ASSESSMENT OF LANDSLIDE VULNERABILITY REGARDING TNB ASSETS IN BUKIT ANTARABANGSA

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ABSTRACT

The assessment of vulnerability to landslides is crucial for effective risk management, especially for infrastructure and human lives. This study aims to evaluate the vulnerability of landslides toward Tenaga Nasional Berhad (TNB) assets in Bukit Antarabangsa, an area known for susceptibility to slope and landslide failures. The TNB assets include substations and pylon towers. Substations were selected based on their proximity to slopes and a landslide inventory within a 50-meter distance. The study uses an Indicator-Based Method (IBM) to quantify the vulnerability level, allowing for a systematic and comprehensive analysis. The IBM involves selecting and assessing key indicators that reflect the physical aspects of vulnerability. These indicators are grouped into clusters, each corresponding to specific indicators and sub-indicators, and then integrated into a geospatial model for the vulnerability assessment. The Bukit Antarabangsa assessment revealed that the Athenaeum Condo substation exhibits very high vulnerability to landslides, while the entire pylon tower generally demonstrates a lower vulnerability level. This assessment provides TNB with critical information to make informed decisions, implement mitigation measures, and prioritize actions to minimize potential risks and maintain service reliability. The study's significance lies in its valuable contribution to infrastructure safety against landslides, safeguarding communities, and ensuring the continuity of essential utilities during natural disasters.

Keywords: *Landslide, Indicator-Based Method, Tenaga Nasional Berhad, Bukit Antarabangsa, Vulnerability map*

INTRODUCTION

Landslides are natural disasters that often occur in Malaysia that have a high impact on life in the area, especially humans (Mafigiri et al., 2022). It can affect the property economy, and the most worrying factor is the loss of life (Akter et al., 2019). Landslide refers to the sudden or gradual movement of rocks, debris and earth down a slope, driven by gravity (Sahrul et al., 2021). These landslides are often repeated and occur in areas with high topography, areas with groundwater movement, or frequent earthquakes and volcanoes. Large-scale landslides can profoundly affect humans and the surrounding environment and potentially reoccur if not addressed (Ali et al., 2020).

Based on a previous study that between 1961 and November 2022, Malaysia recorded many occurrences of landslides with a record number of 31 landslide hotspots identified by the Ministry of Energy and Natural Resources (KeTSA) through a study by the Department of Minerals and Geosciences Malaysia (JMG). Among the famous landslide hotspot areas that are consistently monitored by the authorities are Pahang (Cameron Highlands, Bukit Fraser), Selangor (Bukit Antarabangsa, Hulu Langat, Kuala Kubu Bharu), Kedah (Gun Jerai, Baling), Penang (Tanjung Bungah, Paya Terubong), Negeri Sembilan (Genting Peras, Jalan Seremban-Simpang Pertang), Perak (Ipoh, Kledang), Terengganu (Aring-Kuala Berang-Kenyir), Kelantan (Lojing Gua Musang), Johor (Gun Pulai), Sarawak (Miri, Kapit, Bau), and Sabah (Kota Kinabalu, Kundasang) Malaysia (Ibrahim, 2022). On December 6, 2008, a landslide occurred unexpectedly in Bukit Antarabangsa, which resulted in the death of five victims and the destruction of fourteen bungalows in the area. The evacuation of about 2000 residents was simultaneously carried out in the area to avoid further destruction (Kazmi et al., 2017).

According to the Global Assessment Report on Disaster Risk Reduction (2009), India is the country's most vulnerable to landslides, followed by Indonesia, China, the Philippines, Japan, and Taiwan. More than 90% of all landslides reported worldwide have occurred in developing countries (Moayedi et al., 2020). In Malaysia, Bukit Antarabangsa is an area prone to landslides and is located near Kuala Lumpur. This urban area is considered highly vulnerable to landslides (Kamarudin et al., 2022). In year 2008, a landslide occurred in Bukit Antarabangsa due to the movement of underground water.

The Ampang Jaya Municipal Council (MPAJ) in Ulu Kelang, Malaysia, attributed the 2008 Bukit Antarabangsa landslide to a leaking water pipeline near Jalan Wangsa 11, close to the landslide area (Kazmi et al., 2017). This leakage led to an increase in soil pore water pressure and reduced the slope's ability to withstand the surcharge load (Kazmi et al., 2017). Inadequate maintenance of internal drainage systems and retaining structures can contribute to landslides (Lee et al., 2014). They concluded that most landslides in the area are due to inadequate design of retaining structures and slopes (Lee et al., 2014).

Additionally, the structural integrity of buildings is important for their resilience against natural disasters such as landslides (Singh et al., 2019). According to Alexoudi et al. (2010), buildings and infrastructure are important elements at risk in the vulnerability of landslides. Landslides can cause significant damage to these structures, leading to collapse, cracking, displacement, potential injury, and financial loss (Tao et al., 2022). For this reason, a comprehensive study was conducted to identify potential landslide areas and mitigate the risk, particularly in heavily populated regions. Nevertheless, most previous studies have focused on the vulnerability of residential and industrial areas, while neglecting to examine the vulnerability of essential assets related to electricity, which are critical resources for life on earth. Landslides can also impact critical assets essential for daily community functions, such as electricity substations owned by Tenaga Nasional Berhad (TNB), Malaysia's main electricity utility company.

TNB's assets in areas prone to landslides, such as electric substations, compact substations, electric poles, and overhead or underground electric wires, are highly vulnerable to destruction in the event of a landslide. This destruction can disrupt the electricity supply, leading to economic losses. Furthermore, there are electrical substations constructed before assessing potential landslide areas, which makes it challenging to relocate the assets to safer locations. The relocation would undoubtedly involve significant costs and time. Nonetheless, it is essential to address the issue of landslide expansion. One of effective way to address the issues in by identifying the vulnerability of assets to landslides is a crucial step in mitigating the damage to vital assets like electricity supply.

Therefore, the aim of this research is to assess the vulnerability of TNB's assets in Bukit Antarabangsa and provide important information to the local community. The assessment will include TNB substations and mast towers that could be affected by landslides. The objectives of the study are to identify the at-risk elements associated with TNB's assets, determine the physical vulnerability of these assets to landslides, and develop landslide vulnerability models. The research will result in the production of a vulnerability map, which will visually depict areas particularly susceptible to landslides. This will help raise awareness among the local community about potential risks.

The vulnerability maps can be used for land use planning, emergency preparedness, and risk reduction strategies. They will be useful not only to TNB but also to residents, local authorities, and other stakeholders, empowering them to make informed decisions to enhance safety and resilience in the face of landslide hazards. This study uses the Indicator Based Method (IBM) as the main approach to assess the vulnerability of TNB's assets in Bukit Antarabangsa to landslides. The IBM involves identifying and analyzing relevant indicators to calculate vulnerability levels. This approach consists of different phases, including indicator selection, scoring or weighting, data collection, processing, analysis, and score aggregation.

MATERIALS AND METHODS

Study Area

The study area encompasses the jurisdiction of the Bukit Antarabangsa State Legislative Assembly, stretching from the northern border of Ukay Perdana to Taman Dato Ahmad Razali and Bandar Baru Ampang in the south. Bukit Antarabangsa is situated in the Hulu Kelang district, Selangor, with coordinates of 30°12'00N latitude and 101°46'01E longitude, which has been selected as the study area. Figure 1 illustrates the study area in Bukit Antarabangsa. However, it's important to note that the scale used in this representation may not accurately reflect real-world distances. This area was selected as a study area due to the frequent occurrence of landslides, which necessitates a more thorough investigation. As a result, this study aims to assess the vulnerability of TNB's assets in the area to landslides.

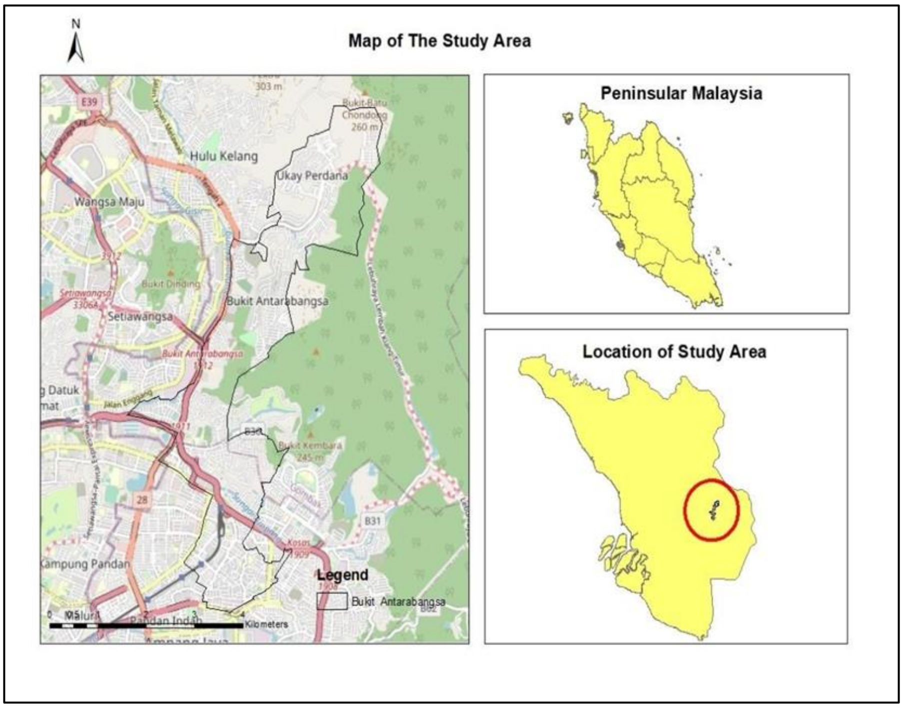


Figure 1: Map of Bukit Antarabangsa, Selangor, Malaysia.

Bukit Antarabangsa is a well-known upscale residential area in Malaysia, situated in the state of Selangor, specifically in the Hulu Kelang district (Gonzalez et al., 2016). Renowned for its upscale properties and scenic views, the area is perched on a hill and surrounded by lush green forests, making it a popular destination for nature lovers. It's important to note, however, that Bukit Antarabangsa is prone to landslides. In 2008, a landslide caused several deaths and the displacement of many residents due to heavy rainfall and the failure of a retaining wall on a hill slope, which led to the collapse of several houses (Kazmi et al., 2017). Various studies have since been conducted to understand the causes of landslides in Bukit Antarabangsa.

Methods

In this chapter, we will discuss the procedures involved in conducting the project. There are three main phases: data collection, data pre-processing, and data processing to create the vulnerability map. The study uses IBM, starting with clustering and identifying indicators and sub-indicators. This is followed by field observations, establishing weights, calculating vulnerability, creating an index, generating a vulnerability map, and conducting validation analysis. Figure 2 shows a step-by-step approach with a flowchart diagram, which gives a detailed representation of the operational flow for each phase.

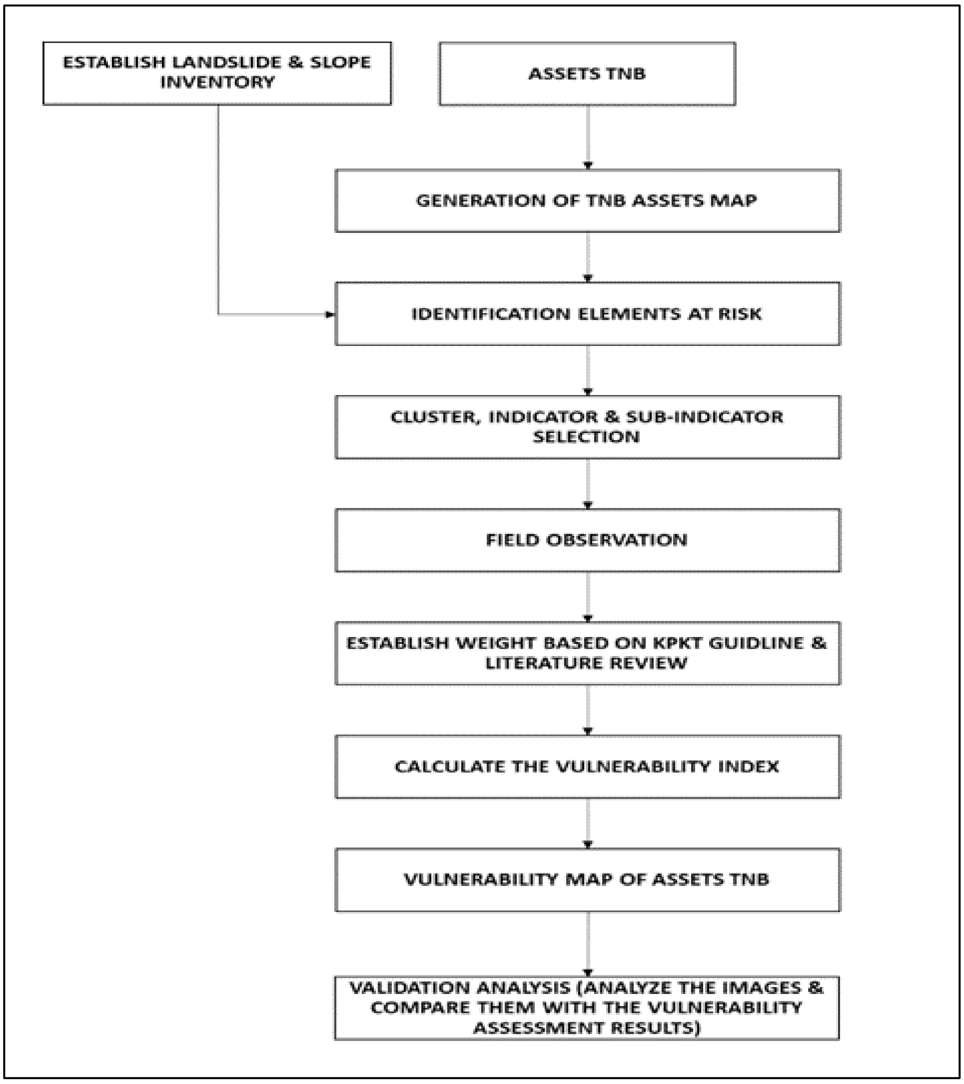


Figure 2: Flowchart of Methodology

Data collection

Data scoping is a crucial aspect of data management as it ensures that the data used in the project is relevant, accurate, and meets the requirements. It is important to have accurate and authentic data before initiating a new research project as it allows for obtaining and measuring information based on the study. The data includes primary and secondary data required for the study. Table 1 depicts the data and analysis requirements for this study. The study collected primary data through detailed field observations carried out in Bukit Antarabangsa. This involved visiting the site in person to confirm and evaluate the factors that pose a risk to TNB's assets. Additionally, secondary data on TNB assets (such as location, geometric attributes, etc.) was obtained directly from TNB. Furthermore, secondary data used in this study includes a topographical map from MPAJ and a landslide inventory from JMG.

Table 1: Data type, data information and source

Type of data	Data information	Source
Electricity substation TNB	Data of assets TNB about location and geometric features.	TNB
	Validating the elements at risk	Field observation
Pylon tower TNB	Obtain the locations of pylon towers	Field survey
	Validating the elements at risk	
Slope inventory	Type of slope, location, shape, height, type, material, drainage, protection.	Mineral and Geoscience Department (JMG)
Landslide inventory	Type of shape, location, accumulation height.	Mineral and Geoscience Department (JMG)

Data Pre-Processing

Data preprocessing is essential for extracting, reducing, and integrating information into the proper form. It involves updating the asset categories based on the asset type list. In this study, data preprocessing includes updating asset categories such as substations and pylon towers before assets TNB are created. The asset type may be updated in the Geodatabase using ArcGIS software. Processing is critical in this step to extract the information appropriately. A good processing technique will produce better outcomes. The method involves the extraction of assets with slope and landslide inventory, generating TNB assets map, and identifying elements at risk before conducting the IBM assessment.

Identification Element at Risk

The practice of in situ element at risk verification involves observing a specific element at risk, such as a structure, in its actual location to determine its susceptibility or vulnerability to potential dangers. Visual inspections may be conducted to gather information about the building's materials, construction, and structural integrity. During this process, relevant indicators for the vulnerability assessment will be chosen. Selecting these indicators is a crucial step in the assessment of vulnerability.

It entails identifying indicators that are pertinent to the vulnerability assessment and capture the key factors influencing vulnerability. By taking these indicators into account, the assessment aims to provide a comprehensive evaluation of vulnerability that considers various factors affecting a region's susceptibility to landslides. Tables 2 and 3 below display the clusters, indicators, and sub-indicators utilized.

Table 2: The building cluster, indicators and sub-indicators

CLUSTER	INDICATORS	SUB-INDICATORS
Susceptibility of Assets	Building type	Indoor substation
		Outdoor substation
	Foundation building	Deep foundation (pile)
		Shallow foundation (pad footing)
	Maintenance	Excellent
		Good
		Bad
	Construction characteristics	Attached (Single chamber/ Double chamber)
		Stand-alone (Single chamber/ Double chamber)
	Number of floors	Single storey
		Medium building (2-5 storeys)
		High-rise building (>5 storeys)
	Quality of construction	Low
		Medium
		High
Surrounding environment	Distance between assets	(>5 meter)
		(3-5 meter)
		(<3 meter)
	Asset's location	Located at a distance more than height of slope
		Located at distance within height of slope
		Located at the toe of slope
		Located at the crest of slope
		Located at the mid-height of slope
	Vertical configuration	Irregular
		Regular
	Horizontal configuration	Irregular
		Regular
	Surrounding wall of building	No/low surrounding wall
		Medium wall
		Strong high wall
Landslide intensity	Accumulation height	(< 0.2 meter)
		0.2 meter – 0.5 meter
		0.5 meter- 2.0 meter
		(> 2.0 meter)
	Landslide volume	(< 500 meter^3)

		500- 10,000 meter^3
		10,000-50,000 meter^3
		50,000- 250,000 meter^3
		(> 250,000 meter^3)
TNB electricity	Capacity of assets	6.6kv
		11kv
		22kv
	Land expansion	14.6m x 14.63 m
		13.6m x 14.63 m
		9.0 x 11.0 m
	Building size	10.67 m x 5.72 m
		7.67 m x 5.72 m
		2.5m x 2.5m
	Transformer capability	0kVA
		500kVA
		750KVa
		1000kVA
		2000kVA

Table 3: The pylon tower cluster, indicators and sub-indicators

CLUSTER	INDICATORS	SUB- INDICATORS
Infrastructure	Foundation	Deep foundation (pile)
		Shallow foundation (pad footing)
	Capacity of assets	Telco tower
		Substation 33KV
		PMU
		GRID 500KV (Height 46-67 meter) (Width 10.5 -19 meter)
		GRID 275KV (Height 34 meter) (Width 7.5 meter)
		GRID 132KV (Height 29 meter) (Width 5.7 meter)
		Hybrid tower (Combination of KV)
	Tower material	Wood
		Steel
		Composite
Surrounding environment	Environment	Normal
		Jungle
		Industries
		Farm
		Coastal
	Slope morphology	Concave
		Convex
		Straight
	Warning system	Yes
		No
Landslide intensity	Accumulation height	(< 0.2 meter)
		0.2 meter – 0.5 meter
		0.5 meter- 2.0 meter
		(> 2.0 meter)
	Landslide volume	(< 500 meter^3)
		500- 10,000 meter^3
		10,000-50,000 meter^3
		50,000 - 250,000 meter^3
		(> 250,000 meter^3)

Field observation

In Figure 3, a picture taken during field observation is shown. The researchers conducted field observation in Bukit Antarabangsa, using Google Earth Pro to analyze slope conditions and assess the inventory of landslides in the area. They collected data during the observation and stored it using the survey123.arcgis.com application, which allowed them to input data for each indicator and sub-indicator related to the study. Additionally, they took photographs for validation purposes, ensuring the accuracy and reliability of the collected data. These photographs serve as important visual documentation to verify the findings and conclusions of the study.

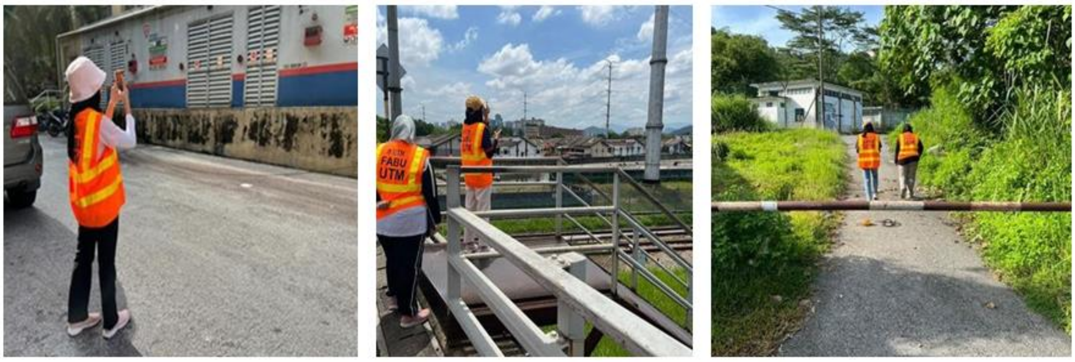


Figure 3: Picture during field observation

Establish Weight Based on KPKT Guideline and Literature Review

A weightage scheme for each indicator was developed based on guidelines from the Ministry of Housing and Local Government (KPKT) and a thorough review of relevant literature. This weightage system was then applied to calculate individual scores for each indicator.

Assessing Vulnerability Using Indicator-Based Method (IBM)

The method used is the same as the one employed in KPKT (2022), which concerns the guidelines for vulnerability assessment and landslide risk in critical infrastructure in Malaysia. This method is semi-quantitative and is known as IBM (Integrated Vulnerability Methodology). IBM helps in evaluating the interactions between landslide events and TNB assets. The main goal of these guidelines is to reduce the risk of landslides in critical public infrastructure in Malaysia. IBM involves selecting relevant indicators, aggregating data, and deriving a quantitative index. Using a semi-quantitative standardization method, the weight of each indicator is evaluated to determine vulnerability or risk. IBM enables the assessment of interactions between Malaysian public infrastructure and landslide events.

Calculate the Vulnerability and Establish Vulnerability Index

To calculate the vulnerability index, combine the scores and convert them into a numerical representation, typically ranging from 0 to 1. Higher values on the vulnerability index indicate a greater level of vulnerability or susceptibility, while lower values represent a lower level of vulnerability. The Vulnerability Index is derived through a comprehensive process that incorporates both tool classification and findings. Based on previous research, vulnerability index scores are classified into five categories, indicating varying levels of vulnerability: very low, low, moderate, high, and very high. To quantify these levels, each category is assigned a corresponding score ranging from 0 (representing low vulnerability) to 1 (representing high vulnerability). Table 4 outlines the specific scores for each response, organized into score ranges of 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0 (Harmoko et al., 2020).

Table 4: Vulnerability index (Harmoko et al., 2020)

Range	Vulnerability Classes	Symbols
0.0-0.2	Very Low Vulnerable	VLV
0.2-0.4	Low Vulnerable	LV
0.4-0.6	Moderate Vulnerable	MV
0.6-0.8	High Vulnerable	HV
0.8-1.0	Very High Vulnerable	VHV

Vulnerability Map

A vulnerability map is a visual representation of the levels of vulnerability in a specific area. It shows the spatial distribution of vulnerabilities based on various indicators and factors assessed during a vulnerability assessment. The vulnerability map is a useful tool for decision-making, risk assessment, and land-use planning. It helps stakeholders, such as TNB and local authorities, identify priority areas requiring attention and resources to mitigate landslide risks.

Additionally, other vulnerability maps are targeting different outcomes. The next map relates to the two highest clusters, considering all values of indicators and sub-indicators. The final map relates to the two highest clusters but only takes into account the highest value of the indicator and sub-indicators.

Weightage for cluster, indicators and sub-indicators

Validating analysis based on images during field observation is a crucial step in the vulnerability assessment process. In this study, images are stored in a database using the Survey123 application, which facilitates efficient data management and organization. During the validation analysis, the images are carefully examined to assess the actual conditions of the TNB assets and their surrounding environment.

Factors such as the proximity of assets to slopes or landslide-prone areas, the presence of vegetation or erosion, and other relevant indicators are observed and compared with the initial assessments, as shown in Table 5 and Table 6.

Table 5: Weightage for substation cluster, indicators and sub-indicators

Cluster	Weight	Indicators	Weight	Sub- Indicators	Weight
Susceptibility of Assets	0.3	Building type	0.15	Indoor substation	0.53
				Outdoor substation	0.83
		Foundation building	0.12	Deep foundation (pile)	0.5
				Shallow foundation (pad footing)	1
		Maintenance	0.12	Excellent	1
				Good	0.75
				Bad	0.25
		Construction characteristics	0.18	Attached (Single chamber/ Double chamber)	0.56
				Stand-alone (Single chamber/ Double chamber)	0.82
		Number of floors	0.1	Single storey	0.8
				Medium building (2-5 storeys)	0.5
				High-rise building (>5 storeys)	0.2
		Quality of construction	0.19	Low	0.5
				Medium	0.75
				High	1
Surrounding environment	0.15	Distance between assets	0.05	(>5 meter)	0.1
				(3-5 meter)	0.5
				(<3 meter)	0.9
		Assets location	0.07	Located at a distance more than height of slope	0.1
				Located at distance within height of slope	0.2
				Located at the toe of slope	0.6

				Located at the crest of slope	0.8
				Located at the mid-height of slope	1
		Vertical configuration	0.08	Irregular	0.5
				Regular	1
		Horizontal configuration	0.08	Irregular	0.5
				Regular	1
		Surrounding wall of building	0.06	No/low surrounding wall	0.33
Landslide intensity	0.31	Accumulation height	0.15	(< 0.2 meter)	0.1
				0.2 meter – 0.5 meter	0.4
				0.5 meter- 2.0 meter	0.7
				(> 2.0 meter)	1
		Landslide volume	0.18	(< 500 meter^3)	0.3
				500- 10,000 meter3	0.5
				10,000-50,000 meter^3	0.7
				50,000-250,000 meter3	0.9
				(> 250,000 meter3)	1
TNB electricity	0.25	Capacity ofassets	0.15	6.6kv	0.6
				11kv	0.8
				22kv	0.9
		Land expansion	0.04	14.6m x 14.63 m	0.76
				13.6m x 14.63 m	0.54
				9.0 x 11.0 m	0.3
		Building size	0.12	10.67 m x 5.72 m	0.8
				7.67 m x 5.72 m	0.6
				2.5m x 2.5m	0.3
		Transformer capability	0.06	0kVA	0.1
				500kVA	0.5
				750KVa	0.66
				1000kVA	0.78
				2000kVA	0.89

Table 6: Weightage for pylon tower cluster, indicators and sub indicators.

Cluster	Weight	Indicators	Weight	Sub- Indicators	Weight
Infrastructure	0.33	Foundation	0.12	Deep foundation (pile)	0.5
				Shallow foundation (pad footing)	1
		Capacity of assets	0.07	Telco tower	0.2
				Substation 33KV	0.3
				PMU	0.5
				GRID 500KV (Height 46-67 meter) (Width 10.5 -19 meter)	0.8
				GRID 275KV (Height 34 meter) (Width 7.5 meter)	0.9
				GRID 132KV (Height 29 meter) (Width 5.7 meter)	0.7
				Hybrid tower (Combination of KV)	0.8
		Tower material	0.06	Wood	0.8
				Steel	0.5
				Composite	0.3
Surrounding environment	0.17	Environment	0.03	Normal	0.02
				Jungle	0.03
				Industries	0.04
				Farm	0.03
				Coastal	0.03
		Slope morphology	0.03	Concave	0.9
				Convex	0.5
				Straight	0.3
		Warning system	0.02	Yes	0.1
				No	1
Landslide intensity	0.5	Accumulation height	0.14	(< 0.2 meter)	0.1
				0.2 meter – 0.5 meter	0.5
				0.5 meter- 2.0 meter	0.7
				(> 2.0 meter)	1
			0.14	(< 500 $meter^3$)	0.3

		Landslide volume		500-10,000meter3	0.5
				10,000-50,000 meter^3	0.7
				50,000-250,000 meter3	0.9
				(> 250,000 meter3)	1

RESULTS AND DISCUSSION

The results of a study on the landslide vulnerability of TNB assets in Bukit Antarabangsa are provided in this section. It includes a vulnerability map and a weight table that can serve as guides for TNB management. These resources provide valuable insights that simplify their work, especially when it comes to monitoring actions and making decisions on risk reduction strategies. With a clear understanding of exposure levels and contributing factors, TNB management can prioritize their efforts and allocate resources effectively to mitigate potential risks. The evaluation employed the IBM to collect the aforementioned data. IBM utilizes a set of indicators and sub-indicators to assess the vulnerability of TNB assets in a systematic and organized manner.

During the field observation conducted over three days, a total of 52 assets were assessed, including 39 substations and 13 pylon towers. In Bukit Antarabangsa, there are a total of 233 assets, comprising 220 substations and 13 pylon towers. However, only 52 assets were selected, with 39 substations chosen based on a 50-meter buffer placed around landslide and slope polygons, while the remaining 13 assets are pylon towers. Figure 4 displays the selected assets in Bukit Antarabangsa.

Besides, the Survey123.arcgis.com application, as shown in Figure 5 below, is used throughout the data collection process as a platform to record and store the obtained data. The user-friendly design of this program makes it possible to input and handle data effectively and quickly. The information collected, which includes multiple indicators and sub-indicators, is systematically documented and organized in a database.

This application offers the capability to include photos, making it convenient to integrate both textual and visual data during field observation. This feature allows for the inclusion of visual evidence, such as images, enhancing the comprehension of the collected data. Furthermore, the utilization of this application streamlines and improves the efficiency of the data collection process, ensuring consistency in data gathering. It also enables easy access to the acquired data through a centralized database, providing secure storage that guarantees the integrity and reliability of the collected data for future analysis, reporting, and decision-making purposes. Thus, this application plays a crucial role in maintaining data integrity throughout the entire data collection procedure.

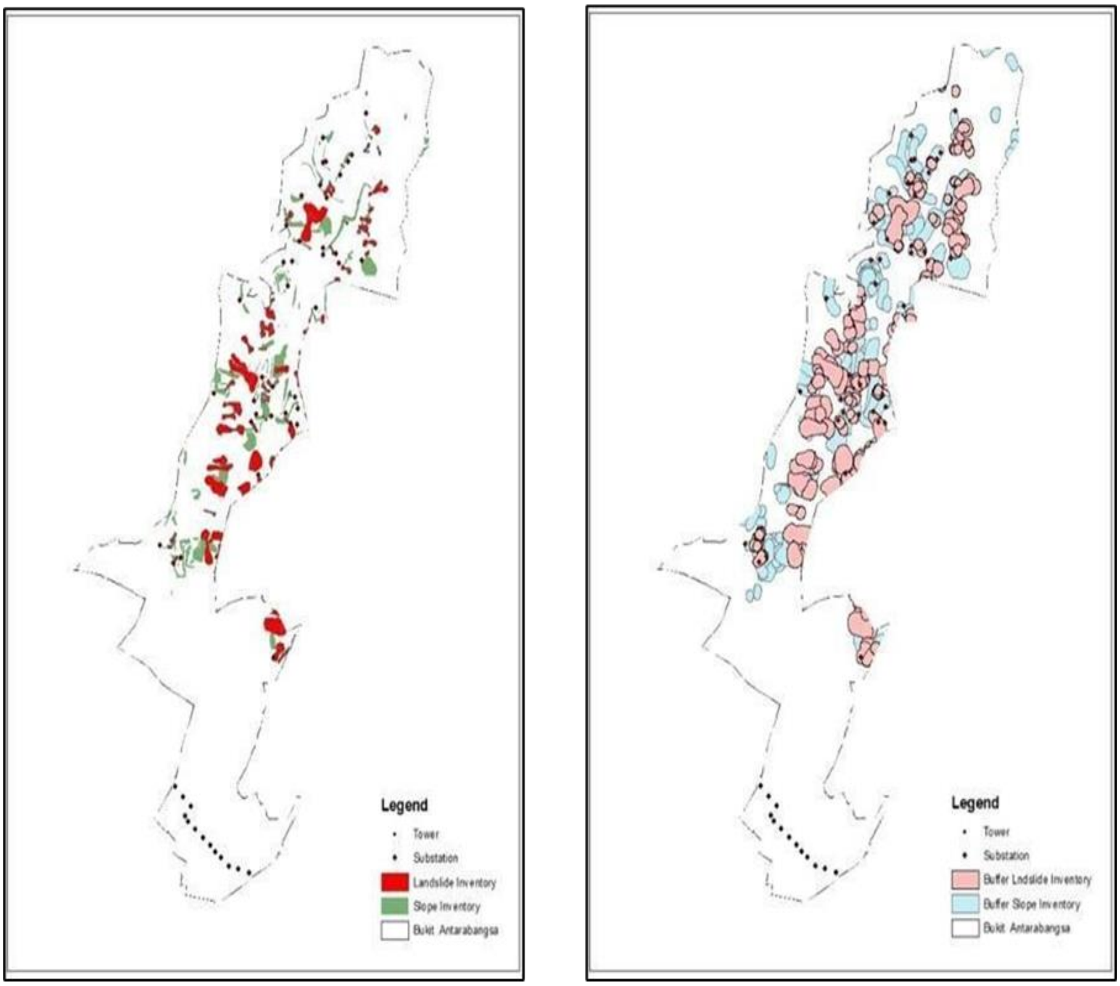


Figure 4: Selected assets in Bukit Antarabangsa

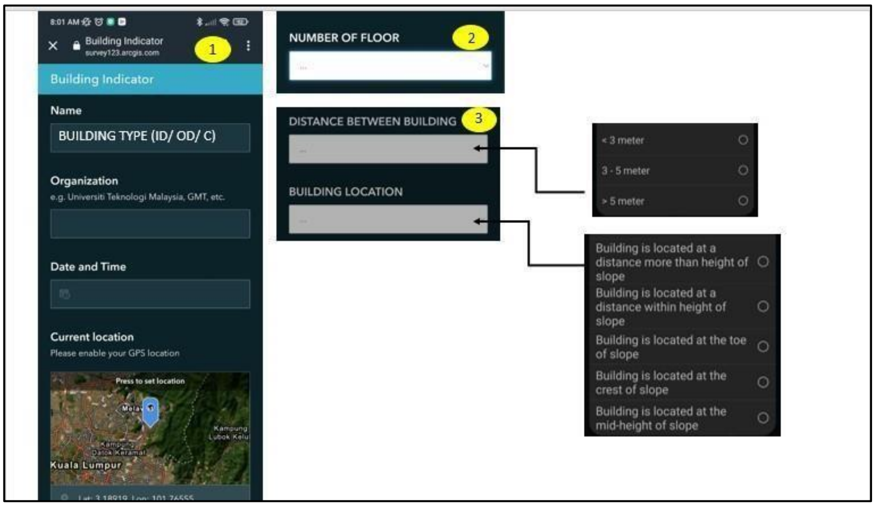
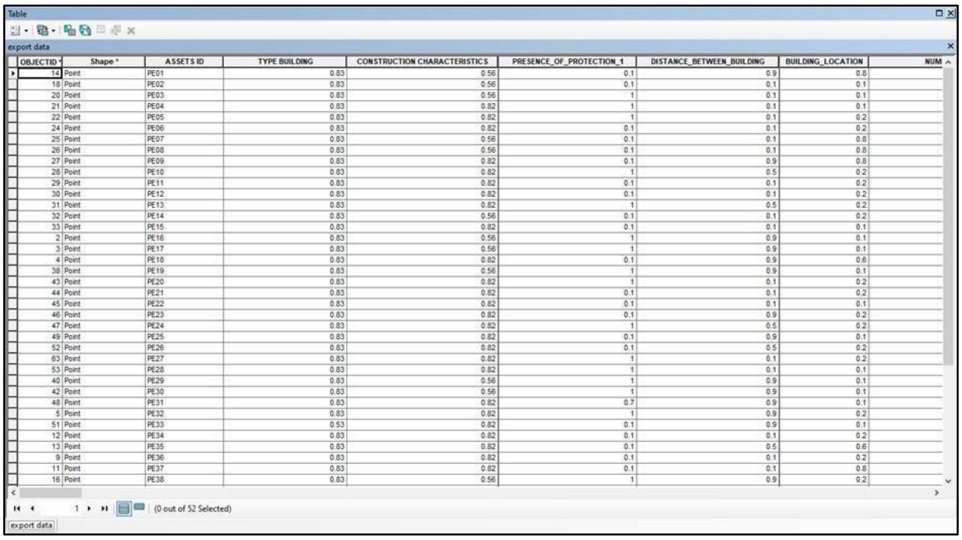


Figure 5: Survey123.arcgis.com application

Indicator-Based Method (IBM) analysis

The indicator-based method (IBM) was a direct method that can be used to assign weightage value for vulnerability multi-hazard assessment developed by Kappes et al.(2012). The concept is similar to AHP, but the question structure of the IBM method is more direct and simpler used for weight score. Score will indicate the weighting value assigned by the expert. Experts are usually based on criteria set such as experience in managing a disaster such as a landslide, or the level of their studies and research on the said disaster. Usually, the score value is between 0 to 1. The section below presents the findings of a study on the susceptibility of TNB's assets in Bukit Antarabangsa to landslides, illustrated in figure 6. The report includes a vulnerability map and a weight table, which can serve as a reference for TNB management. These resources provide valuable insights that can aid their work, particularly in monitoring activities and making decisions regarding risk mitigation strategies.

The weightage value for each indicator and sub-indicator is derived from interviews with experts in the weighting process. These values are then organized according to cluster and indicator and stored as vector data in a database. Figure 6 displays the data along with its respective weightage, which is crucial for understanding how to classify the level of vulnerability of the assets to landslides. With a clear understanding of the level of exposure and contributing factors, TNB management can intensify their efforts and allocate resources effectively to reduce potential risks, as well as plan strategically for future asset construction.



OBJECTID *	Shape *	ASSETS ID	TYPE BUILDING	CONSTRUCTION CHARACTERISTICS	PRESENCE_OF_PROTECTION_1	DISTANCE_BETWEEN_BUILDING	BUILDING_LOCATION	NUM
14	Point	PE01	0.83	0.56	0.1	0.9	0.8	
18	Point	PE02	0.83	0.56	0.1	0.1	0.1	
20	Point	PE03	0.83	0.56	1	0.1	0.1	
21	Point	PE04	0.83	0.82	1	0.1	0.1	
22	Point	PE05	0.83	0.82	1	0.1	0.2	
24	Point	PE06	0.83	0.82	0.1	0.1	0.2	
25	Point	PE07	0.83	0.56	0.1	0.1	0.8	
26	Point	PE08	0.83	0.56	0.1	0.1	0.8	
27	Point	PE09	0.83	0.82	0.1	0.9	0.8	
28	Point	PE10	0.83	0.82	1	0.5	0.2	
29	Point	PE11	0.83	0.82	0.1	0.1	0.2	
30	Point	PE12	0.83	0.82	0.1	0.1	0.2	
31	Point	PE13	0.83	0.82	1	0.5	0.2	
32	Point	PE14	0.83	0.56	0.1	0.1	0.2	
33	Point	PE15	0.83	0.82	0.1	0.1	0.1	
2	Point	PE16	0.83	0.56	1	0.9	0.1	
3	Point	PE17	0.83	0.56	1	0.9	0.1	
4	Point	PE18	0.83	0.82	0.1	0.9	0.6	
38	Point	PE19	0.83	0.56	1	0.9	0.1	
43	Point	PE20	0.83	0.82	1	0.1	0.2	
44	Point	PE21	0.83	0.82	0.1	0.1	0.2	
45	Point	PE22	0.83	0.82	0.1	0.1	0.1	
46	Point	PE23	0.83	0.82	0.1	0.9	0.2	
47	Point	PE24	0.83	0.82	1	0.5	0.2	
49	Point	PE25	0.83	0.82	0.1	0.9	0.1	
52	Point	PE26	0.83	0.82	0.1	0.5	0.2	
63	Point	PE27	0.83	0.82	1	0.1	0.2	
53	Point	PE28	0.83	0.82	1	0.1	0.1	
40	Point	PE29	0.83	0.56	1	0.9	0.1	
42	Point	PE30	0.83	0.56	1	0.9	0.1	
48	Point	PE31	0.83	0.82	0.7	0.9	0.1	
5	Point	PE32	0.83	0.82	1	0.9	0.2	
51	Point	PE33	0.53	0.82	0.1	0.9	0.1	
12	Point	PE34	0.83	0.82	0.1	0.1	0.2	
13	Point	PE35	0.83	0.82	0.1	0.5	0.6	
9	Point	PE36	0.83	0.82	0.1	0.1	0.2	
11	Point	PE37	0.83	0.82	0.1	0.1	0.8	
16	Point	PE38	0.83	0.56	1	0.9	0.2	

Figure 6: Converting the cluster, indicator and sub-indicator in numerical (weightage).

The weightage value for each indicator and sub-indicator is determined using the IBM method, which is crucial for classification. This study follows the KPKT guideline for applying the IBM method in Malaysia, as depicted in Figure 7. The vulnerability value is typically calculated by combining individual indicator scores using weights set by an expert. The calculations start with normalized weights for each indicator, which then produce corresponding sub-indicators.

This process is done to obtain a value within the range of 0 to 1, as set in IBM. To calculate the vulnerability level, a specific formula related to vulnerability calculation is used. In today's technology, this calculation is carried out in ArcGIS using a field calculator, as shown in Figure 8. The calculation formula is represented by equation 1.

Equation 1

Vulnerability Value =
*(Indicator weight1 * sub-indicator weight1) + (Indicator weight2 * subindicator weight2) + ...*
*+ (Indicator weightN * sub-indicator weightN)*

Formula calculation:

$$((0.20 \times 0.50) + (0.11 \times 0.90) + (0.10 \times 0.30) + ((0.05 \times 0.02) + (0.05 \times 0.30) + (0.03 \times 0.10) + ((0.23 \times 0.10) + (0.23 \times 0.30)) = 0.34\ (Low\ Vulnerability)$$

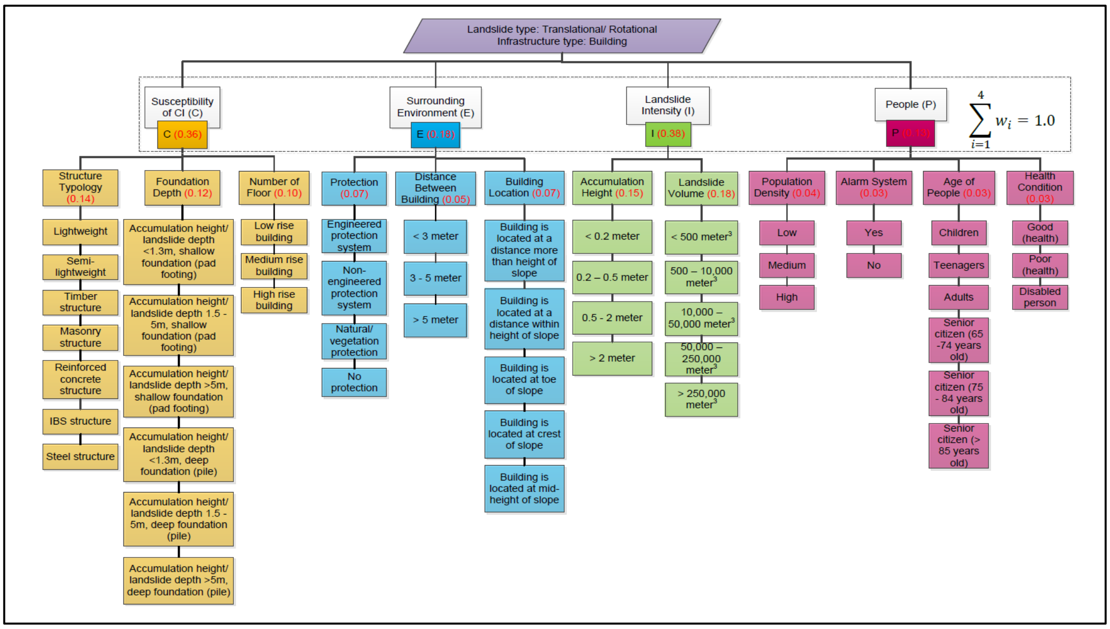


Figure 7: Vulnerability assessment using IBM in KPKT guideline (KPKT, 2022)

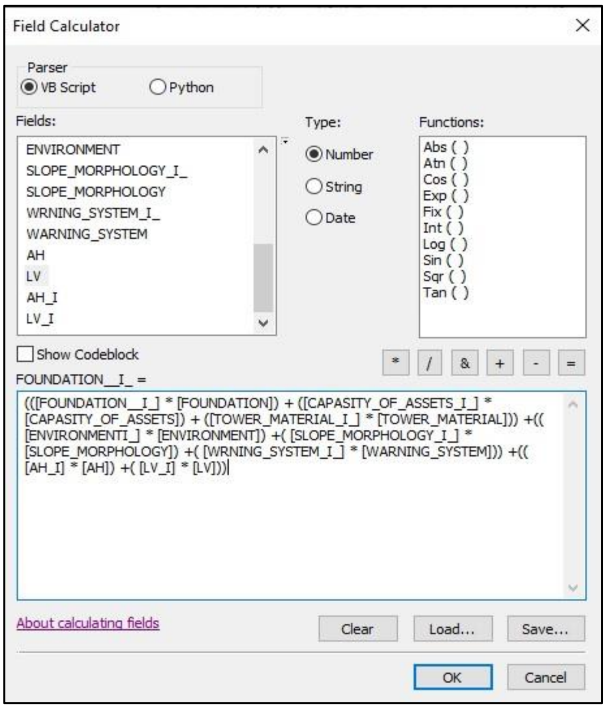


Figure 8: Field Calculator calculates the vulnerability pylon tower

The calculation result shows the vulnerability level index for each asset. Upon analysis, it was observed that the substation has a high vulnerability level. The values are 0.8 (very high), 0.6 (moderate), with a mean value of 0.7, as shown in table 7. All values have been rounded to one decimal place for a concise representation of the vulnerability assessment. This indicates that the substation is more susceptible to the impacts of landslides and is at a higher risk compared to other assets. The higher vulnerability score suggests that the substation is located in an area with a combination of factors, including proximity to slopes, a history of landslides, and surrounding environmental conditions, contributing to its heightened vulnerability.

The vulnerability assessment conducted in Bukit Antarabangsa has revealed that the substation located at Athenaeum Condo exhibits a high vulnerability to landslides. This specific substation is situated in an area known for its scenic views, offering sights of prominent landmarks such as the KLCC towers. However, the area surrounding the Athenaeum Condo has experienced soil movement and related risks before, prompting the implementation of mitigation measures to protect the condominium.

Besides, the pylon tower has a low vulnerability level, with a vulnerability score of only 0.3, as shown in Table 7. This means that the pylon tower is less likely to be affected by landslides and has a lower potential for experiencing adverse effects. The surrounding area where the pylon is located has relatively flat topography along Jalan 15 Ampang Jaya. Additionally, there is a plan in place to ensure the safety of the pylon tower, specifying a minimum distance of 30.5 meters (100 feet) between the edge of the road and any pylon tower. This intentional separation ensures a safe distance between the pylon and nearby residential areas and roads, reducing the potential risks associated with landslides.

Table 7: Vulnerability value for substation and electrical pylon tower

Field	**Count**	**Minimum**	**Maximum**	**Sum**	**Mean**	**Standard Deviation**
Substation	39	0.63915	0.76475	27.44165	0.703632	0.027442
Electrical pylon tower	13	0.34	0.34	4.42	0.34	0

Validation analysis

Validation analysis through photographs taken from field surveys is an important step in assessing the accuracy and reliability of the vulnerability assessment. Vulnerability mapping findings can be compared and verified visually by using pictures of the actual situation in the field. During the field survey, photographs of physical features of the research area, such as TNB assets, slopes, local environment, and other related elements, were captured to showcase these features. These images serve as evidence and provide a visual representation of the conditions observed during the survey, as depicted in figure 9.

The high vulnerability assessment of the substation is logically based on the evidence found in the field observations, as shown in the image below, which depicts a substation located in a risk area. Meanwhile, the low vulnerability of mast towers is also demonstrated in the table below. In fact, landslides are geological events that involve various types of ground movements, including rock falls, slope failures, and shallow debris flows. They can be deadly. While gravity acting on steep slopes is the primary cause of landslides, additional factors such as heavy rainfall or snow accumulation, rock or garbage deposits, and human-built structures can also contribute to slope instability and collapse of structures.

Based on the information provided in the table, five areas have been chosen as verification sites for landslide studies. These areas are connected to landslide studies either nearby or within the same area. The assets of TNB (presumably referring to an organization or a company) are the main focus for assessing the level of vulnerability, whether it is low or high. These areas feature significant indicators that can be classified as either highly vulnerable or not, mainly based on the slope of the area.

TNB's assets comprise electricity substations, electricity poles, and water tanks. Each of these areas has a report and record addressing the slope and elevation where TNB assets are located. The five featured locations, as depicted in the image, are diverse and situated near areas with high slopes. Following the site verification, locations "a", "c", and "d" demonstrate assets positioned in highly vulnerable areas, primarily due to the nearby gradient and slope. This situation poses a threat of landslides, potentially leading to destruction of the assets. A landslide in these areas would cause great uncertainty both economically and socially. Although the assets' structures are concrete, the probability of destruction is high owing to unpredictable changes in the soil structure.

Factors such as prolonged and intense rainfall may lead to landslides and changes in soil composition in specific areas. Additionally, the location of TNB's assets in areas "b" and "e" differs from the others. The asset location in "b" is distant from the landslide-prone area and is not in the landslide zone. Furthermore, the construction there is sturdier and of higher quality.

Nevertheless, it is important to assess the vulnerability level in advance, so that precautionary measures can be implemented for the future. In the "e" area, the pylon towers are situated far from residential areas, and the buildings have a low level of vulnerability. Furthermore, the area does not have a slope or high slope value that could lead to landslides. Therefore, the location of this asset is classified as having low vulnerability to landslides. Detailed variation pictures are shown in the figure 9.

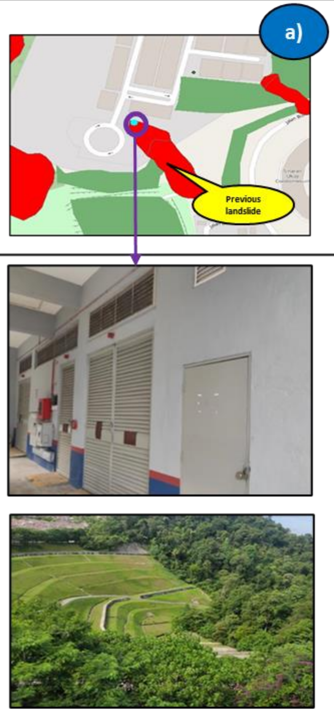
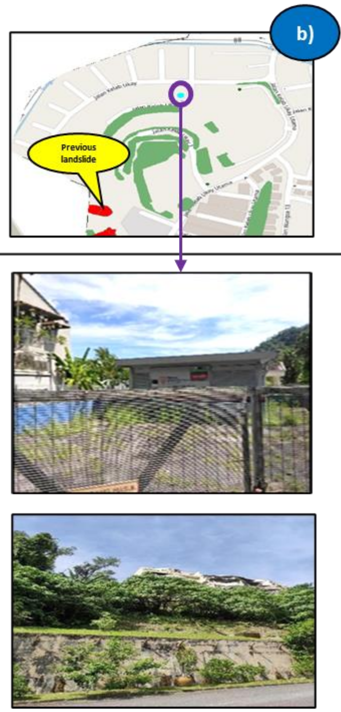
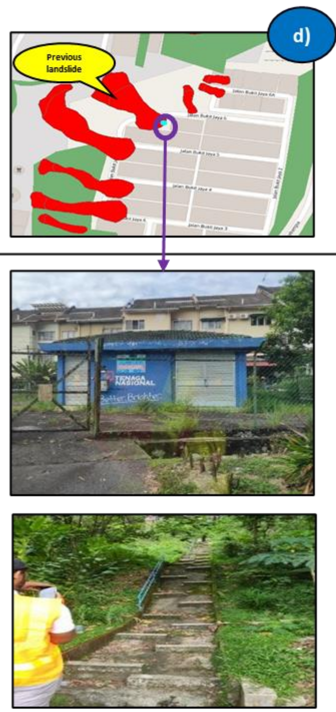
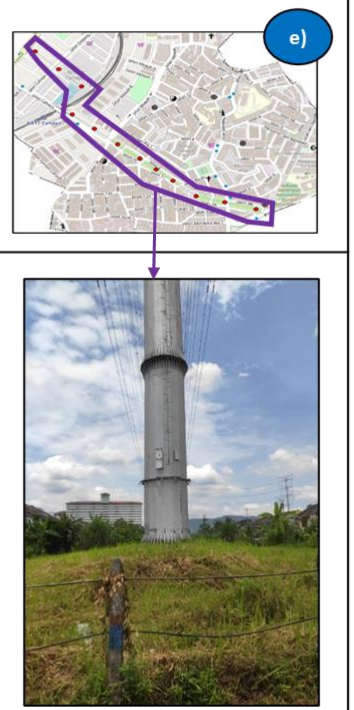
Lat/long: 101.766239,3.18084 *Atheneum Condos*	Lat/long: 101.770571, 3.196775 *Jalan kelab ukay 7*	Lat/long: 101.772584,3.198931 *Jalan su 2c ukay*	Lat/long: 101.769071,3.184300 *Taman bukit jaya no 2*	Lat/long: 3.13868, 101.76086 *Along Jalan 15 Ampang Jaya*
				
Assets located at the crest of slope Landslides have previously occurred around Atheneum Condos	***Assets located at the toe of slope***. Landslide have not happened in asset location. However, it have occurred far from the area	***Assets located at the crest of slope.*** Area does not receive adequate maintenance	***Assets located at distance within height of slope***. There is a significant feature a large water tank on top.	***The assets depicted are pylon towers located low slope*** These towers positioned in far away from residential area
Status: High vulnerability ✔	Status: Low vulnerability ✘	Status: High vulnerability ✔	Status: High vulnerability ✔	Status: Low vulnerability ✘

Figure 9: Site verification on study area

Vulnerability Map

In Figure 10, TNB's asset vulnerability is depicted, showing four levels of vulnerability: very high, high, medium, and low. The vulnerability maps illustrate the different vulnerability levels of substations and mast towers to potential risks and hazards. Substations categorized as having very high vulnerability are exposed to significant impacts and may require immediate attention and mitigation measures. Those classified as having medium vulnerability are relatively resilient and exhibit a lower probability of adverse events. Substations with high vulnerability require appropriate preventive measures.

On the other hand, mast towers consistently show low vulnerability values across all towers, indicating that they are relatively resilient and less likely to be affected by potential threats compared to substations. Additionally, a pie chart displays the number of assets categorized by vulnerability level for both substations and mast towers. For substations, there are 11 assets classified as very high vulnerability, located in areas with a high risk of landslides. In addition, 22 TNB assets are classified as moderate vulnerability, and 6 assets are at medium vulnerability. As for pylon towers, all 13 towers were categorized as having a low level of vulnerability due to their distance from residential areas and the small probability of landslides occurring in their areas. Lastly, Figure 11 shows the projection of the assets' positions using the WGS84 projection, based on the use of coordinate system in Malaysia.

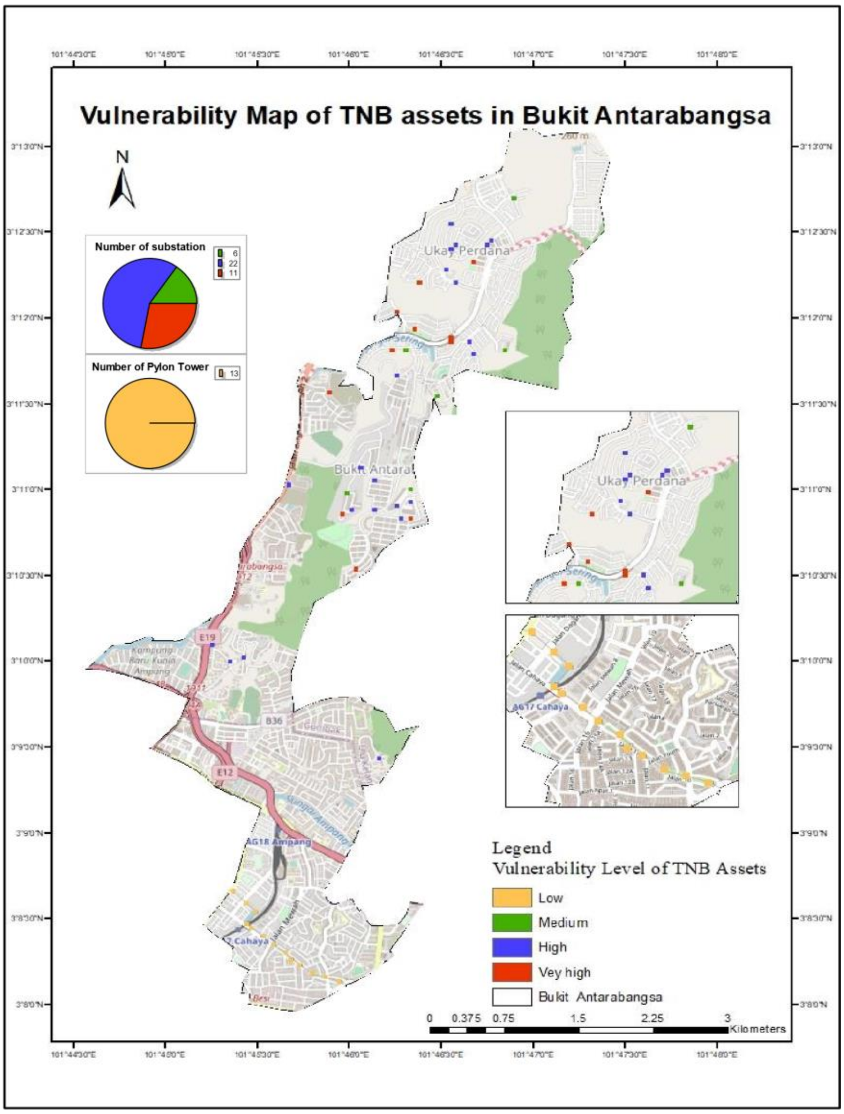


Figure 10: Vulnerability map of assets in Bukit Antarabangsa.

Two Highest Cluster of Substation

In Figure 11 shows the top two substation clusters with high vulnerability. The vulnerability value of all the substations was determined using the IBM method and weightage assessment. The cluster used includes asset vulnerability and landslide intensity, along with all relevant indicators and their respective sub-indicators. According to the map, 20 substations are classified as having a very high vulnerability to landslides, 14 substations are classified as high vulnerability, and 5 substations are classified as medium vulnerability. This data can be used by TNB contractors and responsible parties for monitoring and preparation purposes in the future.

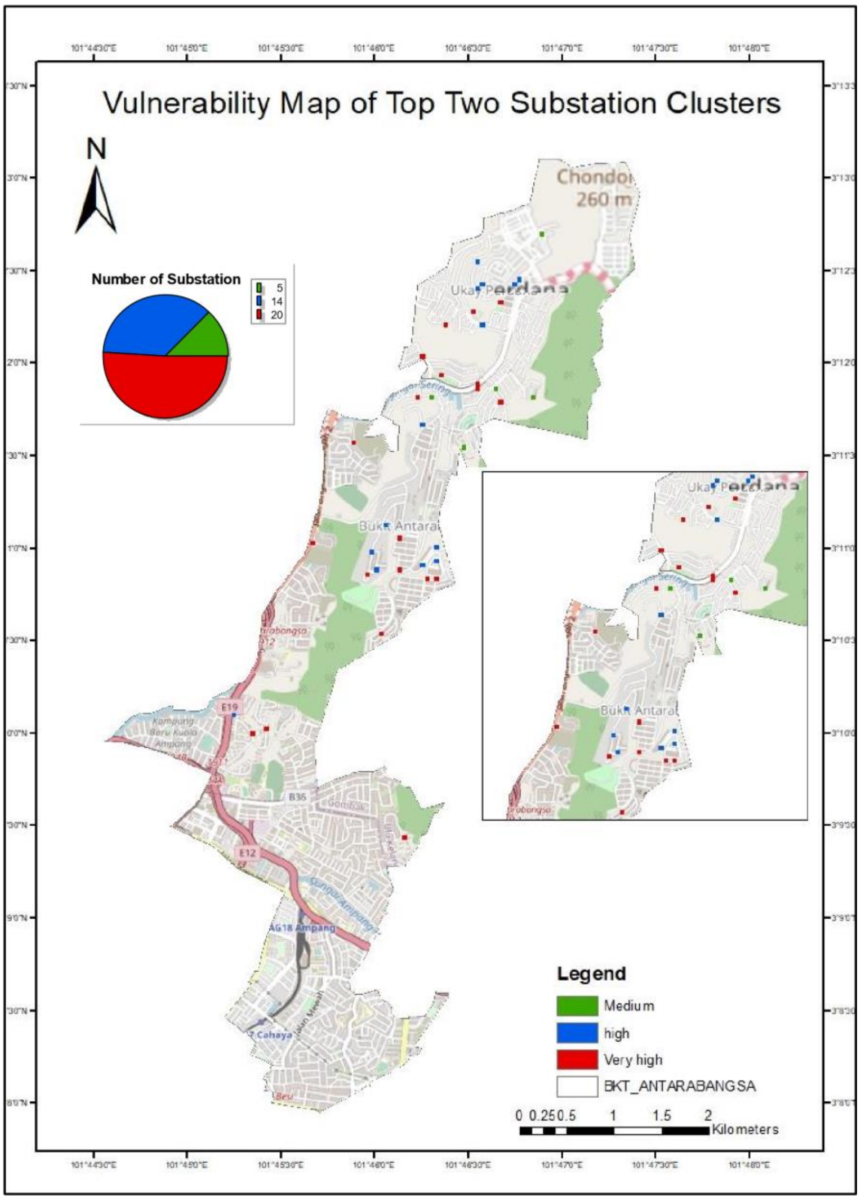


Figure 11: Vulnerability map of top two Substation Cluster

Two Highest Cluster with The Most Critical Indicator of Substation

Based on Figure 12, it shows that the two highest clusters, along with their respective critical indicators and sub-indicator values, focus on asset vulnerability and landslide intensity. The map illustrates that a significant concentration of high-level vulnerability substations is located in the central area of Bukit Antarabangsa. According to the pie chart attached to the map, the classification shows 2 substations with very high vulnerability, 27 with high vulnerability and 10 with moderate level of vulnerability. The determination of the vulnerability value is also based on the weight assessment conducted at the beginning of the study prior to setting the vulnerability value.

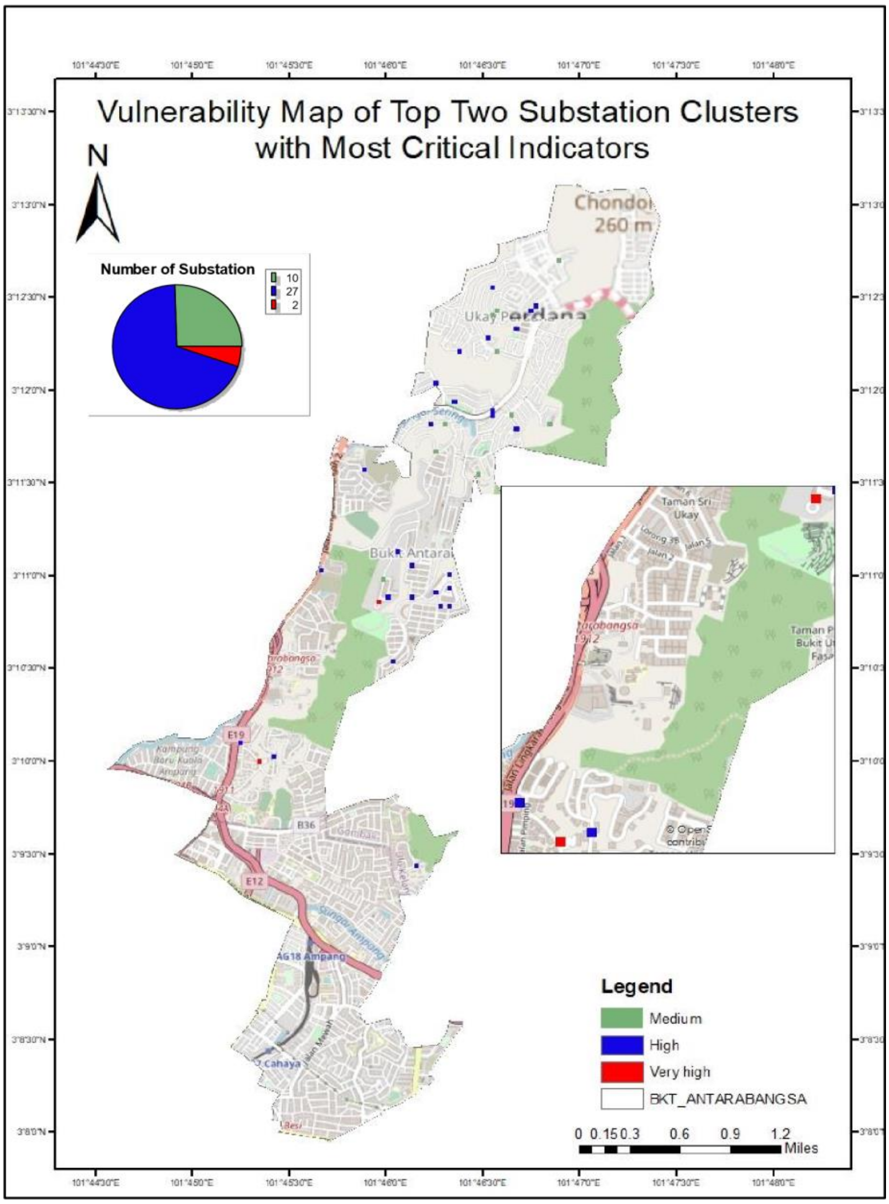


Figure 12: Vulnerability map of top two Substation Cluster with the most critical indicator

CONCLUSION AND RECOMMENDATION

In summary, vulnerability assessment using the Indicator Based Method (IBM) is highly effective and applicable. The assessment indicates that the electrical substation in Bukit Antarabangsa is highly vulnerable to landslides, while the mast tower exhibits a lower level of vulnerability. This is due to the soil structure and indicators that can trigger landslides in the area. The study is supported by field observations, which validate the final results, making it more accurate and clearer. The study suggests that the substation's location directly above the slope inventory area increases its vulnerability to landslides. The study has produced satisfactory and promising results, serving as a reference for future studies. However, the author recommends some considerations for future improvements, including seeking confirmation from more experts, diversifying data sources related to landslides and study areas, and maintaining comprehensive landslide records for future study purposes.

Furthermore, the author suggests enhancing the credibility of the weakness assessment by involving references from various experts from different agencies, such as research and education institutions, government agencies, and NGOs. This collaboration with experts will provide more insightful input and confirmation in both management and technical aspects. It is also essential to have a contingency plan in place in case input from an expert is unavailable. Working with experts can help address potential biases and inaccuracies, leading to more reliable and robust conclusions.

Additionally, future studies are recommended to incorporate a variety of sources and methods in accordance with technological advancements. Although Google Earth Pro is a useful tool for initial assessment, future research should aim to integrate data from multiple sources, including elevation surveys using lidar or drone data. These resources offer greater accuracy and precision in capturing elevation and terrain features, resulting in a more accurate assessment of susceptibility to collapse. Moreover, the quality of available data sources is crucial, as exploring various sources can yield more comprehensive and reliable results.

In conclusion, it is important to create comprehensive land records that include detailed information on landslides, such as volume, intensity, and protection systems. This historical data is crucial for identifying high-risk areas and informing disaster risk management strategies. These records can also be used for validation purposes to ensure accurate results in future studies. By assessing the vulnerability of electrical substation assets, we can help prevent damage from landslides and better prepare residents in potential landslide areas.

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