Analysis of Landslide Occurrence using DTM-Based Weighted Overlay: A Case Study in Tropical Mountainous Forest of Cameron Highlands, Malaysia

Paul Lau Hua Ming * and **Azita Ahmad Zawawi**

Faculty of Forestry and Environment, Universiti Putra Malaysia, Serdang 43300, Malaysia

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* Corresponding author:
E-mail: paulau_94@hotmail.com

ABSTRACT

Landslides are massive natural disasters all around the world. In general, our society is only concerned with the landslides that can cause economic distress and impact human life. Landslides in remote areas such as mountainous forests have often been neglected. Referring to the historical disaster event, forest landslides have vast potential to cause unexpected ecological and social damage. This study reveals the terrain characteristics of the complex mountainous forest area of Cameron Highlands (CH), Malaysia, and demonstrates an approach to evaluate the terrain sensitivity of CH. Terrain assessment can be a powerful tool to prevent or reduce the risk of landslides. In this study, terrain features; elevation, slope gradient, aspect, topography wetness index (TWI), and length-slope factor (LS Factor) were extracted using a Digital Terrain Model (DTM) at 10 m resolution. The selected terrain features were incorporated using weighted overlay analysis to derive a terrain sensitivity map (TSM) using SAGA GIS software. The map identified five types of terrain sensitivity classified as very high sensitivity, high sensitivity, moderate sensitivity, low sensitivity, and very low sensitivity; these areas have a coverage of 0.78 km², 114.31 km², 107.50 km², 102.99 km², and 0.65 km², respectively. The findings suggest that the sensitive areas are scattered throughout all of the mountainous forests of CH; thus, this enhanced the risk of landslide. Results showed 79.25% accuracy, which is satisfactory to be a guideline for forest management planning and assist decision making in the respective region.

1. INTRODUCTION

Terrain is a complicated environmental factor that affects land use, human development, and localized ecology (Gong et al., 2017); and influences the water level as it contributes to total dissolved solid (Ostad-Ali-Askari and Shayannejad, 2021). In a more straightforward form, terrain refers to the features on the Earth's surface (Li and Hsu, 2020). Terrain characteristics can be studied by conducting terrain assessment. According to Beaven and Lawrence (1973), terrain assessment is a study of geo-morphology, terrain features, and limitations of a specific area. It can be applied in various fields. Ahmed and Rao (2019) conducted a terrain assessment to evaluate watershed conditions in Tuirini River, India, while Colby and Dobson (2010) evaluated flood patterns to develop a hazard prevention plan. Kim et al. (2017) conducted a terrain assessment to predict the wind flow in the montane area to identify a suitable spot for wind farm establishment. These studies emphasized that assessing terrain condition is crucial studying environmental phenomena, such as water flow and wind intensity, to evaluate and predict the land use potential.

In addition, terrain assessment can be useful to predict landslides. For example, Wawer and Nowocien (2003) conducted a terrain assessment to predict shallow landslides triggered by shallow groundwater in the Naleczow Plateau. Tarolli and Tarboton (2006) conducted a terrain assessment to find landslide initiation points in the Miozza

catchment area, Italy. Moreover, Gutierrez-Martin et al. (2019) conducted a terrain assessment to study the relationship between landslide susceptibility and heavy rainfall in Hundidero County, Spain. These studies aimed to forecast natural disasters by developing a model for terrain assessment in advance to pinpoint the potential landslide locations.

A landslide can occur naturally due to weathering processes or external triggers such as earthquakes, melting snow, and rainfall (Zhang et al., 2014). According to Cruden (1991) and Froude and Petley (2018), landslides are disaster events when land collapses and leads to soil sliding and rocks falling from the upper slope to lower slope due to gravity. Moreover, terrain with a high gradient of steepness tends to have a higher risk of landslide triggering than ground in flat conditions. These processes and external factors will initiate landslides in the area with high terrain sensitivity. According to Zhou et al. (2002), a landslide is closely related to the terrain condition and its geographical characteristics. Thus, landslides can occur when the land is used without wise management by neglecting the importance of terrain conditions. One of the examples is shown in a construction project at Malaysia Northern State that triggered a landslide as the building was constructed on a steep hill 75 m high and more than 25° steepness of slope, which is critical enough to initiate a landslide (Dermawan, 2019). In 1963, a large-scale landslide in Vajont, Italy caused 2,000 deaths. The high mortality was due to the tsunamis caused by the landslide of mountain parts into a lake (University of Cincinnati, 2018). These cases reflect the importance of terrain related study in order to avoid tragedy by conducting mitigation plans in advance.

Malaysia is one of the countries that are at high risk of landslide disasters (Matori et al., 2011). According to Sim et al. (2018), Malaysia is ranked tenth globally with a high frequency of landslides based on the landslide data between the years of 2007 to 2016. Several big scale landslides were recorded within the time frame. For instance, the landslide that occurred in Mount Kinabalu, Sabah in 2015 caused the death of 18 climbers and massive destruction to nearby farmland, houses, and bridges (Tongkul, 2015). In addition, a landslide tragedy occurred in Bukit Antarabangsa, Selangor in 2008 caused four deaths and destroyed 14 bungalows (The Star Online, 2008). Due to the high frequency of landslides, the Malaysia government had initiated landslide awareness systems such as the Early Warning System (EWS) and Kuala Lumpur Slope Information System (KuLSIS) (Wong, 2014; Zakiah et al., 2019). In addition, researchers had done extensive work by conducting an assessment on landslide occurrences in Malaysia, which covers various aspects such as correlation between the rainfall intensity and landslide frequency along public roads (Tay and Selaman, 2011); the effect of soil type and lithology factors towards landslide occurrence (Mohd et al., 2019); and the influence of land use towards landslide occurrence (Kamilia et al., 2016).

However, most of the landslide related study and prevention planning was focused on the urbanized area. Public and authorities show relatively less concern on landslide hazards in the mountainous region. According to the University of Cincinnati (2018), society tends to show less attention to landslide events in the natural area as these areas are often unpopulated. In fact, landslide risk in less populated areas will cause harm to the public as well. For example, a tourist tour which included 40 Malaysian tourists was trapped in Mount Rinjani, Indonesia due to an earthquake triggered by a landslide (Teh, 2019). This study focused on a detailed terrain sensitivity assessment in the natural area which should not be neglected.

Conventionally, terrain assessments are carried out manually where the information of terrains such as elevation and slope gradient are attained through Global Positioning System (GPS) (Kavitha et al., 2018). This method acquire data with relatively high accuracy, but it comes with higher labor costs, time-consumption, weather dependence, and limited accessibility. Today, terrain assessment can be conducted effectively using information derived from the Geography Information System (GIS) and Remote Sensing (RS). GIS is a powerful tool that is capable of enhancing terrain visualization and enables users to study the relationship of terrain features with its surroundings (Statuto et al., 2017). Through these technologies, terrain assessment can be conducted without physical access to the area. This study aims to develop a terrain sensitivity map through the DTM application and test its accuracy by verification to historical events. This work will provide a guideline for locating sensitive areas in a complex tropical mountainous area. Map outputs of this study may serve as a basis for forest managers, land developers, and policy makers in future planning to maintain sustainable forest resources.

2. METHODOLOGY

2.1 Study area

This study was conducted on the forest area of Cameron Highlands (CH), Peninsular Malaysia. The mountainous highland, which is characterized by dynamic terrain characteristics, plays essential roles in Malaysia's economic growth through the ecotourism sector, plantation, and agriculture production (Figure 1)

(Azita et al., 2019). The rapid development of CH gives both positive and negative impacts on the environment, including landslides, where forest area plays as a stabilizer to the whole ecosystem. Being ranked as one of the mountainous regions listed as landslide hotspots in Malaysia, preservation of this mountainous forest highland is crucial for biodiversity and land stability, as well as community protection.
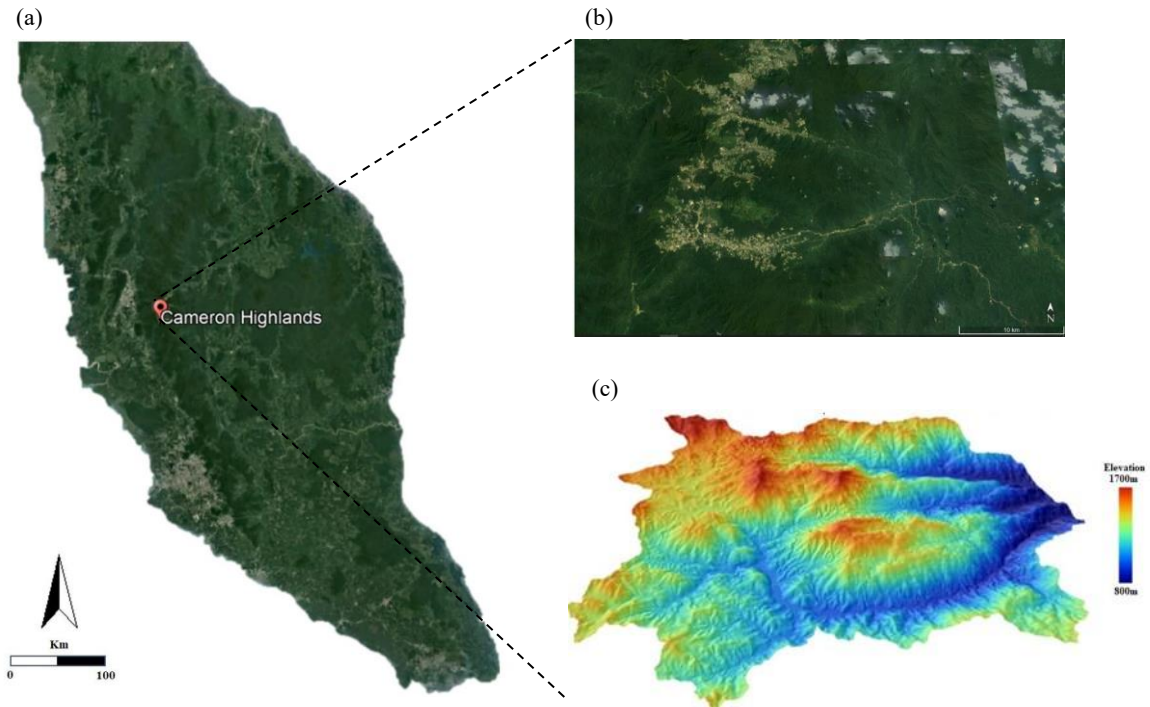

Figure 1. (a) Map of Peninsular Malaysia, (b) Landsat view of Cameron Highlands, and (c) three-dimensional (3D) terrain map of Cameron Highlands (4°31′26.99″N; 101°20′12.00″E)

The geographical characteristics of CH are shown in Table 1. CH possesses an elevation ranging from 1,070 to 1,870 m.a.s.l. It is a high precipitation area that receives an average of 2,852 mm of rainfall every year. According to Larsen and Simon (1993), the threshold value of rainfall to trigger a landslide in a tropical area is 2,000 mm/year. Countries that are

located within wet tropic regions such as Malaysia and Indonesia tend to have the potential of landslides caused by heavy rainfall (Putra et al., 2021). In addition, the dynamic landform of CH and high precipitation makes it an area with high landslide susceptibility

Table 1. Geographical characteristics of Cameron Highlands

Characteristics	Attribute	Source
Coordinate	4°31′26.99″N, 101°20′12.00″E	Matori et al. (2011)
Area coverage	712 km^2	Zaini et al. (2014)
Elevation	1,070-1,870 m	Matori et al. (2011)
Precipitation	2,852 mm/year	Jerkins (2014)
Rainy day	236 day/year	Jerkins (2014)
Mean temperature	18.5°C	Jerkins (2014)
Forest distribution	Upper dipterocarp forest (750~1,200 m)	Kumaran and Ainuddin (2006)
	Lower montane forest (1,200~1,500 m)	
	Upper montane forest (>1,500 m)	

2.2 Research workflow and data acquirement

Figure 2 shows the entire workflow of the research.

2.3 Data acquirement

Spatial data were obtained from two agencies: the Forestry Department of Peninsular Malaysia (JPSM) and the Department of Survey and Mapping (JUPEM), as shown in Table 2. Malaysia is a country that has full coverage of clouds. Thus, the DTM obtained from JUPEM was generated through the

technology of radargrammetry which utilises microwaves as data acquisition vectors as it can penetrate through the cloud cover to achieve relatively higher data accuracy (JUPEM, 2019).

Table 2. Resolution and source of spatial data

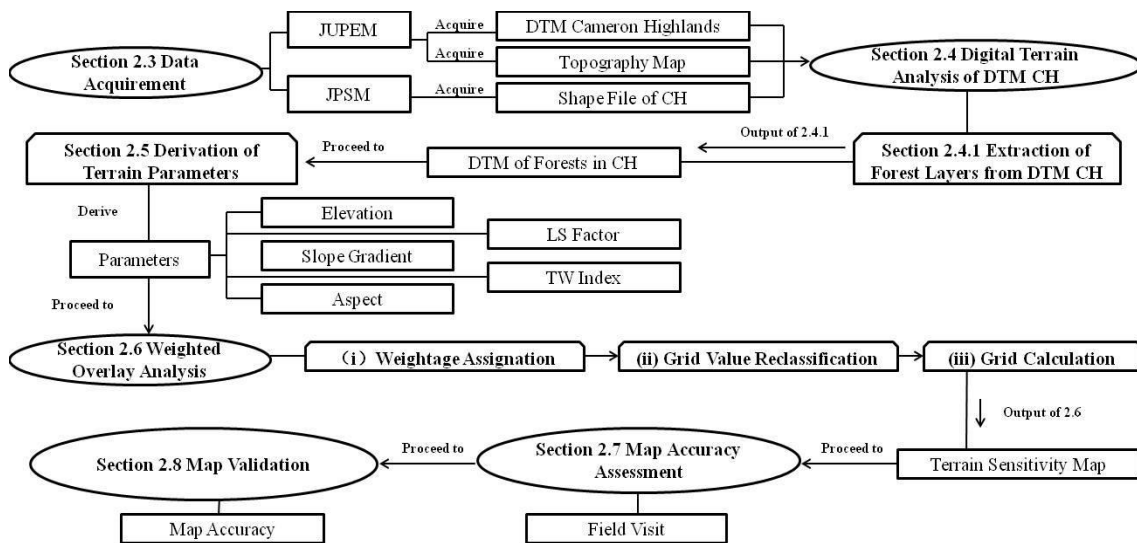| Spatial data	Year	Resolution	Agency
DTM	2018	10×10 m	JUPEM
Shape file of CH	2013	NA	JPSM
Topography map	2008	5×5 m	JUPEM

NA=Not Applicable

Figure 2. Flow of research methodology

2.4 Digital terrain analysis of DTM CH

2.4.1 Extraction of forest layer in Cameron Highlands

A total of 14 forest reserves were selected and extracted from the DTM of Cameron Highlands. Table 3 shows the extracted forest reserves and the digitized area of coverage.

2.5 Derivation of terrain parameters

This section shows the procedure to reveal the terrain characteristics of mountainous forest in CH. DTM-based terrain features were derived using module "basic terrain analysis" within SAGA GIS software (Conrad et al., 2015; Fisher et al., 2017). Selected terrain features were elevation, slope gradient, aspect, length-slope factor (LS Factor), and topography wetness index (TWI). These features exhibit the morphological setting of the terrain surface in the mountainous forests of CH. Table 4 shows terrain features and their respective significance.

Table 3. Forest reserves and their coverage area in Cameron Highlands

Forest Reserve (FR)	Area (km²)
FR Terla	37.87
FR Gunung Siku	18.30
FR Sungai Wi	69.18
FR Hulu ICAT	7.14
FR Batu Gangan	10.17
FR Batu Gangan Tambahan	10.10
FR Sungai Kial	24.24
FR Hulu Bertan	7.44
FR Bukit Jerut	64.22
FR Mentigi	16.07
FR Mentigi Tambahan	2.87
FR Ringlet	14.29
FR Bertam	29.87
FR Gunung Berembun	15.48
Total	326.24

Table 4. Terrain features and their respective significance

Features	Description	Significant
Elevation (m)	Altitude of the slope above sea level	Climate, vegetation
Slope gradient (°)	Incline of terrain surface	Shear force, terrain steepness
Aspect (°)	Direction of terrain facing	Precipitation, effect of monsoon season, and sunlight exposure
LS factor (unit)	Impact of slope length and slope steepness. $* \text{LS Factor} = (\frac{m}{22.13})^t \times (\frac{\sin\beta}{0.0896})^{13}$	Rate of soil loss
TWI (unit)	Terrain moisture $* \text{TWI} = \ln(\frac{As}{\tan\beta})$	Relative size of upslope catchment area, condition of drainage channel, and runoff propensity

* Formula of terrain features

2.6 Weighted overlay analysis

This section shows the framework to derive terrain sensitivity maps that layout the terrain sensitivity spot in the mountainous forest of CH. After derivation of basic terrain features, five different map layers from Table 4 were stacked to generate a terrain sensitivity map. Three phases which were (i) weightage assignation, (ii) grid value reclassification and (iii) grid calculation were executed. Weighting classification method had been applied in various geographical and environmental studies and proven to be effective for susceptibility mapping (Panikkar and Subramaniyan, 1997; Shit et al., 2016; Kouhestani et al. 2016; Ostad-Ali-Askari et al., 2020).

(i) Weightage assignation

Each terrain feature was classified into subclasses and weightage values were assigned from 1 to 5 which represents low terrain sensitivity to high terrain sensitivity as shown in Table 5. Weightage assignation was adopted from Anbalagan (1992) and Matori et al., (2011).

Table 5. Classification and weightage of terrain features

Terrain Parameter		Subclass		Weightage
(a)	Elevation (m)	<805		1
		805-1,070		2
		1,070-1,335		5
		1,335-1,600		4
		>1,600		3
(b)	Slope gradient (°)	0-10.2		1
		10.2-20.4		2
		20.4-30.6		5
		30.6-40.8		4
		>40.8		3
(c)	Aspect (°)	-1	Flat	1
		0-22.5	North	2
		22.5-67.5	Northeast	5
		67.5-112.5	East	3
		112.5-157.5	Southeast	3
		157.5-202.5	South	3
		202.5-247.5	Southwest	4
		247.5-292.5	West	3
		292.5-337.5	Northwest	5
		337.5-360.0	North	2
(d)	LS Factor	<2.8		1
		2.8-5.6		2
		5.6-8.4		3
		8.4-11.2		4
		>11.2		5

Table 5. Classification and weightage of terrain features (cont.)

Terrain Parameter		Subclass	Weightage
(e)	TWI	<3.2	1
		3.2-6.4	2
		6.4-9.6	3
		9.6-12.8	4
		>12.8	5

Explanation on each terrain features and weightage assignation is elaborated as follows.

(a) Elevation

Elevation refers to the altitude of terrain. Based on Dou et al. (2015), the ground in different heights will have different sensitivity levels. A slope in low elevation will have lower terrain sensitivity as it is less likely to trigger landslides due to its gentle terrain. Thus, in this study, subclasses with <805 m and 805-1,070 m were assigned as 1 and 2. The terrain at intermediate level which is 1,070-1,335 m will have the most significant sensitivity due to the high accumulation of colluviums layer from the slope in higher elevation; thus, weightage 5 was assigned to this subclass (Wang et al., 2015). Terrain sensitivity decreases gradually at more upper elevation slope as colluviums material will displace from high elevation slope to intermediate slope from time to time (Roback et al., 2018). Thus, weightage 4 and 3 were assigned to high elevation slopes, which are subclass 1,335-1,600 m and >1,600 m respectively.

(b) Slope gradient

Slope gradient refers to terrain steepness. According to Dou et al. (2015) and Roback et al. (2018), low gradient slopes tend to have lower terrain sensitivity due to the low shear force. Terrain sensitivity increases with the slope gradient as well as shear force. Thus, subclass 0-10.2° and 10.2-20.4° were assigned as weightage 1 and 2 respectively. Terrain sensitivity tends to increase significantly at the intermediate subclass of slope gradient 20.4-30.6° as the slope in this level was loaded with enormous fine sediment from the high level subclass of slope gradient. The fine sediment can be landslide material that can be triggered anytime. Thus, subclass 20.4-30.6° was assigned as weightage 5. As slope gets steeper at high subclass which is 30.6-40.8° and >40.8°, the fine sediment is decreased due to the constant displacement to intermediate subclass of slope from time to time. Thus, subclass 30.6-40.8° and >40.8° were assigned as 4 and 3 respectively.

(c) Aspect

Malaysia is a country with high rainfall intensity. Referring to Matori et al. (2011), the frequency of landslide events is synchronized with rainfall intensity in CH; a high number of landslides were triggered with the increase of rainfall intensity. The weightage assignation of aspect refers to the previous landslide history and indicates the influence of rainfall towards the specific slope facing direction.

(d) Length-slope gradient (LS Factor)

LS Factor defines the soil loss potential regard to the slope length and slope steepness. Greater values of LS Factor indicate higher soil loss potential (Moses, 2017; Taghizadeh-Mehrjardi et al., 2019).

(e) Topography wetness index (TWI)

TWI defines slope runoff propensity. High TWI indicates high runoff propensity due to the large upslope catchment area associated with shallow or insufficient drainage channels (Quinn et al., 1991).

(ii) Grid value reclassification

Every map layer of features in Table 4 was reclassified to the weightage value in Table 5 using module "Grid Value Reclassification" in Saga GIS.

(iii) Grid calculation

These maps were then stacked together to produce a terrain sensitivity map (TSM) by using the following formula adopted from Tas (2016) and Chaudhari et al. (2018).

$$\frac{G1 + G2 + G3 + G4 + G5}{5}$$

Where; symbol "G" represents a single grid layer of terrain features. G1=elevation; G2=slope gradient; G3=aspect; G4=LS Factor; G5=TWI.

The generated TSM was divided into five classes which are (a) very high sensitivity, (b) high sensitivity, (c) moderate sensitivity, (d) low sensitivity, and (e) very low sensitivity. According to the Forest Practices Code of British Columbia (1999),

high-frequency landslides could be expected in areas plotted in sensitivity classes (a) and (b). Mild landslides or a small amount of landslides will be expected in the area plotted in sensitivity class (c) while no landslide will be expected in the area plotted in sensitivity classes (d) and (e).

2.7 Map accuracy assessment

Accuracy assessment was conducted by comparing simulated TSM and the field data obtained from the ground survey. The location of new and former landslides was recorded using Global Positioning System Garmin Montana 610/680.

2.8 Map validation

Accuracy of TSM was calculated based on the formula as follow:

$$Accuracy = \frac{Amount\ of\ landslide\ in\ (a),(b)and\ (c)}{Total\ recorded\ number\ of\ landslide}$$

Table 6. Terrain characteristics of Cameron Highlands

Attribute	Min	Max	Mean	SD
Elevation (m)	765.12	2,053.10	1,452.48	173.19
Slope gradient (°)	0.00	55.91	18.80	7.57
Aspect (°)	0.00	360.00	166.62	98.86
LS factor	0.00	66.51	5.32	2.78
TWI	1.93	22.41	5.55	1.54

The formula was referred to Forest Practices Code of British Columbia (1999), Sharir et al. (2017), and Simon et al. (2017). A study by Battistini et al. (2017) suggested that accuracy assessment or validation of landslide prediction models using geolocalized historical landslide events is possible.

3. RESULTS AND DISCUSSION
3.1 Terrain characteristic of mountainous forest in Cameron Highlands

Table 6 shows the terrain characteristics of mountainous forest in Cameron Highlands (CH). The minimum value (min) represents the lowest point of attribute, while maximum value (max) indicates otherwise. Mean values act as the representative figure of the selected attribute, while standard deviation (SD) represents the level of data dispersion. Figure 3 shows the map layer of selected terrain features, and Table 8 shows the forests' name with the respective code number.

The result indicates that the elevation value on the mountainous forest of CH is 1,452.48±173.19 m. Research by Kalimuthu et al. (2015) stated that more than 70% of CH's historical landslide was located at terrains on elevation higher than 1,200 m. The terrain beyond this point is considered a mountainous zone, and it tends to get unstable (Zainuddin et al., 2016; Azlini et al., 2018a). Thus, terrains in the mountainous forest of CH have high sensitivity in terms of elevation.

Based on Table 6, the slope in CH is considered as low sensitivity at the value of 18.80±7.57°. According to Sabah Environment Protection Department (2012), the threshold gradient for a slope to trigger a landslide is 20°. Thus, even though the slope in CH is relatively low steepness, it is essential to emphasize the total area of the slope that is steep enough to initiate a landslide event. The area coverage of different ranges of slope gradients in mountainous

forests of CH is shown in Table 7. There is 43.23% of the area characterized by a slope gradient of more than 20°. The result shows a similar finding with the research of Azlini et al. (2018b) and Abdullah et al. (2019). These researches stated that CH suited only 30% to 60% of risky slopes that can initiate landslides. The percentage varied due to the different sizes of the study area. Thus, slopes in the mountainous forest of CH are risky in terms of slope gradient.

Table 7. Area coverage of different slope gradient ranges in mountainous forest of CH

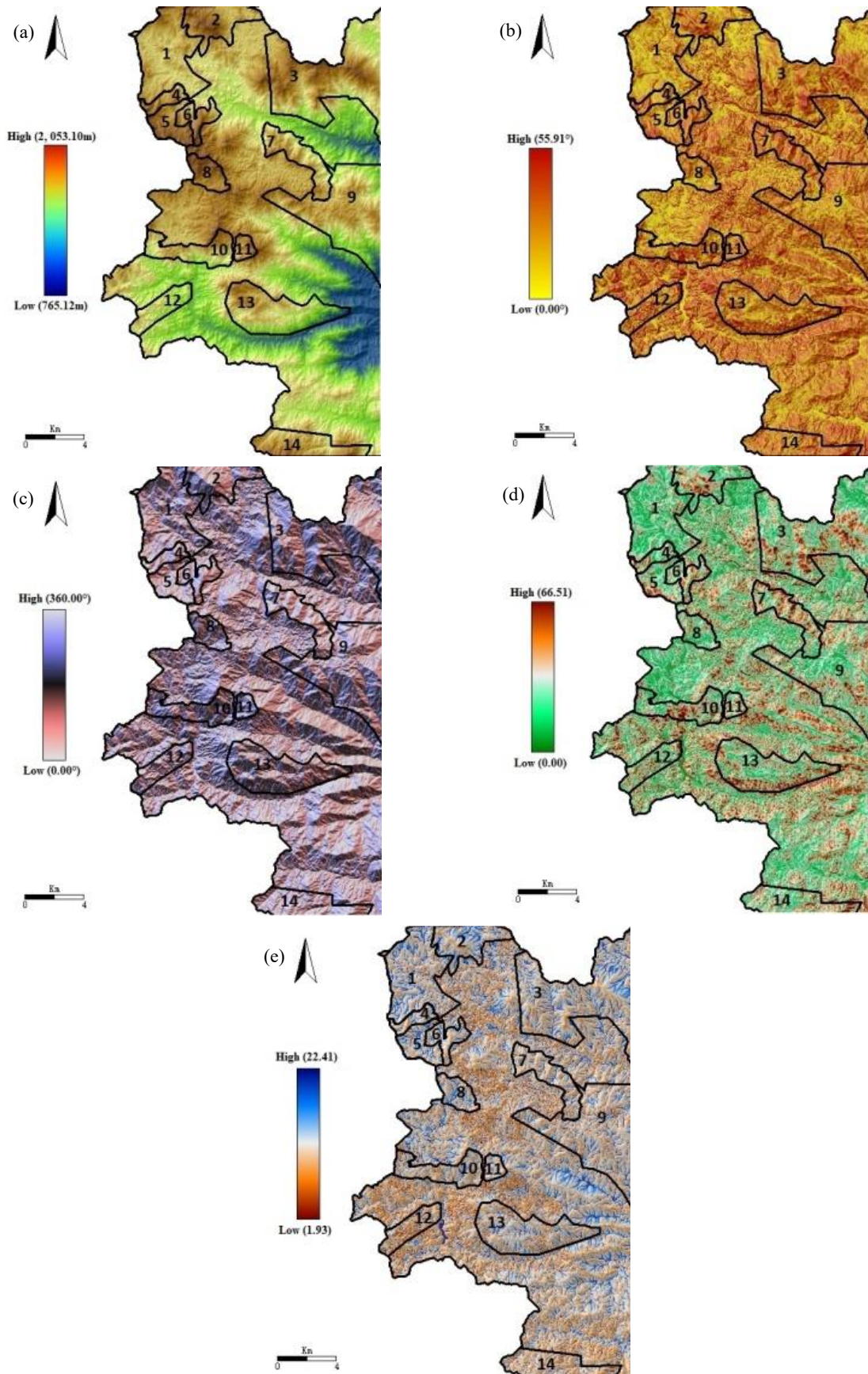| Gradient (°)	Area (km^2)	Percentage (%)
0-10.2	47.60	14.59
10.2-20.4	137.61	42.18
20.4-30.6	123.19	37.76
30.6-40.8	17.45	5.35
>40.8	0.39	0.12

Figure 3. Map layer of (a) elevation, (b) slope gradient, (c) aspect, (d) LS Factor, and (e) TWI of mountainous forest in Cameron Highlands

Table 8. Forest Reserve (FR) in Cameron Highlands with their respective code number as presented in Figure 3.

Code	Forest Reserve (FR)	Code	Forest Reserve (FR)
1	FR Terla	8	FR Hulu Bertam
2	FR Gunung Siku	9	FR Bukit Jerut
3	FR Sungai Wi	10	FR Mentigi
4	FR Hulu ICAT	11	FR Mentigi Tambahan
5	FR Batu Gangan Tambahan	12	FR Ringlet
6	FR Batu Gangan	13	FR Bertam
7	FR Sungai Kial	14	FR Berembum

The mean value of aspect in the mountainous forest of CH is 166.62±98.86° (Table 6). This figure gives generalized information that most of the slope is southward facing. The terrain facing south has high exposure to sunlight since Malaysia is located just above the Earth's equator (Wu et al., 2006; Zakaria et al., 2019). These terrains tend to have relatively dry soil and drought conditions and lead to low vegetation (DeGraff and Romesburg, 1980). However, CH tends to receive a vast amount of rainfall as well. Jerkins (2014) reported that CH would experience 236 days of rain and average 2,852 mm of precipitation annually. Thus, this research assumed that drought and dry soil conditions caused by high sunlight exposure do not affect the terrain sensitivity.

LS Factor reflects the effect of length and steepness of slope towards soil loss. Based on Table 6, LS Factor shows a mean value of 5.32±2.78. According to the research of Mohamed et al. (2012), terrain with LS Factor of more than five is considered as the area with a high risk of slope failure; whereas, an area with LS value of more than ten is considered as a very high-risk area. Thus, mountainous forest in CH has a high risk of soil loss in the LS Factor aspect and deduced that the risk of landslide could be significantly enhanced whenever heavy rainfall is present.

TWI in the mountain forest of CH shows a mean value of 5.55±1.54°. Studies by Acharya et al. (2017) and Pourghasemi et al. (2013) stated that an area would have high water accumulation when its TWI is equal to or more than four, while it will cause a high frequency of landslides when an area is more or equal than seven. The finding suggested that the study area has a risk of landslide in terms of TWI.

3.2 Terrain sensitivity map of Cameron Highlands

The terrain sensitivity map of the mountainous forest in CH is presented in Figure 4. The results suggest that 35.28% (115.09 km^2) of the study area is considered as high sensitivity. Moderate sensitivity area covers 32.95% (107.50 km^2), while low sensitivity area covers 31.77% (103.64 km^2), as shown in Table 9. The result shows no dominant class of sensitivity area in CH. However, Figure 4, Table 10 shows that the high sensitivity area shows scatter distribution. The result is because the mountainous zone is characterized by dynamic landforms such as valleys, open areas, and ridges. Thus, high sensitivity areas are distributed in a sparse manner.
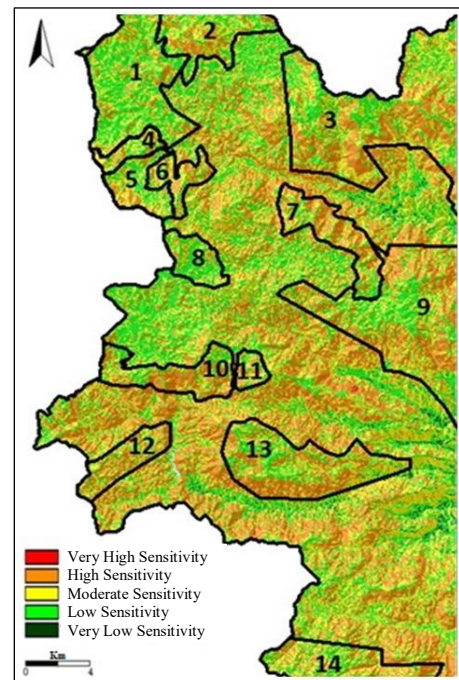

Figure 4. Terrain sensitivity map of mountainous forest in Cameron Highlands

Table 9. Classification of terrain sensitivity in mountainous forest of CH

Classification	Color code	Area (km²)	Percentage (%)
Very low sensitivity	Dark green	0.65	0.20
Low sensitivity	Green	102.99	31.57
Moderate sensitivity	Yellow	107.50	32.95
High sensitivity	Orange	114.31	35.04
Very high sensitivity	Red	0.78	0.24

Table 10. Forest Reserve (FR) in Cameron Highlands with their respective code number as presented in Figure 4.

Code	Forest Reserve (FR)	Code	Forest Reserve (FR)
1	FR Terla	8	FR Hulu Bertam
2	FR Gunung Siku	9	FR Bukit Jerut
3	FR Sungai Wi	10	FR Mentigi
4	FR Hulu ICAT	11	FR Mentigi Tambahan
5	FR Batu Gangan Tambahan	12	FR Ringlet
6	FR Batu Gangan	13	FR Bertam
7	FR Sungai Kial	14	FR Berembum

3.3 Accuracy of terrain sensitivity map

Landslide distribution in the mountainous forest of CH is shown in Table 11. The total number of landslides located within zones of very high sensitivity, high sensitivity, and moderate sensitivity is 42.

Based on the calculation shown in Table 12, the simulated terrain sensitivity map indicated 79.25% accuracy, which is acceptable for the research purpose. The result is similar to the study of Muhammad et al. (2019), who reported that landslide assessment in CH could obtain accuracy as high as 78.0%. The author stated that the accuracy is acceptable and sufficient to be used as a guideline in a landslide mitigation plan. However, to obtain more accurate results, future studies should consider using higher spatial resolution data, with proper algorithms extraction features that may be effective for land use classification in environmental researches, as suggested by Pirnazar et al. (2018).

Table 11. Landslide distribution in different zones of sensitivity of the study area

Terrain sensitivity		Number of recorded landslide (point)
(a)	Very high sensitivity	0
(b)	High sensitivity	37
(c)	Moderate sensitivity	5
(d)	Low sensitivity	11
(e)	Very low sensitivity	0
Total		53

Table 12. Accuracy of terrain sensitivity map

Measure	Attribute
Landslide in zone of (a) + (b) + (c) (unit)	42
Total number of recorded landslide (unit)	53
Accuracy ($\frac{(a)+(b)+(c)}{T} \times 100\%$)	79.25%

Where; (a)=very high sensitivity, (b)=high sensitivity, (c)=moderate sensitivity and, T=total number of recorded landslides.

4. CONCLUSION

This study reveals mountainous forest terrain in CH in terms of elevation, slope gradient, aspect, LS Factor, and TWI. The mountainous forest of CH has a high elevation with a mean value of 1,452.48±173.19 m and 43.23% of the terrain is a steep slope which can easily trigger a landslide. In addition, most of the slopes are southward facing slopes with a mean value of 166.62±98.86°. Moreover, mountainous forests of CH possess a moderate level of soil loss potential (LS Factor) and runoff propensity (TWI) with mean values 5.32±2.78 and 5.55±1.54, respectively. In addition, this study demonstrated a practical application of digital terrain analysis using GIS tools on landslide assessment in the tropical mountainous forests. The simulated terrain sensitivity map shows that the mountainous forest of CH possesses 222.59 km², or 68.23% of the terrain, considered to be landslide-prone. The results showed 79.25% accuracy, which is suggested as acceptable and satisfactory. Due to the forests' complex terrain characteristics, this research highlights an alternative approach that is convenient to

carry out by researchers, forest planners, and decision-makers. In addition, the method provided is cost-effective, less time-consuming, and generates rapid results. The paper also reflects the importance of conserving mountainous forest areas due to the uneven distribution of susceptible areas. Any massive development and construction that might cause irreversible harm to the environment and put tourists, indigenous people, and residents at risk should be avoided.

ACKNOWLEDGEMENTS

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