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LANDSLIDE SUSCEPTIBILITY ANALYSIS USING REMOTE SENSING AND GIS: A CASE STUDY IN HULU LANGAT, SELANGOR, MALAYSIA

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Abstract

Landslides pose significant hazards globally, especially in expanding populations in unstable areas. This study uses geospatial analysis for landslide susceptibility in Hulu Langat, Selangor, Malaysia. The primary objectives are to understand landslide factors, analyse susceptibility, and recommend mitigation strategies. The methodology involves the Analytic Hierarchy Process (AHP) evaluating nine parameters: elevation, slope terrain, slope aspect, lithology, soil types, distance from rivers, land cover, precipitation, and distance from faults. Key findings show lower elevations, specific soils, acid intrusive lithology, and proximity to rivers and faults are particularly susceptible to landslides. Findings show that Landslide Concern Zone (LCZ) are mainly dispersed along the vicinity of Sungai Langat and Sungai Semenyih. The study emphasizes tailored mitigation, proactive land-use planning, and integration of disaster management with urban planning to enhance resilience and inform policy.

Keywords: landslide, susceptibility, remote sensing

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LANDSLIDE HAZARD AND GEOSPATIAL ANALYSIS

Landslides are a significant natural hazard that occurs worldwide, affecting various terrains and climates. These events result in substantial economic losses, fatalities, injuries, and long-term disruptions to communities. A landslide is a movement of soil, rock, and biological materials downslope under the force of gravity (Highland & Bobrowsky, 2008). It also refers to the landform that results from such movement. Landslides can involve various types of materials and movements, such as rockfalls, debris flows, and slope failures, occurring on surfaces of rupture with little internal deformation. Different types of landslides can be recognized by the kind of movement and material involved (Schulte, 2024). Landslides may also exhibit a combination of movements, such as rockslide—debris flow, forming complex failures encompassing more than one type of movement (Highland & Bobrowsky, 2008; Wubalem, 2022).

Landslide susceptibility is a crucial aspect in understanding and mitigating the risks associated with landslide occurrences. Defined as the likelihood of landslides occurring in an area based on terrain conditions, landslide susceptibility mapping involves identifying and evaluating the factors that contribute to slope failures (Wubalem, 2022). Land use/cover characteristics, hydrological, climatological, lithological, geomorphological, geological structure, and seismic elements are frequently among these components.

Heavy precipitation, seismic activity, volcanic eruptions, forest fires, and human activities, can cause landslides (Highland & Bobrowsky, 2008). Landslides can occur on land or underwater and impact a variety of environments, including natural forests and farmed areas. In addition, Highland & Bobrowsky (2008) emphasize that landslides are not limited to a particular climate, as they can affect areas with varying humidity levels.

Landslide analysis much simpler by technological improvements, especially in the areas of computer systems, remote sensing, and geographic information systems. More thorough and precise data gathering, processing, and visualization are possible to be conducted. According to Wubalem (2021), these developments make it easier to create comprehensive maps of landslide susceptibility, which are essential for locating high-risk locations and developing mitigation plans. The process of creating these maps not only highlights the most influential factors in landslide occurrences but also helps in estimating the relative contribution of each factor, thereby enabling the prediction and management of future landslide hazards (Gaidzik & Ramírez-Herrera, 2021; Wubalem, 2021).

In addition to being crucial for comprehending the spatial distribution of probable landslide events, landslide susceptibility mapping is also important for land management and urban planning. Such mapping is particularly important in hilly places with tropical climates that are frequently affected by hurricanes, where landslides can be fatal (Gaidzik & Ramírez-Herrera, 2021). Authorities can improve community safety and resilience by making well-informed decisions about infrastructure development, land use, and disaster preparedness by incorporating susceptibility maps into planning procedures. By integrating susceptibility maps into planning processes, authorities can make informed decisions about land use, infrastructure development, and disaster preparedness, thereby enhancing community resilience and safety. Incorporating a comprehensive Disaster Risk Reduction (DRR) strategy can improve Malaysia's planning delivery system (Ibrahim, 2024).

Remote sensing can be used to map hazards and determine susceptibility without any problems. In their respective works, Chelariu et al. (2023) and Aksha et al. (2020) studied GIS-based multi-criteria decision making (MCDM) techniques, to choose development-friendly locations while considering the danger of natural disasters into account. The study emphasised how crucial it is to incorporate geohazard concerns into spatial design to reduce risks and improve disaster resilience. Using GIS methods, Ntelis et al. (2019) evaluated the Evritania Prefecture's susceptibility to landslides. The study determined that tectonic elements, land cover, precipitation, slope angle, lithology, and distance from streams are important factors that affect the occurrence of landslides. Precipitation was also utilized by Althuwaynee et al. (2015) to examine the occurrence of landslides. These methods offered a framework for comprehending and forecasting the risks of landslides in connection with rainfall events. In order hand, to facilitate the development of effective risk management and mitigation strategies, El Jazouli et al. (2019) and Ibrahim et al. (2022) focused on GIS-multicriteria evaluation and AHP for landslide susceptibility mapping in their respective sites.

Study Area

Hulu Langat (Figure 1) is one of the nine districts of Selangor, located in the southeast of the state of Selangor Darul Ehsan. It covers an area of 829.44 km^3 (207,475.57 acres) and is home to nearly 1.4 million people (Department of Statistics Malaysia, 2022). Selangor's easternmost district is called Hulu Langat. It borders Negeri Sembilan to the east and south, Pahang to the north, Gombak district to the northeast, and Sepang district to the southwest. It borders Kuala Lumpur to the east. There are seven Mukims, or subdistricts, within the district of Hulu Langat. They are Kajang, Semenyih, Hulu Langat, Hulu Beranang, Cheras, and Ampang. Primarily, the district of Hulu Langat is under the jurisdiction of Majlis Perbandaran Kajang (MPKj), except for Mukim Ampang, which is under jurisdiction of Majlis Perbandaran Ampang Jaya (MPAJ).

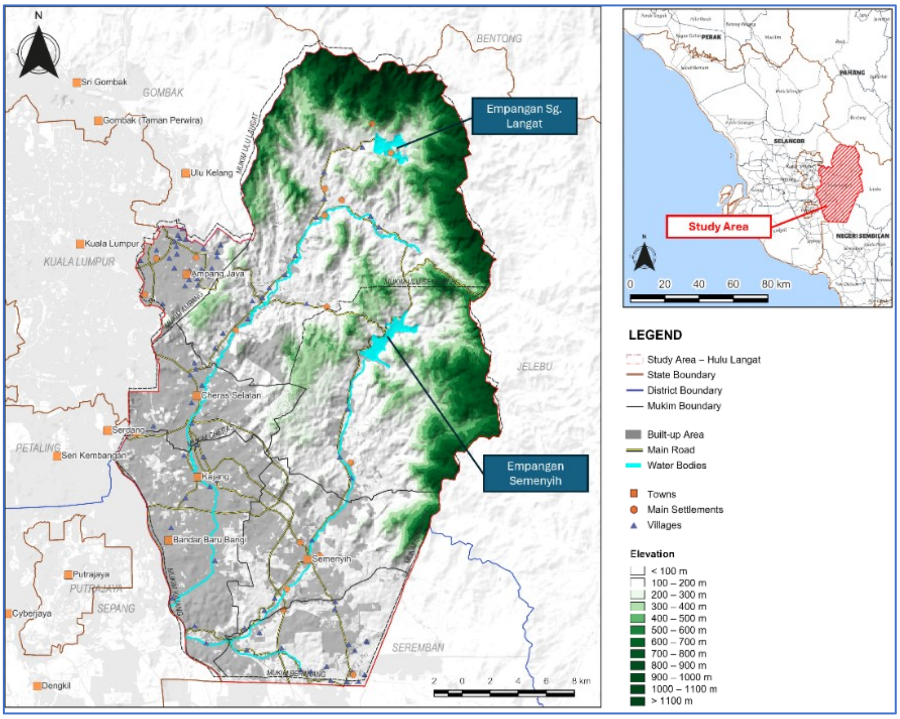

Figure 1: Study area of the Hulu Langat District

The Hulu Langat district in Selangor, Malaysia, is, apart from the extensive urban settlement, also renowned for its rich environmental diversity, encompassing forest reserves, river basins, rivers, dams, and significant elevations. These features not only contribute to the district's ecological health but also play a vital role in supporting the local communities and sustaining biodiversity.

RESEARCH METHODOLOGY

Establishing a systematic framework of conduct can ensure smoothness and seamless work processes, which may eventually lead to a comprehensive output. The methodology for this research can be divided into five parts: preliminary study, literature review, data collection, GIS evaluation, zoning, and reporting. These methodologies have been applied through determined phase accordingly. This research design will also illustrate the methodological process adopted for this research, which will be based on majorly secondary data. Figure 2 shows the overall structure of how process of identifying landslide susceptibility, by using GIS and remote sensing.

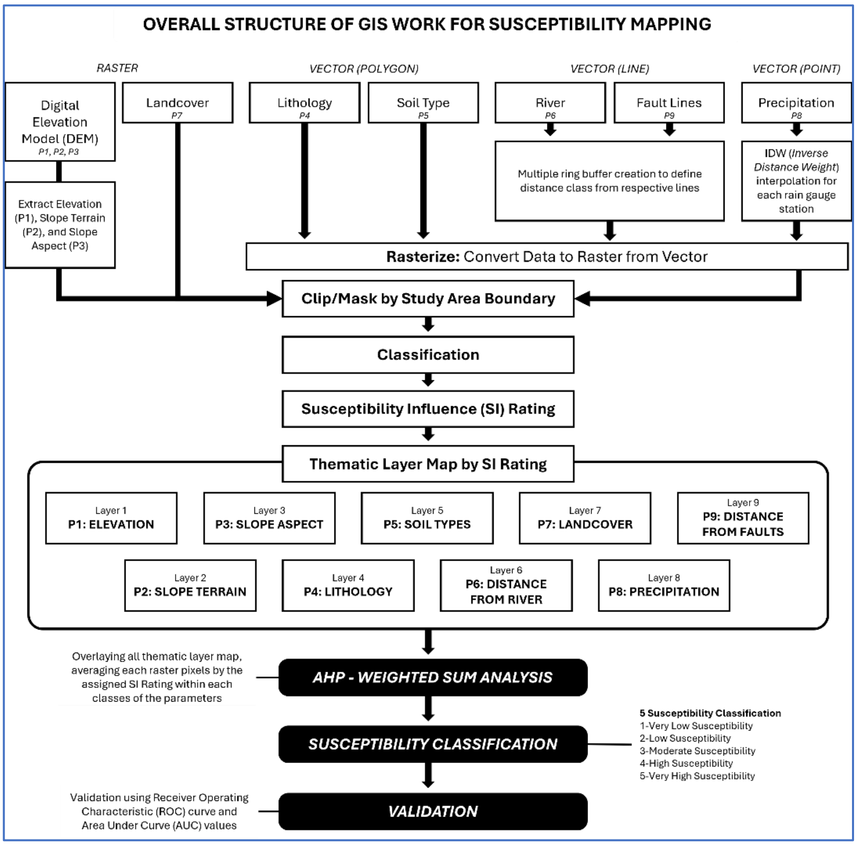

Figure 2: Methodology of the study

The preparation for thematic layers for landslide susceptibility in Hulu Langat will be comprised of nine (9) major parameters. The parameters involved for the analysis are elevation, slope terrain, slope aspect, lithology, soil types, distance from river, landcover, precipitation, and distance from faults. The susceptibility influence (SI) rating assignment is given to each class of parameters.

Table 1: Parameter and detailed used in this study

Parameters	Source	Variable type	Spatial resolution (m) and data type	Classification method
Elevation	DEM (Digital Elevation Model) SRTM (Shuttle Radar Topography Mission) 3-Arc Seconds (90m). https://earthexplorer.usgs.gov/	Continuous (DEM based)	30 (grid data)	Equal interval
Slope terrain	SRTM	Continuous (DEM based)	30 (grid data)	Manual classification
Slope aspect	STR	Continuous (DEM based)	30 (grid data)	Azimuth classification
Lithology	Department of Mineral and Geoscience (JMG – *Jabatan Mineral dan Geosains*)	Discrete (polygon)	30 (vector data)	Lithology classification
Soil types	Department of Agriculture (DOA)	Discrete (polygon)	30 (vector data)	Soil classification
Distance from river	Department of Irrigation and Drainage (JPS)	Discrete (ring buffer from line)	30 (grid data)	Equal interval
Landcover	LANDSAT 8 (OLI_TIRS) https://earthexplorer.usgs.gov/	Discrete (Satellite image based)	30 (grid data)	Supervised classification
Precipitation	Malaysian Meteorological Department (MET Malaysia)	Continuous (IDW interpolation from point)	30 (grid data)	Equal interval
Distance from faults	Malaysian Meteorological Department (MET Malaysia)	Discrete (ring buffer from line)	30 (grid data)	Equal interval

Figure 3 shows the SI maps for all parameters. For elevation (P1), the classification for elevation is initially divided into 200-meter intervals. Within the study area, the elevation ranges from 0 meters (sea level) to 1450 meters. There are four main elevation classes: low land (<150 meters), hilly land (150-300 meters), highland (300-1000 meters), and mountain (>1000 meters) (Bahagian Penyelidikan dan Pembangunan, 2011). These classes are all present within the study area. Literature on landslides in similar regions, such as Selangor and Kuala Lumpur, indicates that landslides are more frequent in areas below 400 meters in elevation (Saadatkhah et al., 2015; Zulkafli et al., 2023). Consequently, a higher SI rating is assigned to the lower elevation classes, reflecting the increased risk of landslides, while the higher elevation classes receive progressively lower SI ratings.

For slope terrain (P2), the interpretation of slope terrain is measured in angular degrees (°), with the steepest slope in the study area being 54.8°. Slopes are categorised into four classes: Class I (<15°), Class II (15°-25°), Class III (25°-35°), and Class IV (>35°) (Bahagian Penyelidikan dan Pembangunan, 2011). In the study area, over half of the land falls within Class I, followed by 24% in Class II, 10% in Class III, and 1% in Class IV. Generally, steeper slopes are more prone to landslides. However, slope alone is not the primary trigger for landslides. In the context of Selangor and Kuala Lumpur, many landslides have been reported on slopes less than 25°, reflecting a complex interplay of factors beyond just slope steepness (Alnaimat, 2013; Lee & Pradhan, 2007; Saadatkhah et al., 2015; Zulkafli et al., 2023). Considering the diverse urban and rural characteristics of Hulu Langat, a higher SI rating will be assigned to steeper slopes, reflecting their greer potential risk for landslides.

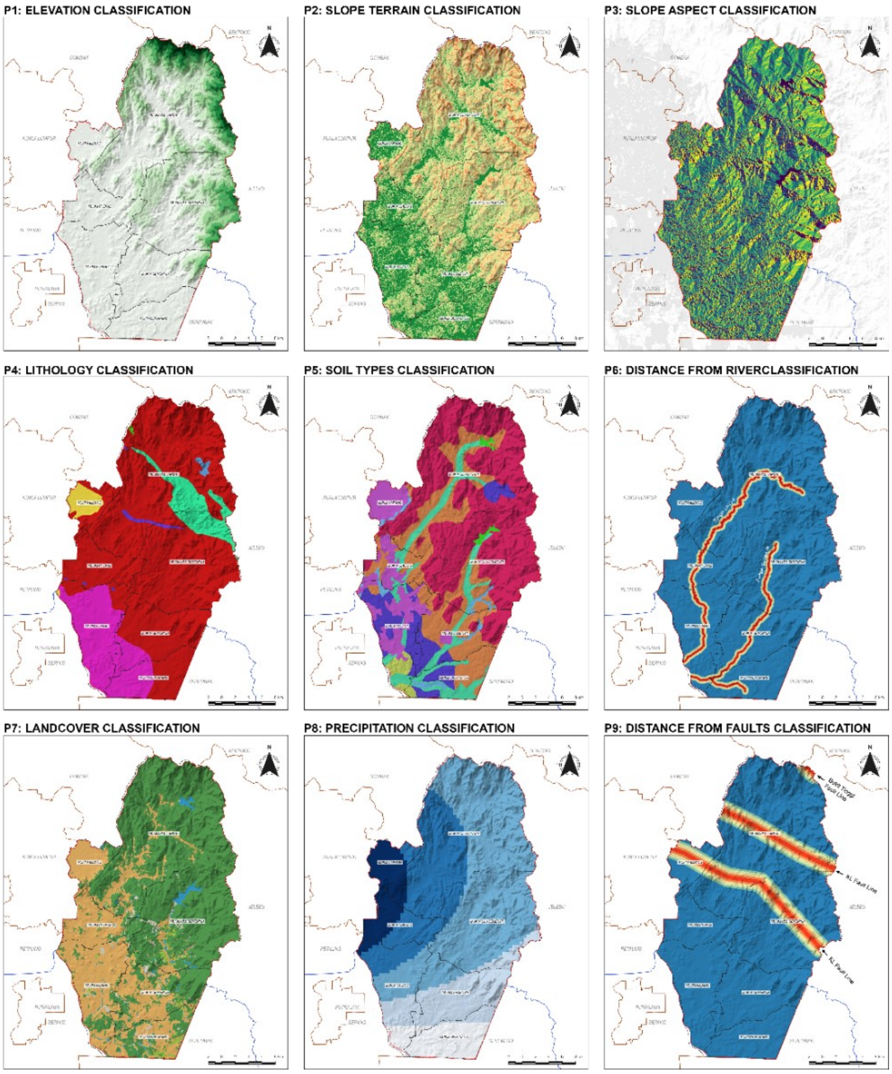

Figure 3: Thematic layer parameters map.

The slope aspect (P3) is a significant factor influencing landslide occurrence. Studies conducted in Malaysia indicate that most landslides occur on slopes facing the monsoon directions, specifically northeast and southwest (Lee & Pradhan, 2007; Saadatkhah et al., 2015). Therefore, higher SI ratings are assigned to slopes with aspects facing northeast and southwest, and the lowest SI ratings are given to slopes facing opposite directions, reflecting their lower risk of landslides.

Within Hulu Langat, seven lithology (P4) classes have been identified. According to landslide studies in Malaysia, most landslides occur in areas with geological compositions predominantly of sandstone, acid intrusive, mudstone, siltstone, granite, conglomerate, and volcanic rocks (Lee & Pradhan, 2007; Sofiyan Sulaiman et al., 2019; Zulkafli et al., 2023). Schist and limestone lithology types have a lower influence on landslide activity (Sofiyan Sulaiman et al., 2019). Acid Intrusive (AI) formations are one of the prominent geological structures within the study area. Other geological compositions include acid to intermediate volcanics, schist, limestone, vein quartz, and others. Based on the literature, the highest SI rating is assigned to acid intrusive formations. The second highest SI rating is given to areas containing acid to intermediate volcanic (AIV) and phyllite-schist-slate (PSS) compositions, due to their volcanic and sandstone compounds. Consequently, lithologies containing schist, limestone, and quartz are assigned lower SI ratings, reflecting their reduced influence on landslide activity.

Eight (8) categories of soil types (P5) have been identified within Hulu Langat. The most prominent soil type is Tanah Churam (TC), covering 46% of the area, followed by Rengam-Jerangau (R-J) at 22%, and Tanah Bandar (TB) at 10%. According to landslide studies in Malaysia, soil types with the highest influence on landslide activity are Tanah Bandar (TB), followed by Tanah Churam (TC), and Serdang-Bungor-Munchong (S-B-M) (Lee & Pradhan, 2007; Sofiyan Sulaiman et al., 2019). Therefore, the SI ratings for the soil type parameter are assigned based on these findings from local literature, ensuring that the most landslide-prone soil types receive the highest ratings.

Saadatkhah et al. (2015) explained that most of the past landslides in the Hulu Kelang area occurred within 0-75 meters of distance from rivers (P6). In contrast, reported landslide events in Kuala Lumpur were within 500 meters from rivers (Zulkafli et al., 2023). Additionally, studies by Lee & Pradhan (2007) indicated that landslides in Selangor predominantly occurred within 357 meters from rivers. Therefore, the highest SI rating for this parameter will be assigned to areas within 200 meters of rivers. Conversely, the lowest SI rating will be given to areas more than 500 meters away from rivers, reflecting the decreased influence on landslide activity with increased distance from rivers.

Landcover (P7) one of the factors of landslide. Hulu Langat has significant forest coverage, accounting for 62% of the area, or approximately 130,000 acres. Built-up areas make up 32%, equating to around 67,000 acres. Other land cover types in Hulu Langat include water bodies, vegetation, and cleared land. According to landslide literature, built-up areas are highly prone to landslides, while areas with green coverage, such as forests, vegetation, and plantations, have a lower likelihood of landslides (Alnaimat, 2013; Kalimuthu et al., 2015; Saadatkhah et al., 2015; Zulkafli et al., 2023). Thus, the SI rating for land cover in Hulu Langat is assigned based on these findings, with the highest rating given to built-up areas and the lowest rating to non-built-up areas (Table 2).

The data of annual cumulative rainfall in 2022 from the rain gauge stations at KLIA (Kuala Lumpur International Airport) and Petaling Jaya is used for parameter P8 – Precipitation. According to this data, Hulu Langat received an annual average rainfall of 3241 millimetres, with a monthly average of 270 millimetres and a daily average of 7 to 9 millimetres. Based on landslide literature and the correlation with rainfall, areas that receive higher rainfall have a significantly higher likelihood of landslides (Alnaimat, 2013; Kalimuthu et al., 2015; S. Lee & Pradhan, 2007).

Within the Hulu Langat study area, there exist two principal fault lines (P9): the Kuala Lumpur fault lineament situated in the northern half of the territory, and a minor segment of the Bukit Tinggi fault lineament, located in the northernmost part of the area as well (Shuib et al., 2017). Landslide incidents are usually reported 400–1200 meters away from fault lines, according to landslide literature relevant to fault lines (Alnaimat, 2013; Dou et al., 2015; Lee & Pradhan, 2007).

Table 2: Weight and SI assignment to parameters.

Parameter	Class	SI Rating	Parameter weight
P1 – Elevation	< 400 m	5 – Very High Susceptibility	**0.12** Rank = 2
	400 m – 600 m	4 – High Susceptibility	
	600 m – 800 m	3 – Moderate Susceptibility	
	800 m – 1000 m	2 – Low Susceptibility	
	> 1000 m	1 – Very Low Susceptibility	
P2 – Slope Terrain	< 15°	1 – Very Low Susceptibility	**0.13** Rank = 1
	15° - 25°	2 – Low Susceptibility	
	25° - 35°	3 – Moderate Susceptibility	
	35° - 45°	4 – High Susceptibility	
	> 45°	5 – Very High Susceptibility	
P3 – Slope Aspect	NE, SW	5 – Very High Susceptibility	**0.12** Rank = 2
	N, E, S	4 – High Susceptibility	
	W	3 – Moderate Susceptibility	
	NW	2 – Low Susceptibility	
	SE	1 – Very Low Susceptibility	
P4 – Lithology	AI	5 – Very High Susceptibility	**0.10** Rank = 3
	AIV & PSS	4 – High Susceptibility	
	S	3 – Moderate Susceptibility	
	L/M	2 – Low Susceptibility	
	SPSL & VQ	1 – Very Low Susceptibility	
P5 – Soil Types	TB	5 – Very High Susceptibility	**0.09**

Parameter	Class	SI Rating	Parameter weight
	TC & S-B-M	4 – High Susceptibility	Rank = 4
	R-J	3 – Moderate Susceptibility	
	R-BT, BM-M & TL	2 – Low Susceptibility	
	T-A-TLT	1 – Very Low Susceptibility	
P6 – Distance from River	< 200 m	5 – Very High Susceptibility	**0.12** Rank = 2
	200 m – 300 m	4 – High Susceptibility	
	300 m – 400 m	3 – Moderate Susceptibility	
	400 m – 500 m	2 – Low Susceptibility	
	> 500 m	1 – Very Low Susceptibility	
P7 - Landcover	Built-up Area	5 – Very High Susceptibility	**0.12** Rank = 2
	Cleared Land	4 – High Susceptibility	
	Vegetations	3 – Moderate Susceptibility	
	Forests	2 – Low Susceptibility	
	Water Bodies	1 – Very Low Susceptibility	
P8 – Precipitation	2801 mm – 2977 mm	1 – Very Low Susceptibility	**0.10** Rank = 3
	2977 mm – 3153 mm	2 – Low Susceptibility	
	3153 mm – 3330 mm	3 – Moderate Susceptibility	
	3330 mm – 3506 mm	4 – High Susceptibility	
	3506mm – 3682 mm	5 – Very High Susceptibility	
P9 – Distance from Faults	< 600 m	5 – Very High Susceptibility	**0.10** Rank = 3
	600 m – 900 m	4 – High Susceptibility	
	900 m – 1200 m	3 – Moderate Susceptibility	
	1200 m – 1500 m	2 – Low Susceptibility	
	> 1500 m	1 – Very Low Susceptibility	

RESULT

Using the equal interval classifier, the study area's landslide susceptibility (LSS) score, which ranged from 1.78 to 4.20, was classed into five landslide susceptibility classes: very low, low, moderate, high, and very high (Figure 4). Very low, low, and moderate susceptible occurrences make up 2.10%, 32.23%, and 50.16% of the entire study region, respectively, according to the analysis results displayed in Table 3. The entire study area is represented by the high (14.74%) and extremely high (0.77%) susceptibility of areas.

Table 3: Landslide susceptibility (LSS) in the study area

CLASS	LSI	Description	AREA (%)	AREA (acres)
5	3.72 – 4.20	Very High Susceptibility	**0.77**	**1,590.39**
4	3.23 – 3.72	High Susceptibility	**14.74**	**30,587.55**
3	2.75 – 3.23	Moderate Susceptibility	**50.16**	**104,072.60**
2	2.26 – 2.75	Low Susceptibility	**32.23**	**66,871.62**
1	1.78 – 2.26	Very Low Susceptibility	**2.10**	**4,353.41**
Interval	***0.484***		**100.00**	**207,475.57**

In order to assess the effectiveness of binary classification models, this study used the receiver operating characteristic (ROC) curve, which plots the true positive rate (sensitivity) against the false positive rate (1-specificity) across a range of thresholds (Sur et al., 2020; Vakhshoori & Zare, 2018). The model's performance is summarized by the area under the ROC curve (AUC): a value of 1.0 indicates a perfect model, while 0.5 indicates no discriminative power. Using 182 historical landslide points, the result of ROC and AUC demonstrate a good degree of satisfaction (AUC = 0.755, 75.5%).

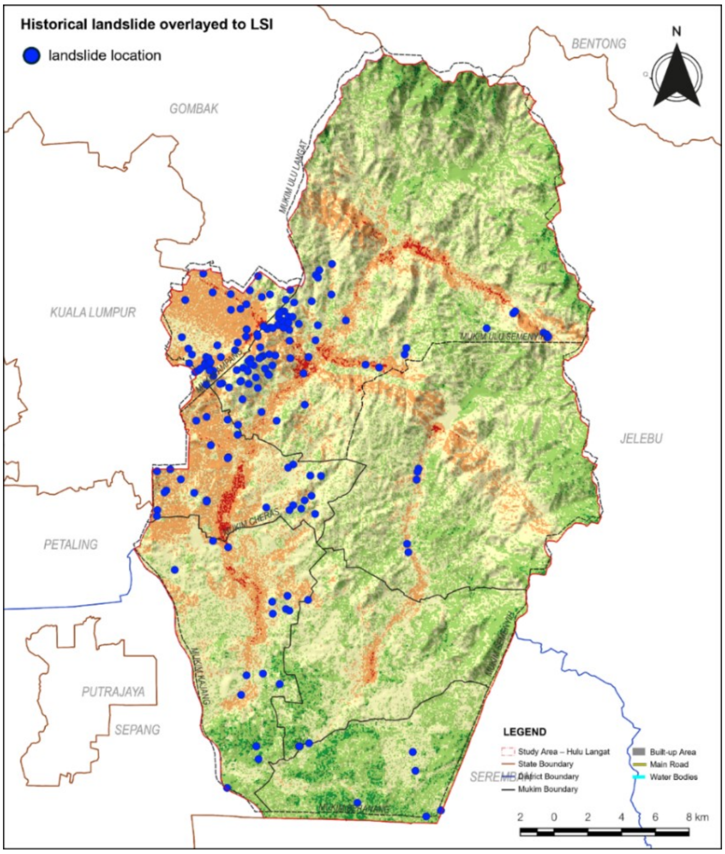

Figure 4: Historical landslide locations overlayed to LSS map

Analysis and Finding

Following the results of LSI (see Table 4-1 and Figure 4-1), there is a total of 32,177.94 acres of land area (15.51%) in Hulu that is subjected to high potential risk of landslides, with most of it being in the area of Bangi, Kajang, Cheras and Ampang. This study has categorized nineteen (19) landslide concern zones (LCZ) identified within the study area, classified into three levels of concern: critical, significant and notable. Figure 5 shows the LCZ for each class. The LCZ Class 1 – critical concerns include seven zones: Ampang Jaya South, Balakong - Cheras, Batu 13 - Batu 14, Empangan Semenyih, Kajang - Sungai Chua, Kampung Sungai Balak - Kampung Batu 10, and Pekan Semenyih.

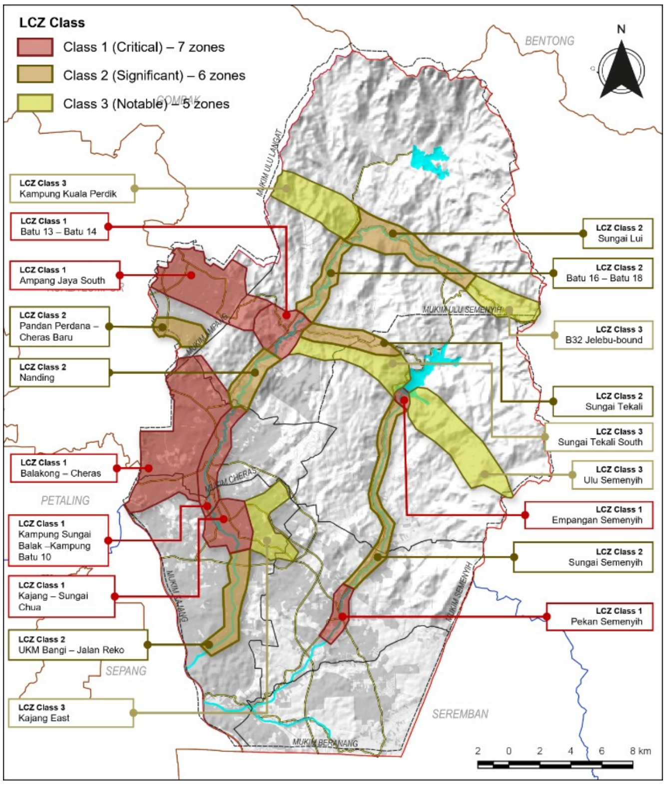

Figure 5: Landslide Concern Zones

These areas are deemed to have the highest risk and require immediate attention and mitigation measures to prevent landslides and ensure the safety of the population and infrastructure. The LCZ Class 2 – significant concerns consist of seven zones: Batu 16 - Batu 18, Nanding, Pandan Perdana - Cheras Baru, Sungai Lui, Sungai Semenyih, Sungai Tekali, and University Kebangsaan Malaysia (UKM) Bangi – Jalan Reko. These zones have a substantial risk of landslides, necessitating significant monitoring and preventative actions to mitigate potential impacts. The presence of critical infrastructure and populated areas in these zones underscores the importance of addressing the risks effectively. Lastly, the LCZ Class 3 – notable concerns include five zones: B32 Jelebu-bound, Kajang East, Kampung Kuala Perdik, Sungai Tekali South, and Ulu Semenyih. While these areas are not as critically endangered as those in Class

1 and 2, they still present a notable risk of landslides. Proactive measures and continuous monitoring are essential to manage and reduce the susceptibility to landslides in these zones.

By delineating these concerning zones into three classes, responsible authorities, interested agencies and stakeholders can observe and prioritize their efforts and resources, focusing first on the most critical areas while also addressing significant and notable concern zones in a systematic manner. This can also be one way to a structured approach for categorizing and addressing landslide risk allows for targeted interventions and resource allocation, focusing on the areas with the highest need for mitigation efforts.

Mitigation efforts including monitoring and engineering solutions for high-risk zones (LCZ 1) as with the highest likelihood of landslides, require immediate and ongoing attention. Frequent observations and monitoring of these zones are essential to detect early signs of landslides and implement timely interventions. Raising awareness among local populations about the risks and preventive measures is also crucial. Engineering solutions such as slope stabilization, constructing retaining walls, and improving drainage systems should be prioritized in these high-risk areas. These measures can significantly reduce the risk of landslides and protect lives and property. To enhance the effectiveness of monitoring and early warning systems, advanced technologies such as Light Detection and Ranging (LiDAR) and Interferometric Synthetic Aperture Radar (InSAR) can be employed.

Significant and notable concern areas (LCZ Class 2 and LCZ Class 3) also require regular inspections and monitoring, albeit less intensively than the critical zones. Ensuring safety in these areas involves implementing stricter building regulations and revising the design of structures to prevent exacerbating the landslide risk. Adopting construction practices that enhance the structural integrity and resilience of buildings can significantly reduce the vulnerability of these areas to landslides. This includes designing foundations and supports that can withstand ground movements and incorporating materials and techniques that improve overall stability.

Emergency preparedness programs play a vital role in equipping local populations to respond effectively to landslide events. Regular community drills can help residents understand evacuation routes and safety procedures, ensuring a coordinated response during emergencies. Infrastructure upgrades, such as reinforcing roads, bridges, and public buildings, can enhance the community's resilience and reduce the impact of landslides. Public awareness campaigns are equally important in educating residents about the risks and encouraging proactive measures to mitigate them. These campaigns can provide information on recognizing early warning signs of landslides, safe construction practices, and steps to take during and after a landslide event.

CONCLUSION

The parameters used in this analysis; elevation, slope terrain, slope aspect, lithology, soil types, distance from river, landcover, precipitation, and distance from faults are important to be used in landslide analysis. However, the established methodology serves as a valuable guide for future susceptibility mapping efforts. While additional disaster studies specific to Malaysia will enhance our understanding of hazard and susceptibility, more powerful tools can significantly impact the integration of socio-economic and physical urban planning with disaster management. These tools include strong legislation, statutory documents, comprehensive planning guidelines, building regulations, and political will. By leveraging these instruments, we can drive effective change and ensure a more resilient urban landscape in the face of disasters.

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