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# Landslide mapping and characterization for agriculturally intensive mountainous region of Cameron Highlands, Malaysia

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**Abstract:** Relatively cool tropical climate with high annual rainfall experienced in mountainous tropical region creates favorable agricultural areas where intensive agricultural practices often correlate with increasing landslide events. While it has long been associated with landslides, agricultural practice in such areas especially in Cameron Highlands, Malaysia continues to flourish with minimal regard to environmental sustainability and safety. Therefore, this study aims to confirm the relationship between human activities and landslide occurrences and identify human practices that directly or indirectly cause landslides. Aerial photograph was used to identify landslides and anthropogenic features while other remotely sensed data including Interferometric Synthetic Aperture Radar (IFSAR) were used to establish the geomorphology of study area. A total of 207 landslides were identified in a 25 km$^2$ area from remote sensing study and field mapping. They were superimposed over several potential contributing factors including geology, slope gradient and human activities. This study found that landslides are more likely to occur in areas greater than 15° of slope angle. The main factor, however, is the human factor where 164 landslides (79.22% of total identified landslides) were located in agricultural lands. Poorly planned and engineered agricultural farms were identified as the main causal factors for landslide occurrences at the study area, either directly or indirectly. These issues were observed through remote sensing study using aerial photograph which were then verified through site observations. New district development plan called for a stricter regulations in new tourism and agricultural developments. Improvements should also be implemented on existing agricultural activities where most of these landslides were located at this area. Therefore, in addition to controlling new developments, improving of existing agricultural practices in Cameron Highlands shall be a major focus in ensuring slope safety and their sustainability.

**Keywords:** Landslide, Cameron Highlands, agriculture

**Abstrak:** Iklim tropika yang relatifnya sejuk dengan taburan hujan tahunan yang tinggi di kawasan pergunungan tropika membentuk kawasan pertanian yang sesuai di mana praktis pertanian tersebut sering kali dikaitkan dengan peningkatan peristiwa tanah runtuh. Walaupun telah lama dikaitkan dengan tanah runtuh, praktis pertanian di kawasan tersebut khususnya di Cameron Highlands, Malaysia terus berkembang dengan pertimbangan minimum terhadap kelestarian dan keselamatan alam sekitar. Justeru, kajian ini bertujuan untuk mengesahkan hubung kait antara aktiviti manusia dan kejadian tanah runtuh serta mengenal pasti praktis manusia yang secara langsung atau tidak langsung menyebabkan tanah runtuh. Imej fotoudara digunakan untuk mengenal pasti tanah runtuh dan fitur antropogenik manakala data penderiaan jauh yang lain seperti Radar Interferometrik Bukaan Sintetik (IFSAR) digunakan untuk menentukan geomorfologi kawasan kajian. Sejumlah 207 tanah runtuh dikenal pasti daripada kawasan seluas 25 km$^2$ menerusi kajian penderiaan jauh dan pemetaan lapangan. Tanah runtuh tersebut ditindih di atas beberapa faktor penyumbang yang berpotensi termasuk geologi, kecuraman cerun dan aktiviti manusia. Kajian ini mendapati tanah runtuh lebih cenderung untuk berlaku di kawasan dengan sudut cerun melebihi 15°. Namun, faktor utama adalah faktor manusia di mana 164 tanah runtuh (79.22% daripada jumlah tanah runtuh yang dikenal pasti) terletak di dalam tanah pertanian. Ladang pertanian yang tidak dirancang dan direka dengan baik dikenal pasti sebagai faktor penyumbang utama untuk kejadian tanah runtuh di kawasan kajian, sama ada secara langsung atau tidak langsung. Isu-isu tersebut dicerap menerusi kajian penderiaan jauh menggunakan fotoudara yang kemudiannya disahkan menerusi cerapan lapangan. Rancangan tempatan daerah terbaharu mencadangkan peraturan yang lebih ketat untuk pembangunan pertanian dan pelancongan baharu. Penambahbaikan juga perlu dilaksanakan pada aktiviti pertanian sedia ada di mana kebanyakan tanah runtuh terletak di kawasan tersebut. Justeru, sebagai tambahan kepada kawalan terhadap pembangunan baru, membaiki praktis pertanian sedia ada di Cameron Highlands sepatutnya menjadi fokus utama dalam memastikan keselamatan cerun dan kelestariannya.

**Kata kunci:** Tanah runtuh, Cameron Highlands, pertanian

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## INTRODUCTION

Multiple landslide cases over the years in Cameron Highlands, Malaysia have been a major concern for authorities, researchers and local populations as its associated to life and economic loss have been documented frequently. Table 1 shows list of selected major landslide incidences in Cameron Highlands. The landslide occurrences have been extensively studied including its identification and distribution mapping (Jebur *et al.,* 2013), landslide hazard and susceptibility map production (Jasmi Ab Talib & Azlikamil Napiah, 2000; Pradhan & Lee, 2009; Pradhan *et al.,* 2011; Himan Shahabi & Mazlan Hashim, 2015; Tien Bui *et al.,* 2018), and establishing relationship between natural and human causes with landslide incidence (Matori *et al.,* 2011; Haliza & Jabil, 2017).

Poorly controlled and regulated developments especially agriculture in highland areas are among primary factors contributing to numerous cases of landslides in Cameron Highlands (Raj, 2002; Barrow *et al.,* 2009). However, most studies focused on erosion from agricultural areas as main causal factor to landslide incidence (Midmore *et al.,* 1996; Raj, 2002). This study aims to establish the relationship between land use and landslide occurrences and explore potential agricultural related factors that induce landslides in Cameron Highlands.

## METHODOLOGY

In this study, the main focus is on identifying landslide over an area of interest in Cameron Highlands. “Landslide” identified refers to a wide array of mass movements on slope including rock-falls, topples and debris flows, that involve little or no true sliding (Varnes, 1984). Systematic landslide identification and mapping was done based on aerial photographs taken in 2015, and field works in 2018. Aerial photographs were chosen due to availability of relatively high resolution imagery of study area. They are sufficient to capture small to large sized landslides, and suitable photograph scale for identification and visualize geomorphological features associated to landslide events (Guzzetti *et al.,* 2012)

Aerial photographs were retrieved from drone data flown over the study area in 2015. The landslide identification from aerial photograph is based on visible incidences, in which relic or dormant landslide overgrown by vegetations may be missed. Figure 1 shows a typical details of identified visible landslides from aerial photograph study in Cameron Highlands. The tropical nature of study area meant only recent (active, suspended and sometimes dormant) landslides can be seen from aerial photograph due to quick revegetation over time. However, some relic landslides can still be identified from morphology based on recommendations by McCalpin (1984) and Miyagi *et al.* (2004).

Description of each landslide was done based on its type, activity and size. The type and size of landslide was described based on classification by Fell (1994), Varnes & Cruden (1996) and Hungr *et al.* (2014). The activity of landslide is determined based on suggestions by UNESCO Working Party on World Landslide Inventory (1993).

## STUDY AREA

The study area encompasses 25 km$^2$ area of southern Cameron Highlands, Malaysia as shown in Figure 2. Major townships included within study area are Ringlet, Lembah Bertam and Habu. This area is chosen due to their intense agricultural activities, several towns and a number of forested areas. The mixed land-use allows for comparison of landslide occurrence in different land-use settings.

The study area is part of Sungai Bertam river catchment. The river flows downstream from Tanah Rata in north into Lake Ringlet. Lake Ringlet is a man-made lake formed by Sultan Abu Bakar Dam. From the dam, Sungai Bertam flows eastward into Lembah Bertam and subsequently merged into Sungai Jelai, one of Sungai Pahang tributaries.

The geology of the study area is predominantly granite of Triassic Age (Hutchinson, 2009) which is part of Main Range Granite that forms higher part of Peninsular Malaysia. Schist of Paleozoic Age in Cameron Highlands forms as a roof pendant being intruded by granite. Some Quaternary deposit of alluvial and colluvial origins were reported (Zakaria & Chow, 2003) but no systematic mapping of their occurrence was recorded. Figure 3 shows the general geology of Cameron Highlands.

Land use pattern within the study area can be divided into several types; agriculture and forested areas dominated the terrain, townships and residential areas form relatively small clusters, while there is minimally disturbed terrain

**Table 1:** List of selected reported past landslide disasters in Cameron Highlands, Malaysia.

| No. | Date | Disaster Type | Location | Casualties | Source |
|---|---|---|---|---|---|
| 1. | 25/1/2017 | Landslide | Kuala Terla, Cameron Highlands | 1 fatality | (Maharan, 2017) |
| 2. | 29/12/2014 | Landslide | Tringkap, Cameron Highlands | 2 fatalities | (Astro Awani, 2014) |
| 3. | 30/12/2014 | Landslide | Kampung Raja, Cameron Highlands | 1 fatality | (Mynewshub, 2014) |
| 4. | 10/11/2013 | Landslide | Lembah Bertam, Cameron Highlands | 1 injury | (Astro Awani, 2013) |
| 5. | 7/8/2011 | Debris Flow | Sungai Ruil, Cameron Highlands | 6 fatalities | (Utusan Online, 2011) |
| 6. | 1996 | Landslide | Kuala Terla, Cameron Highlands | 3 fatalities | (Chan *et al.*, 2013) |
| 7. | 1995 | Landslide | Cameron Highlands (unspecified location) | 7 fatalities | (Chan *et al.*, 2013) |

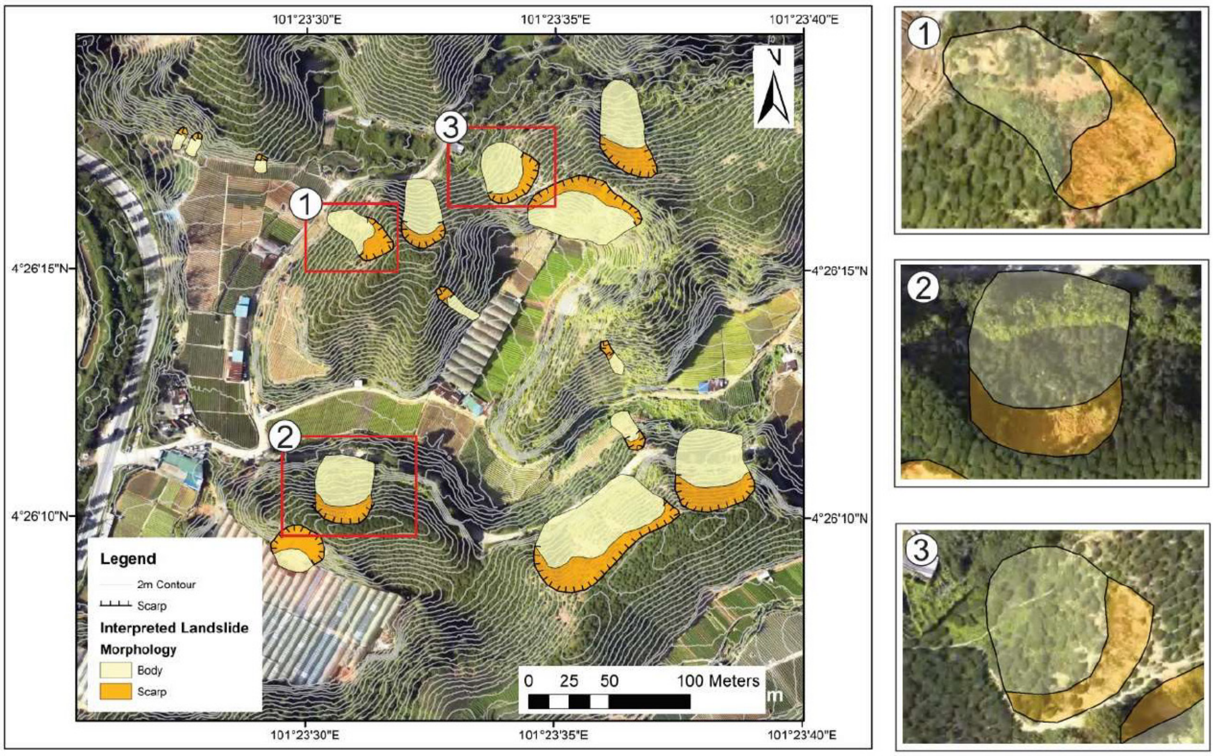



**Figure 1:** A typical details of identified and mapped landslides in a tea plantation area within the study area in Cameron Highlands. (1) is a relatively recent landslide whereas the scarp and the deposit of landslide is still visible. (2) and (3) show relatively older landslides whereas only scarp can be clearly visible. The body, which is poorly consolidated is suitable material for vegetation growth making the vegetation cover thicker. Its extent is identified based on morphology from interpretation and confirmation on site.

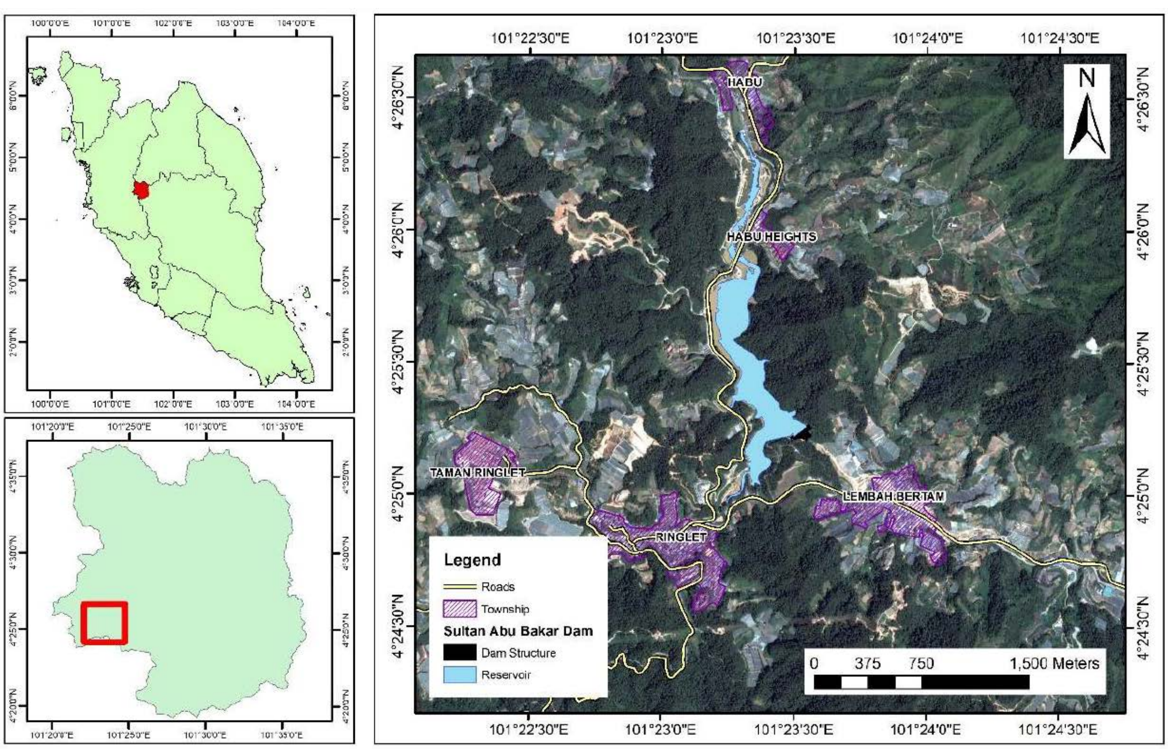



**Figure 2:** The location of Cameron Highlands district within Peninsular Malaysia marked as red (top left), location of the study area (red) within Cameron Highlands district (bottom left), and aerial photograph of the study area (right). The water body at the center is Ringlet Lake, formed by Sultan Abu Bakar Dam.

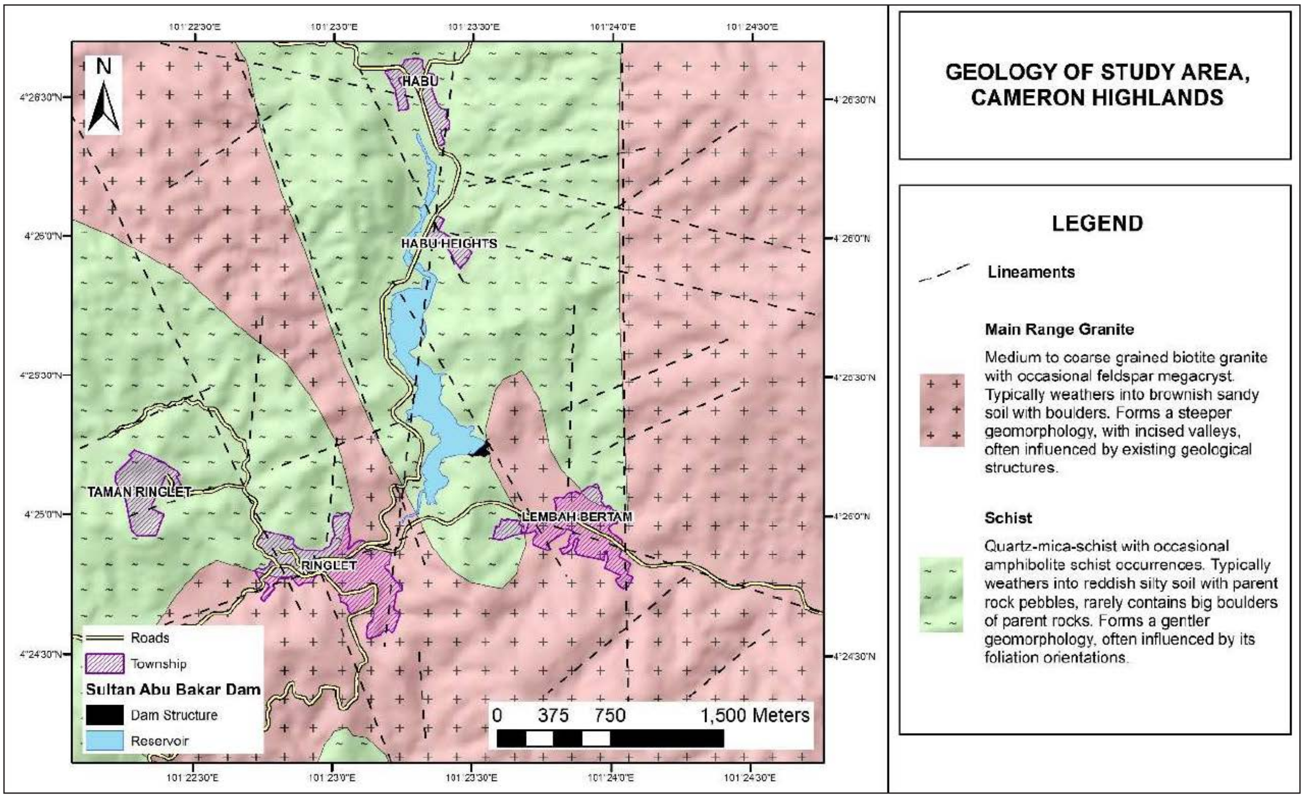



**Figure 3:** Geology of the study area in Cameron Highlands, Malaysia. The main lithologies are granite and schist. Source: Jabatan Mineral dan Geosains Malaysia (2014).

due to land clearing and abandoned farms marked as others. Table 2 shows the area for each land use type within the study area.

## RESULTS

Identified landslides were delineated and confirmed. Prior to establishing the relationship between landslide occurrence with agricultural activity, a landslide inventory was created to systematically record the landslide occurrence.

A total of 207 landslides were identified from aerial photographs. Most of them are accessible for site verification (140 landslides or 67.6%) except for incidence in forested areas, and in areas where public access in private properties were denied (67 landslides or 32.4%). The landslides were spread out within 25 km$^2$ of study area, with notable higher density of landslide occurrence in agricultural areas. An important limitation on aerial photography is its inability to penetrate thick forest canopy, which may reduce the amount of identified landslide within the area.

## LANDSLIDES CLASSIFICATIONS

The landslide type and distribution within the study area were identified. A total of 207 landslide polygons were demarcated. The identified landslides were classified based on materials, movement types and size. Table 3 provides a summary of landslide classifications within this study.

**Table 2:** Area for each land use type within the study area in Cameron Highlands, Pahang.

| Type of Landuse | Area (km$^2$) | Percent Area |
|---|---|---|
| Agriculture | 12.47 | 49.89 |
| Forest | 10.48 | 41.92 |
| Shrubs and partially cleared lands | 0.83 | 3.32 |
| Townships | 0.85 | 3.38 |
| Water body | 0.37 | 1.49 |
| **Total Area** | 25.00 | 100.00 |

### Landslide material

Landslide material within the study area are mostly made of earth. They are highly weathered (Grade IV-V) to completely weathered (Grade VI) soil which are derived from weathering of granite or schist within the study area. Observations on site show that earth materials within the study area are slightly varying based on their parent rock. Weathered materials from granite (highly weathered (Grade IV-V) to completely weathered (Grade VI) materials) are usually described as brownish clayey sand, with rounded boulders (made up of fresh rock (Grade I) to moderately weathered (Grade II-III) rock materials) forming corestones. Weathered materials from schist are brownish-red sandy clay,

**Table 3:** Classification of landslides identified within the study area based on materials, movement (Varnes, 1978; Hungr *et al*., 2014), volume (Fell, 1994), and activity (UNESCO, 1993).

| | | | |
|---|---|---|---|
| **Materials** | | | |
| **Types of materials** | | **No. of landslides** | **Percentage** |
| Earth (Grade IV to VI materials) | | 203 | 98.07 |
| Debris (Boulders, soil, trees and artificial structures) | | 4 | 1.93 |
| Rock | | - | - |
| **Movement** | | | |
| **Types of movement** | | **No. of landslides** | **Percentage** |
| Fall | | - | - |
| Topple | | - | - |
| Sliding | Translational | 23 | 11.11 |
| | Rotational | 154 | 74.40 |
| Flow | | 4 | 1.93 |
| Flow-slide | | 24 | 11.59 |
| Complex | | 2 | 0.97 |
| **Volume** | | | |
| **Range** | **Description** | **No. of landslides** | **Percentage** |
| <500 $m^3$ | Extremely small | 34 | 16.43 |
| 500 – 5,000 $m^3$ | Very small | 101 | 48.79 |
| 5,000 – 50,000 $m^3$ | Small | 53 | 25.60 |
| 50,000 – 250,000 $m^3$ | Medium | 17 | 8.21 |
| 250,000 – 1,000,000 $m^3$ | Medium - large | 2 | 0.97 |
| 1,000,000 – 5,000,000 $m^3$ | Very large | 0 | - |
| >5,000,000 $m^3$ | Extremely large | 0 | - |
| **Activity** | | | |
| **Types of Activity** | | **No. of landslides** | **Percentage** |
| Active | | 21 | 10.14 |
| Reactivated | | 12 | 5.80 |
| Suspended | | 90 | 43.48 |
| Inactive | Dormant | 36 | 17.39 |
| | Abandoned | 17 | 8.21 |
| | Stabilized | 9 | 4.35 |
| | Relict | 22 | 10.63 |

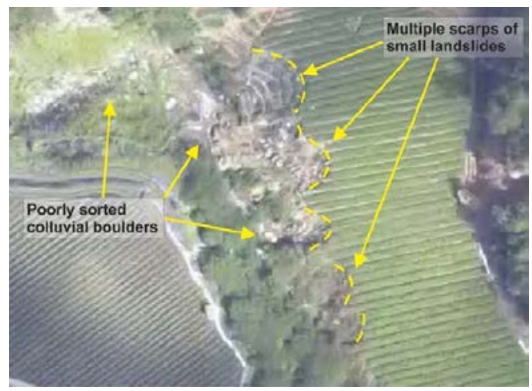
with tabular boulders (made up of slightly to moderately weathered rock (Grade II-III) materials) often present within highly weathered to completely weathered (Grade VI-VI) soil mass. These are the materials observed to form landslides. Grade I-III material failure were not observed, primarily due to lack of exposed rock slopes within study area.

Landslides made of debris were also observed. They usually occurred in fast-moving flows where accumulation of boulders, soil, trees and artificial structures were observed. Earth (Grade IV-VI) material landslides made up 98.07% of total landslides, debris material made up 1.93% of total landslides while no landslides made up of rock. This is due to most landslides being relatively shallow (<5 m depth) and only involve Grade IV-VI materials. Exposed rock slopes within the study area are rare, and all of them were observed stable and hence, no landslide made up of rock materials.

### Movement types

Most identified landslides within the study area can be classified as earth slide, while some developed into flow or flow-slide. Table 4 shows identified landslide type within the study area in Cameron Highlands. Slide type is the most common type, often occurring in weathered soil (Grade IV-VI) while several occurrences were also identified within recent deposits (colluvium). An overwhelming majority of landslides (74.40%) were characterized by rotational

**Table 4:** Types of landslides identified in the study area within Cameron Highlands. The classifications are made based on recommendations by Varnes & Cruden (1996) and Hungr *et al*. (2014).

<table>
<tr><th>Type of movement</th><th>Materials</th><th>Description</th><th>Example with Simplified Sketch</th></tr>
<tr><td rowspan="2">Slide</td><td>Earth<br>(Grade IV-VI material, usually consists of sand, silt and clay)</td><td>Usually rotational, occurring in soil, with speed ranging from fast to slow.</td><td>
</td></tr>
<tr><td>Colluvium<br>(Poorly consolidated mixture of soil and boulder-sized rocks)</td><td>Usually rotational, occurring in gentler colluvial deposit</td><td>
</td></tr>
<tr><td>Flow-slide</td><td>Earth<br>(Grade IV-VI material, usually consists of sand, silt and clay)</td><td>Triggered by landslide upstream, steep topography and heavy rainfall forms it into a flow.</td><td>
</td></tr>
<tr><td>Flow</td><td>Debris<br>(Mix of boulders, soil, trees, and anthropogenic materials)</td><td>Triggered by landslide, or poorly engineered slopes upstream, powered by surge of water during heavy rainfall.</td><td>
</td></tr>
</table>

slide, formed by sliding over a curved failure plane. This is a common failure type, where sliding occurs in almost homogenous materials, often composed of entirely soil material and not influenced by structural geology. 11.11% of observed cases were classified as translational slides, where earth mass simply breaks off the slope and slide along a planar failure plane. This type of failure can be found in very steep slopes where structural geology especially discontinuities plays a role in influencing the failure.

Flow-slides are also common, attributed to steep topographic profile and heavy rainfall often received in the region – making any sliding failure upstream transforms into more fluid flow. They are characterized as very rapid flow of water-saturated granular material on slopes. The landslide deposits are often found at the toe of slope, up to 20 m away from source. Flow-slide accounts for 11.59% of total landslides.

Flow movement is defined as an extremely rapid surging flow of saturated landslide material in a steep channel (Hungr *et al.*, 2014). In the study area, traces of flow movements were observed but uncommon compared to the other types accounting for 1.93%. Another 0.97% of landslides were interpreted to possess complex movement type which involves a combination of more than one type of movement.

### Landslide size (volume)

Classification of landslide sizes by volume was made based on the magnitude of landslide (Fell, 1994) from extremely small (<500 $m^3$) to extremely large (>5,000,000 $m^3$) in terms of volume. This classification is made based on calculations from estimated landslide area and depth. Depth is estimated based on size and landslide type (NIDM, 2012). Based on size, 16.43% of observed landslides were classified as "extremely small", 48.79% as "very small", and 25.60% as "small". These would make a total of 90.82% of landslides classified as "small" (<50,000 $m^3$) or lower. Despite being small in size, these landslides were capable of causing properties destruction especially to infrastructures built close to them.

8.21% of landslides were classified as "medium" (50,000 – 250,000 $m^3$) and another 0.97% as "medium-large" (250,000 – 1,000,000 $m^3$). No landslide classified as "very large" to "extremely large" was observed within the study area.

### Landslide activities

Landslide activities were classified as per recommendations by UNESCO (1993). 10.14% of the landslides were classified as "active" as of during fieldworks. They exhibit signs of constant movements, including recently fallen trees and damaged infrastructures. 5.80% were classified as "reactivated" where new movements occurred on top of old, often much larger, landslide. A large number of observed landslides were considered as "suspended" (43.48%). These landslides were not moving during field observations but were interpreted to move recently (during rainy seasons) and may move again within the next rainy seasons. They are not overgrown by vegetations with relatively fresh landslide deposit.

Another 40.58% of landslides were classified as "inactive". They were interpreted from differences in vegetations, topography and other features associated with landslides. They are made up of "dormant" landslide (17.39%), "abandoned" landslide (8.21%), "stabilized" landslide (4.35%), and "relict" landslide (10.63%). Although they did not exhibit recent movements, these landslides are prone to reactivation upon human interference including land clearance, slope reprofiling and poor drainage managements.

## LANDSLIDES DISTRIBUTION BY POTENTIAL CAUSAL FACTORS

To identify the correlation of landslide occurrence with potential causal factors distribution, the landslides were overlain with geological units, slope gradient, and anthropogenic factors. Then, the landslide density was identified for each causal factor unit. Table 5 shows the number of landslide unit and its density for each contributing factors. Figure 4 shows the distribution of landslides over several contributing factor maps of the studied area.

### Distribution by geological unit

Landslide distribution based on geological lithology shows landslides are slightly more common in area underlain by schist (106 recorded incidence, 51.21% of total number of landslides) compared to granite (101 recorded incidence, 48.79% of total number of landslides). When the comparison is made based on density of landslide per $km^2$, the difference is more notable with more landslides recorded in schist (10.13 landslides/$km^2$) compared to granite (6.95 landslides/$km^2$). This issue may be attributed to different type of weathered material produced by different lithology involved in failure. Schist exhibits schistocity – a weak plane that may transform into potential failure plane even as relic structures in weathered materials.

Another important geological unit present in Cameron Highlands is the Quaternary colluvial deposit. However, lack of mapped extent of colluvial deposit in published geological map (Jabatan Mineral dan Geosains Malaysia, 2014) means establishing the relationship between landslide occurrence and colluvial deposit unfeasible in this study.

### Distribution by slope gradient

A slope gradient map was generated from Interferometric Synthetic Aperture Radar (IFSAR) Digital Elevation Model (DEM). The classification by slope gradient was made based on recommendations in existing terrain mapping guideline by JMG (2010). Range of slope gradient classes are <5°, 5°-<15°, 15°-<25°, 25°-<35°, and >35°.

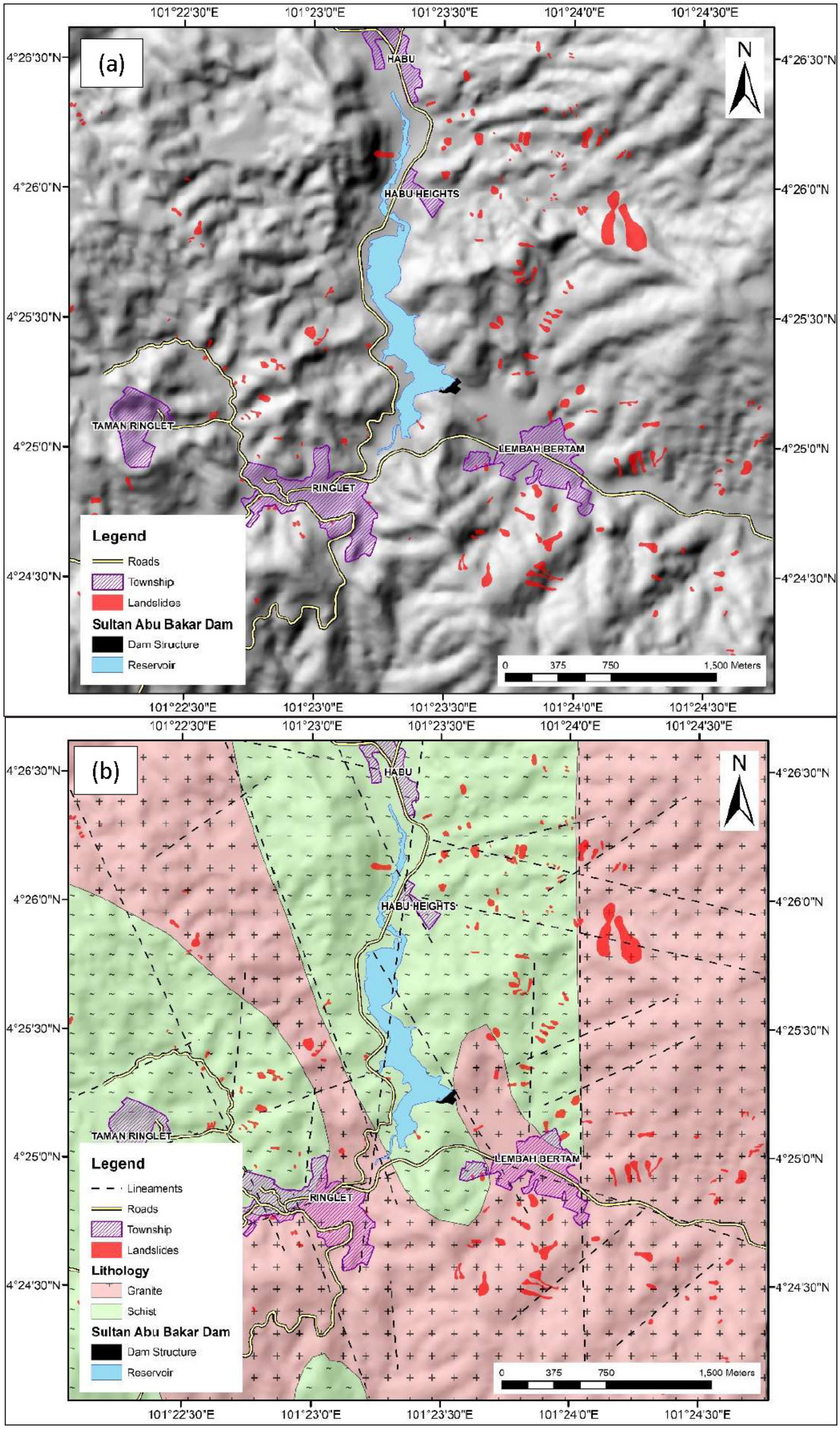



**Figure 4 (a & b):** The distribution of landslide within the study area in Cameron Highlands. (a) is the landslide distribution on the hillshade relief map, (b) shows the landslide occurrence on geological map.

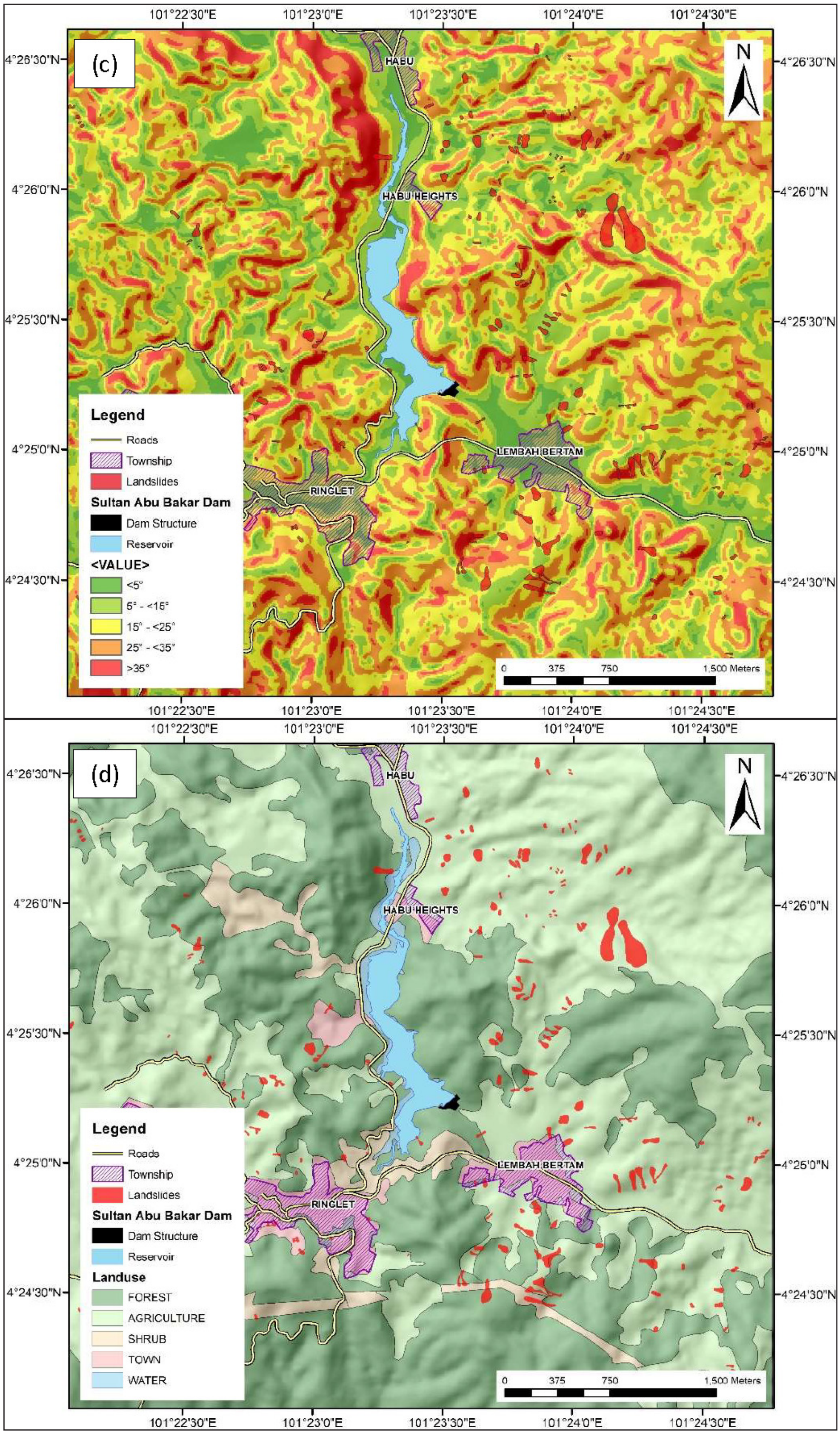



**Figure 4 (c & d) :** The distribution of landslide within the study area in Cameron Highlands. (c) shows the landslide distribution on the slope gradient map, and (d) shows the landslide distribution on the land use map.

**Table 5:** Distribution of landslide based on different categories. The map of landslide distribution is shown in Figure 5.

| **Geology** | | |
|---|---|---|
| **Lithology** | **No. of Landslides** | **Density (No. of unit / km²)** |
| Granite | 101 | 6.95 |
| Schist | 106 | 10.13 |
| **Slope Gradient** | | |
| **Range of slope gradient** | **No. of Landslides** | **Density (No. of unit / km²)** |
| <5° | 1 | 0.45 |
| 5° - <15° | 40 | 6.81 |
| 15° - <25° | 78 | 9.96 |
| 25° - <35° | 59 | 9.32 |
| >35° | 29 | 10.64 |
| **Land-use** | | |
| **Land-use** | **No. of Landslides** | **Density (No. of unit / km²)** |
| Forest | 28 | 2.67 |
| Agriculture | 164 | 13.15 |
| Shrubs and partially cleared land | 10 | 12.05 |
| Townships | 5 | 5.88 |
| Water body | 0 | 0.00 |

For relationship between slope gradient and landslide density, slope gradients less than 5° are almost free of landslide (only 1 case identified). Increasing slope gradient lead to higher landslide density. The difference of density between 15°-<25° (9.96 unit/km$^2$), 25°-<35° (9.32 unit/km$^2$) and >35° (10.64 unit/km$^2$) range classes is relatively small, showing weak correlation in increasing slope gradient with increasing landslides in slopes greater than 15° for the study area.

### Distribution by land use

Relationship between landslide distribution and land use shows a stark difference. Density of landslides in forested area are relatively low (2.67 unit/km$^2$) but this figure increases significantly in agricultural area (13.15 unit/km$^2$) and shrubs / partially cleared land (12.05 unit/km$^2$). This results shows a strong correlation between human activities and landslide density. However, township areas show a relatively lower density (5.88 unit/km$^2$). This phenomenon is attributed to better engineered approach in developing townships compared to poorly engineered slopes for agricultural purposes. The findings call for a more elaborate discussion on relationship between human activities and landslide in the following chapter.

## RELATIONSHIP BETWEEN HUMAN ACTIVITIES AND LANDSLIDE OCCURRENCE

Strong correlation has been found between human activities which are dominated by agricultural activities towards landslide occurrence within the study area at Cameron Highlands. In establishing the relationship between agricultural activities and identified landslides, detailed field observations were made on the landslides to find its causal factor, which often associated with agricultural practice. Field observations on site were made to confirm such relationship derived from aerial photograph interpretation that has been made at earlier stage. Based on aerial photograph interpretation and its verification on site, there are several poor agricultural practices that were identified to cause landslide cases in the study area. Table 6 shows identified agricultural practice that lead to landslides.

Erosion is identified as one of the major human-induced landslide causal factor. Erosion also led to other issues in Cameron Highlands, including silting up of river basins (Raj, 2002). This phenomenon is often observed in agricultural areas, lands cleared for major electricity lines, lands cleared for developments, and abandoned land clearance. Intense rainfall experienced in tropical climate increases surface runoff and exacerbated this issue. Efforts to protect earth surface must be made, especially revegetation of abandoned cleared lands to prevent continuous erosion.

Poor drainage system is another landslide-causing anthropogenic factor. They are often observed in agricultural areas where drainage systems were made without proper engineering design. This leave areas especially near water outlets and drainage leakages to be water-saturated and led to landslides. Poorly engineered slope re-profiling to create arable lands also led to landslide incidents. Overly-steep cut slopes and poorly compacted fill slopes (end-tipping) led to landslide events. These slopes are often poorly engineered without strengthening

**Table 6:** Identified landslides and its relationship with surrounding human (agricultural) practice. The dashed red lines in the attached photograph shows the extent of interpreted landslides.

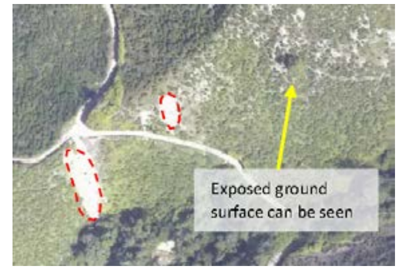
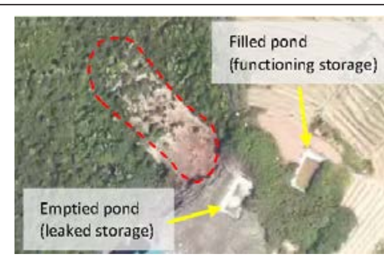
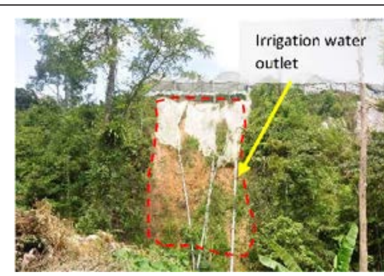
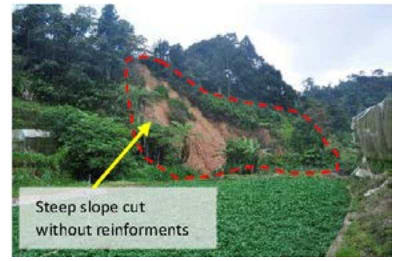
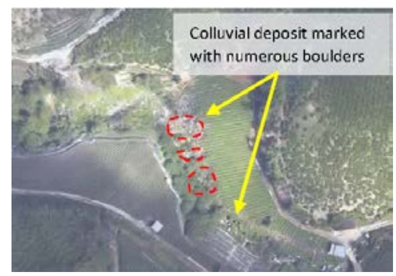
| Causal Factor | Influence contributing towards landslide | Associated agricultural practice | Example |
|---|---|---|---|
| Erosion | Erosion associated with surface water runoff and existing streams carve away portions of soil on slope, creating instability which leads to landslides. | -Sparsely vegetated farmland (relatively sparse compared to tropical rainforest cover) |  |
| | | -Fresh excavation for farming without soil cover / revegetation. |  |
| | | -Abandoned farmland without proper revegetation. |  |
| Poor drainage system | Poor drainage system especially in managing water collection system and outlet from irrigation runoff lead to water saturation in soil triggering landslides. | -Poorly maintained (leaking) water storage system. |  |
| | | -Poorly managed water outlet from irrigation system. |  |
| | | -Surface runoff from rain/ irrigation not managed in a systematic pipe/ drains. |  |

**Table 6 (cont.):** Identified landslides and its relationship with surrounding human (agricultural) practice. The dashed red lines in the attached photograph shows the extent of interpreted landslides.

| | | | |
|---|---|---|---|
| Slope re-profiling | To prepare the land for agricultural activities, original topography needs to be cut / filled. Such slope re-profiling activities without proper engineered approach often lead to failures | - Overly steep cut without any engineered slope reinforcements. |  |
| | | -End tipping (fill) without proper compaction / reinforcements |  |
| Adverse geological conditions | In certain areas, sensitive geological materials and relic landslides were turned into agricultural land, prompting fresh failures on site. | -Sensitive geological deposit (colluvium) turned into agricultural land |  |
| | | -Disturbance of relic landslides for agricultural purposes |  |

structures which are relatively expensive. Landslides were also recorded in agricultural areas developed in adverse geological conditions included colluvial deposit and relict landslides.

Based on observations through aerial photographs and field observations, most landslides caused by agricultural activities can be avoided if they were designed and built with proper engineering considerations. Such considerations include excavation methods, suitable reprofiling to create agricultural space, drainage systems, and methods to reduce erosion. Although such engineering considerations were initially expensive, they can be more cost-effective in longer term, especially curbing landslide events. Such landslide events are often expensive for agricultural farm owner, in terms of property loss, working time loss, and in worst cases, manpower loss.

## REDUCING FUTURE LANDSLIDE RISK IN CAMERON HIGHLANDS

The Department of Town and Country Planning (PLANMalaysia) and Cameron Highlands District Council (MDCH) have published Rancangan Tempatan Daerah Cameron Highlands 2030 (Cameron Highlands District Local Plan 2030). The district council has put forward a development plan with considerations to existing Construction Suitability Map. In the plan, the first "core" (*teras*) is land use planning, disaster risk management and natural environment. Within the plan, the local district council has put forward a stringent procedure for future development procedure with regards to disaster risk management.

The plan also calls for good practice in hillslope developments and implementing low-impact development concept. Under primary industry and sustainable agricultural practice core, the plan also calls for good practice in agricultural lands, implemented as requirements for *"Kebenaran Merancang, KM"* (Planning Permission). Among the requirements are; reducing cut and fill, revegetation of steep slopes and open ground (hydro-seeding), and proper drainage systems.

If implemented, such measures would reduce anthropogenic-caused landslide incidences. The measures should not be limited to future development plan, but also need to be widened to include existing agricultural facilities. The plan also calls for controlled new developments, with designated allowed development areas. As the residence and businesses are located in disaster (especially landslides) prone areas, business continuity plan (BCP) for private businesses and public sector shall be established to increase community resilience towards future disaster.

As for active landslides identified within the study area, landslides which did not immediately threaten any infrastructure generally do not require immediate mitigations. Periodical checks are needed to determine whether it can deteriorate into threatening conditions. If the active landslide threatens infrastructures, immediate mitigation measures must be taken proportionate to the risk posed.

Overall, reducing landslide risk in Cameron Highlands would require improvements in agricultural and development practices to reduce landslide susceptibility. Disaster-resilient communities shall be shaped, aware to the dangers of landslide and living in infrastructures which are less vulnerable to landslide events. It is important to lower landslide risk, without major interference to existing local economic activities and culture.

## DISCUSSIONS AND CONCLUSIONS

This study focuses on a 25 $km^2$ area near Habu, Ringlet and Lembah Bertam township in Cameron Highlands, Pahang. Aerial photograph interpretations and subsequent field confirmations identifies 207 landslides within the study area. There are some limitations to this study. Inaccessibility and dense tropical cover of forested areas may hide more landslide units which are usually visible in less covered agricultural areas. This may lead to bias that may lower the landslide figure in forested area from the actual number. Use of Light Detection and Ranging (LiDAR) capable of penetrating the tree cover may be able to bridge the information gap inside forested areas.

Classifications made found out that the landslide materials are predominantly soil (98.07%) while majority of them exhibit rotational sliding (74.40%). Vast majority of landslides were also classified as "small" or lower (<50,000 $m^3$) accounting for 90.82% of total observed landslides. Landslide activity classification shows a varying landslide activity status, with "suspended" classification accounts for the highest number of landslide (43.48%). The creation of landslide inventory and its classifications allows for a more accurate identification with its potential causal factors.

Geological unit plays a marginal role in influencing landslide occurrence, with landslide density is slightly higher in schist areas compared to granite areas. Slope gradient influences landslide occurrence too where majority of landslides occur in areas >15° in slope gradient. Differences in landslide density in steeper gradients are less obvious, potentially due to interference from other landslide causal factors.

This study found a strong correlation between human activities and landslide occurrence within the study area at southwestern Cameron Highlands, Pahang, Malaysia. The correlation is made with a distinct difference of landslide density in agricultural land compared to forested area. Furthermore, a detailed observation found out the direct link between agricultural activity with landslide event, often directly attributed to poor agricultural practice. Therefore, instead of focusing the landslide assessment entirely on natural terrain hazards, attention must be given to agricultural practice in this region to minimize contribution towards landslide event. "Cameron Highlands District Local Plan 2030" published by PLANMalaysia and MDCH shall serve as the basis for future good practice in agriculture and developments. Sustainable development with good practice with regards to hillslope developments will gradually reduce landslide risk associated with human activities in Cameron Highlands.

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## AUTHOR CONTRIBUTIONS

AF conducted the interpretation and mapping of landslide with guidance from ARJ. AF also conducted the landslide classifications and distributions. ARJ advised with the relationship establishment and manuscript writing. All writing and interpretations were done with review by ZM.

## CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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