# APPLICATION OF UAV-BASED LIDAR FOR IDENTIFYING LANDSLIDE AND EROSION AREAS AT CANADA HILL, MIRI, SARAWAK, MALAYSIA

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**Key Words:** LiDAR, Digital Terrain Model (DTM), landslides, erosion

## SUMMARY

Landslides and surface erosion are common geomorphological processes in tropical regions characterized by steep terrain, intense rainfall, and expanding urban development. In Malaysia, hilly urban environments are particularly susceptible due to dense vegetation, slope modification, and limited accessibility for conventional field investigations. This study evaluates the application of UAV-based Light Detection and Ranging (LiDAR), integrated with high-resolution RGB imagery, for identifying and characterizing landslides and erosion at Canada Hill (Bukit Kanada), Miri, Sarawak.

A UAV LiDAR survey was conducted using a WingtraOne Gen II platform to acquire dense three-dimensional point cloud data over approximately 2 km² of hilly terrain. The LiDAR data were processed to generate a high-resolution Digital Terrain Model (DTM) representing bare-earth morphology beneath dense tropical vegetation. High-resolution RGB imagery was acquired concurrently to produce an orthophoto for surface interpretation and validation. Terrain derivatives, including slope and drainage networks, were derived from the DTM to support geomorphological analysis.

The LiDAR-derived DTM successfully resolved micro-topographic features associated with slope instability, including scarps, slope breaks, hummocky terrain, and incised erosion channels. Integration with orthophotos improved interpretation of surface conditions, while cross-section analyses provided quantitative evidence of slope deformation and erosion processes. These results demonstrate that UAV LiDAR is highly effective for site-scale identification of landslides and erosion in vegetated urban hills where optical imagery alone is insufficient.

Multi-temporal terrain analysis was performed by comparing the UAV LiDAR-derived DTM with a pre-existing DTM from 2011. The resulting DTM of Difference (DoD) revealed spatially variable elevation changes, highlighting zones of erosion, deposition, and relative terrain stability. Overall, the study confirms that UAV LiDAR provides a robust framework for slope assessment, terrain monitoring, and geomorphological analysis in tropical urban environments.
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## 1. INTRODUCTION

Landslides and surface erosion represent persistent geohazards in tropical regions characterized by steep terrain, intense rainfall, and rapid land-use change. In Malaysia, slope instability is a recurring issue in hilly and urbanized environments, where natural geomorphological processes are often exacerbated by anthropogenic activities such as slope cutting, drainage modification, and vegetation removal. Accurate identification and characterization of landslides and erosion features are therefore critical for hazard assessment, land-use planning, and slope management. Conventional approaches for landslide and erosion mapping, including field surveys and interpretation of aerial or satellite imagery, are often limited by accessibility, vegetation cover, and spatial resolution. In densely vegetated tropical environments, optical imagery alone may fail to capture subtle geomorphological indicators such as scarps, tension cracks, and shallow failures concealed beneath forest canopies. Moreover, medium- to low-resolution digital elevation models (DEMs), commonly derived from satellite data, are often insufficient to resolve the micro-topographic features required for detailed slope instability analysis.

Recent advances in unmanned aerial vehicle (UAV)–based remote sensing have significantly improved the ability to acquire high-resolution topographic data at site scale. In particular, UAV-mounted Light Detection and Ranging (LiDAR) systems provide dense three-dimensional point clouds with the capability to partially penetrate vegetation, enabling the generation of high-resolution Digital Terrain Models (DTMs) that more accurately represent the bare-earth surface. When combined with high-resolution RGB imagery, UAV LiDAR offers a powerful framework for integrating quantitative terrain analysis with visual interpretation of surface features, thereby enhancing the detection and mapping of landslides and erosion.
Canada Hill (Bukit Kanada), located in Miri, Sarawak, represents a geomorphologically sensitive area where steep slopes, tropical rainfall, and ongoing urban and recreational land use contribute to slope instability and surface degradation. The area has experienced visible signs of erosion and slope movement, making it an appropriate site for evaluating the effectiveness of high-resolution UAV-based terrain mapping techniques. Despite its significance, detailed site-scale studies employing UAV LiDAR for landslide and erosion identification in this region remain limited.

This study aims to evaluate the application of UAV-based LiDAR integrated with high-resolution RGB imagery for identifying and characterizing landslides and erosion at Canada Hill, Miri. Specifically, the objectives are to (i) generate a high-resolution LiDAR-derived DTM capable of resolving micro-topographic features in a vegetated, hilly environment; (ii) identify and map landslide and erosion features using terrain derivatives, orthophotos, and cross-sectional analyses; and (iii) assess terrain changes through comparison with a pre-existing DTM acquired in 2011 to highlight areas of elevation loss and accumulation. By demonstrating the effectiveness of UAV LiDAR for site-scale geomorphological analysis, this study contributes to improved landslide assessment and slope management practices in tropical urban environments.

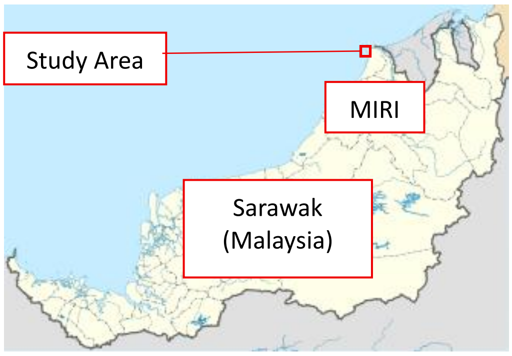
## 2. STUDY AREA

The study area is located at Canada Hill (Bukit Kanada) in Miri, Sarawak, Malaysia, covering approximately 2 km² of hilly terrain (**Figure 1**). Canada Hill is a prominent topographic feature within the urban setting of Miri and is characterized by steep slopes, dissected terrain, and mixed land use, including recreational areas, infrastructure, and vegetated slopes. Its proximity to urban development and public facilities makes slope stability and surface erosion key concerns for land management and hazard mitigation.

Topographically, the area exhibits moderate to steep slopes, with pronounced ridgelines and incised drainage channels that facilitate surface runoff concentration. These terrain characteristics, combined with tropical climatic conditions, create a geomorphological setting that is highly susceptible to erosion and slope instability. Subtle micro-topographic features such as scarps, shallow depressions, and irregular slope profiles are present but are often obscured by dense vegetation cover.

The climate of Miri is humid tropical, with consistently high temperatures and intense rainfall events throughout the year, particularly during the monsoon seasons. Prolonged and high-intensity rainfall is a major triggering factor for landslides and erosion processes in the area, promoting soil saturation, reduction in shear strength, and increased surface runoff. These conditions contribute to both shallow slope failures and progressive erosion along hillsides and drainage pathways.

Vegetation within Canada Hill consists predominantly of dense tropical cover, including secondary forest and managed greenery associated with recreational and urban landscapes. While vegetation provides some degree of slope protection, it also limits the effectiveness of conventional optical remote sensing techniques for terrain analysis. As a result, the accurate identification of bare-earth morphology and subtle deformation features requires remote sensing approaches capable of penetrating vegetation cover.
Canada Hill has shown visible signs of surface erosion, slope modification, and localized landslide activity, particularly in areas influenced by human intervention such as cut slopes, pathways, and drainage structures. These conditions make the site particularly suitable for evaluating the capability of UAV-based LiDAR and high-resolution imagery to capture detailed terrain morphology, identify landslides and erosion features, and assess terrain changes over time through multi-temporal DTM comparison.



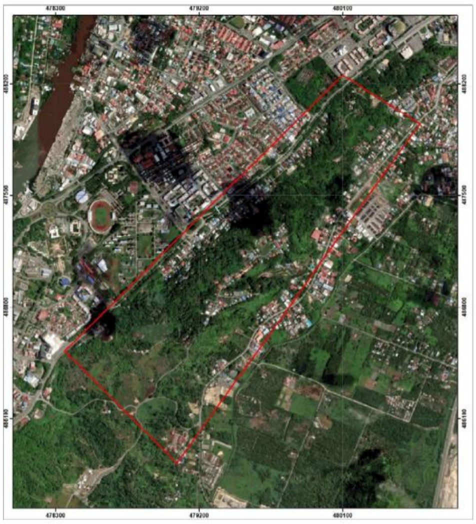



**Figure 1:** Location of the Study Area - Canada Hill, Miri, Sarawak, Malaysia

## 3. MATERIALS AND METHODS

### 3.1 UAV Platform and Sensor Configuration

Data acquisition was conducted using a WingtraOne Gen II VTOL fixed-wing UAV, selected for its ability to operate safely in urban and hilly terrain while maintaining high positional accuracy and survey efficiency. The platform was equipped with two complementary sensors operated in separate missions: (i) a survey-grade UAV LiDAR system for terrain mapping and (ii) a 42 MP high-resolution RGB camera for orthophoto generation and visual interpretation. The LiDAR system integrates a laser scanner with an onboard GNSS/IMU unit, enabling direct georeferencing of the point cloud. The system is capable of recording multiple returns, allowing partial penetration through dense tropical vegetation and facilitating the extraction of ground points for Digital Terrain Model (DTM) generation. The RGB camera data were acquired to provide detailed surface context and support geomorphological interpretation of landslide and erosion features identified from the LiDAR-derived terrain products.

### 3.2 Flight Planning and Data Acquisition

Flight planning was performed using WingtraHub (v2.18.0), with survey parameters optimized separately for the RGB and LiDAR missions to meet their respective data quality requirements (**Figure 2 & 3**).

#### 3.2.1 RGB Photogrammetry Flight

The RGB mission was designed to generate high-resolution orthophotos covering the entire Canada Hill study area. Key parameters included:

- Terrain following: enabled
- Flight altitude: approximately 120 m above ground level (AGL)
- Ground sampling distance (GSD): ~1.6 cm/pixel
- Front overlap: 70%
- Side overlap: 70%

- Flight directions: multiple orientations to improve image geometry and reduce shadow effects

These settings ensured sufficient image overlap and spatial resolution for accurate orthophoto generation and visual identification of surface features such as scarps, erosion channels, and disturbed ground.

### 3.2.2 LiDAR Flight

A separate LiDAR mission was conducted over the same area to ensure optimal point density and terrain representation. The LiDAR flight parameters were as follows:

- Terrain following: enabled
- Flight altitude: approximately 90 m AGL
- Average point density: ~55 points/m²
- Side overlap: 70%
- Multiple flight lines: including different orientations to minimize terrain shadowing and improve ground point distribution

The lower flight altitude and high overlap were selected to enhance point density and ensure reliable ground returns in steep and vegetated sections of the study area.

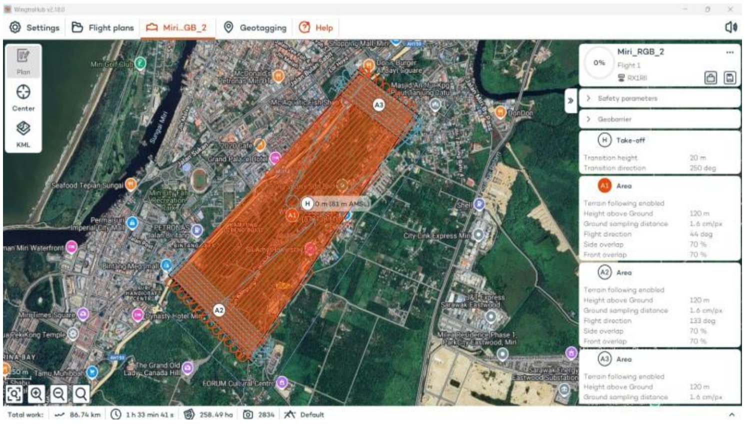



**Figure 2:** Flight Plan for RGB Photogrammetric Flight

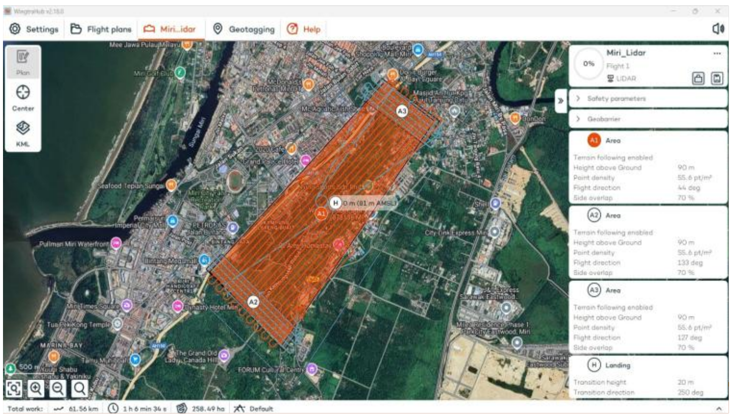



**Figure3:** Flight Plan for LiDAR Data Acquisition

### 3.3 LiDAR Data Processing and Point Cloud Classification

Raw LiDAR data were processed by integrating laser range measurements with GNSS/IMU trajectory data to produce a georeferenced three-dimensional point cloud. Initial processing included noise filtering to remove outliers and non-physical returns. The processing employed the usage of Global Mapper v26.2

Ground point classification was carried out using progressive filtering techniques suitable for steep and vegetated terrain. Particular attention was given to areas with abrupt slope changes, such as landslide scarps and erosion gullies, to avoid misclassification and over-smoothing of critical geomorphological features. Manual inspection and localized refinement of ground classification were performed where necessary to preserve terrain discontinuities relevant to slope instability analysis.

### 3.4 Digital Terrain Model (DTM) Generation

A **high-resolution Digital Terrain Model (DTM)** was generated using only the classified ground points. Interpolation was performed using a triangulated irregular network (TIN)–based approach, which is well suited for preserving terrain breaks and steep slopes.

The final DTM was produced at a spatial resolution of 0.2–0.5 m, balancing point density, terrain complexity, and noise reduction. Minimal smoothing was applied to retain micro-topographic features such as shallow depressions, scarps, and small erosion channels that are indicative of landslide and erosion processes.

### 3.5 Orthophoto Generation

RGB images acquired during the photogrammetry mission were processed using a standard Structure-from-Motion (SfM) workflow to generate an orthophoto mosaic. The orthophoto was co-registered with the LiDAR-derived DTM to ensure spatial consistency between datasets. This integration enabled combined analysis of terrain morphology and surface characteristics, enhancing confidence in the identification and interpretation of landslide and erosion features.

### 3.6 Terrain Analysis and Feature Identification

DTM-derived terrain parameters were computed to support landslide and erosion mapping, including:

- Slope gradient
- Curvature (profile and plan)
- Hillshade and shaded relief
- Flow direction and flow accumulation

These derivatives were analysed together with the orthophoto to identify landslide features such as head scarps, displaced material, and hummocky terrain, as well as erosion features including gullies, rills, and incised drainage paths.

### 3.7 Cross-Section Analysis

Topographic cross-sections were extracted from the DTM across selected landslide bodies and erosion channels. These profiles were used to quantify slope geometry, identify scarp heights, and examine changes in slope morphology. Cross-sectional analysis provided additional evidence of slope instability and erosion processes that are not always apparent in plan-view representations.

### 3.8 Multi-Temporal DTM Comparison

To assess terrain change over time, the UAV LiDAR–derived DTM was compared with a pre-existing DTM from 2011 covering the same area. The two DTMs were co-registered to a common coordinate system and resolution prior to analysis. A DTM of Difference (DoD) was generated to identify areas of elevation loss and gain, allowing detection of material removal, accumulation, and progressive slope modification associated with landslide and erosion activity.

## 4. RESULTS

### 4.1 LiDAR Point Cloud Characteristics and Ground Representation

The UAV LiDAR survey over Canada Hill, Miri produced a dense three-dimensional point cloud covering the entire study area, capturing both terrain and surface features across steep and vegetated slopes. (**Figure 4**) The point cloud exhibits continuous spatial coverage with minimal data gaps, reflecting the effectiveness of the flight design, terrain-following configuration, and high side overlap employed during data acquisition. The LiDAR data clearly resolve variations in land cover, including dense vegetation, built-up areas, road networks, and open ground. Despite extensive tropical vegetation, the point cloud contains a sufficient number of ground returns beneath canopy cover, enabling reliable separation of ground and non-ground points. This is particularly evident in forested sections of the hill where vegetation density would otherwise obscure terrain features in optical imagery alone.

Vertical continuity within the point cloud allows clear differentiation between canopy layers, built structures, and the underlying terrain surface. In urbanized portions of the study area, buildings and infrastructure are well defined, while in vegetated slopes the point cloud demonstrates penetration through foliage to capture ground elevations along ridgelines, hillslopes, and drainage paths. These characteristics are critical for generating an accurate Digital Terrain Model (DTM) in complex terrain.

The overall quality of the point cloud confirms that the selected LiDAR flight parameters—namely low flight altitude, terrain-following mode, and high overlap—were effective in achieving the point density and ground point distribution required for detailed geomorphological analysis. The resulting dataset provides a robust foundation for ground classification, DTM generation, and subsequent identification of landslides and erosion features within the study area.

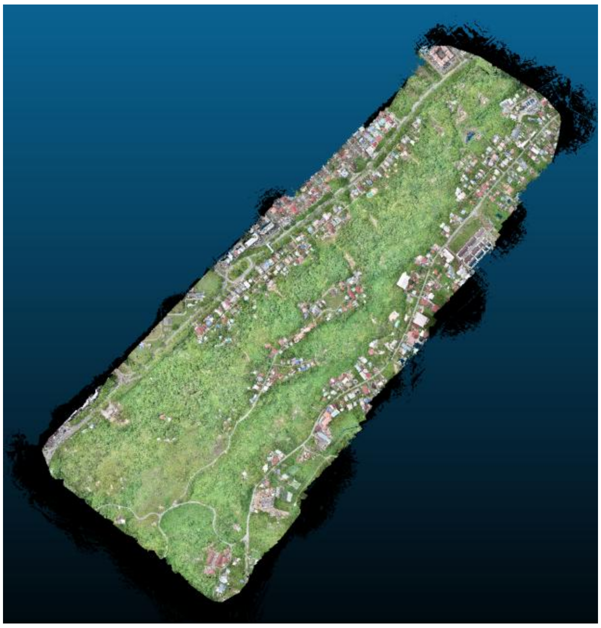


**Figure 4:** Classified UAV LiDAR point cloud

### 4.2 High-Resolution Digital Terrain Model and Terrain Representation

The LiDAR-derived Digital Terrain Model (DTM) (**Figure 5**) provides a detailed representation of the bare-earth surface across the Canada Hill study area, successfully resolving terrain variability despite dense vegetation cover. The DTM captures the elongated ridge morphology of Canada Hill, with elevated terrain forming a continuous crest and progressively lower elevations extending downslope toward the surrounding urban and low-lying areas.

The terrain model clearly delineates steep slopes along the flanks of the hill, as well as gentler gradients in localized depressions and valley-like features. Subtle variations in elevation are evident along hillsides, reflecting micro-topographic expressions such as shallow scarps, concave slope segments, and small incised channels. These features are not readily identifiable from optical imagery alone but are distinctly preserved in the LiDAR-derived terrain surface.

Comparison with the orthophoto highlights the advantage of the DTM in isolating ground morphology beneath dense tropical vegetation. While the orthophoto shows continuous canopy cover across much of the study area, the DTM reveals underlying slope breaks, linear depressions, and irregular surface textures that are indicative of geomorphological processes. In built-up areas, the removal of structures during ground classification results in a smooth yet topographically consistent surface, allowing the terrain to be analysed independently of anthropogenic features.

The color-coded elevation representation further emphasizes relative height differences across the study area, with higher elevations concentrated along the central ridge and lower elevations toward the periphery. This elevation contrast supports subsequent derivation of slope, curvature, and hydrological parameters, which are critical for identifying zones susceptible to landslides and surface erosion.

Overall, the high spatial resolution and continuity of the DTM demonstrate that the UAV LiDAR survey successfully captured the terrain complexity of Canada Hill. The quality of the DTM provides a reliable foundation for landslide identification, erosion mapping, cross-sectional analysis, and multi-temporal terrain comparison presented in the following sections.

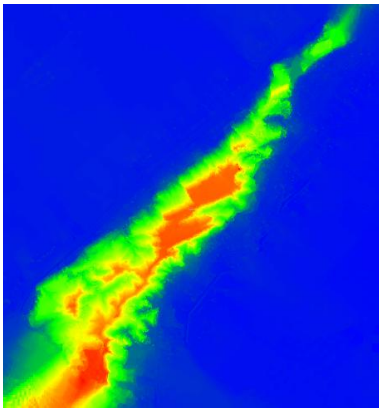


**Figure 5:** LiDAR-derived Digital Terrain Model (DTM)

**4.3 Identification of Landslides Using LiDAR-Derived DTM and Orthophoto**

The integration of the DTM (**Figure 5)** with the high-resolution orthophoto (**Figure 6:** High-resolution Orthophoto) enabled the identification of landslide features across the Canada Hill study area. While the orthophoto provides detailed visual information on land cover and surface conditions, the DTM reveals the underlying terrain morphology that is essential for detecting slope failures, particularly in densely vegetated areas. Several zones exhibiting geomorphological characteristics consistent with landslide activity were identified from the DTM. These include distinct slope breaks, arcuate and linear scarps, uneven and hummocky surface textures, and localized depressions indicative of displaced material. In many cases, these features are subtle or entirely obscured in the orthophoto due to continuous vegetation cover, highlighting the advantage of LiDAR-based terrain representation for landslide detection in tropical environments.

The orthophoto was used to corroborate DTM-based interpretations by identifying surface expressions associated with instability, such as exposed soil patches, disrupted vegetation patterns, bare-earth scars, and alignment of downslope disturbances. In areas where vegetation regrowth has occurred, the orthophoto alone does not clearly indicate slope failure; however, the DTM reveals persistent terrain irregularities that suggest past or ongoing landslide processes. Landslide features were most commonly observed along steep hillslopes adjacent to drainage pathways, road cuts, and areas of slope modification. These locations exhibit a combination of steep gradients and disrupted terrain geometry, consistent with zones of increased susceptibility to slope failure. The spatial correspondence between DTM-derived slope breaks and orthophoto-observed surface disturbances strengthens the interpretation of these features as landslides rather than natural undisturbed slopes.

Overall, the combined use of the DTM and orthophoto allows for more reliable identification of landslides than either dataset alone. The DTM provides objective, quantitative evidence of terrain deformation, while the orthophoto offers contextual information on surface conditions and land use. This integration improves confidence in landslide mapping in landslide mapping in vegetated, urban hill environments such as Canada Hill.

**Figure 6:** High-resolution Orthophoto

**4.4 Erosion Features and Drainage-Controlled Terrain Modification**

The LiDAR-derived DTM enabled detailed mapping of surface drainage patterns and erosion-related terrain modification across the Canada Hill study area. **Figure 7** shows the topography and drainage map reveals a well-defined elongated ridge, with elevations increasing toward the central crest and decreasing toward the surrounding lowlands. This elevation gradient strongly controls surface runoff pathways and erosion processes. (Figure

Dense drainage networks are observed along the flanks of the hill, particularly in areas with moderate to steep slopes. These drainage lines correspond to zones of concentrated surface runoff and are closely associated with incised channels and erosional features. The high drainage density visible in the DTM-derived network indicates efficient runoff routing, which promotes soil removal and channel deepening during intense rainfall events.

Erosion features are most pronounced along the mid- to lower-slope sections, where multiple small channels converge downslope into larger drainage paths. These areas exhibit irregular terrain textures and localized elevation lowering, consistent with active or progressive erosion. In contrast, the ridge crest exhibits comparatively lower drainage density and smoother terrain, suggesting more stable surface conditions.

The spatial correspondence between steep elevation gradients and dense drainage patterns highlights the role of topography in governing erosion processes at Canada Hill. In several locations, noticeable alignment between drainage pathways and anthropogenic features such as roads and cleared areas can be observed, indicating that surface modification may influence runoff concentration and erosion development.

Overall, the DTM-derived drainage network provides clear evidence of terrain modification driven by surface runoff and erosion. These features, when analysed together with landslide-related terrain deformation, demonstrate that slope instability at Canada Hill is influenced by the combined effects of topography, drainage concentration, and surface disturbance.

**4.5 Cross-Section Analysis of Landslides and Erosion Features**

Topographic cross-sections extracted from the LiDAR-derived DTM provide detailed insight into slope geometry and surface deformation across selected landslide and erosion-affected areas at Canada Hill. The profiles capture elevation changes along transects that intersect identified slope instability features, enabling quantitative assessment of terrain modification that is not readily apparent in plan-view representations.

The cross-sections reveal distinct slope breaks and localized steepening associated with landslide scarps and erosion zones. In several profiles, abrupt changes in gradient are observed upslope, corresponding to head scarp locations, followed by irregular and undulating slope surfaces downslope that are characteristic of displaced or reworked material. These features indicate active or past slope movement and surface disturbance.

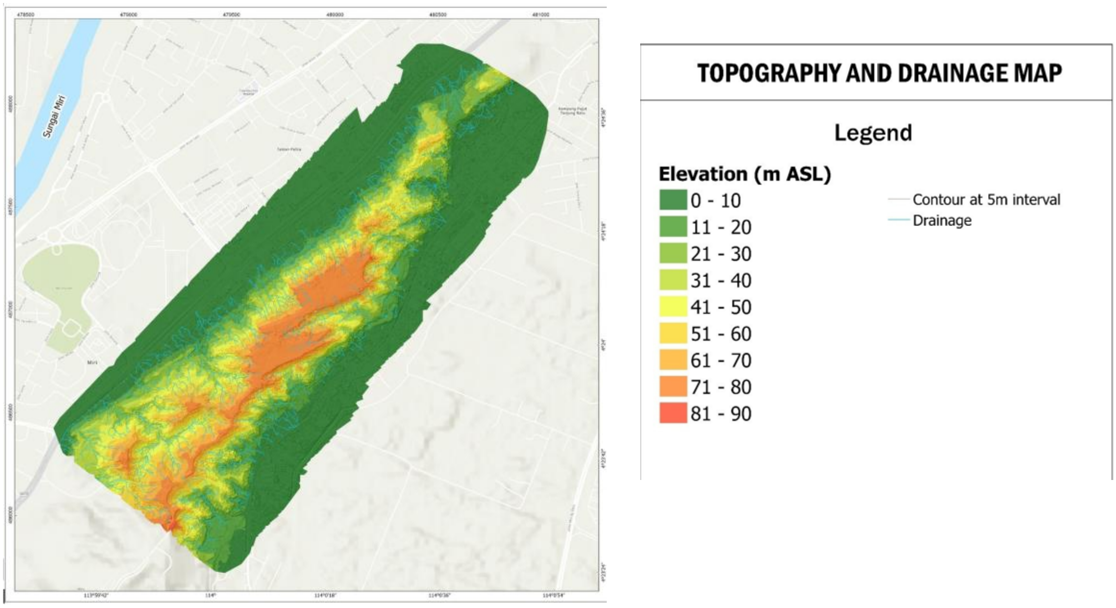



**Figure 7:** Topography and drainage map derived from the LiDAR DTM, highlighting elevation classes and surface drainage networks.

Comparison between terrain segments along the same profile shows clear differentiation between relatively stable sections and zones affected by erosion or landslide activity. Stable areas generally exhibit smooth, near-linear slope profiles, whereas unstable sections display concave or stepped morphologies, reflecting material removal and redistribution. In profiles intersecting erosion channels, localized incision is evident, with depressions and lowered elevations marking the position of concentrated runoff paths.

The inclusion of field photographs along selected profiles provides visual confirmation of DTM-derived interpretations. Exposed soil surfaces, shallow failures, and eroded channels observed in the field correspond spatially with zones of elevation change and slope irregularity identified in the cross-sections. This correspondence demonstrates the reliability of the LiDAR-derived DTM for capturing real ground conditions beneath vegetation cover.

Overall, the cross-section analysis confirms that the UAV LiDAR-derived DTM successfully resolves micro-topographic expressions of landslides and erosion at Canada Hill. The profiles complement plan-view terrain analyses by providing quantitative evidence of slope deformation, demonstrating the value of cross-section-based assessment for understanding slope instability processes in hilly, vegetated environments.

**4.6 Multi-Temporal Terrain Change Detection (2011 DTM vs UAV LiDAR DTM)**

Multi-temporal terrain change detection was performed by comparing the LiDAR-derived Digital Terrain Model (DTM) with a pre-existing DTM acquired in 2011. The resulting DTM of Difference (DoD) highlights spatial patterns of elevation change, enabling identification of areas affected by erosion, deposition, and relative terrain stability.

The results indicate widespread but spatially variable terrain modification across Canada Hill. Areas of elevation loss are predominantly distributed along steep hillslopes and drainage pathways, reflecting active erosion and slope degradation processes. These zones often coincide with locations where landslide-related terrain deformation was identified from DTM morphology and cross-section analysis.

Conversely, areas of elevation gain are concentrated in downslope and lower-lying sections of the study area, indicating zones of material accumulation. The juxtaposition of erosion and deposition patterns demonstrates ongoing sediment redistribution within the hill system.

The DoD analysis confirms that geomorphological processes at Canada Hill are active and persistent rather than isolated events. The ability of UAV LiDAR to detect subtle elevation changes relative to historical terrain data highlights its effectiveness for monitoring slope deformation and erosion in vegetated and urban hill environments.

Overall, the multi-temporal DTM comparison provides quantitative evidence of ongoing geomorphological change at Canada Hill. The ability of UAV LiDAR to detect subtle elevation differences relative to earlier datasets demonstrates its effectiveness for monitoring landslide and erosion dynamics in complex, vegetated, and urban hill environments.

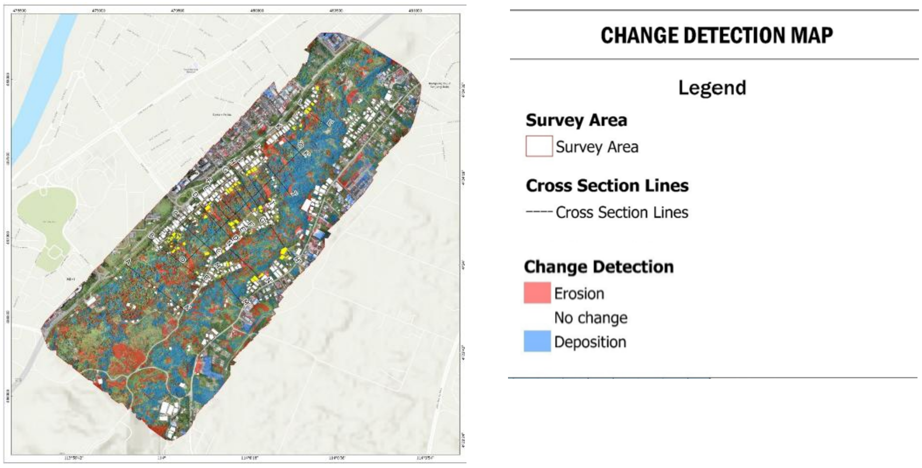
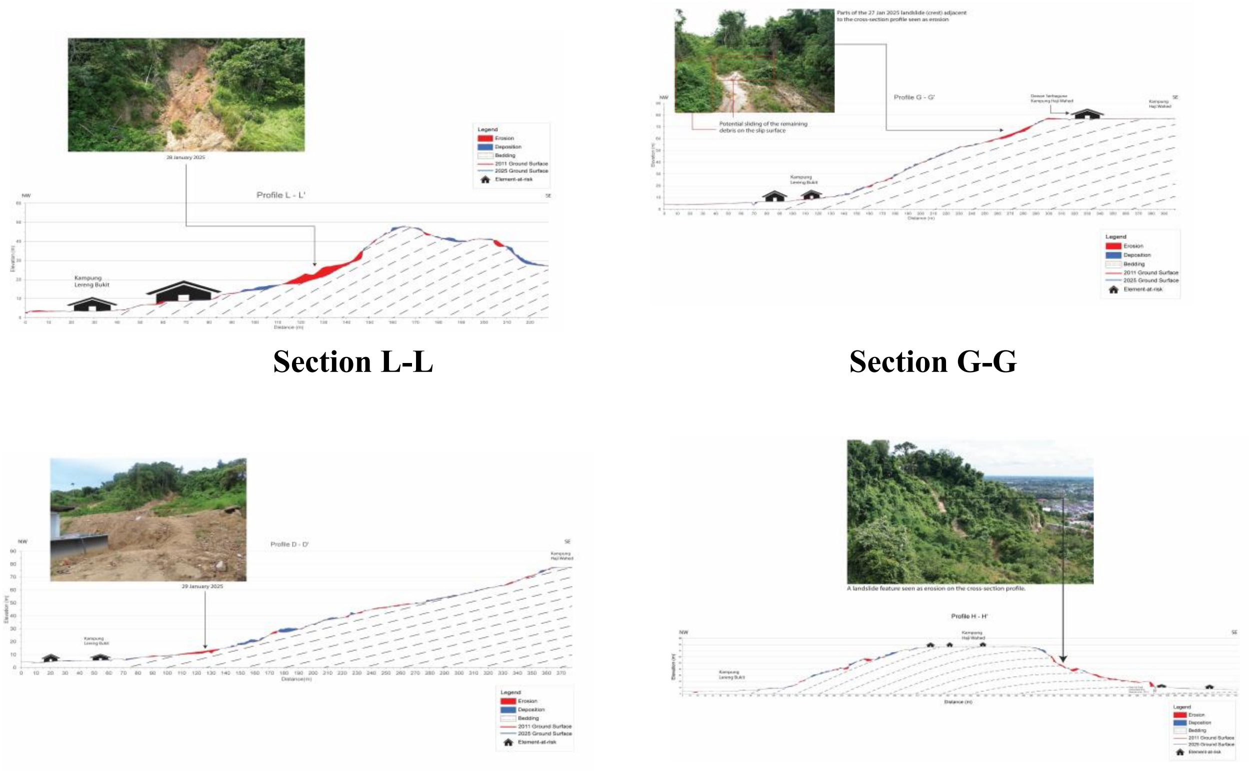



**Figure 8:** DTM of Difference (DoD) map showing elevation changes between the 2011 DTM and UAV LiDAR-derived DTM, highlighting erosion and deposition patterns.




**Section L-L** **Section G-G**

**Section D-D** **Section H-H**

**Figure 9:** Representative cross-section profiles extracted from the LiDAR DTM illustrating slope deformation, erosion channels, and landslide-related terrain modification.

## 5. CONCLUSIONS

This study demonstrates the effectiveness of integrating UAV-based LiDAR and high-resolution RGB imagery for identifying and characterizing landslides and erosion in a hilly, vegetated urban environment at Canada Hill, Miri, Sarawak. The UAV LiDAR survey enabled the generation of a high-resolution Digital Terrain Model (DTM) that accurately represents bare-earth morphology beneath dense tropical vegetation.

The LiDAR-derived DTM successfully resolved micro-topographic features associated with slope instability, including scarps, slope breaks, hummocky terrain, and incised erosion channels. Integration with orthophotos enhanced interpretation of surface conditions, while cross-section analyses provided quantitative evidence of slope deformation and erosion processes. Multi-temporal comparison with a 2011 DTM further revealed measurable terrain changes, highlighting ongoing erosion and deposition across the study area.

Overall, the results confirm that UAV LiDAR provides a robust and reliable framework for site-scale identification and monitoring of landslides and erosion in complex tropical hill environments. The approach is particularly valuable in urban areas where vegetation and accessibility limit conventional mapping methods and offers strong potential for supporting slope assessment and long-term terrain monitoring.

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## BIOGRAPHICAL NOTES

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