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Influencing Physical Characteristics of Landslides in Kuala Lumpur, Malaysia

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ABSTRACT

Landslide is one of the natural disasters that commonly occurs in terrestrial environments with slopes throughout the world. Located among countries with tropical climates, the hot and humid conditions expose Kuala Lumpur, Malaysia, to the risk of landslides. This paper aims to delineate the influencing physical characteristics of landslide occurrences in Kuala Lumpur. In this study, a 100 landslides historical data set and eight landslide factors were obtained from proper field validation and maps provided by those concerned in the government, such as distance to roads, distance to streams, elevation, slope angle, curvature, slope aspect, land use, and lithology. These factors were processed using GIS as geospatial analysis provides a useful tool for planning, disaster management, and hazard mitigation. By using ArcMap 10.8.2, a GIS software, different spatial analyses in which maps for each physical factor were layered with landslide events distribution. The weights for each factor were determined using the ANN approach resulting in the slope angle having the highest relative importance with a 100.0% value. In comparison, 8.3% represents the slope aspect as the most insignificant factor out of the eight selected characteristics for this study area. Therefore, a proper perspective and a thorough understanding of the certain slope condition have to be established for future mitigation action to support the agenda of SDG 15.

Keywords: ANN, GIS, geospatial, Kuala Lumpur, landslide

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INTRODUCTION

Landslide is one of the natural disasters that commonly occur worldwide, mainly in terrestrial environments with slopes. This disaster has had a devastating toll on lives and the economy. More than 8,935 landslide incidents were recorded worldwide, with approximately 1,120 landslides scattered in Southeast Asia until 2019 (NASA, 2020). Although landslides caused a lower death toll than other disasters, the destructive effects of the latter consequences on the economy are rather devastating because landslides have affected nearly 130 billion USD worth of assets across the world (Ritchie & Roser, 2014). These examples of bad economic outcomes of landslides demonstrate that having a good disaster preparedness program in a particular region is vital to reducing the chances of a disaster and its impacts.

For a record, the US National Aeronautics Space Administration (NASA) affirmed that Malaysia had 171 landslides between 2007 to 2016, making it the 10th country with the highest frequency of landslides (Sim et al., 2018). A total of 262 landslide cases were discovered in recent circumstances across the country, with which Kuala Lumpur and Selangor contributed to most landslide occurrences in Malaysia (The Star, 2022). On the other hand, numerous landslide history data have been accumulated near Kuala Lumpur, indicating that several more landslide occurrences have occurred since the first event (excluding the non-reported cases). Due to the high frequency of landslides, Kuala Lumpur is selected as the area of interest for this study.

Figure 1 clearly shows that Kuala Lumpur is an urban area with the highest population density of 7,188 people per square kilometer, where multiple conversions have been ongoing for decades (Department of Statistics Malaysia, 2022). As a developed region, Kuala Lumpur is often planted with shallow-rooted greenery for aesthetics with fewer infiltration capabilities that would loosen soil particles, specifically during uncertain intense precipitation, leading to slope movements (Huang et al., 2012). Overgrowing urbanization has also become one of the major contributors to landslides for years. The latest statistics for 2019, recorded by the Department of Statistics, found that urbanization covered 76.2% of Malaysia (Department of Statistics Malaysia, 2020). In short, unsustainable land expansion may soar illegal logging activities, which later cause erosion of the covered soil masses, posing a serious threat to slope stability (Pradhan & Lee, 2009).

Landslides can be triggered by many factors and occasionally correspond to one another. Apart from the most common landslide-triggering factor, rainfall, the rising events of landslides are also closely linked to the instability of slopes due to soil gestures failures. This high-risk catastrophe has encouraged the experts and scientific community to construct several landslide research in the past few years to provide proper information to planners, geotechnical consultants, and governments. With the introduction of GIS, multiple physical characteristics of landslides can be analyzed. Many researchers have continuously

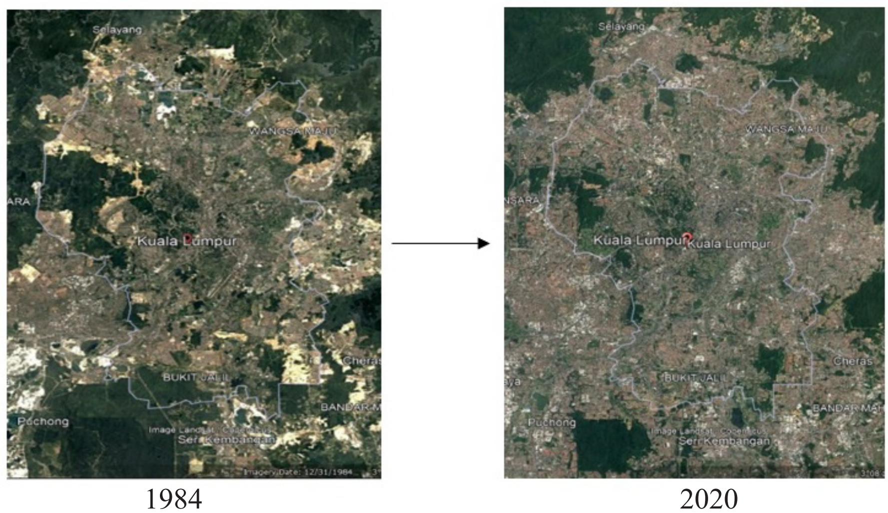

Figure 1. Land use conversion of Kuala Lumpur from 1984 to 2020
Source. Google Earth Pro 1984 and 2020

constructed different types of landslide analyses, for instance, landslide susceptibility and assessments (Shahabi & Hashim, 2015; Majid et al., 2017; Majid et al., 2018; Mersha & Meten, 2020; Majid & Rainis, 2019; Naseer et al., 2021). However, the scope of this study will be narrowed down to the selected physical factors initiation to landslides in a growing city, Kuala Lumpur, as it requires greater precise spatial analysis to be done down to the local level. This study will also encourage the efficiency of landslide prevention and mitigations, as well as enhance the conservation of the physical environment and human safety (Kyriou et al., 2021).

Advanced computing performance and the development of accessible geographical information system (GIS) platforms have further contributed to the extensive use of such reliable landslide forecasting targeted to the regional scale (Song et al., 2020). GIS is also often used as a tool to predict the occurrence of slope failures by warning of potential slope failures in the future (Majid & Ibrahim, 2015). In addition, GIS provides information and tools to quantitatively analyze multiple variables' functional relationships (Psomiadis et al., 2020; Simon et al., 2017). Therefore, spatial analysis using GIS software, namely ArcMap 10.8.2, is efficient for landslide studies as it always delivers high credibility of methods and results. By means, GIS will indirectly decrease the inaccuracy of landslide studies that could lead to major faults in analyzing and predicting landslide occurrences in Kuala Lumpur.

MATERIALS AND METHODS

Study Area

The Federal Territory of Kuala Lumpur was selected as the study area, which covers approximately 243.6 sq km within Selangor (Figure 2). Located at latitude 03º 2´N to 03º 12´N and longitude 101º 38´E to 101º 46´E, Kuala Lumpur is a part of Klang Valley with a population of 1.7 million as of 2015 (Alnaimat et al., 2017). Situated on the west coast of Peninsular Malaysia, Kuala Lumpur territory receives a higher rainfall during the southwest monsoon from April to November annually (Saadatkhah et al., 2014). The temperature in Kuala Lumpur remains at a fairly constant 22–33°C all year round, with average annual precipitation of around 2,800 mm (Department of Irrigation and Drainage, 2018). With an average population growth of 2% per year, increasing housing and facilities demand have made developments in hilly areas around Kuala Lumpur. However, slope, drainage, and vegetation are disrupted during these developments, exposing the neighborhood to potential landslide risk (Mahmud et al., 2013). Apart from human factors, the lithology structure of Kuala Lumpur and its surroundings comprised of the pre-existence of a variety of weak zones in granite and ski rocks has led to slope movement (Yusoff et al., 2016).

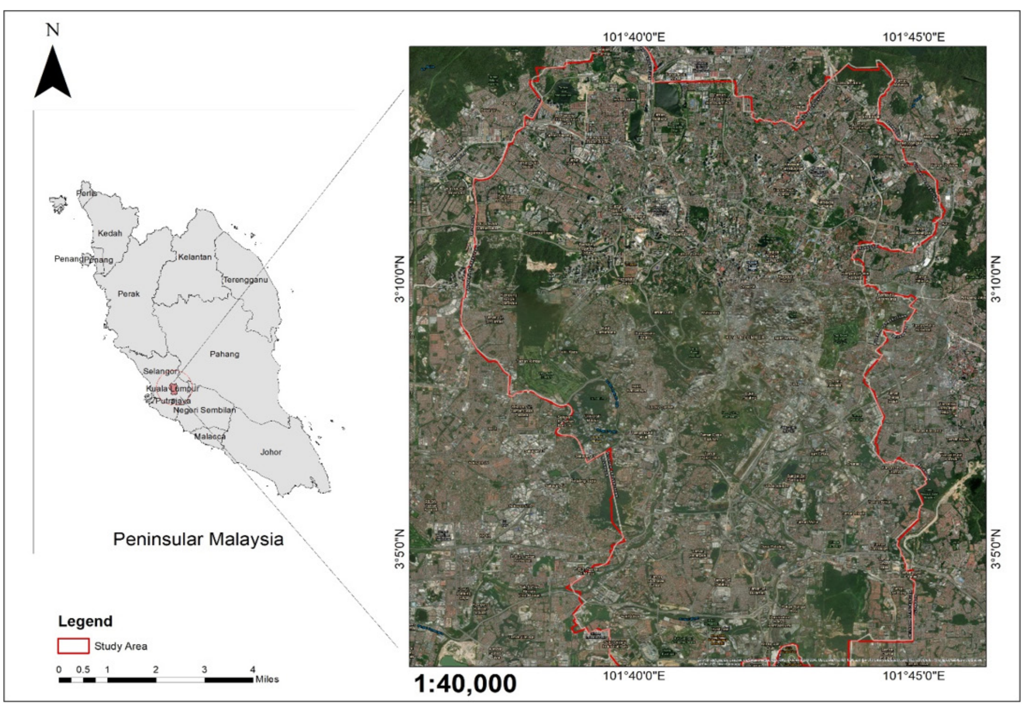

Figure 2. Federal Territory of Kuala Lumpur, Malaysia

Data Acquisition

In many landslide studies, preparing landslide inventory maps is crucial to understanding their previous occurrences and causes in predicting future landslide-susceptible zone. Therefore, a landslide inventory map was constructed with 100 landslide locations identified using the combined findings of previous studies, the interpretation of Google Earth images, and fieldwork validation. According to Zhang et al. (2022), there are no specific rules for choosing landslide characteristics. Thus, based on analysis of the landslide inventory map and the underlying geomorphometric conditions, eight physical characteristics, including roads and highways, stream network, DEM, slope angle, slope aspect, curvature, land use, and lithology were selected as landslide physical factors (Table 1). These physical characteristics were considered based on observation of past landslides and their possible contribution to inducing instability to the slopes in the area (Mahmud et al., 2013; Alnaimat et al., 2017; Ismail & Yaacob, 2018; Rahman et al., 2020). Considering this study's aim and the scale of available data, the landslide incidents were depicted as points in GIS shapefile format and later used to overlap as maps for each physical factor.

Table 1
Dataset based on GIS

Data	Type	Format
Landslides	Points	Vector
Road network	Polyline	Vector
Stream network	Polyline	Vector
Digital elevation model (DEM)	Grid	Raster
Slope angle	Grid	Raster
Curvature	Grid	Raster
Slope aspect	Grid	Raster
Land use	Polygon	Raster
Lithology	Polygon	Raster

Data Processing

Spatial Analysis Using GIS. For the data analysis, most layers in this study were projected in the Kertau RSO coordinate system. A layer of roads and highways in Kuala Lumpur obtained in polyline stretching throughout this territory was processed to produce a physical map with the landslide incidents layer on top. A multiple ring buffer analysis with 125 meters is appointed as the interval distance based on the nearest and farthest landslide locality from the road and equally classified into five equal classes. Furthermore, multiple analyses on different buffer distances were carried out, and 125 meters were deemed the buffer distance for this study. Meanwhile, the same buffer analysis is conducted towards stream characteristics at 500-meter intervals with five equal classes. On the other hand, the stream data layer represents the branches of the stream network and water bodies across Kuala Lumpur. The river network layer was combined with the same landslide distribution layer to generate the physical map in GIS.

A contour map acquired was used to derive a 10-meter DEM resolution using the 3D Analyst extension of ArcMap. DEM is further classified using a natural break of five classes and the slope layer is extracted from DEM from the spatial analyst tool. In 2002, the Department of Minerals and Geoscience Malaysia (JMG) constructed official guidelines on hillside development where slopes are classified into four categories (Class I, II, III, and IV) (Gue & Wong, 2009). Since then, the guidelines have been used in most landslide studies in Malaysia. Class I is determined as the least severe slope angle and ranges below 15° meanwhile Class II is reserved between 15° to 25°. Slopes between 25° to 35° are for Class III and any slope angle greater than 35° is classified as Class IV. Aside from the slope, the curvature values represent the topography's morphology (Rasyid et al., 2016). Curvature is categorized as negative or concave, indicating valleys, zero or flat surfaces, and positive or convex indicating peaks. It is generally related to a surface that can hold more water and retains water from heavy rainfall for a longer period (Lee & Thalib, 2005). The slope aspect is the orientation of a slope between 0° and 360° from the northern direction (Erener & Duzgun, 2010). The slope aspect map is derived from DEM with 1 additional class for flat ground and 9 directional classes: flat (-1°), north (337.5°–360°, 0°–22.5°), northeast (22.5°–67.5°), east (67.5°–112.5°), southeast (112.5°–157.5°), south (157.5°–202.5°), southwest (202.5°–247.5°), west (247.5°–292.5°), and northwest (292.5°–337.5°) and north (337.5°–360°) (Rahmati et al., 2016).

As Kuala Lumpur is a highly developing region, it is essential to observe the land use type in this area and its relation to landslide incidents spatially. Thus, the land use data obtained from Plan Malaysia were analyzed and reclassified into five differentiations: (1) water bodies, (2) forest, (3) built-up, and (4) bare land. Furthermore, based on the provided geological map by the Department of Mineral and Geoscience Malaysia (JMG), lithology is classified into ive different types of soil: (1) acid intrusive (undifferentiated), (2) limestone/marble, (3) mainly sandstone with subordinate shale, mudstone, siltstone, conglomerate, and volcanic, (4) schist and gneiss, and (5) vein quartz. This classification determines the factors and types of soil compositions involved in landslides.

Artificial Neural Network (ANN). ANN can learn and generalize from experience (Mandal & Mondal, 2019). The purpose of ANN is to build a model of the data-generating process so that the network can generalize and predict outputs from inputs that it has not previously seen (Pradhan & Lee, 2009). However, for this study, the ANN method was used to determine the weight of each selected physical characteristic involving a set of training data. In order to determine the weight of the characteristic, another 100 points were generated from ArcMap. This generation is taken into consideration to represent non-landslide events to avoid overfitting issues (Selamat et al., 2022). Hence, a total of 200 points were used in this analysis, randomly separated into 70% training set and 30% for testing.

RESULTS AND DISCUSSIONS

Frequent landslide incidents in Kuala Lumpur can be observed distributed particularly along the west of this city, also known as the Damansara Penchala zone, and in the northwest or the Sentul Menjalara zone according to Kuala Lumpur City Hall Government Agency (Figure 3).

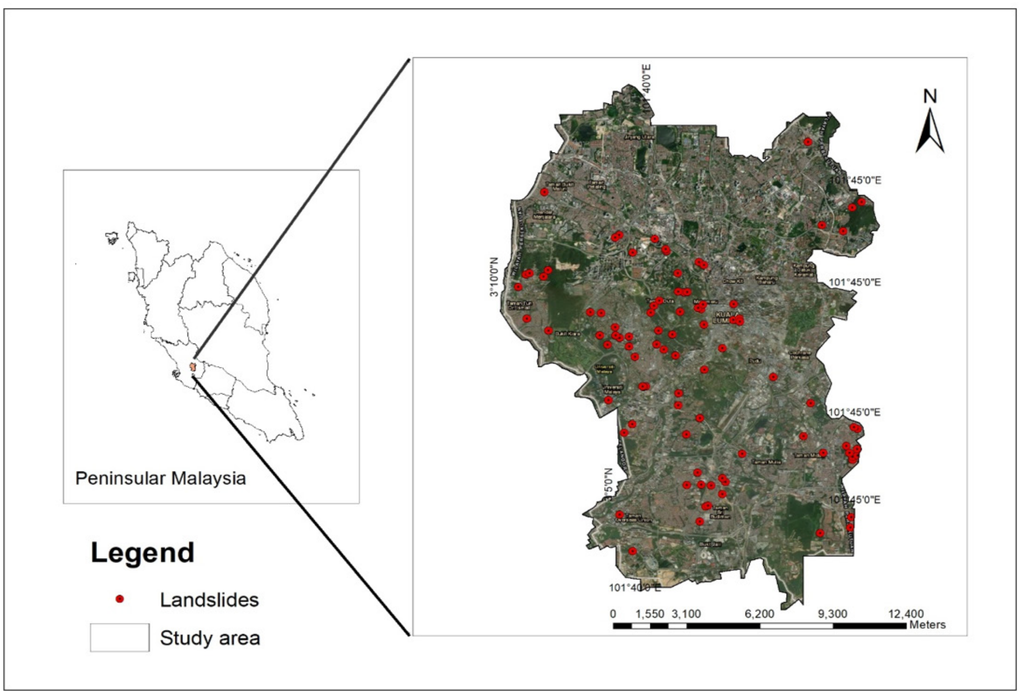

Figure 3. Landslide distribution map

New infrastructure, for instance, highways, road networks, and dams have a significant relationship to landslides in Kuala Lumpur (Department of Irrigation and Drainage, 2018; Hong & Hong, 2016). Therefore, rampant soil reclamation and slope deforestation for urban development can cause unprecedented devastation to ecological sustainability, especially during road construction. In addition, the proximity to the road network is often related to an increase in landslide occurrences, so disturbance zones were created around the road network of the study area (Skilodimou et al., 2018).

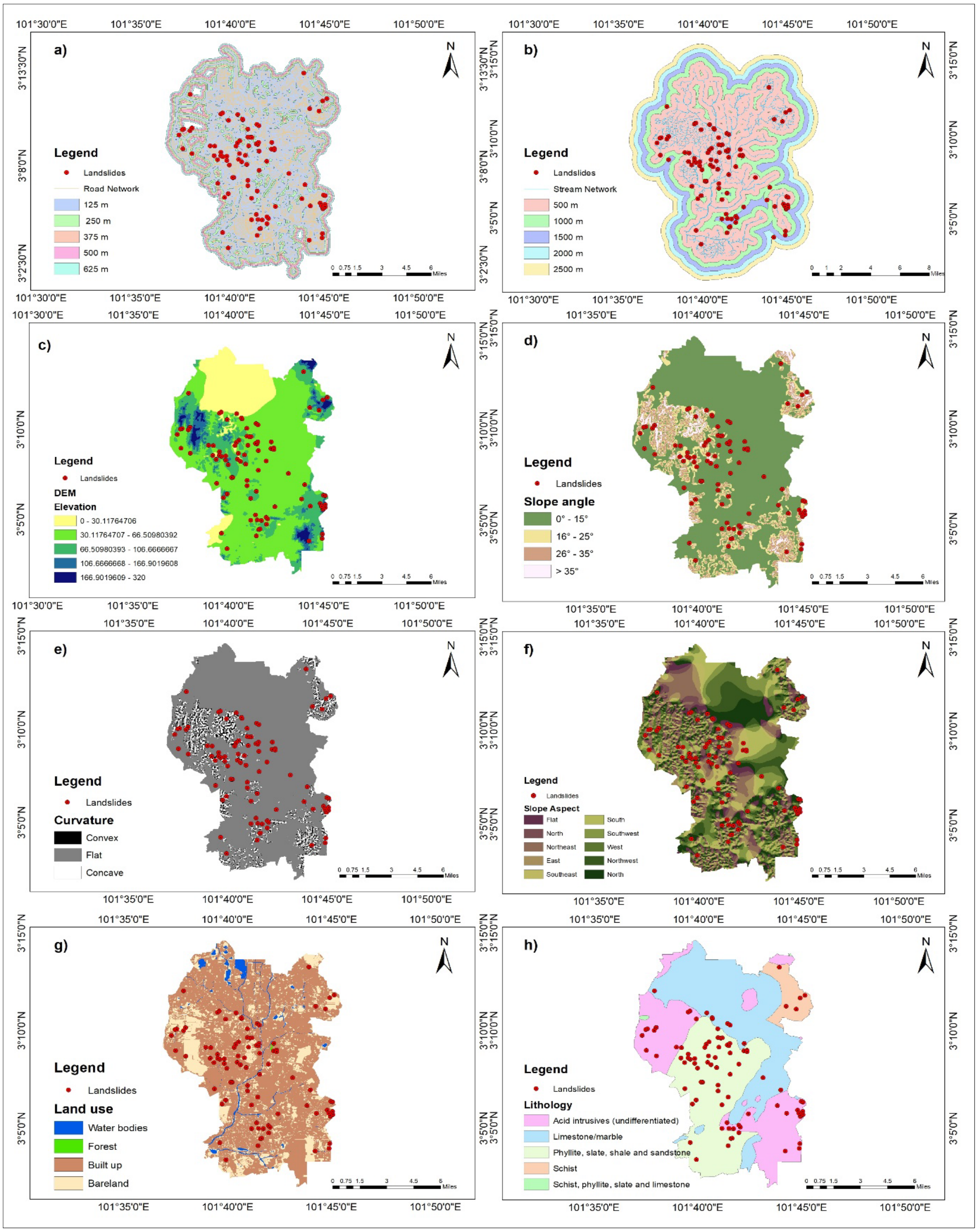

Figure 4. Landslide distribution on physical characteristics: a) distance to road, b) distance to stream, c) DEM, d) slope angle, e) curvature, f) slope aspect, g) land use, h) lithology

Kuala Lumpur is well-known for its complex roads and highways for faster accessibility within the territory. Figure 4(a) shows that most landslides have occurred at road embankments and highways compared to off-roads with a 0 to 250 meters range. These constructions inadvertently cause slope instability and disturb the natural topology. In addition, highways can have the highest percentage of losses during landslides, located in highly hazardous areas. For example, highways in Damansara Penchala zones on the north and west part of Kuala Lumpur with over 10 km experienced frequent landslide occurrences as most highways pass through the high-risk area landslide-prone in that zone (Althuwaynee & Pradhan, 2017). It has demonstrated that unsustainable slope cutting for road constructions influences the changes in gradient flow, leading to slope inclining.

About 120 kilometers long river network flow covering the whole territory, which originated from Besar Range, almost half of the Klang River Basin. It is observed that the Klang River is the mainstream in this city, forking its branch into smaller streams known as the Kerayong river towards the east, the Batu River towards the northwest, the Jinjang river towards the north, and the Gombak River towards the southeast of Kuala Lumpur. Landslide incidents were observed around the Klang River, Kerayong river, and the smaller streams of the Batu River. Figure 4(b) shows that most landslides occurred from the streams' 0–500 meters range. It supports that the distance to the stream is significantly related to landslides as water flow density naturally creates different types of erosion thus, increasing the vulnerability of slope angle (Mahmud et al., 2013).

Furthermore, Kuala Lumpur is surrounded by mountainous topography with the highest peak elevates at more than 300 meters and is often associated with high-rise buildings due to their luxurious viewpoint. Figure 4(c) shows that most landslide incidents took place at 0–106 meters in height. Landslide occurrences in this area were also concentrated in developed areas where human activities have significantly disturbed and altered most slopes. For instance, in 2021, one of the hilly developments known as the Sri Duta 1 residence building experienced a slope failure affecting four blocks and 34 residential units. Damaged columns, surface tension fractures, and floor cracks are all signs of soil movement that surfaced before the landslide event and further quickly declared that the residence is unsafe (Palansamy, 2021). This situation proves that hilly developments will always be at risk of landslides.

However, a slope is considered to have a greater influence on landslides than elevation. Therefore, slope angle has always been recognized as one of the crucial landslide factors by many studies. Generally, the slope indicates the surface's degree of inclination and shows the elevation change rate (Paudel et al., 2016). A slope with a steeper degree of inclination is more susceptible to instability than a gentle slope. In this study, however, most landslides occurred at slope gradients of 0° to 15° (Figure 4(d)) as former mining sites mostly cover this region. This situation explains the rationale for landslide occurrences on flat surfaces in Kuala Lumpur over the past decades (Sanusi et al., 2017). Furthermore, the Kuala Lumpur area is also covered with 92% of slopes ranging between 0° to 15° while the steep slopes only represent 8% area showing landslides that occurred in this area are shallows. In addition, Kuala Lumpur has recorded a notable rise in population growth; thus, development has expanded in the hilly regions. Slope alteration and heavy materials on top of undercutting slopes have also significantly affected slope stability, inducing landslides.

Figure 4(e) shows a landslide distribution map of the curvature layer. The curvature also plays a significant role in landslide occurrences. In this study, it is found that a concave surface that represents negative values is favorable for landslides in Kuala Lumpur. Meanwhile, the convex surface recorded the least number of landslide occurrences. As the slope with a concave surface is in the upward direction, it tends to hold rainfall and infiltrate more water into the slopes, contrasting the convex surface (Lee et al., 2003). On top of that, infiltration forces a slope under a complex stress state as it will be fully saturated with water. It supports that if the negative value increases, the probability of landslide occurrences will increase too. In addition, there is no clear agreement exists in the context of aspects as one of the contributing factors, however, it acts as a geomorphological factor that indirectly triggers landslides occurrences indicating that the slope aspect is an important factor in landslide studies (Erener & Duzgun, 2010; Pawluszek & Borkowski, 2016; Silalahi et al., 2019). Figure 4(f) shows that landslides are concentrated on the Northwest-facing slopes. Following this, landslides are mostly spread from the Northeast-facing to the Northwest-facing slopes. It shows that exposure to sunlight and drying winds could control soil moisture concentration and, in the end, lead to landslide occurrences (Sharir et al., 2017). It indirectly influences the flow of landslide incidents as the direction of the slope face depends on exposure to sunlight, rainfall, evaporation, and vegetation distribution on slopes (Jaafari et al., 2014; Jebur et al., 2014; Wen & Jiang, 2016).

Land use elements in the northwest stretching towards the northeast of Kuala Lumpur are the safest compared with those in the western and southern parts (Figure 4(g)). The highest percentages of affected elements due to landslides were found in urban areas with high populations including residential areas, commercial buildings, industrial buildings, and utility areas (Althuwaynee & Pradhan, 2017). The development of residential buildings on hilltops has expanded dramatically as a result of the depletion of flat land (Gue & Tan, 2003). In the future, this will cause changes in water flow from the highland to the ground. It is also found that landslides are greatly influenced by the lithological properties of the land surface (Dhianaufal et al., 2018).

Moving on to Figure 4(h), which represents lithology appears that landslide events in Kuala Lumpur are scattered mainly on sandstone with subordinate shale, mudstone, siltstone, conglomerate, and volcanic. The weathering of the shale and sandstone from sedimentary rocks of the Kenny Hill formation have metamorphosed into metasediments of schist, quartzite, and phyllite (Sanusi et al., 2017). Lithology profiles of the acid intrusive region, also known as the Kuala Lumpur granite, were observed to have separated largely from the northwest to the southeast. Some parts are surrounded by limestone lithology southwest of this study area. It is also discovered that the same lithology profile can be found in patches in the upper northwest and southeast, and some part of it is surrounded by limestone in the southwest. Landslide incidents on schist and gneiss are the least distributed in southeast Kuala Lumpur. Another large part of the lithology type with landslide incidents reported on it is the area with a limestone profile, locally known as the Kuala Lumpur Limestone. This limestone is characterized by a thin layer of topsoil for vegetation and is comprised of the alluvial soil beneath this region which contained heavy mineral and tin-bearing soil. Frequent quarries on slopes and cliffs in the past few decades to acquire limestone as the main source of construction materials have threatened the stability of its soil layers (Althuwaynee & Pradhan, 2017).

The weight of each landslide is calculated using the ANN approach. A higher-weight factor indicates a higher contribution to landslide occurrences (Ibrahim et al., 2022). Among these landslide physical characteristics, slope angle plays the most significant role in influencing the landslides with a 100% normalized importance value. In contrast, the slope aspect represents the least significant landslide factor (Table 2). According to the expert, gravity is the prime cause of landslides when it overcomes the internal resistance of the rock, soil, or sediment and friction. Hence, a steeper slope combined with other contributing factors is always susceptible to landslides. In addition, rapid developments in hilly areas also significantly induce slope instability (Rahim et al., 2022).

Table 2
The weight of each landslide factor

Independent Variable Importance	
Factors	**Weight of Landslide Factors**
Distance to road	43.30%
Distance to stream	16.00%
DEM	25.90%
Slope aspect	8.30%
Slope angle	100.00%
Curvature	32.40%
Land use	28.70%
Lithology	31.70%

Meanwhile, distance to the road shows the second highest value with 43.3%. Considering that the artificial and natural parts of the slopes around a road network are more sensitive to landslide manifestations, making both slope angle and road network associated strongly with one another. In the meantime, road constructions often cause slope instability as the process often creates cut slopes and inadvertently disturbs the natural topology exposing prone areas to possible landslides.

From this weightage calculation, it is also found that the slope aspect has the least value of significance to landslide. In many studies, the slope aspect is also insignificant to most landslide occurrences as its role in landslide contribution remains unclear (Capitani et al., 2013; Yuri & Andri, 2021). The slope aspect only influenced landslides if they were superficial and in clayey deposits (Capitani et al., 2013). However, the slope aspect can still be used as one of the conditioning factors in landslide studies to understand the role or influence of the slope aspect on landslide occurrences. By implication, it shows the accuracy of the factor weightage results for this study.

CONCLUSION

Landslide occurrences in an urbanized region increase the risk of a high population. This study conducted physical characterizations of landslides in Kuala Lumpur. Landslide mitigation, especially in urban areas, requires critical planning and monitoring. This study found that 18.0% of landslides occurred along the Northwest of Kuala Lumpur, where most of these areas are surrounded by altered slopes. It indicates that the authorities are responsible for constructing an advanced prevention and mitigation procedure as the landslide-prone areas require critical planning and monitoring. In the meantime, a higher slope inclination can contribute to a higher gravity force in pulling materials down the slope, thereby increasing the risk of landslides. Therefore, a proper perspective and a thorough understanding of the certain slope condition have to be established to avoid more landslide occurrences in the future to ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems as stated in the 15th SDG.

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