Utilizing Drone Mapping Technology for Hazard Assessment of Steep Slope

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Abstract **:** *During the thawing season, when frozen ground begins to melt, the risk of slope-related disasters such as rockfalls, landslides, and road subsidence increases significantly. Coastal steep slopes, particularly cliff-type terrains adjacent to seaside roads, are prone to frequent rockfalls due to continuous wave-induced erosion and weathering. In the Republic of Korea, annual inspections are conducted under the "Act on the Prevention of Disasters on Steep Slopes," led by expert teams that assess slope stability. However, conventional ground-based surveys often face limitations in visibility and accessibility due to vegetation and slope height. To overcome these challenges, this study explores the use of drone mapping technology as a complementary method for hazard assessment. The study focuses on Hyeonpo-ri District in Ulleungdo, where a massive rockfall event involving approximately 100 tons of debris occurred in March 2025. Drones were deployed to capture high-resolution imagery of inaccessible upper slopes. High-resolution images were captured from multiple angles, and processed into orthomosaics, 3D models, and point clouds. These products enabled detailed identification of rockfall zones, slope geometry, and collapse features, surpassing the capabilities of traditional visual inspections. The estimated collapsed area was also quantified using point cloud analysis. Consequently, the Hyeonpo-ri district received a hazard risk score of 69 (Grade D). This study demonstrates the applicability of drone mapping technology for evaluating slope hazard potential in the Hyeonpo-ri area, where a significant rockfall had occurred. By overcoming the accessibility constraints of conventional ground-based surveys, drone-based methods provide high-resolution spatial data that enable more accurate and quantitative risk assessments. The approach holds promise for future disaster prevention and hazard analysis in similar topographic settings.*

Keywords: *Drone, Disaster risk assessment, Point cloud, 3D modeling, Geospatial analysis*

Introduction

Due to its topographical characteristics, about 63% of South Korea's land area consists of mountains, making it highly vulnerable to accidents such as landslides and soil erosion (Suk, 2019). In particular, during the thawing season when frozen ground melts after winter, accidents can occur even under small external forces. To prevent such disasters in advance, the Ministry of the Interior and Safety of Korea, in accordance with the Act on the Prevention of Disasters on Steep Slopes (hereinafter referred to as the Steep Slope Act), organizes expert inspection teams to check safety conditions before the rainy season and thawing season. They classify steep slopes at risk of collapse into grades and designate them as hazardous areas for management (Kim et al., 2020). However, due to limited visibility caused by slope height and vegetation, on-site inspections based solely on visual observation are challenging, and investigations are often conducted according to field conditions rather than by quantitative measurements. A potential solution to overcome these limitations is drone mapping technology, which requires relatively low cost and time, is easy to operate, and allows the rapid collection of large amounts of data (Zolkepli, 2021).

Drones, developed from small UAVs (Unmanned Aerial Vehicles), are now widely used across various fields, including disaster management (Oh & Jun, 2023). Kim et al. (2019) utilized drones and mapping technology at sites damaged by heavy rains and typhoons to generate 3D terrain information and orthomosaics, enabling quantitative analysis of natural disaster damage. Jung et al. (2023) scanned facility collapse sites using drones equipped with LiDAR sensors, and through comparative analysis with high-precision terrestrial LiDAR, verified the applicability of such methods. Furthermore, Kim et al. (2019) evaluated the accuracy of drone mapping under various shooting conditions to quickly acquire disaster site information, using commercial small drones and specialized investigation vehicles, and discussed constructing high-precision point clouds by integrating LiDAR and drone sensing data. Kim et al. (2023) assessed the performance of three drone mapping techniques to evaluate the accuracy of 3D terrain and object models, employing high-precision RTK (Real Time Kinematic) equipped drones.

Drone applications have also proven effective in large-scale disaster sites such as landslides. Lim et al. (2024) proposed investigation and analysis methods using drone mapping for landslide damage assessment. Park and Jung (2018) used drones to analyze deforested areas, confirming that drones are more efficient for constructing highly visible forest spatial information compared to conventional field surveys using visual inspection and measuring tapes.

Recent studies have focused on improve drone precision in disaster investigations. Shin et al. (2020) examined three approaches ground control points, 3D flight, and RTK drones for drone utilization in forested areas with dense vegetation during disaster damage surveys.

Wang et al. (2024) investigated erosion and deposition patterns on various slope forms under natural rainfall using high-precision UAV photogrammetry. Gutierrez et al. (2020) evaluated the performance of three filtering techniques for ground and non-ground classification in LiDAR point clouds, while Hao et al. (2023) described UAV-DP (Unmanned Aerial Vehicle–Data Processing) methods and principles for geological investigation of high-steep rock slopes.

As these studies demonstrate, the potential of drones in steep-slope disaster investigations is significant. Oh and Jun (2023) conducted topographic surveys using drones, collecting terrain data including digital maps and aerial photographs, and confirmed the efficiency of drones by comparing elevation, slope, and slope area. Kim et al. (2020) conducted disaster risk assessment and analysis of steep slopes using drones and terrestrial LiDAR, producing meaningful results. Accordingly, this study aims to evaluate disaster risk levels using orthomosaics and 3D models generated through RTK drone mapping of steep slopes.

The study area is the Hyeonpo-ri district of Ulleungdo, South Korea, where a rockfall accident of over 100 tons occurred in March 2025. Using drones, we surveyed the upper and slope areas, which are difficult for investigators to access. Data were obtained through drone mapping and close-range photography from various angles. These data were processed with software to generate orthomosaics, 3D models, and point clouds, which were then analyzed for quantitative disaster risk assessment of rockfall hazard areas. The 3D model accurately reproduced collapse points and rockfall sites, allowing effective identification of features such as collapse sections, rockfall size, and slope height compared to conventional visual surveys. Furthermore, point cloud data were used to estimate collapse areas. Through this quantitative analysis, the disaster risk level of the Hyeonpo-ri district was evaluated as 69 points (Grade D).

This study examines the applicability of drone-based steep-slope investigation by conducting disaster risk assessment in the Hyeonpo-ri district of Ulleungdo, where a rockfall accident occurred. By employing drones, we overcame the accessibility limitations of conventional ground surveys and conducted more quantitative risk assessments using precise spatial data. These findings suggest that the approach can be applied to disaster prevention and risk analysis in similar topographic settings in the future.

Research Method

a. Study Area :

The study area is the Hyeonpo-ri district of Ulleungdo, South Korea, where rockfall accidents have frequently occurred in recent years. In March 2025, a rockfall of over 100 tons occurred in the Hyeonpo-ri district. Although there were no casualties, the incident damaged approximately 50 meters of coastal ring road and rockfall protection fences, resulting in restricted road access.

Ulleungdo is a volcanic island with an area of about 72.9 km^2, making it the second-largest island in South Korea after Jeju Island. Its topography is largely volcanic in origin, directly reflecting past volcanic activity. Over time, weathering, erosion, and sedimentation of volcanic landforms have given rise to diverse geomorphological features such as weathered terrain, river valleys, coastal landforms, and structural landforms (Kwon, 2012).

Encircling the island is a 44 km-long coastal ring road, much of which is located adjacent to steep cliff terrain, thereby exposing it to risks. In particular, during the thawing season, repeated cycles of freezing and thawing cause cracks within soil and rock, increasing the likelihood of accidents such as rockfalls, landslides, and road subsidence under even minor external forces. Ulleungdo has a total of 23 steep slope sections along its ring road, among which the Hyeonpo-ri district is the most recent site of rockfall accidents.

b. Data Acquisition using Drone Mapping :

The equipment used in this study consisted of a DJI Matrice 350 RTK drone and a Zenmuse P1 optical camera sensor. The detailed specifications of the equipment are presented in Table 1 and Table 2.

Table 1: Specifications for Drone.

<table>
<tr><th>Drone Model</th><th colspan="2">Specification</th></tr>
<tr><td rowspan="6">
< Matrice 350 RTK ></td><td>Size</td><td>810×670×430 mm
(Unfolded, excluding propellers)</td></tr>
<tr><td>Weight</td><td>6.47 kg(with battery installed)</td></tr>
<tr><td>Flight speed</td><td>Max. 23 m/s (P mode)</td></tr>
<tr><td>Flight time</td><td>Max. 55 minutes</td></tr>
<tr><td>Hovering accuracy</td><td>Hor. ±0.1 m, Ver. ±0.3 m</td></tr>
<tr><td>RTK accuracy</td><td>Hor. ±1.0 cm, Ver. ±1.5 cm</td></tr>
</table>

Table 2: Specifications for Sensor.

Built-in Seonsor	**Specification**	
	Size	198×166×129 mm
	Weight	800g
	Sensor size	35.9×24 mm (Full frame)
	Effective pixels	45 MP
	Image size	8192×5460(3:2)
< Zenmuse P1>	Aperture range	f/2.8 ~ f/16

In conducting field surveys using drones, it is essential to consider on-site conditions such as terrain and surrounding objects. Particularly in areas with complex forested slopes like steep terrains or landslide sites, or in urban areas with tall buildings, flight restrictions can arise, making site-specific planning crucial. The drone used in this study was equipped with high-precision positioning correction functions, unlike general drones, and applied RTK technology to achieve centimeter-level accuracy.

In steep-slope areas like the study site, vertical-only photography may result in differences in shooting altitude due to abrupt elevation changes, which can lead to inconsistent resolution and reduce accuracy. To overcome this, the Terrain Follow flight method—which maintains a constant altitude relative to the ground according to terrain can be applied to obtain higher precision results. However, Ulleungdo, the study area, is an island located about 217 km east of Pohang City on the Korean peninsula, where satellite signal reception for the RTK sensor was unstable, making it difficult to apply the Terrain Follow method. Therefore, an automated vertical flight mission was planned in advance, based on the maximum slope height. In addition, to improve accuracy in steep slope sidewalls and recessed areas, manual close-range flights were conducted to capture oblique photographs.

Table 3: Results of Data Acquisition using Drone Mapping.

	Average Flight Altitude	**Overlap Ratio**	**Ground Coverage**	**Number of Photos**	**GSD***
Hyeonpo-ri district	45 m	80%	0.024 ㎢	720 Photos	1.07 cm/pixel

* *Ground sampling distance*

Table 3 presents the data acquisition results using the drone. A total of 720 photographs were obtained through vertical and oblique shooting at an altitude of 45 m above the highest point in the Hyeonpo-ri district, with an overlap ratio of more than 80%. The acquired data were processed using DJI Terra software. The concept of the image processing workflow is shown in Fig. 1.

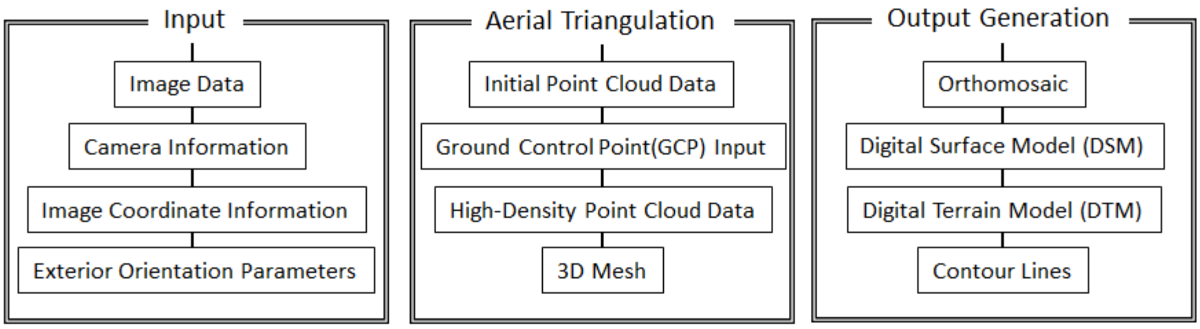

Figure 1: Image Processing Workflow.

Through this processing, outputs such as an orthomosaics and a 3D model of the Hyeonpo-ri district were generated. In this study, these outputs were applied to disaster risk assessment.

c. Hazard Assessment :

Steep slopes can be broadly classified into naturally formed slopes shaped by geological processes and artificially constructed slopes, with differences in the evaluation criteria for disaster risk assessment. The Hyeonpo-ri district of Ulleungdo, the study site, is categorized as a naturally formed slope.

The disaster risk of natural slopes is primarily evaluated based on collapse risk (70 points) and social impact (30 points), with an additional investigator adjustment score (20 points) contributing to the final assessment. Collapse risk is further subdivided into terrain, ground and geological conditions, protective facilities, and rainfall, while social impact is assessed based on surrounding environment, affected population, number of lanes and traffic volume, and distance to nearby facilities. Table 4 presents the list of criteria used for disaster risk assessment.

Table 4: Hazard Assessment Factors.

Major Factors	Sub-Factors	Description
Risk of collapse	Topography	Slope angle, Height, Longitudinal section, Cross section
	Ground/Geolog y	Ground deformation, Ground fissures, Depth of surface layer, Overlying external force
	Facilities	Condition of protective facilities
	Rainfall	Slope valley(Length/Width), Groundwater condition
Social impact	Surrounding environment	Forest land·park facilities, Residential land·roads·Railways
	Affected population /Lanes/Traffic volume	Steep slopes adjacent to roads(Number of lanes/Traffic volume), Other areas(Affected population)
	Distance from nearby slopes and adjacent structures	
Investigator adjusted score	Rainfall-related factors	Debris flow from upper slope, Steep slope drainage facilities, Surface water
	Social impact factors	Areas with expected impact on vulnerable population, Areas with unclear management or difficult self-maintenance

As shown in the criteria in Table 4, disaster risk assessment for steep slopes considers not only the geomorphological characteristics of the slope but also the potential damage caused by slope failure. Additionally, investigator adjustment scores for rainfall and social impact factors allow for a more realistic evaluation.

To accurately evaluate the items in Table 4, investigators must physically ascend steep slopes or directly inspect hazardous points, which exposes them to significant risk and requires considerable time. In this study, these tasks were replaced with 3D models generated via drone mapping to improve survey efficiency.

Results Analysis

The orthomosaics and 3D models generated through drone mapping were used to assess hazard and disaster risk in the Hyeonpo-ri district.

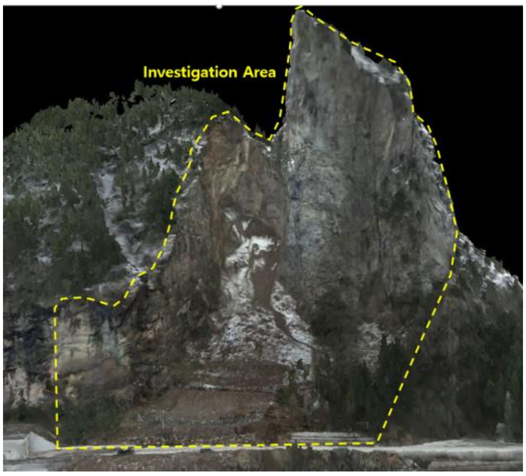

Figure 2 : 3D Terrain Model of Hyeonpo-ri District.

a. Assessment of Collapse Risk :

First, terrain was evaluated based on slope angle, height, longitudinal and cross-sectional forms. Using the 3D model, cross-sections were extracted at the slope collapse area (A) and the tuff slope (B) where future collapse is expected. The slope angle was measured between the slope and the horizontal plane, and the height was measured vertically from the horizontal plane to the slope summit, resulting in a height of 138 m and a slope angle of 48°. The longitudinal form refers to the slope's shape in the horizontal direction, while the cross-sectional form refers to the slope's appearance from the side. Overlaying orthomosaic with contour lines (Fig. 3) indicated that both longitudinal and cross-sectional forms exhibited complex geometries.

Figure 3 : Slope Shape (Left: Longitudinal, Right: Cross-sectional).

Next, the ground and geological conditions were assessed. This evaluation considered ground deformation and cracks, soil layer depth, external loads from above, and history of collapse or erosion. Ground deformation and cracks refer to phenomena such as subsidence, fissures, and misalignment of the slope material itself. The 3D model revealed jointing at the slope summit and cracks on the collapse slope surface. Soil layers were not detected in the rock-based steep slope. External loads refer to structures, roads, or towers at the slope top that could negatively affect slope stability; none were observed at the study site. Collapse and erosion history includes evidence of previous collapses, rockfalls, or surface erosion. Since a large rockfall occurred in September 2024, the slope has experienced recurring rockfalls, leaving visible traces across more than 20% of the slope, including rocks accumulated at the base rockfall barriers.

For protective facilities, the 3D model showed a three-tiered rockfall protection system at the slope base. The topmost barrier was severely damaged and saturated with accumulated rocks, while the lower tiers were less damaged and could provide limited protection against small rockfalls. However, the overall protection was deemed insufficient, and repair of damaged facilities is required, indicating very poor conditions.

Finally, the rainfall factor was evaluated by considering the presence of gullies and groundwater. No gullies were observed at the slope summit, but steep, narrow, and elongated gully-shaped incisions formed by slope collapse could significantly affect slope stability. Additionally, continuous surface water flow was observed on the left side of the tuff area.

b. Social Impact Assessment :

Social impact was assessed based on the surrounding environment, roads, and nearby facilities. Orthomosaics showed that the slope base was adjacent to Ulleungdo's ring road, indicating high potential damage in the event of rockfall (Fig. 4). The nearby road is a single-lane one-way road with an average daily traffic volume of 1,343 vehicles. No other adjacent facilities were present, suggesting a low risk of direct casualties.

Figure 4 : Surrounding Environment.

c. Investigator Adjustment Score :

Investigator adjustment scores were applied to rainfall and social impact factors. Rainfall factors were evaluated based on the presence of debris flows from the upper slope, the existence and condition of slope drainage systems, and susceptibility to surface water damage from the slope top. Hyeonpo-ri was identified as vulnerable to debris flow damage, with no drainage facilities observed, and experienced rainfall exceeding the one-hour design rainfall threshold within the past five years. The design rainfall threshold is the amount of rain the protective facility is designed to withstand.

Social impact factors included the presence of vulnerable populations (elderly, children, disabled) or areas where residents are unable to perform self-maintenance due to unclear management responsibility. Since the Hyeonpo-ri district is adjacent to a road and not a residential area, no adjustment was required.

d. Assessment of Hazard and Disaster Risk in Hyeonpo-ri District :

The disaster risk of the Hyeonpo-ri district was assessed using orthomosaics and three-dimensional models generated through drone mapping (Table 5). In this scoring system, higher values indicate greater risk, categorized into five grades. Hyeonpo-ri obtained a total score of 69, corresponding to grade D, indicating a high disaster risk that necessitates the establishment of a management plan.

Table 5: Hazard Assessment Results of Hyeonpo-ri District.

Division	**Survey Results**	**Score**
Slope angle	45°-53°	8
Height	138 m	5
Longitudinal profile	Complex Type	4
Cross profile	Complex Type	4
Ground deformation	Cracks, Ground Loosening	5
Soil layer depth	-	1
Overlying external force	-	1
Collapse history	Rockfall traces ≥ 20 %	8
Condition of protective facilities	Very poor	4
Slope valley length	≥ 51 m	4
Slope valley width	< 1 m	4
Groundwater condition	Surface water	4
Surrounding environment	Residential areas, Roads, Railways, etc.	5
Number of road lanes	Single lane	1
Traffic volume	500 ~ 5,000	2
Distance to steep slope	No facilities	0
Investigator adjustment	Expected damage	9
Total		69

The district consists of tuff intruded by diorite, where prolonged weathering and erosion have caused collapse in the weaker tuff areas, forming abrupt undulating terrain. Three-tiered rockfall barriers were installed along a 110 m section of the ring road to mitigate falling rocks, but continuous rockfalls rendered them ineffective. Given the unpredictability of rockfall locations and volumes, applying reinforcement methods such as bypass roads or protective tunnels is considered appropriate.

Conclusion

This study demonstrates that using RTK drone mapping to generate orthomosaics and 3D models allows accurate hazard and disaster risk assessment in steep slopes.

Drone-based surveys enabled access to slope summits and faces that are otherwise difficult to reach, capturing detailed data from multiple angles. The 3D model precisely reproduced rockfall and collapse points, allowing better identification of slope sections, rockfall scale, and height compared to traditional visual inspections. Point cloud data also facilitated estimation of collapse areas.

Based on three major evaluation categories collapse risk, social impact, and investigator adjustment scores the overall disaster risk for Hyeonpo-ri was assessed as 69 points (Grade D). Since the locations and volumes of potential rockfalls are difficult to predict, it is considered necessary to establish management plans that include reinforcement measures designed to avoid falling rocks, such as protective tunnels and bypass roads.

This study highlights the utility of drone-based mapping for steep-slope investigations, overcoming accessibility limitations of conventional ground surveys and enabling more quantitative risk assessments. The approach is expected to be applicable for disaster prevention and risk analysis in similar terrains in the future.

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