

UAV-BASED 1/500 TOPOGRAPHIC MAPPING FOR ESTIMATING LIMESTONE VOLUME AT TRAI SON QUARRY, VIETNAM

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ABSTRACT: Calculating the amount of limestone extracted is important for managing resources and protecting the environment at quarries. However, traditional methods are expensive, take a lot of time, and are not very accurate, especially in the areas like Trai Son Quarry. This study solves these problems by using UAV (Unmanned Aerial Vehicle) technology to generate a highly accurate 1/500-scale topographic map with 1-meter contour intervals and boundaries delineated at a 1/1000 scale for precise volume estimation. The research used drone-based photogrammetry to capture high-resolution images of Trai Son Quarry, with ground control points measured by GNSS (Global Navigation Satellite System) to ensure accuracy. The obtained data was used to generate a DEM (Digital Elevation Model) and orthophoto maps. The results indicated that the drone-generated map was extremely accurate, with m_{xy} (horizontal accuracy) of less than 0.082 m and an m_h (vertical accuracy) of less than 0.1 m. The study determined that the remaining limestone volume above +5 m elevation is 519,324 m³, while the excavated volume below +5 m is 84,078 m³. Using drones also reduced fieldwork time by 60% while keeping costs low, providing reliable data for quarry operations and legal requirements. The use of UAV technology at Trai Son Quarry proves that it is an effective and accurate way to map and measure limestone extraction, even in difficult terrains. Future research will expand UAV applications to other quarries in Vietnam, with regular map updates and GIS (Geographic Information System) integration to improve resource management and environmental planning.

Keywords: Limestone Extraction, Topographic Map, Trai Son Quarry, UAV Technology, Vietnam

1. INTRODUCTION

UAV (Unmanned Aerial Vehicle) technology has been increasingly recognized as an innovative and efficient tool for the acquisition of high-resolution spatial data and the construction of detailed 3D terrain models. Its application has been found to improve safety, reduce cost, and increase operational efficiency in comparison with conventional surveying techniques [1]. In recent years, UAV photogrammetry has been widely used in mapping, mining, and volumetric analysis, supported by continuous advancements in remote sensing, digital cameras, and photogrammetric processing [2].

Traditional surveying methods, including total station and ground-based GNSS (Global Navigation Satellite System) surveys, have been considered time-consuming, labor-intensive, and difficult to apply in large, rugged, or hazardous quarry environments [3,4]. Therefore, the use of UAVs for topographic mapping has been regarded as an effective alternative that can ensure both accuracy and efficiency under complex terrain conditions.

Numerous studies have been conducted to evaluate UAV applications in geological and mining contexts. The team of Suasti [5] integrated UAV imagery with geophysical methods to analyze fault zones related to the Kajai earthquake, which

demonstrated the effectiveness of UAV data for geological structure mapping. The group of Török [6] combined UAV and terrestrial laser scanning (TLS) data to model limestone quarries and identify major fault lines, although limitations in field data at higher quarry levels affected the precision of results.

The research conducted by Eskandari [7] applied UAV images and machine learning to identify chromite mineralization zones, while the group of Kim and Hong [8] evaluated UAV LiDAR data for karst terrain mapping, showing superior 3D accuracy compared with conventional photogrammetry but with increased costs and technical constraints. The team of Adeyemi [9] applied UAV photogrammetry to estimate extracted rock volumes in Nigeria, demonstrating good accuracy but also revealing discrepancies related to material loss and loading variability. The study by Zapico [10] utilized UAVs to improve topographic surveys and detected more structural discontinuities than traditional methods. The research group of Nizar [11] employed UAV photogrammetry to assess rock mass conditions in underground mines, emphasizing the potential of UAV-based structural data but also identifying differences between automated and manual interpretations.

UAV technology has also been widely used in environmental and engineering geology studies.

The research group of Nguyen [12] used UAV photogrammetry to monitor dust dispersion in open-pit mining areas, while the team of Do [13] employed UAV data for forest fire susceptibility mapping. Both studies confirmed the high spatial precision of UAV-derived datasets but also noted their dependence on environmental conditions. UAVs have been further applied to analyze landslides and other geological hazards by the team of Hoang [14] and the group of Le [15], offering valuable high-resolution data for terrain analysis and natural hazard assessment.

Although these studies have demonstrated the effectiveness of UAV photogrammetry in mapping, environmental monitoring, and mining management, most have been conducted at medium mapping scales or under relatively simple terrain conditions. Limited research attention has been given to high-precision UAV-based topographic mapping in active quarry areas characterized by steep slopes, fragmented excavation surfaces, and variable elevations. Such terrain features are typical of the Trai Son limestone quarry in Thuy Nguyen City under the administration of Hai Phong City, Vietnam, where traditional surveying methods face significant challenges due to safety risks, inaccessibility, and irregular topography.

In the present research, UAV photogrammetry was utilized to establish a large-scale (1/500) topographic map with 1-meter contour intervals for accurate estimation of limestone extraction volumes in a complex quarry environment. The approach was designed to enhance mapping accuracy, efficiency, and safety while reducing fieldwork time and cost compared with conventional techniques. By combining UAV imagery with GNSS-based ground control points, the method was optimized to achieve high positional precision suitable for engineering-scale applications. This research contributes to advancing UAV photogrammetry for topographic mapping and resource quantification in challenging quarry settings, highlighting a methodological improvement and practical advantage over previous works that primarily focused on simpler terrain or smaller mapping scales.

2. RESEARCH SIGNIFICANCE

The application of UAV photogrammetry for topographic mapping and volume estimation provides a highly efficient, accurate, and cost-effective approach for quarry management. By reducing fieldwork time and ensuring worker safety, the method supports sustainable resource exploitation and compliance with national regulations on mine surveying and environmental protection. In addition, the methodological framework developed in this study has been

designed to be adaptable and replicable for other quarry sites with similar terrain and extraction conditions. The combination of UAV photogrammetry and GNSS-based control points can be standardized as a reference procedure for large-scale mapping and monitoring in open-pit mines. This standardization would enable consistent data quality, facilitate legal documentation, and promote best practices in quarry management and environmental assessment. The findings of this study therefore contribute not only to the improvement of UAV-based mapping accuracy but also to the establishment of a technical reference model for broader implementation in resource management and spatial monitoring.

3. CASE STUDY

This mapping project focuses on the Truot Mountain area, specifically the northern and northeastern parts of Zone B in the Trai Son limestone mine (Fig. 1). The mine is in Thuy Nguyen City under the administration of Hai Phong City. The surveyed area is bordered by rice fields and the Hon Ngo Canal to the north, Zone A and the Han Mau River to the west, and industrial sites, including lime plants and the Tan Hoang An Quarry, to the east.

The region has several major industrial operations, including Mo Tan Mao Khe, Hoang Thach Cement Plant, Phuc Son Cement Plant, and Chinfon-HP Cement Plant. Many local businesses are also involved in stone extraction and cement additive production. Due to the rough terrain and poor soil, agriculture is limited. Traditional handicrafts are mainly connected to the long-standing stone quarrying industry. Most local workers are employed in farming, quarrying, or mechanical repairs to support mining activities.

The area's landscape is mostly terraced, sloping from west to east, and includes two main types of terrain: karst and plains. Karst formations are dominant, with limestone peaks rising 120–160 meters, steep slopes (60–80°), vertical cliffs, and many grooves and caves formed by Middle Devonian geological units. On the other hand, the plains, which are only 2–5 meters above sea level, are used for small farming and housing.

The area has a tropical monsoon climate. The rainy season lasts from April to October, with an average temperature of 27°C, while the dry season runs from November to March, with an average temperature of 19°C. Because there is not much vegetation and mining is still happening, scattered rocks and debris make surveying more difficult. However, the mine's location near the Da Bac River gives it access to a good waterway system, which makes transportation and logistics easier.

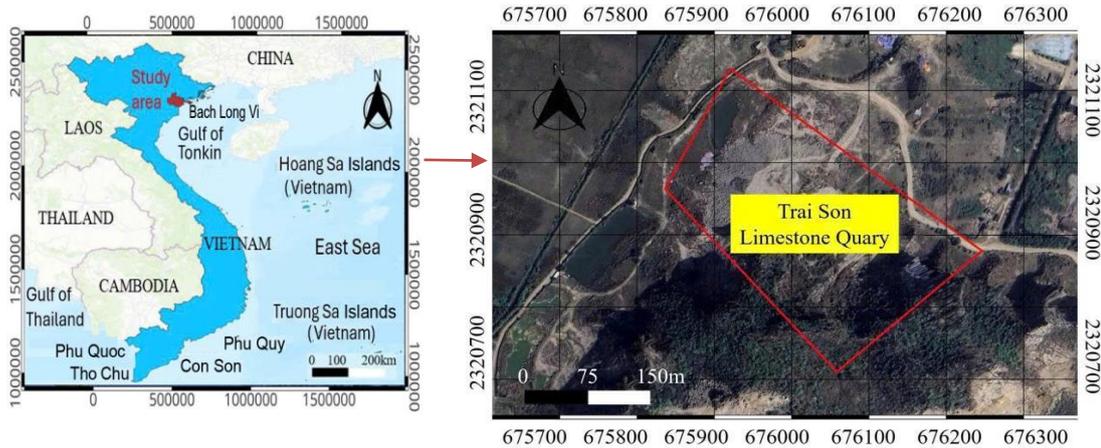


Fig.1 The Trai Son limestone quarry in Hai Phong City

4. METHODOLOGY

The process is systematically in the following steps (Fig. 2):

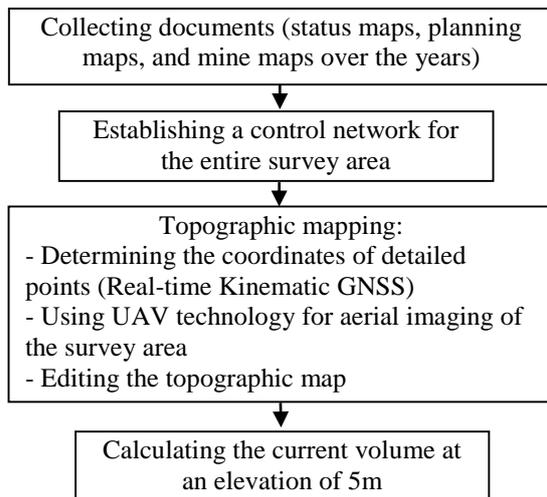


Fig.2 Process of the research

- Collecting documents

The available current status and planning maps of construction projects and mine area maps from previous years of the local area are collected and used as references for designing the control survey network and supporting the construction planning process.

- Design of the traverse control network

The traverse control network is established using GNSS positioning technology. The network is designed with pairs of inter-visible points, with a sufficient density of points to serve as a basis for detailed surveying and mapping, and to provide photo control points across the entire survey area. The signal receiver should not be placed too close to reflective surfaces such as metal components, water surfaces, electrical equipment, or telecommunication devices.

- Topographic map survey at a scale of 1:500

- + Mathematical basis of the topographic map

This topographic map uses the WGS-84 projection and the VN-2000 coordinate system, with a central meridian at 105°45' and a 3° projection zone. The map is created at a 1:500 scale with 1-meter contour intervals. To ensure accuracy and full data coverage, the mapping process combines detailed surveying with total stations and aerial imaging using UAV technology.

- + Map sheet division

The 1:500 scale map is divided into sheets using the kilometer grid system for better organization. To fit the entire survey area on a single A0-sized sheet, the map is scaled down to 1:1000 for easier use and display. This adjustment should be understood as a display or utility scale rather than a modification of the original mapping scale.

- + Topographic Mapping Process

Ground surveying was performed using Real-Time Kinematic (RTK) technology with specialized equipment. From a third-order control point, six second-order points were established as Ground Control Points (GCPs) for aerial imagery and detailed measurements. Based on terrain complexity and mapping scale, the GCPs were evenly distributed at varying elevations to ensure accurate georeferencing and model stability. Coordinates were obtained using an RTK-GNSS system, meeting 1:500-scale accuracy standards under Circular No. 68/2015/TT-BTNMT, dated December 22, 2015, by the Ministry of Natural Resources and Environment [16].

A UAV survey using six pre-surveyed control points ensured high accuracy. Data were acquired with a DJI Phantom 4 RTK (20 MP CMOS camera) and a Trimble R10 GNSS receiver, then processed using MicroStation (V8i), Agisoft PhotoScan (1.8), and Global Mapper (v24.0). In Agisoft Metashape 1.8, images were aligned with high accuracy and a 40,000 tie-point limit to generate a dense point cloud (High-quality, Moderate depth filtering),

from which the DSM, DEM, and orthophoto (GSD ≈ 0.025 m) were derived. All datasets were georeferenced to VN-2000 (Zone 48N) with precise X, Y, H coordinates and Omega, Phi, Kappa orientation angles.

A Digital Elevation Model (DEM) was generated from UAV-derived point cloud data stored in LAS format, while a Digital Surface Model (DSM) was produced in binary GRID and ASCII formats. The creation of DEMs followed the technical guidelines specified in Circular No. 39/2014/TT-BTNMT, dated July 3, 2014, issued by the Ministry of Natural Resources and Environment [17]. The final orthophoto map was produced in GeoTIFF format, providing a high-resolution base for topographic analysis.

- Topographic map editing

Topographic map editing is the process of making detailed maps at a 1:500 scale that depict landscape, natural features, buildings, and infrastructure like highways, irrigation systems, and construction sites. These maps must adhere to government regulations and requirements.

- Volume Calculation

For volume calculations, direct survey data and orthophoto maps are combined, resulting in a point cloud of 5,737,724 points covering a 10.55-hectare area. Each point is recorded with its coordinates and elevation. Using specialized software, we create a DSM and develop a surface model with clearly defined boundaries. The Global Mapper volume calculation tool was used to determine the remaining exploitable volume above +5 m and the extracted volume below this level. Calculations

were performed by comparing the UAV-derived surface model with a reference base plane at +5 m, allowing accurate estimation of both remaining and excavated volumes through surface-to-plane differencing.

5. RESULTS AND DISCUSSIONS

The second-order traverse control network is measured using dual-frequency GNSS receivers with an accuracy of $M_s = (5\text{mm} + 1\text{ppm})$. The positioning method used is relative satellite positioning with geostationary satellites. The instrument is centered using optical centering, with a centering error ≤ 0.001 m. A steel tape with millimeter accuracy is used to measure the antenna height. The required range for the satellite elevation angle is 30° to 150° . The control network measurement adheres to the technical standards specified in the GNSS control network measurement specifications as well as the operating instructions of the instrument.

Each measurement station is supported by a base station, whose coordinates are derived from first-order or higher control points to ensure geodetic precision. The distance between the base and rover points is kept under five kilometers to maintain reliable signal transmission and accurate RTK positioning.

It is necessary to fix measurements at the rover site. The positional error of connected measurement locations, or the discrepancy between the current coordinates and the reference point used for verification, cannot be greater than 0.05 m.

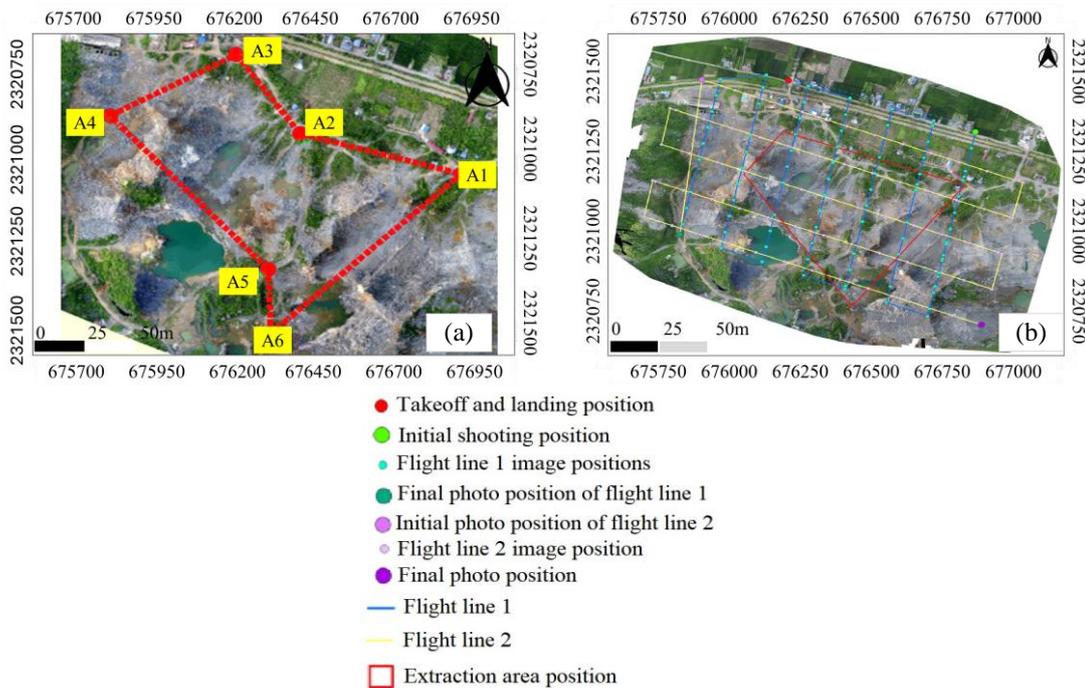


Fig.3 Ground control point layout (a) and Flight path design (b)

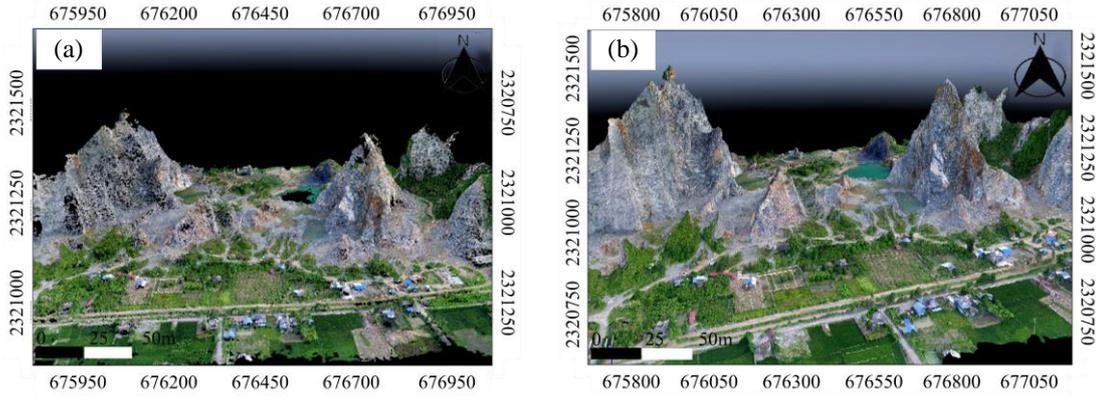


Fig.4 (a) Point cloud model (DEM); (b) 3D terrain model (DSM)

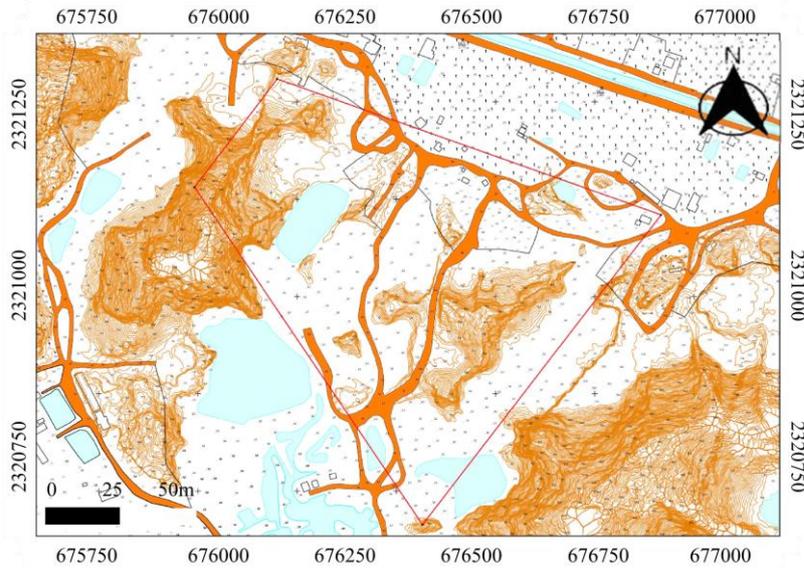


Fig.5 Digital topographic map at 1/1000 scale

A UAV was used to collect aerial data, supported by six pre-surveyed control points to enhance georeferencing accuracy and alignment (Fig. 3a, Table 1). A detailed flight plan was created to optimize coverage and ensure high-quality photogrammetry (Fig. 3b). Flight design software facilitated rapid, accurate planning based on specific areas or routes, displaying image centers on a DEM to guarantee complete coverage and providing precise, stable control via direct integration with the navigation system.

The drone survey consisted of two flight passes. The first pass used 60% \pm 5% longitudinal overlap (\geq 65%) and 25–30% \pm 10% lateral overlap (\geq 35%) to ensure continuous image coverage. A second pass, perpendicular to the first, maintained the same overlap to improve 3D model and ortho-image accuracy. Flights were conducted at 200 m above average ground level, with a structured and organized plan to ensure consistent, reliable, and highly accurate data collection.

Table 1. Coordinates of control points in the survey area

No	X(m)	Y(m)	H(m)
A1	2323859.081	585294.198	4.04
A2	2323930.165	585034.104	4.50
A3	2324069.907	584930.905	2.88
A4	2323962.099	584726.876	4.07
A5	2323690.625	584982.154	4.96
A6	2323577.327	584987.182	4.83

Table 2. Errors of check points

Check Measurement Data				DTM Data			Error		
No	X(m)	Y(m)	H(m)	X(m)	Y(m)	H(m)	X'(m)	Y'(m)	H'(m)
1	2323936.178	584907.694	5.580	2323936.231	584907.724	5.519	0.053	0.030	0.061
2	2323944.091	585024.709	3.370	2323944.111	585024.732	3.355	0.020	0.023	0.015
3	2323907.243	585018.259	3.570	2323907.314	585018.282	3.577	0.071	0.023	0.007
4	2323852.173	584975.004	3.790	2323852.255	584975.091	3.806	0.082	0.087	0.016
5	2323794.947	584963.682	3.380	2323794.983	584963.645	3.442	0.036	0.037	0.062
6	2323906.857	585098.957	3.430	2323906.889	585098.987	3.361	0.032	0.030	0.069
7	2323750.411	585033.137	11.980	2323750.375	585033.177	11.880	0.036	0.040	0.100
8	2323696.099	584995.006	6.310	2323696.051	584995.056	6.244	0.048	0.050	0.066
9	2323785.12	585200.09	7.29	2323785.168	585200.055	7.316	0.048	0.035	0.026
10	2323745.551	585137.461	5.91	2323745.571	585137.435	5.932	0.020	0.026	0.022
11	2323879.699	585130.894	3.54	2323879.652	585130.871	3.581	0.047	0.023	0.041
12	2323584.749	585226.625	3.22	2323584.771	585226.605	3.159	0.022	0.020	0.061
13	2323844.478	584918.465	4.48	2323844.443	584918.498	4.438	0.035	0.033	0.042
14	2323768.109	584913.247	3.2	2323768.135	584913.211	3.262	0.026	0.036	0.062
15	2323790.079	585037.59	12.22	2323790.056	585037.567	12.174	0.023	0.023	0.046
16	2323750.411	585033.137	11.78	2323750.457	585033.191	11.717	0.046	0.054	0.063
17	2323811.691	585166.294	10.632	2323811.639	585166.252	10.658	0.052	0.042	0.026
18	2323996.401	584970.982	3.75	2323996.436	584970.96	3.681	0.035	0.022	0.069
19	2323952.818	584949.636	6.11	2323952.855	584949.656	6.052	0.037	0.020	0.058
20	2323950.853	584983.619	4.7	2323950.886	584983.67	4.662	0.033	0.051	0.038

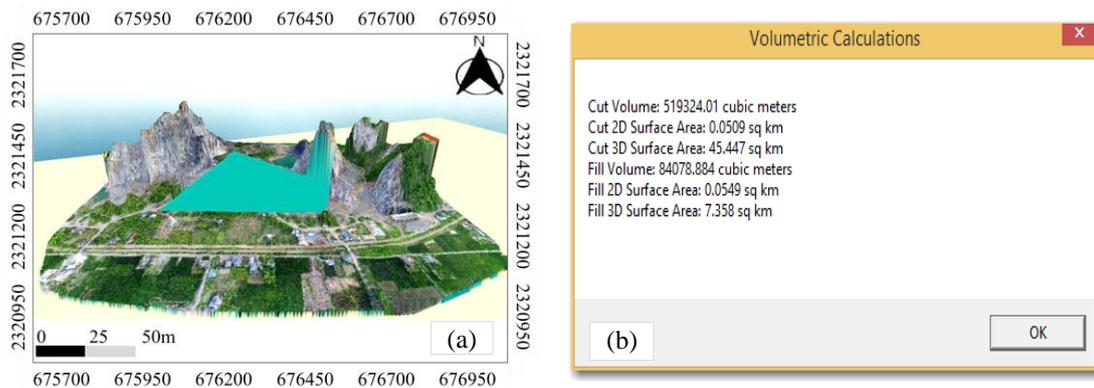


Fig.6 (a) Volume model (>5 m remaining, <5 m excavated); (b) Field excavated and lime-treated volumes

All UAV flights were conducted under clear sky conditions with light winds and stable illumination to ensure optimal image quality and high positional accuracy during data acquisition. The drone is equipped with GNSS and an Inertial Measurement Unit (IMU), which record the exact location and orientation of each captured image. The full flight process - from setting up the GPS/IMU, taking off, flying automatically, capturing aerial images,

landing, to retrieving all collected data - follows a carefully planned and systematic procedure.

The UAV must strictly follow altitude, navigation, and overlap requirements, under the supervision of a flight operator. To improve image accuracy, Ground Control Points (GCPs) are set at key geodetic and image control points. Each GCP is cross-shaped, measuring 1m × 1m with a 0.2m width, making them easily identifiable in aerial images.

Following the aerial survey, a DEM and a 3D terrain model (DSM) were generated (Fig. 4). The topographic map was created at 1:500 scale with 1 m contours, and the quarry boundary delineated at 1:1000 scale (Fig. 5). Accuracy was ensured by measuring 20–35 elevation points per 1 dm², with all symbols following national mapping standards (1:500–1:5000). The UAV-derived map (Fig. 5) accurately represents terrain morphology and quarry boundaries, consistent with previous studies [6,10].

Errors of used check points are shown in the Table 2. Images were captured at 0.026 m resolution, using six GPS-measured GCPs to achieve horizontal accuracy <0.05 m and vertical accuracy <0.10 m. The UAV-derived DEM and 3D model were validated with evenly distributed GNSS checkpoints, yielding $m_{xy} = 0.082$ m and $m_h = 0.1$ m, satisfying national 1:500-scale topographic mapping standards.

Volumetric calculation reliability was verified through DEM elevation errors, with uncertainties from camera calibration, point cloud density, and interpolation minimized using dense GNSS-based GCPs and high image overlap. The total propagated error was below 2.5%, ensuring accurate and stable results. A +5 m elevation threshold, based on field surveys, design drawings, and the Trai Son quarry plan, defines the boundary between the active excavation and remaining limestone, with negligible impact on accuracy, as the UAV-derived DTM showed a vertical error below 0.1 m.

The volume calculation model in Fig. 6 shows the remaining volume above +5 m (519,324 m³) and the excavated volume below +5 m (84,078 m³), including lime-treated material. The 3D model, generated from the UAV-derived DTM and quarry boundaries using Global Mapper, visualizes terrain morphology and distinguishes remaining and excavated zones. This method accurately represents quarry geometry and aligns with previous UAV-based volumetric studies [6,9], confirming the reliability of UAV photogrammetry for 3D volume estimation.

Drone mapping in limestone quarries provides significant benefits for measuring excavation and embankment volumes. Drones rapidly capture high-resolution imagery and generate detailed 3D models for accurate volume estimation, saving time, reducing manual work, enhancing accuracy and safety, and enabling regular monitoring for better decision-making and resource management. UAV photogrammetry is economically feasible for small-scale projects, offering substantial reductions in manpower, field time, and equipment costs while maintaining high mapping accuracy and data reliability compared to traditional surveying methods.

While UAVs offer major advantages for quarry mapping, challenges persist in accurately estimating excavation and embankment volumes. UAV operations are weather-dependent, as strong winds, rain, or fog can delay flights or degrade image quality. Reliable models require precise calibration and well-distributed GCPs, demanding additional fieldwork and skilled personnel. High equipment, software, and training costs, along with computing demands and flight restrictions, remain constraints. As UAVs capture only surface features, integrating LiDAR or GPR is recommended for subsurface analysis. In this study, flights were conducted under stable weather with carefully established GCPs to ensure data accuracy and consistency.

6. CONCLUSION

The study successfully produced a 1/500-scale topographic map using UAV technology to measure limestone extraction at Trai Son Quarry, with contour intervals of 1 m and boundary features established at a 1/1000 scale. The data collection and mapping process achieved high accuracy. By using dual-frequency GNSS receivers, precise ground control points (GCPs), and well-planned UAV flights, the study captured sharp aerial images with a resolution of 0.026 m. These photographs contributed to the creation of accurate 3D landscape models and orthophotos. The analysis found that the residual limestone volume above +5 m elevation was 519,324 m³, while the excavated volume below +5 m was 84,078 m³.

The study showed that UAV photogrammetry can generate high-accuracy topographic maps for limestone quarries, ensuring safety, efficiency, and compliance with national standards. It significantly reduces survey time and costs while improving workflow flexibility, visualization, and resource management. Despite limitations such as weather dependence, high costs, and regulatory constraints, the methodology is practical and replicable for small- to medium-scale quarries in complex terrain.

To enhance UAV use in mining, flights should occur under favorable weather with advanced UAVs capable of moderate winds or light rain. Proper training for equipment calibration and GCP setup is essential. Small enterprises can reduce costs by leasing UAVs or using open-source software, while integrating LiDAR and increasing computing power can improve mapping accuracy and support continuous monitoring.

Although UAV photogrammetry is effective, this study faced limitations such as weather dependence, restricted flight paths in steep terrain, and high equipment costs. Future research should integrate AI, machine learning, and multi-sensor UAVs (e.g., LiDAR, hyperspectral imaging) to

improve accuracy and support environmental assessment and sustainable quarry management. Developing cost-effective UAV solutions for small quarries, enabling real-time data sharing, and monitoring temporal changes in quarry morphology are also recommended to promote safer and more sustainable mining.

7. ACKNOWLEDGMENTS

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