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Mapping Disaster Hazards and Risks – A Case Study in Kuala Lumpur City (KLC)

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ABSTRACT

Kuala Lumpur, the capital city of Malaysia, is vulnerable to various natural and man-made disasters. Kuala Lumpur City (KLC) encounters distinctive difficulties in managing urban disasters, mainly because of its dense population, critical infrastructure, and economic importance. Mapping the hazards and risks of disasters in KLC is crucial for enhancing its resilience against disasters and ensuring the effectiveness of emergency response, humanitarian aid, and disaster relief efforts. The objective of this study is to develop a comprehensive master plan for the management of disasters in KLC. The plan will serve as the initial phase in the civil-military coordinating response architecture for humanitarian aid and disaster relief (HADR). The approach entails creating a hazard map delineating regions susceptible to flash floods and landslides, frequently occurring in KLC. In addition, a vulnerability map was generated to evaluate the region's proneness to disasters and identify safe areas within KLC. Additionally, road vulnerability assessments were performed to determine the most direct route for HADR activities. Furthermore, a customised disaster risk map was created exclusively for the KLC. This work contributes to the growing body of literature on urban disaster management, offering valuable insights for other metropolitan areas facing similar challenges.

Keywords: Urban disaster; landslides; flash flood; hazard map; vulnerability map; risk map

INTRODUCTION

The capital city of Malaysia, Kuala Lumpur, is vulnerable to a variety of natural and man-made disaster risks (Jamaludin and Hussein, 2006; Althuwaynee and Pradhan, 2017; Bhuiyan et al. 2018; Bhuiyan et al. 2019; Mohtar et al. 2020; Abd Majid et al. 2022; Bhuiyan et al. 2022; Mohd Rofi et al. 2022). Several disaster dangers confront Kuala Lumpur City (KLC), including the natural hazards, such as flood, landslide, earthquake, epidemic or pandemic, and man-made hazards, such as urban fires, transportation accidents, and air quality issues.

KLC's vulnerability to flooding is attributed to its geographic positioning between the Klang and Gombak Rivers. An example of a recurring phenomenon in KLC on an annual basis is flood, which is particularly severe during the monsoon season. In low-lying areas, severe precipitation can generate flash floods, which disrupt daily life and cause property damage (Bhuiyan et al. 2022). A devastating flash flood incident transpired in January 1971 (Maqtan et al. 2022) because of severe monsoon rainfall throughout the season, which caused the Klang, Batu, and Gombak rivers to overflow. Consequently, 180,000 people were affected, and 32 lives were lost. Another devastating flash flood occurred in KLC on June 10, 2007, after an intense downpour that continued for over two hours, resulting in a flood depth of 1.8 metres (Samsuri et al. 2018). Due to Tropical Depression 29W, KLC experienced the most severe flash floods in fifty years during the latter

half of 2021 and the beginning of 2022 (Buddhist Tzu Chi Foundation, 2022).

Additionally, construction operations that disrupt the natural environment or occur during periods of severe rainfall make KLC particularly vulnerable to landslides. On April 25, 2023, for instance, a severe landslide occurred on a slope situated on the premises of the Malaysian Anti-Corruption Academy (MACA) in Bukit Tunku, KLC (Perimbanayagam 2023). The landslide was triggered by water accumulation after recent heavy rainfall and an underground pipe burst.

Due to its location on a stable tectonic plate, the occurrence of earthquakes in KLC is exceedingly improbable. Nonetheless, three earthquakes that occurred in the vicinity of Sumatera generated tremors in KLC. The seismic events transpired on April 29, 2004, February 24, 2011, and October 5, 2015, respectively, inducing earthquakes in KLC that measured Ritcher scales of 4.1 to 4.2 (database.earth 2023). As per the Meteorological Department of Malaysia, the probability of harm resulting from a magnitude not surpassing 5 on the Richter scale is low (Chen 2023).

KLC, being a highly populated urban region, is susceptible to urban fires, which have the potential to rapidly propagate and inflict substantial destruction. For instance, a fire devastated the Campbell Shopping Complex in 1976, destroying the shopping complex and the twenty-storey office tower building (Ng 2017). Also, twenty-three children and teachers perished in a fire at a KLC religious school in 2017 due to a firework assault, and the victims were unable to escape as the fire spread very quickly and many were trapped behind the metal window grills (Ahmad et al. 2017). A short circuit recently caused a fire at the Pavilion shopping mall in 2022 (Tee 2022), while a fire at the TNB substation of the Mid Valley Megamall in 2023 (Kit 2023) also posed a danger to the community.

Transportation accidents are a prevalent occurrence in KLC, resulting in near-daily fatalities and injuries among vulnerable road users, including motorcyclists and pedestrians. From 2009 to 2019, the Royal Malaysian Police reported that KLC accounted for 3% of all traffic fatalities in Malaysia (data.gov.my, 2023). In another transportation accident, over two hundred passengers were injured in 2021 when two light rail transit trains collided in an underground tunnel near the Petronas Twin Towers in KLC (Loheswar 2023).

KLC is also at risk from disease outbreaks, particularly pandemics, which can significantly affect healthcare infrastructure and public health. The high population density observed in KLC in 2020 has been identified as a significant factor in the accelerated transmission rates of the COVID-19 pandemic inside Malaysia (COVIDNOW 2022).

In view of this, the objectives of this research are to assess existing and potential disaster hazards and risks based on the city and development plan for KLC, to develop a hazard and risk map for KLC, and to develop a master plan for emergency response and HADR operations in KLC. The urban disaster management in KLC will incorporate the master plan of this research with its logistic support and health response frameworks through the civil-military coordination framework.

The remaining sections of the paper are structured in the following manner: Section 2 explores the topic of risk management in KLC, whereas Section 3 delves into hazards and risk mapping. Section 4 discusses the proposal of a master plan for disaster management in KLC, and the final section addresses and draws conclusions from the research.

RISK MANAGEMENT

To perform a thorough risk assessment for KLC, an extensive investigation would be necessary to identify potential hazards, assess vulnerabilities and exposures, quantify risk, account for climate change, and evaluate emergency response and preparedness (Jamaludin and Hussein 2006; Zurairi 2018; Zio 2018). These processes are highlighted in Figure 1 for reference, replication, or future revisions.

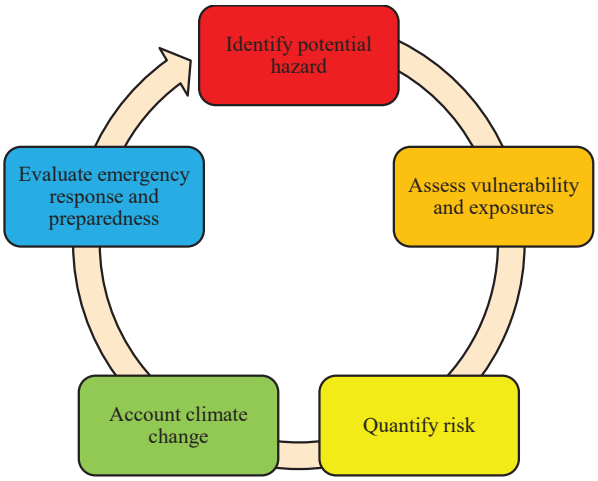

FIGURE 1. Risk Assessment Process

The first step in the assessment is to examine natural and man-made hazards that can impact KLC. This encompasses all potential hazards, even those with a lower likelihood of occurring, such as floods, landslides, earthquakes, urban fires, transportation accidents, etc. In KLC, landslides and flash floods are among the most frequently occurring and damaging hazards.

An analysis is undertaken to identify potential hazards by examining the susceptibilities of the city inhabitants, and infrastructure. Various factors were considered, including critical infrastructure, housing conditions, transportation systems, and healthcare facilities (Eini et al. 2020). This process entails the delineation of vulnerable regions and the evaluation of the potential ramifications across various industries, commercial, and residential zones. The estimation of the potential losses in terms of human lives, property damage, economic repercussions, and social disruption (Koks et al. 2015) is used to quantify the risks associated with each hazard using a combination of historical data, hazard modelling, and impact assessments.

Climate change is one of the significant factors that can affect the frequency and severity of hazards, such as increased precipitation and heatwaves (Simpson et al. 2021). Incorporating climate change into the risk assessment process could significantly enhance the projection outcome. The evaluation encompassed the current disaster response and preparedness protocols, which comprised early warning systems, evacuation strategies, and the readiness of emergency services.

HAZARD ABD RISK MAPPING

Hazard and risk mapping is an important technique for visualising and comprehending the numerous hazards and risks that a city such as Kuala Lumpur may encounter. The public, city officials, and emergency personnel can all utilise these maps to make more informed decisions regarding disaster readiness, response, and mitigation. The purpose of this project is to generate a risk assessment and mapping tool for landslides and flash floods in KLC.

For risk analysis, it is critical to combine numerous hazard maps to generate composite risk maps that illustrate the interactions and cumulative effects of multiple hazards. It is imperative that these maps be consistently updated and disseminated to the public via diverse communication platforms, including government websites and mobile applications, to augment public consciousness and readiness (Son et al. 2019; Uekusa and Matthewman 2023). Moreover, these maps can inform urban planning, zoning restrictions, and disaster management plans, thereby strengthening KLC's resilience. Local authorities and pertinent agencies frequently engage experts and stakeholders in collaborative efforts to develop and uphold these maps.

PROPOSAL OF A MASTER PLAN FOR DISASTER MANAGEMENT IN KLC

A collaborative effort is required to design an all-encompassing disaster response master plan for KLC, involving emergency services, community organisations, and government agencies. The integration of many dimensions of disaster management, for instance, readiness, response, recovery, and mitigation, into the strategy is crucial. Thus, several different maps were produced to facilitate the collaborative efforts involving civil and military actors. These include maps on common hazards, vulnerability analysis, hazards, and disaster risks for Kula Lumpur city. The aim is to aid in the identification of safe evacuation routes and spaces, the mapping of relevant civil-military actors, and recommendations for improved civil-military coordination efforts.

Several different maps are included in this document as part of risk assessment process and can used as reference for decision-making processes for disaster response planning (Koks et al. 2015; Eini et al. 2020) in KLC.

DIVIDING KLC INTO PARCELS

Figure 2 illustrates the initial step of dividing KLC into 18 parcels for the purpose of conducting hazard, vulnerability, and risk assessments. The KLC's vulnerability to natural disasters necessitates the division of the city into parcels, which will provide comprehensive disaster preparedness more effectively.

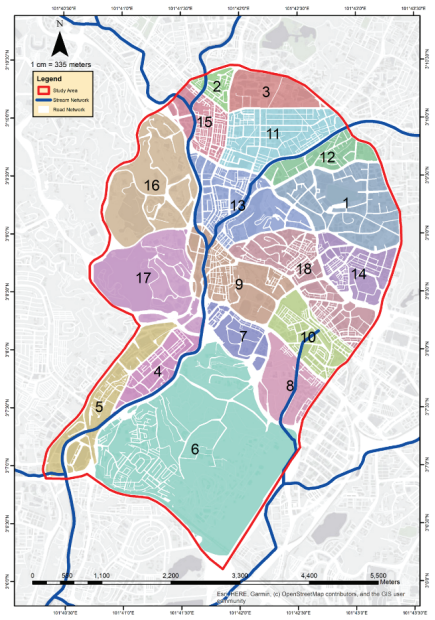

FIGURE 2. The proposed KLC division

By using the main roads as the reference for the boundaries of the 18 parcels, the master plan for disaster management framework captures the spatial variation and heterogeneity of the city's physical, social, and economic characteristics, as well as the population's exposure, sensitivity, and adaptive capacity. The investigation also relied on the Kuala Lumpur City Hall City Planning System and Kuala Lumpur Structure Plan 2020.

Each of the 18 parcels has a main road access point, allowing natural disasters to be localised and response activities to be efficient. The division makes emergency response more targeted and effective, minimising disruption to key services and infrastructure. Aligning parcel boundaries with key roads creates evacuation routes and emergency service access locations. This strategic organization enhances overall resilience by providing rapid and coordinated natural disaster responses, lowering response times, and protecting residences and infrastructure.

During disaster response and recovery, the main road layout-based parcel division enhances resource allocation and sector cooperation. This approach may help stakeholders prioritise risky locations and strategically invest resources, creating a more resilient and adaptable urban environment. Figure 3 shows the hazard, vulnerability, and risk analysis framework.

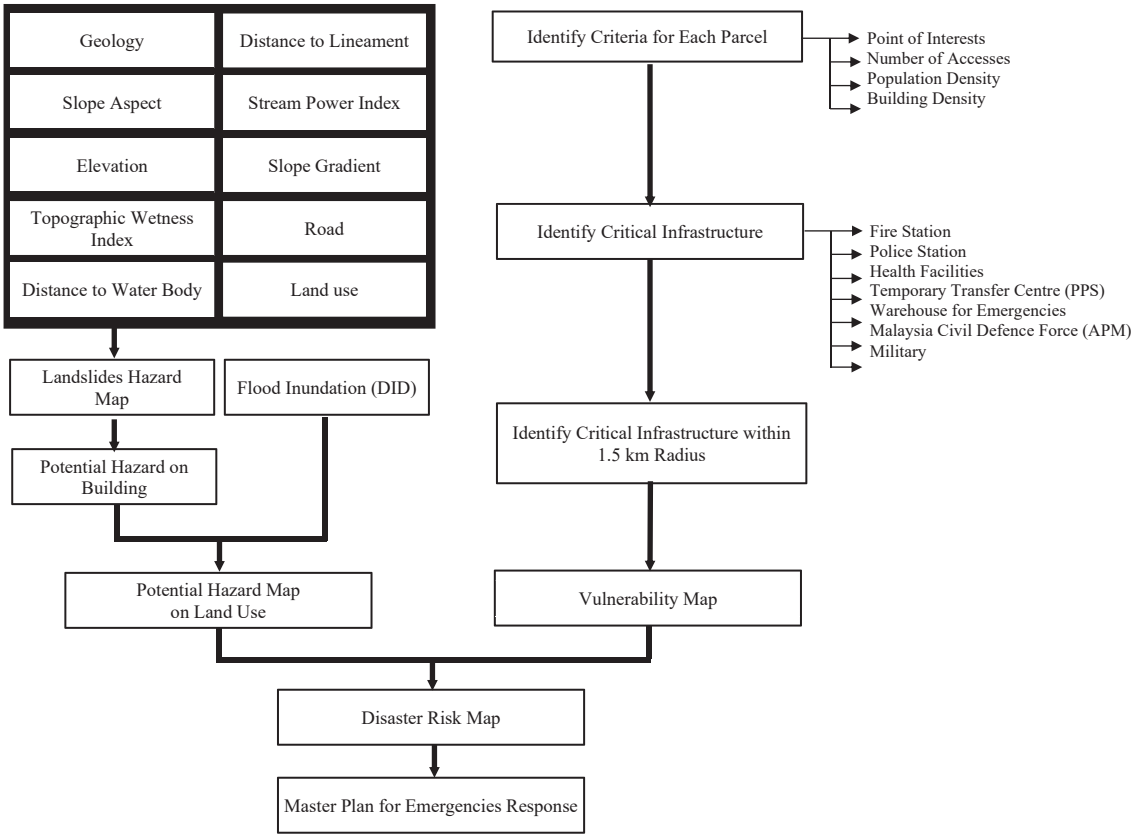

FIGURE 3. Hazard, vulnerability, and risk framework for master plan development

DISASTER HAZARD MAP FOR KLC

Two frequently occurring hazards in KLC were analysed and mapped. The landslide susceptibility map used the frequency ratio model based on historical landslide points gathered from NASA databases and news reports, with a total of 37 historical landslides for the years 2007 until 2021. Factors such as slope, slope aspect, elevation, distance from streams, stream power index (SPI), topographic wetness index (TWI), road network, drainage system, and land use, as suggested by Devkota et al. (2013), Bathrellos et al. (2017), and Aksha et al. (2020), were analysed.

The landslide susceptibility map was produced using frequency ratio (FR) values, which were used to classify the study area into three classes of relative landslide susceptibility (low, moderate, and high). The results were validated by calculating the area under a curve (AUC) as proposed by Chen and Lin (2021) and cross-validation with historical landslides in the study area, indicating an accuracy of 64%.

Meanwhile, flood hazards are mapped using the inundation map procured from the Department of Irrigation and Drainage (DID). Both the landslide and flood hazard maps were subsequently integrated together and transformed into numerical values to ensure a comprehensive understanding of the combined hazard landscapes.

TABLE 1. Categorisation for the hazard map

Score	Category	Description
1	Safe area	This area has no potential to be affected by natural disaster hazards.
2	Flood-prone area	This land area has potential to be inundated by flood.
3	Landslide-prone area	This land area has potential to be affected by landslides.
4	Multi-hazard prone area	This land area has is exposed to both flooding and landslide hazards.

The numerical values derived from the integrated maps were strategically embedded into the land-use map using the classification listed in Table 1, while the integrated map is shown in Figure 4.

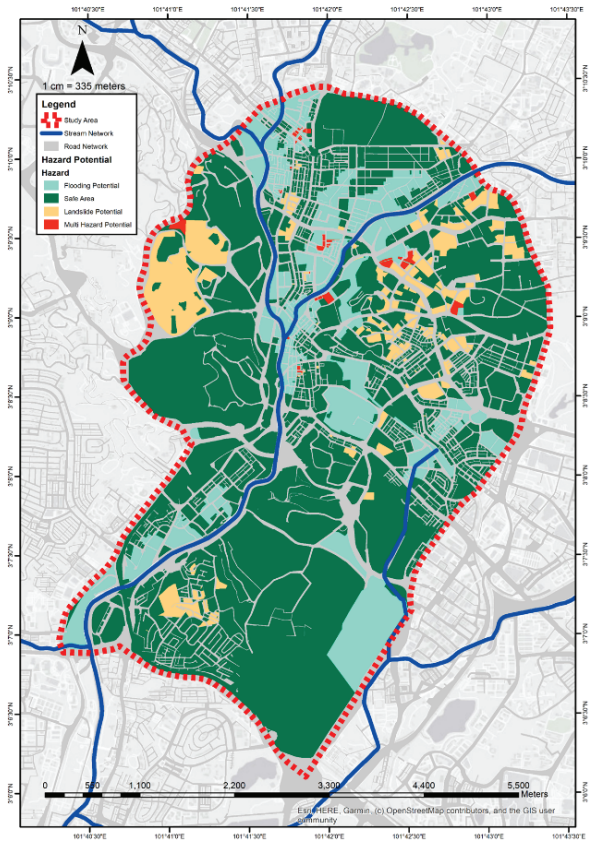

FIGURE 4. Hazard map for KLC

DISASTER VULNERABILITY MAP FOR KLC

A disaster vulnerability map is a specialized geographic representation that focuses on assessing a community's vulnerabilities within a specific area when coping with or responding to a disaster event. This map integrates multiple layers of data to provide a comprehensive understanding of the factors that contribute to a community's resilience in the face of disasters. Listed in Figure 5 are the processes and indicators used to assess disaster vulnerability for KLC.

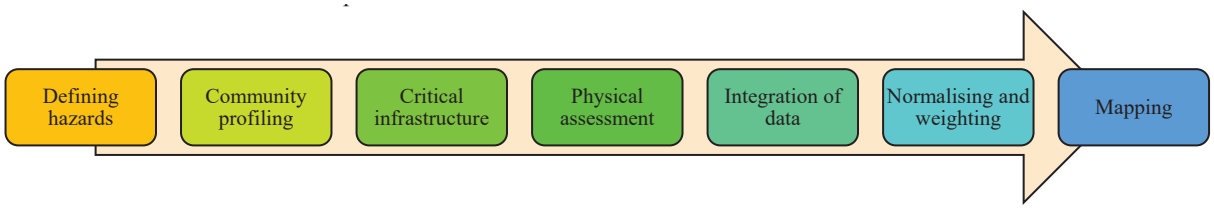

FIGURE 5. Disaster vulnerability assessment process for KLC

The hazards that may pose a disaster risk in KLC are flash floods and landslides. The community profiling is conducted using population density data from 2022 for each parcel obtained from the Department of Statistics Malaysia. The critical infrastructure in each parcel is identified. At the same time, the location and number of fire stations, police stations, health facilities, and temporary evacuation centres within a radius of 1.5 km from the central point of each parcel were determined and identified.

The physical assessment based on land use pattern, transportation network access points, proximity to potential hazard sources, and other infrastructure was also assessed. The point of interest or targets for terrorism activities, based on the analysis of records from the Global Terrorism Database and the Royal Malaysian Police. Using ArcGIS, the data was integrated and overlaid to create a comprehensive spatial representation of parcel vulnerability for each parcel. The data is normalized to a common scale, and weights are assigned to each parameter and indicator.

The vulnerability map, as indicated in Figure 6, for KLC was developed.

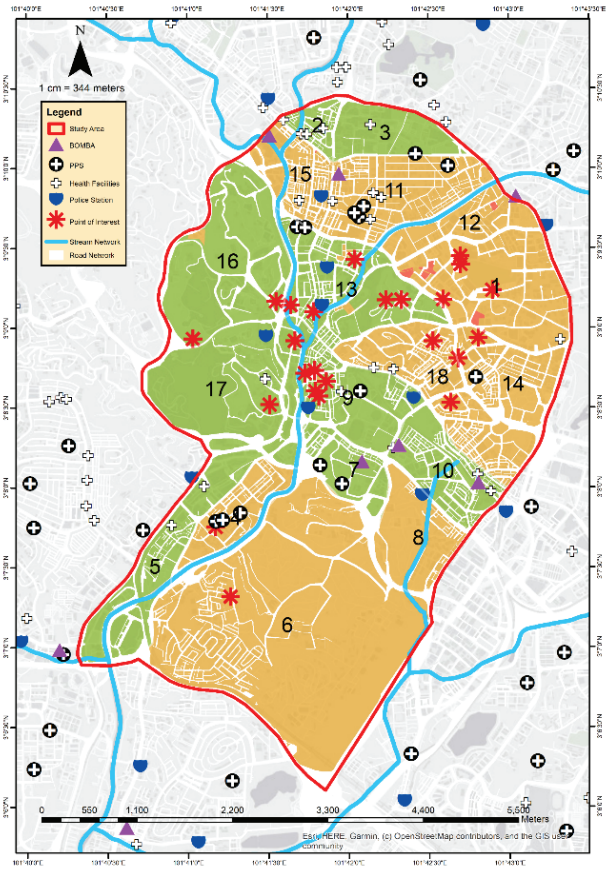

FIGURE 6. Disaster vulnerability map for KLC

The vulnerability map employs a 0 to 1 scale, where 0 represents “not vulnerable” and 1 represents “high vulnerability.” Each parcel’s vulnerability is depicted visually in the map. Green is used for low vulnerability ($V < 0.5$), orange for medium ($0.50 \leq V \leq 0.6$), and red for high vulnerability ($V > 0.60$). It is important to note that

the vulnerability map developed for disaster risk management required the collaboration of all stakeholders. The map's effectiveness in supporting informed decision-making and disaster management activities necessitates regular updates through stakeholder engagement.

ROAD VULNERABILITY ASSESSMENT FOR KLC

One cannot overstate the importance of road vulnerability assessment for rapid response in disaster management. Such assessments serve as critical tools for identifying weaknesses in road infrastructure that could impede emergency response efforts during times of crisis.

By evaluating the condition of roads, bridges, and transportation routes, emergency planners can pinpoint areas susceptible to damage or disruption due to natural disasters, accidents, or other unforeseen events. Additionally, road vulnerability assessments enable emergency responders to develop contingency plans, identify alternative routes, and optimize resource allocation, ensuring swift and effective response in the face of adversity (Singh et al. 2018; Wang et al. 2022).

The assessment of road vulnerability is based on factors such as road hierarchy, road geometrics, and betweenness centrality measure (Papilloud et al. 2020; Chen 2023). Table 2 presents the analysis findings about road vulnerability in KLC, whereas Figure 7 illustrates the corresponding map.

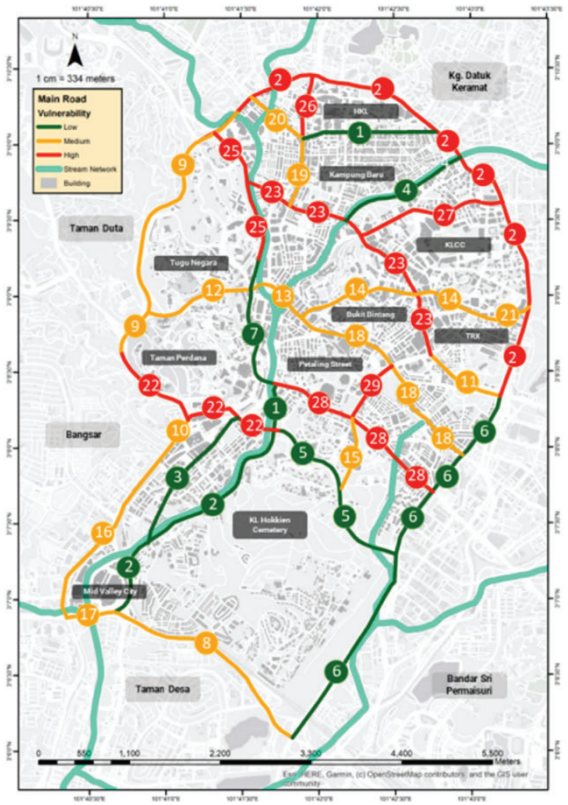

FIGURE 7. Road vulnerability map for KLC

TABLE 2. Road vulnerability analysis for major roads and access points in KLC

No.	Low Vulnerability	Medium Vulnerability	High Vulnerability
1	Jalan Raja Muda Abdul Aziz	Salak Highway (East-West Link)	Jalan Damansara
2	Jalan Syed Putra	Lebuhraya Sultan Iskandar	Jalan Sultan Ismail
3	Jalan Tun Sambathan	Jalan Travers	Jalan Tun Razak
4	AKLEH	Jalan Kampung Pandan	Jalan Kuching
5	Jalan Istana	Jalan Parlimen	Jalan Pahang
6	Jalan Sungai Besi	Jalan Tun Perak	Jalan Ampang

continue ...

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7	Jalan Kinabalu	Jalan Raja Chulan	Jalan Loke Yew
8		Jalan Dewan Bahasa	
9		Jalan Bangsar	
10		Federal Highway	
11		Jalan Pudu	
12		Jalan Tuanku Andul Rahman	
13		Jalan Sultan Azlan Shah	
14		Jalan Bukit Bintang	

DISASTER RISK MAP FOR KLC

A disaster risk map, the culmination of hazard and vulnerability mapping, is a visual representation of both potential hazards and vulnerabilities. It can help disaster risk management by identifying regions most vulnerable to natural or man-made hazards and those with the most resources, assets, or capabilities to cope with or recover from them. Despite the existence of several models for disaster risk assessment, the risk map developed in this research solely relies on two parameters: hazard potential and vulnerability.

In correlation to the previous two mapping processes, risk mapping involves the following activities: information for each parcel, hazards, vulnerability indicators, and the integration of hazards and vulnerability maps to create the risk map. At first, the information for each parcel is analyzed for the urban context, including physical, social, economic, and environmental characteristics, historical disaster events and their intensities, existing policies and land use plans, and stakeholder involvement in disaster response.

Hazards that may affect the area of interest are identified and mapped for all 18 parcels, including the types, frequencies, and locations of past hazardous events. Vulnerability indicators that may affect the ability of relevant stakeholders to cope, including emergency response agencies, are identified and mapped. The hazard and vulnerability maps are integrated to create the risk map, which shows the potential intensities of disaster events in KLC. Additionally, the map can be utilized in the identification of priority areas for urban disaster response. The risk assessment is done using a 3 by 3 matrix, as shown in Table 3.

TABLE 3. Risk assessment matrix for KLC

Risk Assessment Matrix Low		Vulnerability level		
		Medium	High	
Hazard level	Low	Low	Low	Medium
	Medium	Low	Medium	High
	High	Medium	High	High

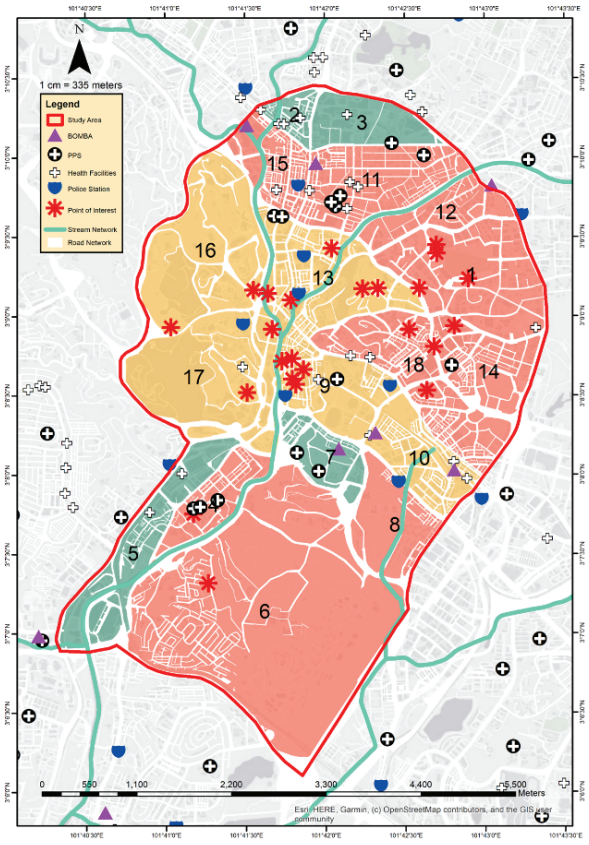

FIGURE 8. Disaster risk map for KLC

Five parcels were identified as medium-risk areas, suggesting a moderate level of vulnerability and potential for hazards. This category acknowledges a greater susceptibility compared to low-risk areas because the level of risk should be manageable with appropriate mitigation measures. A significant focus, however, needs to be directed

towards nine parcels earmarked as high-risk zones, indicating an elevated level of vulnerability and exposure to multiple disaster hazards. These areas demand increased attention and strategic planning to mitigate risk effectively, enhance resilience, and safeguard communities from the potential impact of disasters. It is noteworthy that most of the land use within the mapped region predominantly falls within the low- to medium-risk spectrum. This distribution is indicative of a thoughtful and resilient urban planning strategy; aligning land use not only contributes to the overall resilience of the region but also reflects a proactive approach to disaster preparedness and sustainable development.

CONCLUSION

The comprehensive mapping of disaster hazards and risks in KLC provides crucial comprehension of the city's susceptibilities and capabilities in disaster management. This study utilised ArcGIS to examine the spatial dispersion of landslides and flash flood hazards, incorporating historical data, topographic data, land utilisation patterns, and socio-economic determinants. The hazard, vulnerability, and risk maps that are produced are crucial for identifying areas with a high risk of disasters and important infrastructure that is susceptible to such events. These maps serve as a fundamental tool for urban planners, policymakers, and emergency management agencies during HADR operations. The main findings of this research reveal that flash floods and landslides pose the greatest risks to KLC, with some areas being especially vulnerable to these dangers. Ultimately, the process of mapping disaster hazards and risks in KLC is an essential measure in constructing a more resilient urban environment. This study equips stakeholders with comprehensive, dynamic, and practical data, enabling them to make well-informed decisions that improve disaster preparedness, reduce risks, and safeguard the city's residents and infrastructure. Given the ongoing processes of urbanization and climate change, it is imperative to embrace these solutions based on solid facts to protect KLC's future.

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DECLARATION OF COMPETING INTEREST

None.

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