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Landslide Susceptibility Mapping in NDUM Campus, Kuala Lumpur, Malaysia

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Abstract

Landslides are among the most destructive natural disasters, frequently resulting in significant loss of life as well as property each year, particularly in regions with high elevations and steep slopes. With an advanced technological approach, the integration of geographic information system (GIS) as well as remote sensing has been extensively utilised to identify areas susceptible to landslides, providing crucial insights for disaster preparedness and mitigation. This study aims to create a landslide susceptibility map (LSM) for the National Defence University of Malaysia (NDUM) campus. This study adopted the Analytic Hierarchy Process (AHP) modelled in ArcGIS 10.8 software to integrate five major landslide-induced parameters: slope angle, elevation, drainage density, soil type, and lithology. The slope angle and elevation thematic maps were obtained from the Digital Elevation Model (DEM). Lithology and drainage density data were sourced from Malaysia's Department of Mineral and Geoscience (JMG) as well as the Department of Survey and Mapping, Malaysia (JUPEM). The local soil type was obtained from the NDUM site investigation report. The resulting LSM was classified into five levels of risk zones, with 0.1%, 29.1%, 2.3%, 2.8%, and 65.7% falling under very low risk, low risk, moderate risk, high risk, as well as very high risk, respectively. The LSM was verified with a previously failed slope on the NDUM campus, showcasing good agreement for both methods. The accuracy of the landslide hazard zonation map may be enhanced by integrating additional factors, for instance, land cover, land use, rainfall, as well as other relevant elements.

1. Introduction

Landslides are among Malaysia's most common natural disasters, frequently resulting in significant loss of life and property, particularly in regions with high-elevation and steep terrain. The situation can be worsened by the presence of heavy and prolonged rainfall [1], exacerbating the vulnerability of this landscape. According to the Meteorological Department of Malaysia (METMalaysia), the landslide occurrence between 1993 and 2019 caused more than 100 casualties with an estimated US$1 billion in economic losses. The incidents not only endure the physical consequences of landslides but also face socio-economic impacts, including social pressure on families, land border conflicts, and soil degradation.

Landslide risk analysis is, like many other forms of risk management, an attempt to reduce risk imposed by landslides on humans, property damage, and loss of life. The evolution of landslide risk management includes the construction of protective structures [2], real-time monitoring and early warning systems [3], and mapping areas prone to landslides [4]-[6]. The latter technique, however, has limited databases available in Malaysia [7].

With advanced technological approaches, GIS has been widely used to determine landslide-prone areas due to its capability to manage vast amounts of spatial data, which aids in the decision-making process in several fields. Bera et al. [8] utilised multi-geo-environmental parameters such as lineament density, rainfall distribution map, slope aspect, drainage density, land use/land cover (LULC), geology, as well as soil map to generate landslide hazard mapping in the Namchi region. Menggenang & Samanta [9] employed GIS and remote sensing techniques to estimate landslide hazard and risk assessment. Moreover, the instruments utilised included ArcMap 10, DEM, and LANDSAT 5 TM. Thomas et al. [10] compared the Analytical Hierarchy Process (AHP) and Frequency Ratio (FR) methods for identifying landslide-prone zones. Chimidi et al. [11] conducted landslide evaluation and zonation using secondary data such as topographical maps, geology maps, satellite pictures, DEM, and meteorological data.

This study focuses on utilising GIS to develop a landslide risk map for the NDUM campus since no previous research has been conducted. Covering almost 1.5 km^2 area, the boundary of the NDUM campus excludes the nearby housing area. The resulting LSM will be useful for future development planning within the campus area.

2. Materials and Methods

2.1 Study Area

Fig. 1 illustrates the NDUM campus, which is situated in Sungai Besi province, roughly 12 km south of Kuala Lumpur. The research area is bordered by steep terrain, and the highest elevation is Bukit Gemilang. The increasing demand for facilities like lecture halls, laboratories, and road infrastructure has led to the development of these facilities on hillsides. Few studies have been conducted to assess the cut slope stability constructed within the campus area due to the occurrence of several slope failures after the completion of construction projects [12], highlighting the urgent need for managing landslide risk in the area.

The lithology of the NDUM campus is composed of granite, which makes up most of the bedrock of Sungai Besi. The alluvial deposits consist of loose silty sand and gravel that accumulated during the quaternary period. The average annual temperature is 32°C, with annual precipitation varying between 2,000 and 2,500 mm.

2.2 Data Sourcing and Processing

In this research, spatial data related to the factors influencing landslides were obtained from secondary and digitised sources, such as satellite imagery, geological maps, topographic maps from the United States Geological Survey (USGS), and DEM. Each data source and its format type are tabulated in Table 1.

2.3 Thematic Map Preparation

Different thematic maps were prepared from a variety of sources to demarcate the landslide-prone area. This study leveraged available variables influencing landslides, including slope angle, elevation, drainage, soil type, and lithology. Both the soil type and lithology maps were created based on the results of previous research in the study region [13]. Meanwhile, the drainage, elevation and slope angle are derived by digitising data in ArcGIS 10.8. The methodology for the development of NDUM LSM is shown in Fig. 2. All thematic maps are in raster format, facilitating integration, and spatial analysis was conducted employing the Analytic Hierarchy Process (AHP). This approach assigns specific weights to each thematic layer based on its contribution to landslide risk. By overlaying these thematic maps, a landslide susceptibility map (LSM) is created, categorising areas into different risk levels, from very low to very high.

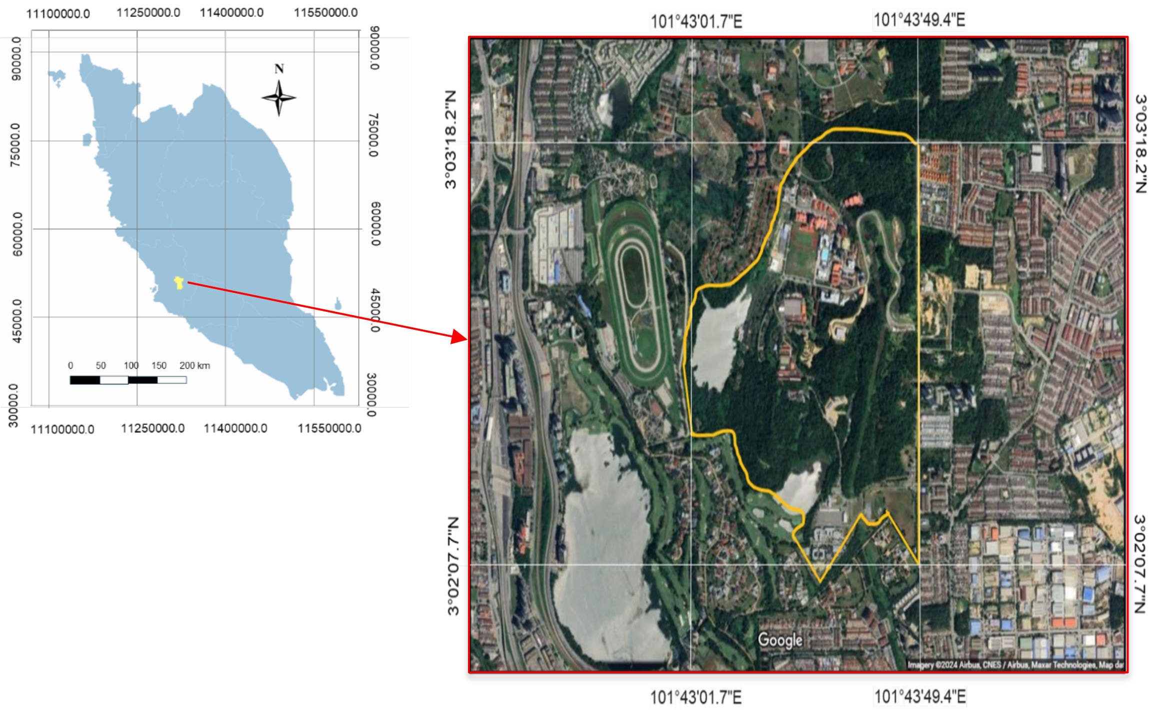

Fig. 1 *Location and area of study*

Table 1 *Data sources and format type*

No	Particulars	GIS data format	Data source
1	Lithology	Raster, Polygon coverage	Department of Mineral and Geoscience, Malaysia (JMG)
2	Slope Angle	Raster, Polygon coverage	DEM Aster data set
3	Elevation	Raster, Polygon coverage	DEM Aster data set
4	Soil	Raster, Polygon coverage	Secondary data - Previous literature
5	Drainage	Raster, Line coverage	Department of Survey and Mapping Malaysia (JUPEM)

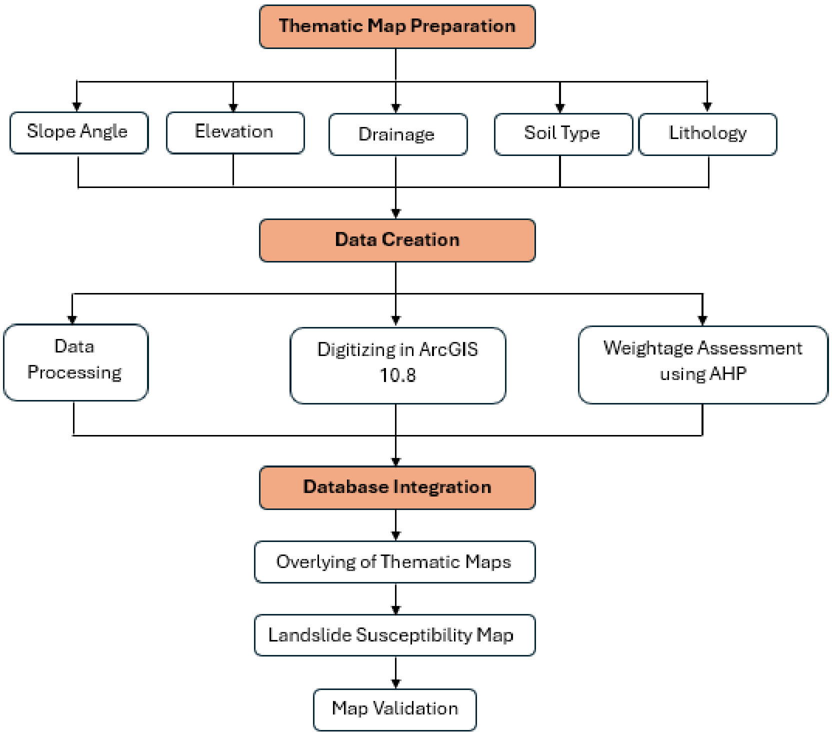

Fig. 2 *Flowchart of study*

3. Results and Discussion

3.1 Slope Angle

Slope angle resembles a substantial factor which contributes to landslides [8]. Steeper slopes are more prone to landslide occurrences. The slope angle map was prepared using a dataset from the DEM. The GIS data raster format and polygon coverage were used as input data in the ArcGIS 10.8 application. The slope angles were categorised into 5 classes, which are (40°-50°) very high, (30°-40°) high, (20°-30°) moderate, (10°-20°) low, as well as (0°-10°) very low. The eastern part of the research area is dominated by moderate to high slope angles (20°-40°), whereas very low to low slopes are located in the western part of the study area. The moderate to high slope angle represents the Bukit Gemilang region. The slope angle map obtained is presented in Fig. 3.

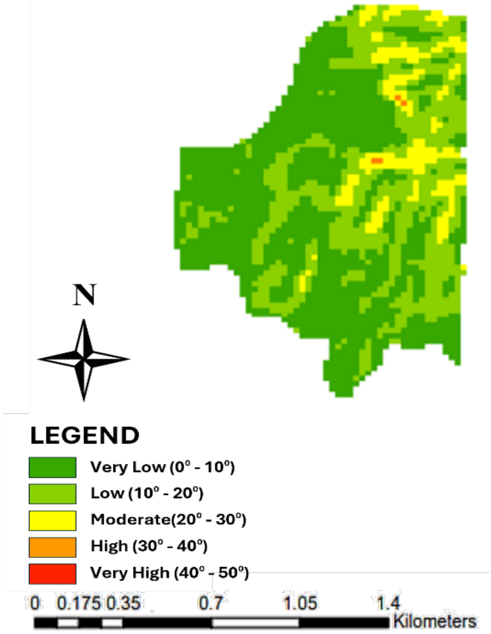

Fig. 3 *Slope angle map*

3.2 Elevation

The elevation of the terrain has a substantial role in identifying areas prone to landslides. Elevated regions are more vulnerable to landslides than flatlands [14]. The map not only depicts landforms like mountains and rivers, but it also depicts fluctuations in land level. Elevation data of the study area is generated from JUPEM and was segregated into five categories, which are very high (141-196) m, high (112-141) m, moderate (89- 112) m, low (70-89) m and very low (41-70) m. The data was then processed using the ArcGIS application, and its spatial reference was adjusted according to the 1984 WGS to produce an elevation map, as illustrated in Fig. 4. The highest point of the NDUM campus is located at the peak of Bukit Gemilang, approximately 196 m above sea level, whereas the lowest point is 41 m.

3.3 Drainage

Drainage density is a key aspect of landslide management since it determines the composition of the soil and its geotechnical qualities [15]. The process of infiltration and drainage density is inversely connected. The most significant single factor in landslide initiation is poor drainage. In this study, the drainage system is delineated in ArcGIS to develop a drainage topographic map, which is segregated into five categories, for example, very low, very high, low moderate as well as high. The water movement is from the highest areas of Bukit Gemilang to the lowest areas where the lake exists. All areas with drainage have been delineated, including the upper and lower-density regions (see Fig. 5).

3.4 Soil Type

According to Dauren et al. [16], soil composition has a significant relation to landslide risk. Soil composition that has a clay content of more than 2.5% is prone to failure. Soil of the NDUM campus area is mainly composed of residual soil, which consists of clay 13%, silt 33%, sand 42%, and gravel 12% [12]. Based on the British Standard, the soil is classified as sandy silt. The preparation of soil maps is based on data available in the previous studies. The thematic soil type map is shown in Fig. 6.

3.5 Lithology

The bedrock of the NDUM campus is dominated by acid-intrusive rock, i.e., granite, which features medium-grained muscovite that occasionally contains tourmaline. Other than that, the residual soil originates mainly from the granitic rock weathering and typically consists of silty sand as well as sandy silt with traces of gravel deposits from the Quaternary period. According to Sulaiman et al. [17], acid-intrusive rock is susceptible to landslides due to fractures, shear zones, and discontinuities. The lithology map of the NDUM campus was obtained from the JMG, as illustrated in Fig. 7.

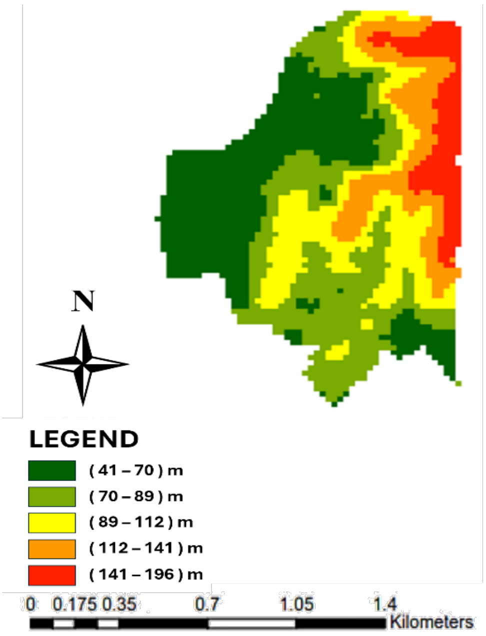

Fig. 4 *Elevation map*

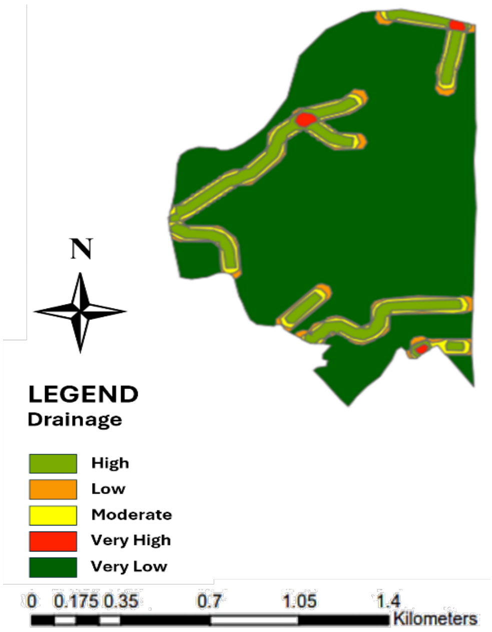

Fig. 5 *Drainage map*

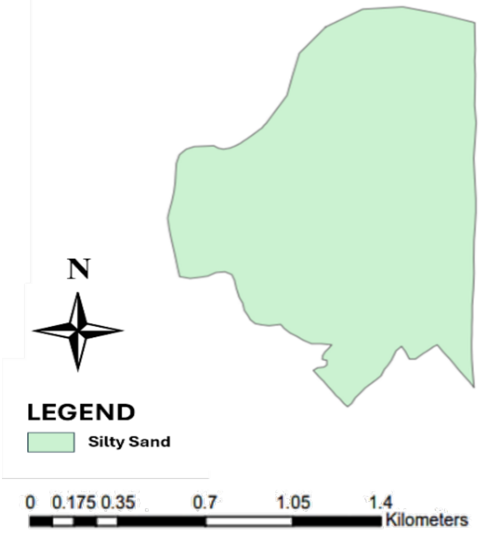

Fig. 6 *Soil-type map*

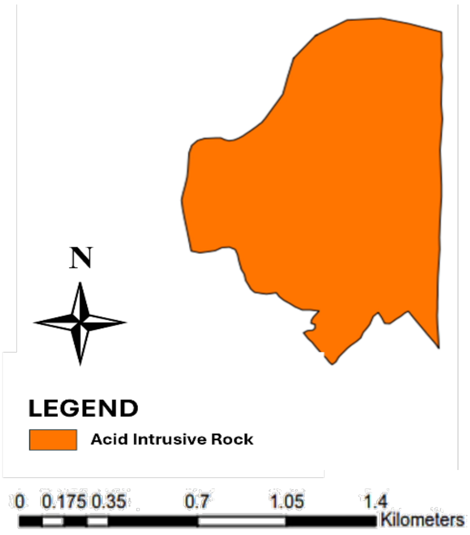

Fig. 7 *Lithology map*

3.6 Analysis Data Using The Analytical Hierarchy Process (AHP)

The AHP is employed to identify the scaling values as well as the weightage of each thematic layer. Subclasses have been allocated to the relative rating values for each thematic tier based on their causative factors influencing landslides. The categories of different thematic layers are also assigned ratings on a scale ranging from 1 to 5, with a higher rating value indicating a greater risk of landslides. All thematic maps were saved in raster format. The final landslide risk map was generated through a spatial overlay analysis of the thematic layers. The AHP serves as a powerful method for evaluating multiclass maps by considering the relative significance of each thematic layer and its corresponding classes. Hence, utilising Eq. (1), the components were integrated and summarised to produce an LSM.

$$\begin{aligned}\text{LSM} = (0.44\times \mathit{Slp}) + (0.22\times \mathit{Elev}) + (0.15\times \mathit{Drn}) + (0.11\times \mathit{Soil}) \\ +(0.08\times \mathit{Litho})\end{aligned} \tag{1}$$

where *Slp* = Slope angle, *Elev* = Elevation, *Drn* = Drainage density, *Soil* = Soil type, and *Litho* = Lithology.

3.7 Weightage Assessment

The weightage assessment in the AHP model was tabulated in Table 2 based on a previous study by Menggenang et al. [9]. The AHP comparison matrix has an equal number of rows and columns. Moreover, scores are entered on one side of the diagonal, while the diagonal itself is filled with ones. To construct the pairwise comparison matrix, each criterion was evaluated relative to every other criterion using a dominance scale from 1 to 5 [18]. The weighted values for each criterion were then derived from the AHP pairwise comparison matrix (see Table 3).

Table 2 *Landslide hazard weights value and rating system of different layers of thematic maps*

Factors	Weight	Rank	Rating
(i) Slope Angle			
Very Low	44	1	44
Low		1	44
Moderate		2	88
High		3	132
Very High		4	176
(ii) Elevation			
41-70	22	1	22
70-89		1	22
89-112		2	44
112-141		2	44
141-196		4	88
(iii) Drainage			
Very Low	15	1	15
Low		2	30
Moderate		3	45
High		4	60
Very High		5	75
(iv) Soil			
Silty Sand	11	4	44
(v) Lithology			
Acid Intrusive	8	4	32

Table 3 *Pairwise comparison matrix, factors, and weights of the data for the thematic layers*

Factors	Slope Angle	Elevation	Drainage	Soil	Lithology	Weights
Slope Angle	5	4	3	2	1	0.44
Elevation	5/2	4/2	3/2	2/2	1/2	0.22
Drainage	5/3	4/3	3/3	2/3	1/3	0.15
Soil	5/4	4/4	3/4	2/4	1/4	0.11
Lithology	5/5	4/4	3/5	2/5	1/5	0.08
					Total	1

3.8 Landslide Susceptibility Map (LSM)

The lithology component received the lowest weightage percentage of 8% due to its diminished value in the ranking evaluation. It is followed by two more characteristics (soil and drainage), each with a weightage percentage of 11% and 15%, respectively. Slope angle and elevation, on the other hand, are highly ranked, accounting for 44% and 22% of the total weightage, respectively.

The resulting landslide risk map is classified into 5 categories: very high, high, moderate, low, as well as very low (as shown in Fig. 8). A very high landslide risk zone is approximately 65.7% of the total NDUM campus area, which covers most of the Bukit Gemilang. The area has a moderate to high steep slope and is located at a high elevation, thus contributing to the risk of landslides. The high landslide risk zone covers about 2.8% of some parts of the NDUM area, such as the NDUM garage and Royal Military College (RMC). About 2.3% of areas are classified as moderate risk zones, including accommodation areas at the former RMC block and nearby forest areas. The low landslide risk zone encompasses a small portion of the remainder of the land, accounting for 29% of the total area. The area has a very low to low slope angle and elevation, which contributes to a low risk of landslide.

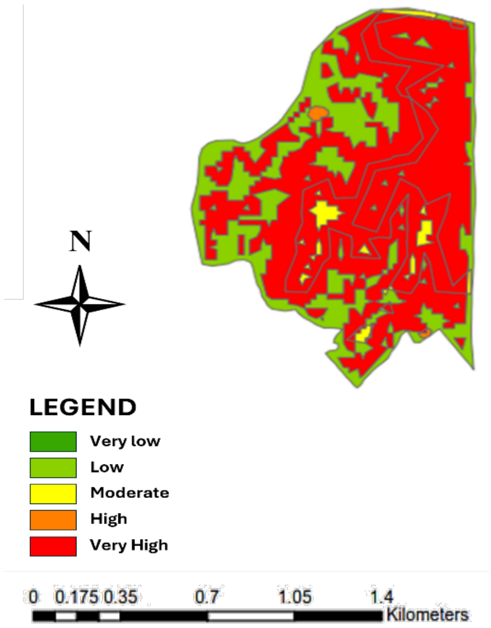

Fig. 8 *NDUM Landslide susceptibility map*

3.9 Verification of NDUM Landslide Susceptibility Map (LSM)

The precision of the resulting LSM was evaluated based on a field survey and by comparing the actual landslide site on the NDUM campus. There were three landslide incidents delineated based on their sizes, where two were located at very high-risk zones (3.5×10^{-4} km^2) and one at low-risk zones (2×10^{-5} km^2), as illustrated in Fig. 9.

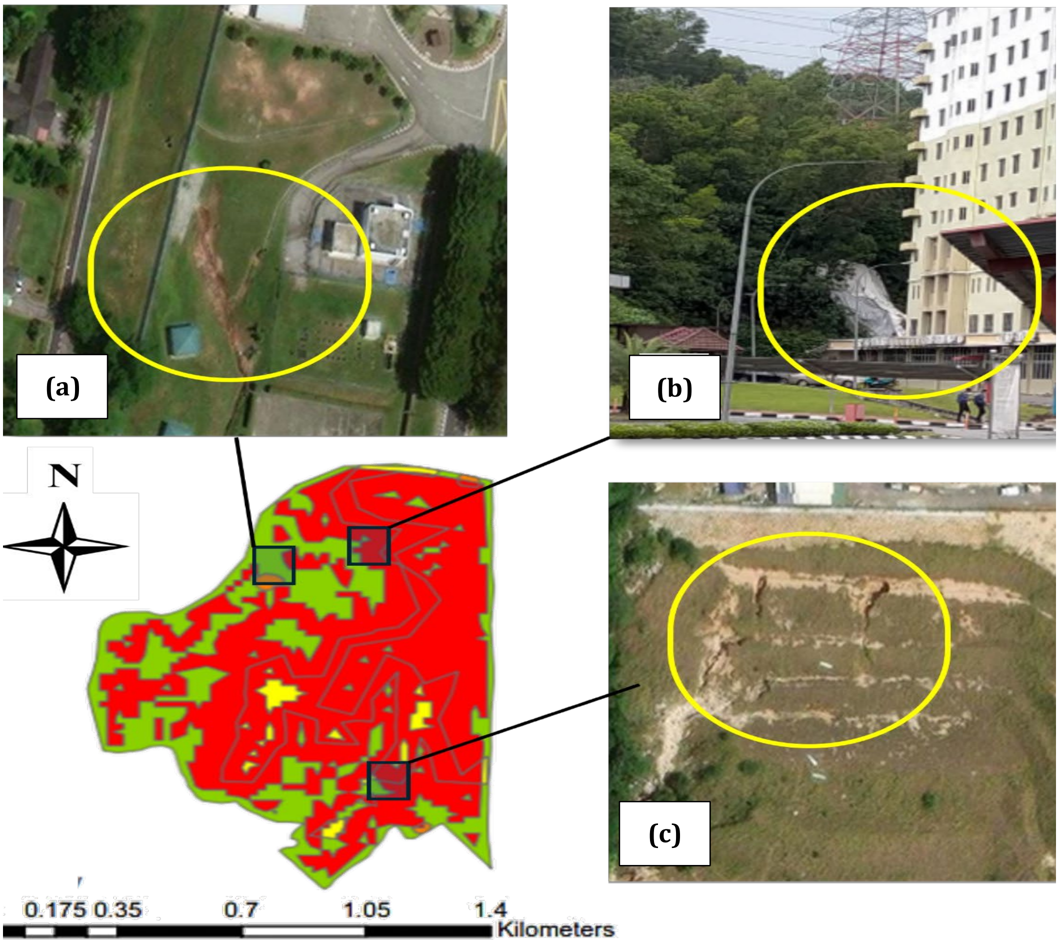

Fig. 9 *Locations of previously failed slopes: (a) Located in the low-risk zone; (b) and (c) Located in the very high-risk zone*

The relative distribution of landslide risk zones (in percentages) and the corresponding frequency of landslide incidents (in percentages) is shown in Fig.10. The very high-risk landslide zone encompasses 65.7% of the total study area but accounts for only about 0.04% of landslide occurrences. In contrast, the low-risk landslide zone, covering 29% of the area, has a landslide frequency of approximately 0.007%. The LSM agreed well with the field survey in prospecting the probable area of landslides. The accuracy with respect to the landslide hazard zonation map may be enhanced by integrating additional factors, such as land cover or land use, rainfall, as well as other relevant elements.

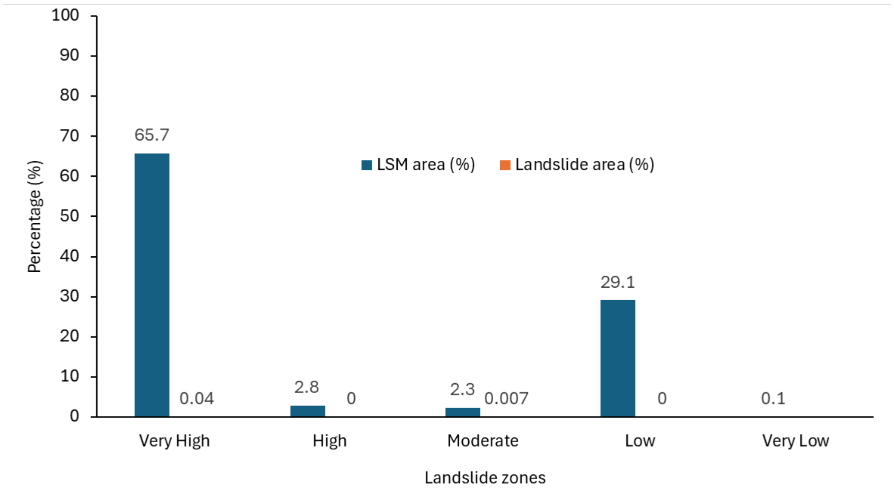

Fig. 10 *Distribution of distinct risk zones and landslide incidents within each zone*

4. Conclusion

Utilising modern geospatial techniques for landslide assessment and mapping saves time and resources. The purpose of this article is to develop the LSM for the NDUM campus. Slope angle, height, drainage, and lithology were among the most essential characteristics influencing landslides. The resulting LSM was classified into five zones, with 0.1%, 29.1%, 2.3%, 2.8%, and 65.7% of the study area falling under very high potential, high potential, moderate potential, low potential, and very low potential, respectively. Two factors play the highest role in contributing to the landslide risk zone: elevation as well as slope angle. The LSM was verified with a previously failed slope on the NDUM campus, showcasing good agreement for both methods. Nevertheless, the accuracy with respect to the landslide hazard zonation map may be enhanced by incorporating additional factors such as land cover, rainfall, land use, as well as other relevant elements.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design****: Jestin Jelani, Nik Muhammad Iqbal Hakimi Safaruddin & Wan Mohamed Syafuan Wan Mohamed Sabri;* ***Data collection****: Nik Muhammad Iqbal Hakimi Safaruddin, Jestin Jelani & Nordila Ahmad;* ***Analysis and interpretation of results****: Jestin Jelani, Wan Mohamed Syafuan Wan Mohamed Sabri & Zuliziana Suif;* ***Draft manuscript preparation****: Nik Muhammad Iqbal Hakimi Safaruddin, Jestin Jelani & Rusnardi Rahmat Putra. All authors reviewed the results and approved the final version of the manuscript.*

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