Applicability Assessment of Drone Mapping for Causal Analysis in Landslide Damage Sites

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Abstract: This study aims to propose a more efficient and accurate method for investigating landslide damage and analyzing causes using drone mapping technology. The research employs two key methodologies: Terrain Follow method, which adjusts the drone's altitude to match the terrain and creates precise 3D models, and vegetation removal analysis, which reveals obscured ground features, allowing for detailed examination of landslide paths. Additionally, Pix4Dmapper software was used to calculate debris volume, providing a quantitative assessment of landslide movement. The main findings show that drone mapping surpasses traditional methods by offering higher accuracy in identifying landslide causes and measuring damage. The conclusion emphasizes the potential of drone mapping to significantly improve landslide prediction and monitoring, contributing to better risk mitigation and damage prevention.

Keywords: Landslide, Drone mapping, Disaster investigation, 3D model, Terrain Follow

Introduction

a. Background:

Recent disasters are increasingly interconnected, complex, and large-scale, resulting in significant damage. In particular, climate change-induced heavy rainfall and typhoons are major causes of landslides, which threaten both lives and property. In July 2023, heavy rainfall triggered large-scale landslides in central South Korea (Gyeongsangbuk-do, Chungcheongbuk-do, and Chungcheongnam-do), leading to 24 fatalities, 2 missing persons, 16 injuries, and approximately 142.8 billion KRW in recovery costs.

Although rainfall is the primary cause of landslides, specific factors such as terrain, soil conditions, vegetation, and unregulated development vary by site. To prevent the recurrence of landslides, it is essential to identify controllable factors beyond rainfall and improve them. Thus, conducting accurate field investigations and analyzing the relationship between landslides and site-specific characteristics is crucial.

Geographic information about landslide-affected areas plays a significant role in this process. Traditionally, investigators have used portable GPS devices and laser rangefinders to collect data from the affected sites. However, manpower-based surveys are often limited by time and space constraints, particularly in steep slopes and inaccessible areas like cliffs, making it difficult to thoroughly assess landslide damage. Ground-based LiDAR has recently been used to acquire high-resolution point clouds for analysis, but mobility issues can reduce the resolution in long-distance scans. Additionally, obstacles such as trees or steep slopes can cause important data to be missed.

Satellite imagery has been used as a traditional method for landslide damage assessment, but it faces limitations in terms of capture intervals, weather conditions, and resolution. Even when conditions are favorable, satellite imagery provides only general overviews, making it difficult to quantify collapse shapes, areas, or lengths. Moreover, such qualitative mapping methods have limitations in building a comprehensive database of landslide history, which hinders long-term landslide case analysis.

Therefore, there is a pressing need for quantitative investigation and analysis methods for understanding landslide occurrences and collapse causes, which are essential for identifying the causes of large-scale landslide-related casualties and establishing effective preventive measures.

b. Utilizing Drone Mapping Technology for landslide:

Recent drone-based mapping technology is being utilized in various research fields. Unlike satellite imagery or aerial photographs, drone mapping technology allows for the acquisition of high-resolution image data for the required areas, making it highly efficient (Oh & Jun, 2023). Particularly, it can relatively easily access areas that are difficult for humans to reach, such as steep slopes, high mountains, and cliffs, and can quickly survey with a small number of personnel, making it economically efficient in terms of time and cost (Tanze et al., 2016). Additionally, the payloads that can be attached to drones vary according to the purpose, which increases their utility. Thus, drone mapping technology plays a crucial role in overcoming the limitations of traditional research.

Drone mapping involves several stages: flight planning, data acquisition, and result production. For flight planning, factors such as the surrounding environment, wind direction, wind speed, and distance to target points are checked. Calibration of the drone or camera may also be performed as needed to maintain optimal conditions. For data acquisition, setting the flight altitude and overlap rate is necessary, as the mapping resolution is determined by the relationship between these two factors, making it very important. Finally, the results of drone mapping, including 3D point clouds, orthoimages, and DSM/DTM, are used to accurately assess field information (Kim et al., 2019).

This section reviews various cases where drone mapping technology was applied to investigate the causes of landslides. In the past, drones suffered from significant positional errors and relied on ground control points measured by GNSS equipment. However, recent developments in RTK-equipped drones have enabled more accurate mapping results without complex procedures. Shin et al. (2020) demonstrated more effective results by using RTK drones and traditional methods to overcome the limitations of drone mapping in mountainous areas. Similarly, equipping drones with VRS equipment allows monitoring of slope displacement and displacement rates, providing more accurate analysis results when combined with ground control points (Cho et al., 2021).

The most commonly used analysis data in drone-based landslide analysis are the results of drone mapping, and related research is actively ongoing. DEMs and DSMs produced by drones can be used for landslide simulations to investigate ground displacement in steep slopes (Choi et al., 2021). Additionally, 3D modeling based on drone images is efficient for assessing soil volume and detecting soil movement in displaced areas (Mokhtar et al., 2014). Comparing drone mapping results with traditional topographic data used for landslide investigation can more accurately confirm their efficiency. Shin et al. (2017) showed that drone-based surveys were highly efficient and accurate in terms of time and personnel when comparing elevation, slope, and area accuracy with results from traditional topographic maps and GPS surveys. Oh & Jun (2023) compared the accuracy of altitude and slope differences by comparing drone DEM with digital terrain maps and aerial photos for terrain change analysis in landslide-prone areas. Furthermore, drone mapping results and analyzable data can be combined or integrated with orthoimages, point clouds, and DSMs to compare and analyze landslide collapses, cracks, and movements (Eker et al., 2018; Lian et al., 2020).

Landslide research involves utilizing various sensors as payloads on drones to acquire and analyze data. To obtain high-resolution terrain information in landslide-prone areas, systems incorporating LiDAR, optical cameras, and multispectral cameras on drones can efficiently extract landslide areas (Choi & Kwon, 2021). Integrating various sensor-based drone technologies enhances the understanding of static and dynamic landslide characteristics and includes temporal and spatial monitoring of landslide processes, including surface change detection for cracks (Sun et al., 2023).

To effectively investigate landslide damage, technologies that classify and analyze the affected and surrounding ground are crucial. Among the ground separation techniques, the most commonly used CSF algorithm classifies ground and non-ground points based on point cloud data acquired from drone LiDAR, making it effective for landslide sites (Koo et al., 2023). Analysis of ground LiDAR data using algorithms like CSF, PTD, and MCC has shown that the accuracy of classification results varies depending on the density of vegetation on the ground (Gutierrez et al., 2020). Moreover, to detect landslide risk information from drone images, a deep learning neural network-based detection model has been developed, achieving a high detection result of 91% for actual landslide areas (Chen et al., 2020).

This study proposes a method for efficient cause investigation and damage analysis in landslide-affected areas caused by heavy rainfall, utilizing high-resolution camera sensors for data acquisition and drone mapping results including orthoimages and 3D models.

Methodology

a. Drone mapping methods considering mountainous terrain:

In traditional field surveys centered around human resources, mapping of landslide occurrence locations and affected areas is typically done using commercial satellite images (Fig 1). While these images can provide a general overview, they have limitations in quantifying details such as collapse shapes, areas, and lengths. Such qualitative mapping has limitations in building a database for landslide history, and thus cannot extend to analyzing landslide characteristics based on long-term occurrences.

(a) Debris flow mapping (b) Landslide mapping

Figure 1: Example of landslide mapping using satellite imagery.

If a landslide expert investigates the terrain and geological characteristics on-site to determine the cause of the landslide, drones can play a complementary role by capturing three-dimensional records of the site and quantitatively expressing the causes. In this context, drones need to record the site from the same perspective as the expert and provide extensive spatial information to the expert.

Considering the above points, accurately understanding three-dimensional information about mountainous terrain is essential for utilizing drones in landslide investigations.

Typically, drone photogrammetry involves a series of processes. Photos are captured from above the target area while maintaining a consistent flight altitude and overlap. Feature points are then extracted from the overlapping images, and alignment is performed to generate a low-density point cloud data set. Using this point cloud data, camera calibration and ground control point survey results are employed to create a high-precision three-dimensional terrain model and orthoimage. However, traditional drone mapping involves flying along a fixed path at a fixed altitude and camera angle, which can limit model production in mountainous terrains with significant elevation changes.

Debris flows occur when landslides in mountainous areas flow down valleys with water, increasing in scale and kinetic energy, and cause damage to life and property as they deposit in lower areas of the mountain. Therefore, debris flows should be categorized into three sections: the source area where landslides occur, the flow area along the valley, and the deposition area in the lower mountain region. Typically, the investigation range extends up to 2 kilometers from the mountain summit, through the valley, to the lower village. The equipment used for this investigation includes the DJI Matrice 300 RTK drone and a Zenmuse P1 optical sensor-based camera, which are owned by the research institute (Fig 2). This drone has a maximum flight time of 55 minutes, which is about 30 minutes longer than commercially available drones, making it efficient for surveying relatively large areas such as debris flow sites (Table 1, 2).

Figure 2: Drone and Sensor(left: Matrice 300 RTK, right: Zenmuse P1).

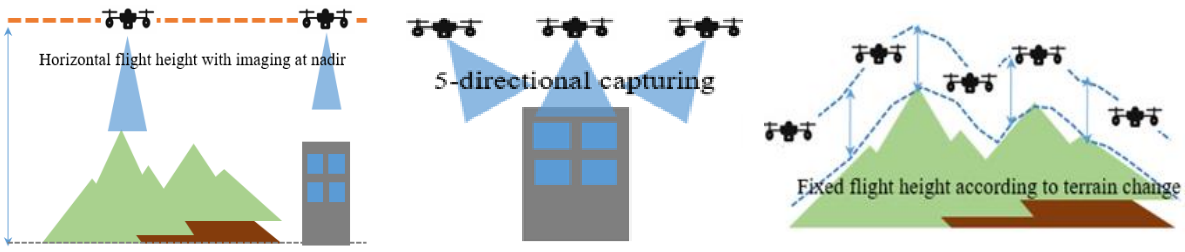
Table 1: Specs of a Matrice 300 RTK.

Dimensions	**Wight**	**Speed**	**Flight time**	**Positioning accuracy**
810×670×430 mm (Unfolded)	9 kg (Max)	17 m/s (P mode)	55 min	Hor. ± 0.1m Ver. ± 0.1m (RTK mode)

Table 2: Specs of a Zenmuse P1.

Sensor size	**Pixel Size**	**FOV**	**Aperture range**	**ISO**
35.9×24mm	45MP	63.5°	f/2.8-f/16	100-25600

Fig 3 illustrates the concept of aerial photography using drones. To map the entire debris flow site using a drone, the Terrain Follow method, which is suitable for mountainous terrain, was employed. The Terrain Follow method maintains an altitude that reflects the terrain in complex topographies, and is known to produce a more complete three-dimensional model of mountainous areas compared to other mapping methods like the Normal method or Smart Oblique method (Kim et al., 2023).



(a) Normal mode

(b) Smart oblique mode

(c) Terrain follow mode

Figure 3: Drone mapping methode.

Fig 4 shows photos mapped using the Terrain Follow method for a landslide occurrence area. For landslides with relatively narrow photography ranges, high-resolution three-dimensional images could be generated from the source location to the area where the debris was deposited. Notably, detailed close-up photos of the collapse site were obtained, allowing for precise geological and topographical analysis related to the collapse. This photographic information can be used to verify field data recorded by investigators on-site and provide additional information, making it effective for cause analysis.

(a) Overall view 1 (b) Overall view 2

(c) Close-up photo of the collapse site (d) The deposition starting point

(e) The sediment deposition area

Figure 4: Drone mapping result of the landslide occurrence area.

In the case of debris flow sites, the investigation area spans a very wide range, from the collapse point to the area where debris is deposited in the lower mountain village (Fig 5). The drone's survey range was set to record a continuous series of photos documenting the process from the collapse of the debris to its flow down the valley and subsequent deposition in the lower area.

Similar to landslide investigations, high-precision three-dimensional photos of the collapse point were obtained at the debris flow site. This allowed for the identification of terrain and geological characteristics that were not visible to the naked eye. Additionally, for the deposition area, the overall deposition surface area, number of damaged houses, and the extent of damage to the houses, which were not accurately discernible through visual inspection, could be assessed.

(a) Overall view

(b) Close-up photo of the collapse site (c) The sedmiment deposion area

Figure 5: Drone mapping result of the debris flow occurrence area.

b. Derivation of landslide features after vegetation removal

One of the biggest limitations when using drones for aerial photography of mountainous areas is that the ground is often obscured by vegetation. To capture features observed locally along the landslide path (such as rock slopes, soil layer thickness and change points, gullies, and erosion) with drone imagery, it is necessary to obtain images of the ground obscured by trees.

Fig 6 shows a three-dimensional photo of a landslide site that occurred in Chunyang-myeon, Bonghwa-gun, Gyeongsangbuk-do. While a large-scale landslide with a width of 15 meters and a length of approximately 70 meters was recorded during the field survey, the three-dimensional photo does not accurately represent the landslide origin point due to obstruction by vegetation.

Figure 6: Landslide occurrence site obscured by vegetation.

In this study, the Pix4Dmapper program was used to remove vegetation. By utilizing the field drone aerial photographs, point clouds and meshes were generated in Pix4Dmapper, and seven automatically classified groups could be identified in the layer window. To remove vegetation around the landslide origin point, high-density point cloud editing was employed to designate the range of surrounding vegetation. The designated point cloud group was then either set to "Disabled" or classified as "high vegetation" to remove the vegetation. Fig 7 illustrates the general process of vegetation removal at the landslide origin point.

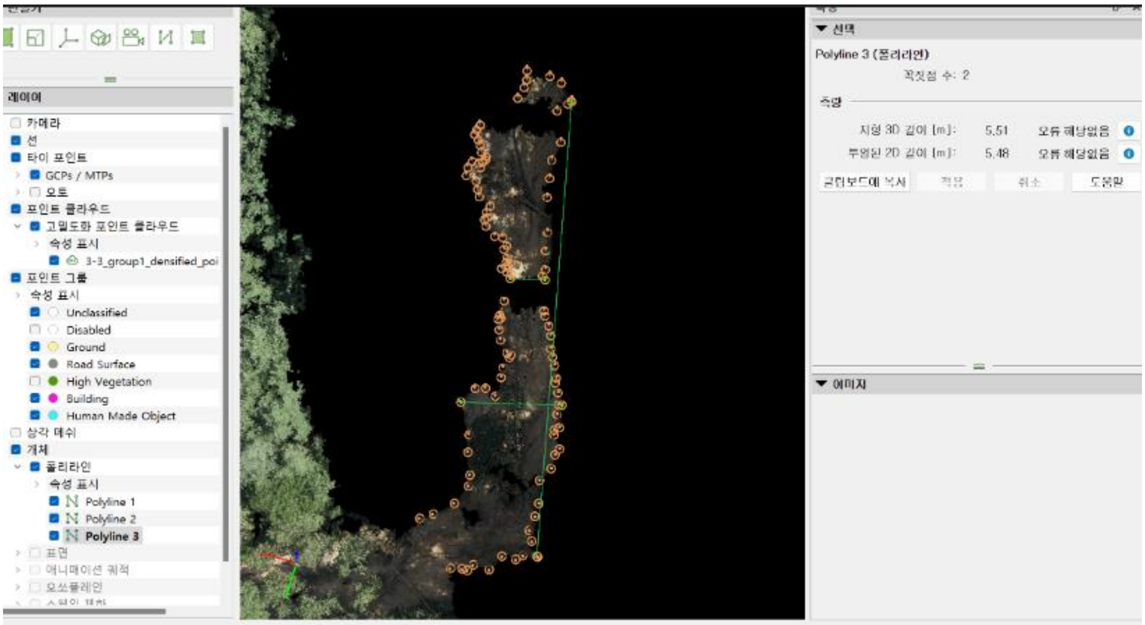
(a) Before vegetation removal

(b) Selection of vegetation to be removed

(c) After vegetation removal

Figure 7: Example of vegetation removal process using Pix4Dmapper

Fig 8 shows the ground conditions at the landslide origin point after vegetation removal. Generally, field surveys collect information on the landslide occurrence point, width, collapse thickness, length, terrain shape, and movement path. On the three-dimensional terrain model with removed vegetation, all these details were observable. Furthermore, in traditional field surveys, if the landslide is large, describing the terrain and soil layers at the specific location can be challenging, often resulting in only a general description of the situation. However, creating a terrain model with removed vegetation using drones allows for a more detailed and three-dimensional explanation and analysis of the landslide conditions.



Polyline 3 (폴리라인)
꼭짓점 수: 2
지형 3D 길이 [m]: 5.51 오류 해당없음
투영된 2D 길이 [m]: 5.48 오류 해당없음

Figure 8: Landslide occurrence site obscured by vegetation.

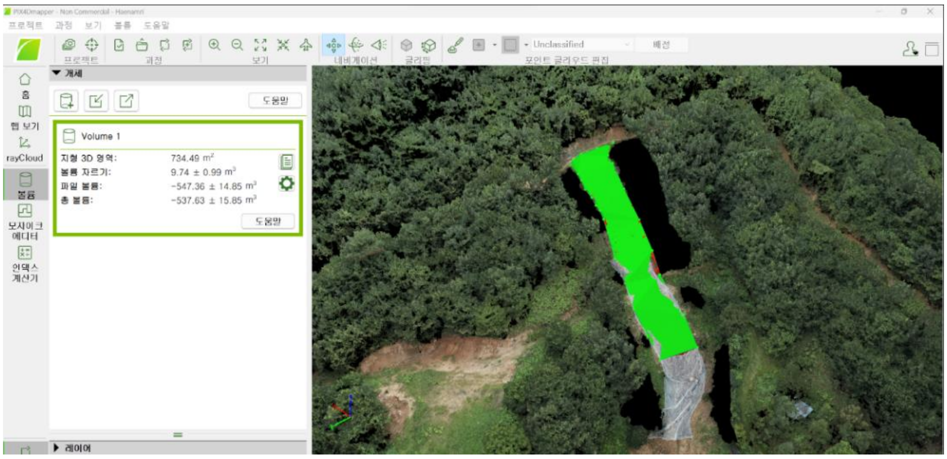
Discussion

Identifying the origin point of a landslide is the most critical process for determining its cause. Traditional survey methods collect only general information about the origin point, as shown in Fig 9. The collapse volume is related to the extent of damage and can be crucial information when analyzing medium- to long-term landslide trends. In on-site visual inspections of the collapse point, it is generally difficult to estimate the total volume because the debris often collapses in an irregular shape. In fact, many landslide investigation reports rarely record the collapse volume, and when they do, the accuracy is often very low. This study aimed to address these issues using drones for landslide investigation.

Figure 9: Example of measuring landslide magnitude using satellite imagery.

The volume of the collapsed debris was calculated using the Pix4Dmapper program. To estimate the volume from the DSM (Digital Surface Model), point clouds and meshes were first created, followed by the generation of the DSM. For accurate volume measurement, vegetation was classified and removed, along with any outlier point clouds. By setting the range for volume generation and performing the calculations, four types of volume values are obtained: the area of the selected 3D terrain, the volume above the reference surface, the volume of the empty space below the reference surface, and the remaining volume after subtracting the volume below the reference surface from the volume above it. The volume of the collapsed debris of interest in Pix4Dmapper is as shown in Fig 10.

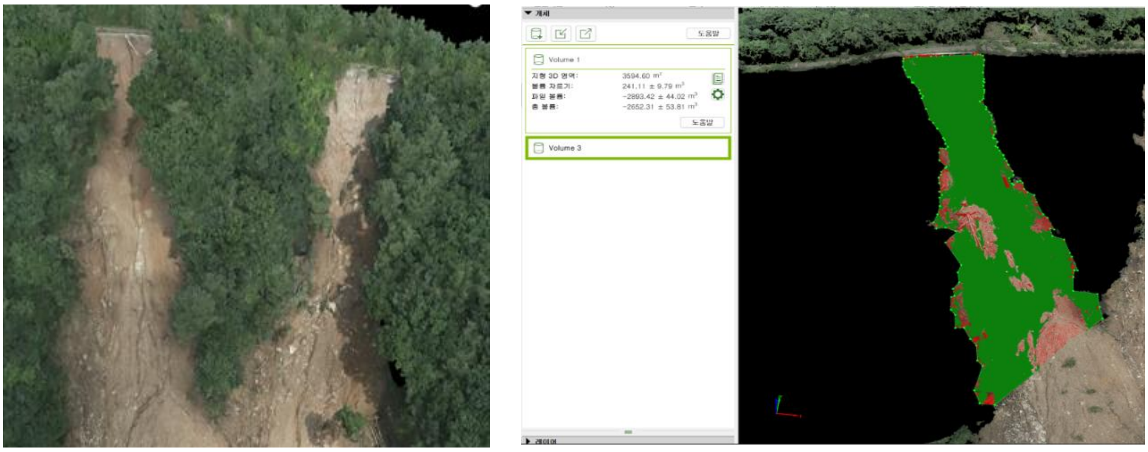
The volume of the landslide is considered as the amount of debris that has collapsed and flowed from the original ground, so the reference surface is set at the boundary line between the original ground and the landslide occurrence point. In this study, the boundary line was set using the triangulation method.



Volume 1
지형 3D 영역: 734.49 m²
볼륨 자르기: 9.74 ± 0.99 m³
파일 볼륨: −547.36 ± 14.85 m³
총 볼륨: −537.63 ± 15.85 m³

Figure 10: Calculation of the collapse volume at the landslide occurrence site.

Fig 11 shows an example of volume estimation for a large debris flow site using the method described above. Even for collapse areas with complex terrain and long extension lengths, effective volume estimation was achieved. The volume estimation can vary depending on the shape of the set reference surface. Although the measurement errors observed during the analysis were considered to be within a reliable level, it is anticipated that future work will need to include an analysis of quantitative measurement errors.



Volume 1
지형 3D 영역: 3594.60 m²
볼륨 자르기: 241.11 ± 9.79 m³
파일 볼륨: −2893.42 ± 44.02 m³
총 볼륨: −2652.31 ± 53.81 m³
Volume 3

(a) Debirs flow collapse site

(b) Volume estimation of the debris flow collapse site

Figure 11: Collapse volume estimation at the debris flow occurrence site.

The fundamental process of landslide cause investigation involves deriving the causes of collapse and damage based on information collected on-site, incorporating the investigator's opinions. This year's landslide field investigation focused on utilizing drones to collect high-resolution three-dimensional information, providing a range of detailed data that investigators could use effectively. By employing drone mapping methods suited for mountainous terrain, high-quality three-dimensional terrain models were created, and vegetation was effectively removed to generate ground information with reduced interpretation errors. Additionally, a method for estimating the volume of irregular landslide sites was applied, making it possible to measure quantitative scales that were previously considered a limitation in visual inspections. As a result, combining information recorded by investigators with additional data measured from three-dimensional drone images enabled an improved cause investigation.

< Seodong-ri, Chunyang-myeon, Bonghwa-gun (2 fatalities) >

(Incident Details) A 20m wide, 89m long, and 2-3m deep soil layer collapsed from the hillside①, completely destroying② a panel house located 15m away, and burying the orchard in front of the house③.

<Schematic Diagram of Landslide Occurrence>

(Cause of the Collapse) The slope of the mountain is relatively gentle at 20°, but it is presumed that the saturated soil layer collapsed along the steep underlying bedrock (34°) due to infiltration water.

- The colluvial soil (1-1.5m thick) contains a significant amount of rock fragments, making it prone to water infiltration.
- The 34° granite bedrock at the top of the collapse acted as the failure plane.
- Groundwater flow, which likely influenced soil saturation along the failure plane, was observed.

[Composition of Soil Layers]

[Diagram of Collapsed Ground]

※ Colluvial Soil: A loose soil layer formed by weathered materials from the mountain, deposited by gravity.

Figure 12: Summary of the current status and causes of collapse at the landslide site.

< Mungyeong-si, Dongro-myeon, Supyeong-ri (1 fatality) >

(Incident Details) Heavy rainfall caused a large volume of water to flow downstream along the valley, carrying soil and debris through a transportation process. The water overflowed the small stream, leading to a loss of life.

<Schematic Diagram of Debris Flow Occurrence>

(Cause of the Incident) As surface water from the mountain merged with the small stream, the flow exceeded the drainage capacity of the stream (Muraicheon), causing overflow into nearby homes and farmland.

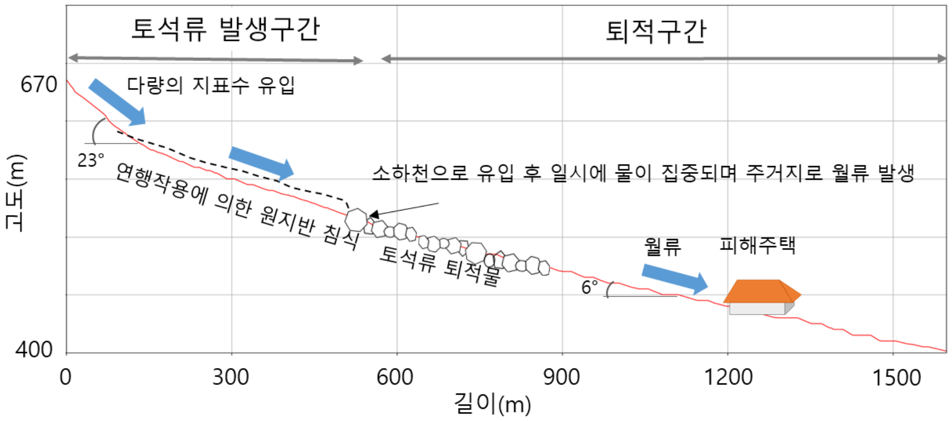


Figure 13: Summary of the current status and causes of collapse at the Debirs flow site.

Conclusion

The study proposed methods for damage investigation and cause analysis in landslide-affected areas due to heavy rainfall, utilizing drone mapping technology. Traditional manual landslide investigations had temporal and spatial limitations and relied on qualitative data, making quantitative analysis challenging. However, drone mapping technology offers the advantage of rapidly acquiring high-resolution imagery and obtaining precise terrain information even in hard-to-access steep slopes and valleys.

Landslide investigations using drones were carried out through two main methods. First, the Terrain Follow mode was used to automatically adjust altitude according to mountainous terrain, generating accurate three-dimensional terrain models. This allowed for three-dimensional analysis of the landslide causes and precise terrain information about the collapse location. Second, after removing vegetation and analyzing the data, previously hidden ground information was revealed, allowing for clear identification of the landslide origin and its path. This helped in detecting important topographical features that might have been missed in traditional field surveys.

Additionally, the study introduced a method for quantitatively estimating the volume of landslide sites using software like Pix4Dmapper. This enabled accurate calculation of the volume of soil displaced by debris flows and landslides, including areas not visible to the naked eye. Such quantitative analysis can contribute to a more accurate evaluation of landslide causes and the development of medium- to long-term prevention measures.

In conclusion, drone-based landslide damage investigation provided more efficient and accurate results compared to traditional methods, opening new possibilities for landslide cause analysis and damage assessment. Future advancements in drone mapping technology, combined with various sensors, could be used for landslide prediction and monitoring of risk areas, playing a crucial role in reducing casualties and property damage caused by landslides.

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