132	Jalan Wirawati 2	6	1	7

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

No	Road	RVS	Freq	RVI
133	Lengkok Kelapa	6	1	7
134	Lorong Ayer Leleh	6	1	7
135	Lorong Masjid India 4	5	2	7
136	Lorong Tiong Nam 6	6	1	7
137	LRT Sungai Besi (Jln Sungai Besi - Jln Lingkaran Tengah 2)	6	1	7
138	Jalan Raja Muda Musa	6	1	7
139	Jalan 2 (Taman Len Seng)	5	1	6
140	Jalan Taman Sri Rampai	5	1	6
141	Lorong Raja Mahadi	4	2	6
142	Jalan Kampung Pasir Baru	4	2	6
143	Lorong Medan Pasar	5	1	6
144	Lorong Kiri 15	4	1	5

4.4 Flash Flood Risk Map

The final flash flood risk map is displayed in Figure 5. The black line outlined the six strategic zones of Kuala Lumpur. Upon observing the spread of the roads throughout the city of Kuala Lumpur, most cases were reported from the city centre zone, with a total of 48 roads (33.3%) that had recorded events of flash floods. On the other hand, the fewest roads affected by flash floods were in the Bukit Jalil-Seputeh zone, where there were only four roads (2.78%) within this region. Moreover, it is noteworthy to mention that the high-risk roads (i.e., those in red with an RVI score of 20 or higher) were situated near the central-northern part of Kuala Lumpur, except for Jalan Cheras, and lesser roads were affected by flash floods further away from the centre of Kuala Lumpur.

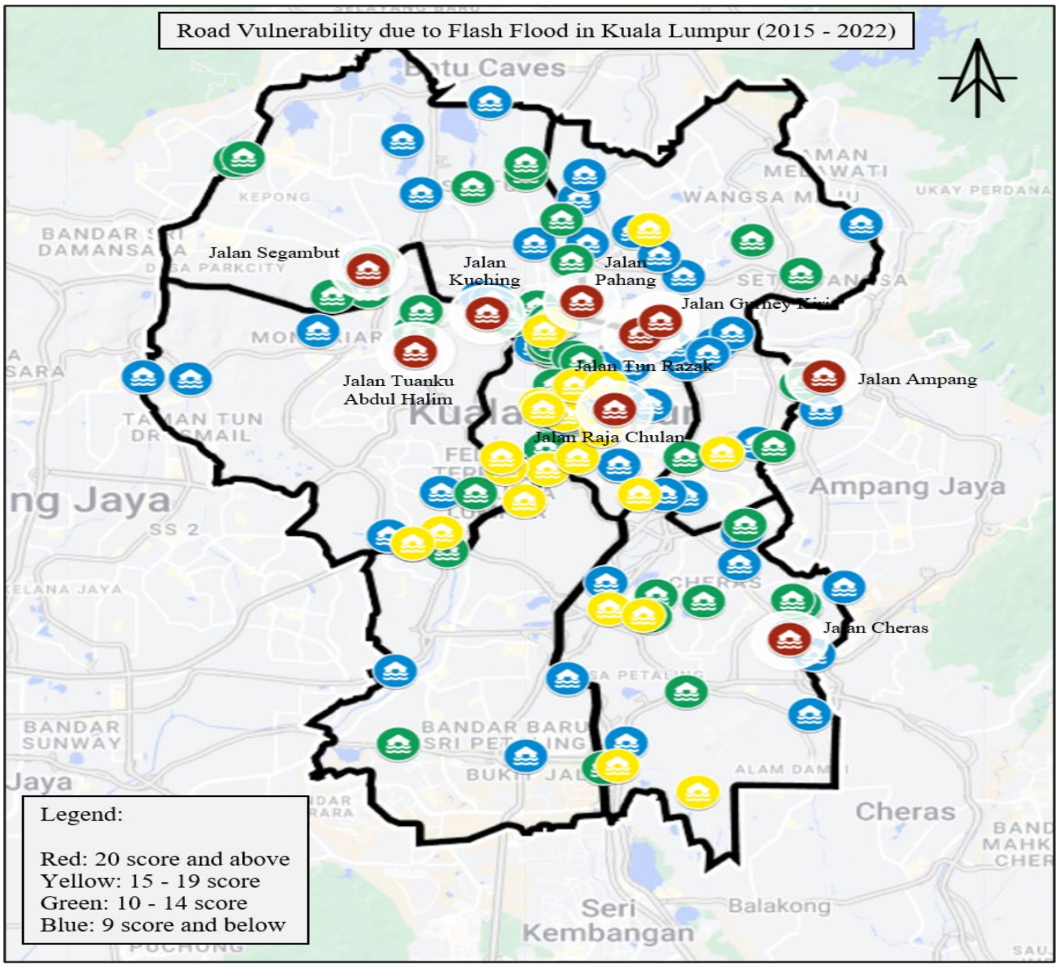


Figure 5. Kuala Lumpur's road network's risk to flash floods (2015 - 2022)

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

5.0 CONCLUSIONS

The research's major objective is to assess the vulnerability of Kuala Lumpur's road network based on the frequency of flooding and ten road-geometry features. This study includes twenty-two incidents of flood events that happened between 2015 and 2022. According to the estimate, the central region of Kuala Lumpur is the most vulnerable to the flash flood events. Jalan Gurney Kiri, Jalan Tun Razak, and Jalan Raja Chulan have the highest RVI due to the higher frequency of flash flood incidents and road features that may enhance the negative effects of flash floods. Although natural factors such as the city's geographic location and heavy rainfall contribute to the occurrence of flash floods in Kuala Lumpur, anthropogenic factors such as insufficient and clogged drainage systems, construction events and garbage disposal in the rivers play a significant role. Past research indicates that urban developments have negatively impacted the city's drainage and road system [6]. Hence, if the issue of the vulnerability of roads in the urban area is not taken into action, a rise in flash flood occurrences is more likely to happen. In the future, researchers can use these results to not only find places that are likely to be hit by flash floods but also to make immediate plans for evacuation and damage reduction. As informed, indirect losses are a big concern [11].

Such mitigation plans are critical in a densely populated area like Kuala Lumpur to reduce as much damage as possible. This may not only help to reduce the number of affected individuals but can also promote preparedness among the residents in case of flash flood occurrences. Relevant authorities should also take further actions to enhance the road and drainage system throughout the city. In line with earlier studies that suggested flash floods become worse when roads are vulnerable, the current analysis indicated that the top three roads with the highest RVI are also among the routes with the highest road vulnerability scores [7]. A well-maintained road network is an essential component of modern society, particularly in urban areas. It promotes economic growth by facilitating the movement of people and goods. Flash floods, on the other hand, have the potential to expose the vulnerability of urban road networks and cause significant deterioration in their performance. Often, roads serve as alternative channels for stormwater because inadequate or poorly maintained drainage systems are incapable of handling large amounts of runoff. Inundated roads can potentially cause a wide range of problems, including significant delays and temporary traffic interruptions. The study findings are useful for relevant authorities in planning mitigation measures during flash floods as well as traffic diversion to avoid congestion caused by flash flood incidents and will be helpful for researchers and policymakers in improving the city's structural plan and development.

6.0 CONFLICT OF INTEREST

The authors declare no conflicts of interest.

7.0 AUTHORS CONTRIBUTION

Mohd Rofi. M. F. (Writing – original; Formal analysis)
Ng, C. P. (Data curation; Writing - original draft; Resources; Supervision)
Law, T. H. (Project administration; Supervision)
Ismail, N. (Supervision)

7.0 ACKNOWLEDGEMENTS

The authors fully acknowledged the Ministry of Higher Education (MOHE) and the National Defence University of Malaysia (NDUM), which makes this important research viable and effective. This research is fully supported by the Trans-disciplinary Research Grant Scheme (TRGS/1/2020/UPNM/02/1/1).

List of Reference

[1] Bisht, D. S., Chatterjee, C., Kalakoti, S., Upadhyay, P., Sahoo, M., & Panda, A. (2016). Modeling urban floods and drainage using SWMM and MIKE URBAN: A case study. *Natural Hazards, 84*, 749–776.

[2] Sandink, D. (2016). Urban flooding and ground-related homes in Canada: An overview. *Flood Risk Management, 9*(3), 208–223.

[3] Gholami, V., Saravi, M. M., & Ahmadi, H. (2010). Effects of impervious surfaces and urban development on runoff generation and flood hazard in the Hajighoshan watershed. *Caspian Journal of Environmental Sciences, 8*(1), 1–12.

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my

[4] Sohn, W., Kim, J. H., Li, M. H., Brown, R. D., & Jaber, F. H. (2020). How does increasing impervious surfaces affect urban flooding in response to climate variability? *Ecological Indicators, 118*, 106774.

[5] Floodlist. (2015). Malaysia floods – Kelantan flooding worst recorded as costs rise to RM1 billion. Retrieved April 24, 2024, from http://floodlist.com/asia/malaysia-floods-kelantan-worst-recorded-costs

[6] Samsuri, N., Abu Bakar, R., & Unjah, T. (2018). Flash flood impact in Kuala Lumpur – Approach review and way forward. *International Journal of the Malay World and Civilisation, 6*(1), 69–76.

[7] Papilloud, T., & Keiler, M. (2021). Vulnerability patterns of road network to extreme floods based on accessibility measures. *Transportation Research Part D: Transport and Environment, 100*, 103045.

[8] Jamaluddin, M. (1985). Flash flood problems and human responses to the flash flood hazard in Kuala Lumpur area. *Akademika, 26*, 45–62.

[9] Hong, J. L., & Hong, K. (2016). Flood forecasting for Klang River at Kuala Lumpur using artificial neural networks. *International Journal of Hybrid Information Technology, 9*(3), 39–60.

[10] Doré, G., Drouin, P., Pierre, P., & Desrochers, P. (2005). *Estimation of the relationships of road deterioration to traffic and weather in Canada* (Final Report, BPR Reference: M61-04-07 (60ET), TC Reference: T8080-04-0242).

[11] Gaitan, S., van de Giesen, N. C., & ten Veldhuis, J. A. E. (2016). Can urban pluvial flooding be predicted by open spatial data and weather data? *Environmental Modelling & Software, 85*, 156–171.

[12] Yao, L., Wei, W., & Chen, L. (2016). How does imperviousness impact the urban rainfall runoff process under various storm cases? *Ecological Indicators, 60*, 893–905.

[13] Abdullah, J., & Julien, P. Y. (2014). Distributed flood simulations on a small tropical watershed with the TREX model. *Journal of Flood Engineering, 5*(1-2), 17-37.

[14] Coulthard, T., Frostick, L., Hardcastle, H., Jones, K., Rogers, D., & Scott, M. (2007). *The June 2007 floods in Hull: Interim report by the independent review body*.

[15] Suparta, W., Rahman, R., & Singh, M. S. J. (2014). Monitoring the variability of precipitable water vapor over the Klang Valley, Malaysia during flash flood. *IOP Conference Series: Earth and Environmental Science, 20*, 012057.

[16] Zibulewsky, J. (2001). Defining disaster: The emergency department perspective. *Baylor University Medical Center Proceedings, 14*(2), 144–149.

[17] UNISDR. (2009). *Terminology on Disaster Risk Reduction*. United Nations International Strategy for Disaster Risk Reduction (UNISDR). Retrieved from http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf

[18] Chamorro, A., Serrano-Estrada, L., & Otero, J. (2022). The impact of natural disasters on road networks: A review of recent studies and future research directions. *Transportation Research Part A: Policy and Practice, 162*, 184–202.

[19] Nelson, A., Perez, J., & Gassman, P. (2019). Landslide and flood vulnerability assessment of road networks in mountainous regions: A case study in Nepal. *Natural Hazards, 95*(1), 349–366.

[20] Zhu, W., Tang, J., & Liu, X. (2020). Cyclone risk assessment for road networks: A case study of Southeast Asia. *International Journal of Disaster Risk Reduction, 42*, 101339.

[21] Dong, X., & Ranzi, R. (2022). Assessment of road network vulnerability to flooding in urban areas: A case study in northern Italy. *Natural Hazards, 114*(3), 1759–1780.

[22] Tomaszewski, B. (2014). *Geographic Information Systems (GIS) for Disaster Management*. CRC Press.

[23] Huang, C., & Inoue, H. (2007). Soft risk maps of natural disasters and their applications to decision-making. *Information Sciences, 177*(7), 1583–1592.

[24] Department of Statistics Malaysia Official Portal. (2020). *Kawasanku*. Retrieved from https://open.dosm.gov.my/dashboard/kawasanku/W.P.%20Kuala%20Lumpur

[25] Kuala Lumpur City Hall. (2023). *Kuala Lumpur Structure Plan 2040*. Retrieved from https://ppkl.dbkl.gov.my/en/pskl2040/

[26] Department of Statistics Malaysia Official Portal. (2011). *Federal Territory of Kuala Lumpur*. Retrieved from https://www.dosm.gov.my/v1/index.php?r=column/cone&menu_id=bjRlZXVG

*Corresponding Author | Ng, C. P | cpng@upnm.edu.my