

Drone Surveying for Landslide Risk Assessment: DEM Generation, Contour Extraction and Slope Analysis

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Abstract

Landslides pose significant threats to infrastructure and human safety in mountainous regions, particularly in Sarawak, Malaysia, where steep topography and tropical climate conditions create favorable conditions for slope instability. This study presents a comprehensive landslide risk assessment for the Matang Wildlife Road area using advanced drone surveying techniques. The study employed a DJI Mavic Air 2S unmanned aerial vehicle to capture 69 high-resolution images, which were processed using Agisoft Metashape Professional software to generate detailed Digital Elevation Models (DEMs), orthomosaic imagery and topographic contour maps. The methodology followed a systematic six-phase approach encompassing site reconnaissance, pre-flight planning, data acquisition, photogrammetric processing and terrain analysis. Three cross-sectional profiles were analyzed using Global Mapper software, revealing an average slope angle of 21° and average slope height of 12.00 meters. Application of the Slope Priority Ranking System (SPRS) yielded a hazard score of 79% which categorizing the slopes as "Very High" hazard rating, indicating significant potential for slope instability requiring immediate remedial measures. The study demonstrates that UAV-based photogrammetry provides a cost-effective and accurate alternative to traditional surveying methods, offering enhanced spatial resolution and comprehensive coverage for slope stability assessment. The findings contribute valuable scientific data to support improved disaster management strategies, enhance early warning capabilities and inform better planning decisions for landslide-prone infrastructure in challenging topographic environments. This study also underscores the critical need for prompt remedial measures and continued monitoring of high-hazard slopes to mitigate potential risks to infrastructure and public safety.

Key Words: *Landslide, Digital Elevation Model (DEM), Unmanned Aerial Vehicle (UAV), Slope Priority Ranking System (SPRS).*

1.0 Introduction

Landslides represent one of the most significant natural hazards affecting mountainous and hilly regions globally, causing substantial economic losses and posing serious threats to human lives and infrastructure. In Malaysia, particularly in Sarawak, the combination of steep topography, tropical climate conditions, and intense rainfall patterns creates favorable conditions for slope instability. The state's natural beauty and mountainous terrain, while economically and ecologically valuable, inherently increase susceptibility to landslides, especially in areas with steep slopes and unstable soil conditions during heavy rainfall events or ongoing construction activities.

Traditional methods of landslide assessment and monitoring often face limitations in terms of accessibility, cost-effectiveness, and the ability to capture comprehensive spatial data across hazardous terrain. Recent advances in remote sensing technology, particularly Unmanned Aerial Vehicles (UAVs), have revolutionized landslide investigation and monitoring practices. Non-contact remote sensing techniques, such as terrestrial laser scanning (TLS) and unmanned aerial vehicle (UAV) photogrammetry, have been globally applied for landslide monitoring in high and steep mountainous areas, providing enhanced capabilities for data acquisition and analysis (Jiawen Zhou et al., 2023). Technological advancements have led to compact, high-resolution thermal sensors integrated into UAV platforms, with examples including the DJI Mavic 3 Thermal and Autel Evo II Dual systems offering superior monitoring capabilities for slope stability assessment (Boneng Chen et al., 2025).

The integration of UAV technology with advanced sensors has proven particularly effective for comprehensive landslide investigation. Recent studies demonstrate that landslides are global hazards that contribute significantly to worldwide catastrophes, necessitating improved

monitoring approaches that leverage the latest technological developments. Modern UAV platforms equipped with RTK modules, such as the DJI Mavic 3 Enterprise, have been successfully utilized for high-resolution remote sensing applications in landslide research, providing centimeter-level accuracy for detailed terrain analysis.

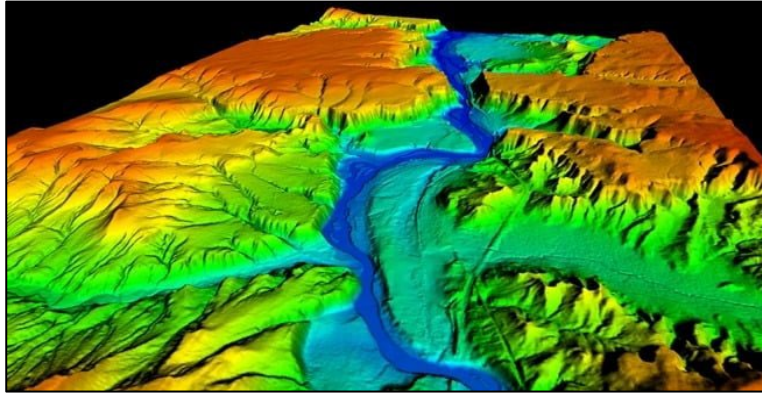


Figure 1: Digital Elevation Model (DEM)

Figure 1 shows the Digital Elevation Models (DEMs) generated through UAV photogrammetry have emerged as critical tools for slope stability assessment and landslide risk evaluation. For landslides, the majority of researchers used DEMs with a spatial resolution of between 10 m and 30 m, while for rockfalls, they used DEMs with a spatial resolution of between 5 m and 20 m (Maria P. Kakavas et al., 2021). DEMs with a very high resolution (less than 5 m) provide superior accuracy for detailed landslide analysis. Digital elevation models (DEMs) are the primary data sources in landslide susceptibility assessments, serving as the foundation for generating multiple landslide conditioning factors essential for comprehensive risk evaluation.

The quality and accuracy of DEMs significantly influence landslide susceptibility mapping outcomes. A high-precision DEM is desirable to achieve a reliable prediction of landslides, as these models represent regional topography and are subsequently used to derive critical input parameters, including slope maps, curvature analysis, and drainage patterns. Recent developments in DEM technology have led to the creation of global merged models that provide enhanced surface and bedrock elevation data for improved landslide analysis capabilities. The integration of UAV technology with advanced processing software has proven particularly effective for post-event analysis and ongoing monitoring. Landslide displacements can be determined by comparing dense point clouds, digital terrain models, and digital orthomosaic maps resulting from different measurement epochs (Ivan Jakopce et al., 2023). This approach enables systematic slope extraction and displacement analysis, providing valuable insights into slope behavior patterns and evolutionary processes. Additionally, real-time monitoring technologies of surface deformation represented by the global navigation satellite system (GNSS) are essential for landslide early warning, with innovative UAV-deployed GNSS systems offering new possibilities for continuous monitoring applications (Qin Zhang et al., 2024).



Figure 2: Matang Wildlife Road

The Matang region in Sarawak exemplifies the challenges faced by hilly landscapes with rocky terrain that increase landslide susceptibility. The area's vulnerability was dramatically demonstrated on December 22, 2019, when a significant landslide occurred along Matang Wildlife Road (Figure 2), causing major traffic disruptions and endangering local residents' safety. Unlike Peninsular Malaysia, where comprehensive landslide risk studies and detailed mapping have been conducted, systematic landslide mapping and monitoring remain limited in the Matang area of Kuching. This gap in scientific assessment hinders the development of effective preventive planning and early warning systems.

Recent case studies from similar tropical environments have demonstrated the effectiveness of UAV-based approaches for landslide analysis. UAV photogrammetry to obtain the DEM of the study area has been successfully applied in landslide investigations, with elevation data converted for computational modeling and kinematic process analysis. These applications showcase the potential for comprehensive landslide characterization using modern UAV technology integrated with advanced analytical software.



Figure 3: DJI Mavic Air 2S

This study addresses the critical need for comprehensive landslide risk assessment in the Matang Wildlife Road area through the application of advanced UAV surveying techniques. By employing DJI Mavic Air 2S drone (Figure 3) technology integrated with Agisoft Metashape Professional and Global Mapper software, this research aims to generate high-resolution Digital Elevation Models, extract detailed contour maps, and conduct thorough slope

analysis of the landslide-affected terrain. The study leverages recent advances in UAV photogrammetry and DEM processing to provide accurate terrain modeling and comprehensive slope stability assessment.

The findings will contribute valuable scientific data to support improved disaster management strategies, enhance early warning capabilities, and inform better planning decisions for landslide-prone infrastructure in Sarawak's challenging topographic environment. This research aligns with current trends in landslide monitoring that emphasize the integration of UAV technology with advanced analytical techniques for comprehensive hazard assessment and risk mitigation planning.

1.1 Objectives

The primary aim of this study is to assess landslide risk at Matang Wildlife Road, Sarawak, through advanced UAV-based surveying techniques. The research addresses two specific objectives: Objective 1 is to create a Digital Elevation Model and Contour Map. To generate high-resolution Digital Elevation Models (DEMs) of the Matang Wildlife Road landslide site using DJI Mavic Air 2S unmanned aerial vehicle and validate the accuracy of UAV-derived topographic data through Structure-from-Motion photogrammetry processing via Pix4D Mapper software while an objective 2 is to analyze slope characterization to extract detailed contour maps and perform comprehensive slope analysis using Global Mapper software.

2.0 Methodology

The methodology employed in this study follows a systematic approach integrating UAV photogrammetry, digital photogrammetric processing, and terrain analysis. The workflow consists of six interconnected phases designed to ensure data quality, accuracy, and reliability of results. The methodology employed in this study follows a systematic approach integrating UAV photogrammetry, digital photogrammetric processing, and terrain analysis. The workflow consists of six interconnected phases designed to ensure data quality, accuracy, and reliability of results.

2.1 Phase 1: Site Selection and Reconnaissance

The initial phase involves comprehensive site assessment and preparation activities. The study area encompasses the Matang Wildlife Road landslide site (coordinates: 1°35'N, 110°10'E) in Sarawak, Malaysia, where a significant slope failure occurred on December 22, 2019.



Figure 4: Study area

2.2 Phase 2: Pre-flight Planning

This phase encompasses comprehensive preparation activities to ensure optimal data acquisition conditions. All the parameters have been applied. There are flight altitude, flight speed for optimal image quality, and overlap specification (80% forward overlap and 60% side overlap).

2.3 Phase 3: Data Acquisition

Data collection involves systematic aerial photography which using Mavic Air 2S. There are 69 images was collected according the flight planning setting. Coordinates are recorded in WGS84 UTM Zone 50N projection system with comprehensive metadata documentation.

2.4 Phase 4: Photogrammetric Data Processing

Digital photogrammetric processing is conducted using Agisoft Metashape Professional software following established workflows: Initial Processing → Dense Point Cloud Generation → 3D Model and DEM Creation → Contour

2.5 Phase 5: Result & Discussion

In this phase, the DEM (Digital Elevation Model) will be analyzed using Global Mapper software for slope analysis.

3.0 Result and Discussion

The results from the flight mission utilizing the DJI Mavic Air 2S drone yielded a total of 69 images collected with altitude and overlap parameters. Image quality was evaluated using standardized metrics that assess sharpness, contrast and overall image fidelity. Quality scores were normalized to a scale of 0.0 to 1.0, where higher values indicate superior image quality. Geometric alignment verification was performed to ensure suitability for photogrammetric processing. Below is the result of quality scores distribution.

Mean quality	: 0.832 ± 0.007
Range	: $0.817 - 0.844$ ($\Delta = 0.027$)
Maximum quality	: 0.844 (DJI_0884)
Minimum quality	: 0.817 (DJI_0855)
Coefficient of variation	: 0.84%

The figure below presents the outcomes of data processing conducted using Agisoft Metashape Professional software.

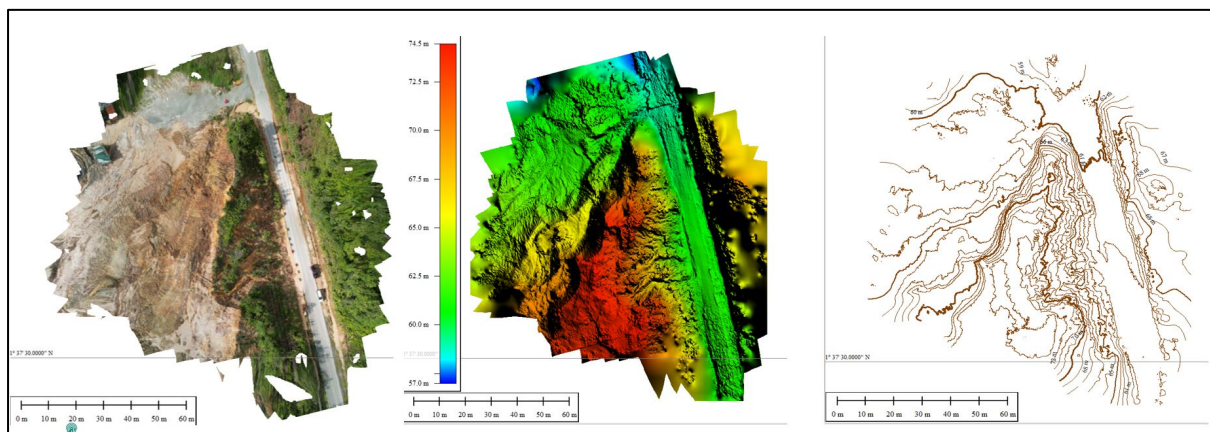


Figure 5: Orthophoto

Figure 6: DEM

Figure 7: Contour

The processed imagery demonstrates three distinct visualization outputs: Figure 5 shows the orthomosaic imagery providing a comprehensive aerial view of the surveyed area, meanwhile Figure 6 shows the digital elevation model (DEM) with color-coded elevation gradients ranging from lower elevations (blue-green) to higher elevations (red-yellow), and Figure 7 shows the topographic contour map illustrating the terrain relief and elevation patterns of the study area.

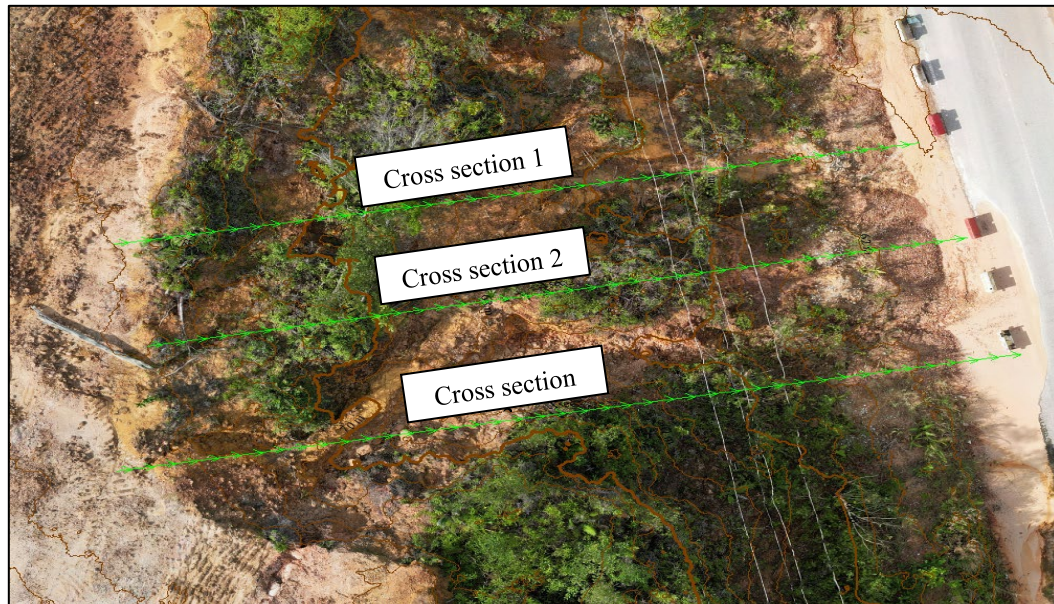
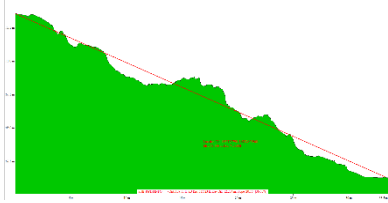
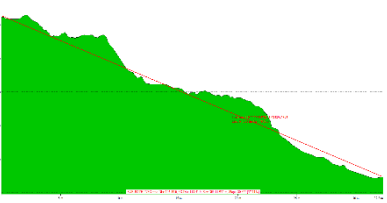
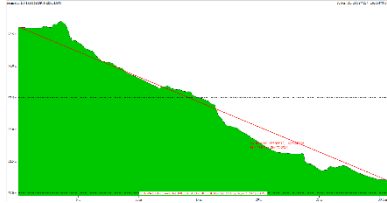


Figure 8: Cross-section profile lines of study area.

Figure 8 shows three cross-section lines that have been designed using Global Mapper software. The details of these three lines are shown in Table 1

Based on all three profile lines, the average slope angle is 21 degrees and average slope height is 12.00 meters. Slope Priority Ranking System (SPRS) as a tool for quick assessment of all slopes in Malaysia to enable repair work to be prioritized and carried out. The SPRS also helped in identifying budget requirements for slope repairs. The hazard score used in the SPRS was established using a very simple approach with associated ratings of 0, 1, and 2, according

Table 1: Slope analysis and elevation profile

 <u>Profile line 1</u> Slope angle : 21.54° Height of slope : 12.204 m	 <u>Profile line 2</u> Slope angle : 20.36° Height of slope : 11.931 m	 <u>Profile line 3</u> Slope angle : 21.54° Height of slope : 12.07 m
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to the definitions of each parameter (Hussein et al., 1999). The hazard attributes for a cut slope include slope angle, height of slope, slope cover, surface drain, natural water path, seepage, ponding, erosion, slope failure, surroundings upslope (human activity), soil type, weathering grade and discontinuities.

Referring to the data in Table 1, that was found the total attribute score is 19, while the maximum hazard score is 24. The hazard score percentage is calculated using the following formula:

$$\text{Hazard Score Percentage} = (\text{Total Attributes Score} / \text{Total Maximum Hazard Score}) \times 100\%$$

$$\text{Hazard Score Percentage} = (19 / 24) \times 100\% = 79\%$$

Table 2: Hazard score and rating used in the SPRS (Hussein et al., 1999)

Cut slope	
Hazard Score	Hazard Rating
40% to 100%	Very High
30% to 40%	High
19% to 30%	Moderate
8% to 19%	Low
0% to 8%	Very Low

Based on the calculated hazard score of 79%, the assessed slopes fall within the 40% to 100% range according to the SPRS classification system (Hussein et al., 1999). This categorizes the slopes under the "Very High" hazard rating, indicating significant potential for slope instability and the need for immediate attention and remedial measures.

4.0 Conclusion

This study successfully demonstrated the application of drone-based remote sensing technology for comprehensive slope stability assessment and hazard evaluation. The deployment of the DJI Mavic Air 2S drone captured 69 high-resolution images at predetermined altitude and overlap parameters, which were subsequently processed using Agisoft Metashape Professional software to generate detailed orthomosaic imagery, digital elevation models (DEM), and topographic contour maps.

Analysis of three cross-sectional profiles revealed an average slope angle of 21 degrees and average slope height of 12.00 meters. The application of the Slope Priority Ranking System (SPRS) yielded a hazard score of 79%, categorizing the slopes as "Very High" hazard rating according to the established classification system.

This methodology provides a cost-effective and accurate alternative to traditional surveying techniques, offering enhanced spatial resolution and comprehensive coverage for informed decision-making in slope stability management. The results underscore the critical need for prompt remedial measures and continued monitoring of the identified high-hazard slopes to mitigate potential risks to infrastructure and public safety.

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