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ASSESSING VEGETATION AND SOIL CONDITIONS IN THE RUSCHITA MARBLE QUARRY USING DRONE-BASED MULTISPECTRAL REMOTE SENSING

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Abstract: *This study proposes using drone-based multispectral remote sensing technology to assess vegetation health and soil conditions in the Ruschita Marble Quarry. The research aims to evaluate land degradation, soil erosion patterns, and vegetation coverage in the quarry area through multispectral imaging and post-processing in Agrowing Multispectral Software. The methodology involves deploying drones equipped with multispectral sensors to capture data across multiple spectral bands, enabling detailed analysis of vegetation health indices, soil surface characteristics, and erosion patterns. Vegetation Indices (VI) are derived directly from multispectral imagery, while high-resolution terrain mapping is performed to identify topographical features influencing erosion and vegetation recovery. This approach provides valuable insights for quarry restoration management by showcasing the potential of advanced remote sensing technologies in environmental monitoring, contributing to the development of sustainable quarry management practices and helping identify areas requiring intervention.*
Keywords: *remote sensing, vegetation, soil, drones, restoration, sustainability*

1. Introduction

The extraction of ornamental stones, such as marble, often leads to significant land degradation, including deforestation, soil erosion, and biodiversity loss. Restoration of such sites poses a critical challenge, necessitating innovative technologies for monitoring and management. The Ruschita Marble Quarry in Romania, renowned for its high-quality marble, serves as a case study for applying advanced remote sensing techniques to assess and guide restoration efforts. [1]

Remote sensing, particularly drone-based multispectral imaging, has emerged as a powerful tool for environmental monitoring. Drones equipped with multispectral sensors allow for detailed, high-resolution data acquisition over large areas, offering new opportunities for assessing vegetation health, soil conditions, and erosion patterns. Integrating this technology with post-processing software enhances the analysis and visualisation of spatial data, providing actionable insights for sustainable quarry management. [2, 3]

2. Background on the Ruschita Marble Quarry in Romania

The Ruschita Marble Quarry (Fig. 1), located in Caras-Severin County, Romania, is a historic and significant source of high-quality decorative marble. Renowned for its warm beige, pink, and white tones with subtle veining, this marble has been used in prestigious architectural and sculptural projects since the late 19th century, particularly under the Austro-Hungarian Empire.

The quarry marble is prized for its durability, crystalline structure, and ability to take a high polish, making it suitable for both interior and exterior applications. It has significantly contributed to the local economy through employment and exports, with international markets valuing its unique aesthetic and physical properties. [4]

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Modern quarrying techniques, including diamond wire saws, have improved the extraction efficiency while reducing environmental impacts; however, challenges such as landscape alteration, dust emissions, and waste generation remain.

Efforts are ongoing to adopt sustainable practices that align with European environmental regulations, including landscape restoration and recycling of by-products. Additionally, the quarry holds potential for tourism due to its historical and aesthetic significance.

Fig.1. Ruschita Marble Quarry

3. Remote Sensing Protocol for Quarry Assessment

This study employs a drone-based multispectral remote sensing approach to assess vegetation health and soil conditions in the Ruschita Marble Quarry.

Using drone technology equipped with advanced multispectral sensors enables precise and efficient data acquisition across the quarry area, providing a robust framework for evaluating ecological restoration efforts.

3.1. Data Collection and Drone Specifications

The data collection was conducted using a multirotor drone DJI M200 L1/L2 PPK, equipped with a multispectral camera capable of capturing reflectance data in five spectral bands: blue, green, red, red edge, and near-infrared (NIR). These bands were selected for their ability to detect vegetation health indicators and variations in soil reflectance, which are critical for assessing the environmental conditions in the Ruschita Marble Quarry.

A pre-defined flight plan was programmed into the drone, ensuring comprehensive coverage of the quarry area. Flight parameters were optimised for data quality, with the drone flying at 120 meters and 5 meters per second.

An overlap of 70% in the forward direction and 60% in the side direction was maintained to ensure seamless image stitching. Data acquisition was scheduled during clear weather conditions and at consistent times of the day to minimise shadows and atmospheric distortions.

Multispectral Sensor Specifications

The selected drone was a multirotor UAV (Unmanned Aerial Vehicle), chosen for its manoeuvrability and ability to hover, which is essential for capturing detailed imagery in uneven terrain like a quarry.

The drone was equipped with TOPODRONE P61 - A7CR 61MP camera and AGROWING QUAD Multispectral lens, which captured data across 10 narrow spectral bands or 9 bands and Wide RGB: blue (405, 430, 450 nm), green (550, 560, 570 nm), red (650, 685 nm), red edge (710 nm), and near-infrared (850 nm).

These spectral bands are ideal for vegetation analysis and soil condition monitoring, enabling the computation of key indices such as NDVI and SAVI.

The camera was factory-calibrated to ensure accurate radiometric measurements, and a calibration target was used before each flight to account for variations in light intensity during data acquisition.

An image of the multispectral camera used in this paper is presented in Fig. 2, and the monitor screen with images captured during the flight. [5, 6]

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Fig.2. Agrowing multispectral lens equipped on a DJI M200 UAV

Agrowing Alpha 7RCR-based sensor has a resolution of 12 Megapixels per band. The distribution of the chroma bands with their corresponding filters is presented in Fig. 3.

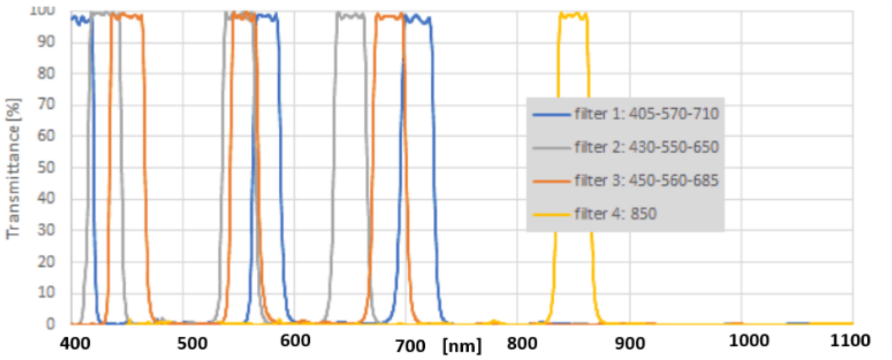

Fig.3. Agrowing A7CR 61 MP multispectral 10 channels

Flight Planning and Execution

A detailed flight plan was created using DJI Pilot App software, allowing precise route mapping and parameter optimisation.

The total survey area of the quarry was divided into overlapping grid patterns to ensure complete coverage and avoid gaps in the data.

Specific flight parameters included:

- Altitude: 150 meters above ground level (AGL) to balance resolution and coverage;
- Ground Sampling Distance (GSD): Approximately 5 cm/ pixel, ensuring high-resolution imagery suitable for detailed analysis;
- Speed: 5 meters per second to minimize motion blur;
- Overlap: 70% frontal overlap and 60% side overlap to facilitate seamless image stitching during processing

The drone operated within visual line of sight (VLOS), in compliance with local aviation regulations, and flights were conducted under favourable weather conditions (e.g., no precipitation, wind speeds below 5 m/s).

The survey timing was carefully chosen to match peak daylight hours, minimising shadow effects and maximising data consistency across flights.

Pre-flight and In-flight Operations

Before each flight, the drone and multispectral camera were thoroughly inspected to ensure functionality. The calibration panel provided by the sensor manufacturer was used to capture radiometric

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calibration images, which were later used to normalise the reflectance values in the imagery. GPS waypoints and altitude restrictions were pre-loaded into the flight software to prevent deviations during data collection.

During flights, real-time telemetry was monitored to ensure adherence to the planned route and to detect any anomalies. Each flight lasted approximately 20 minutes, with multiple flights conducted to cover the entire quarry area. Battery levels were closely monitored.

Fig. 4 and Fig. 5 present the positions of flight stripes and the locations where the multispectral camera took images / measurements. Due to the large files, the two data sets were processed independently.

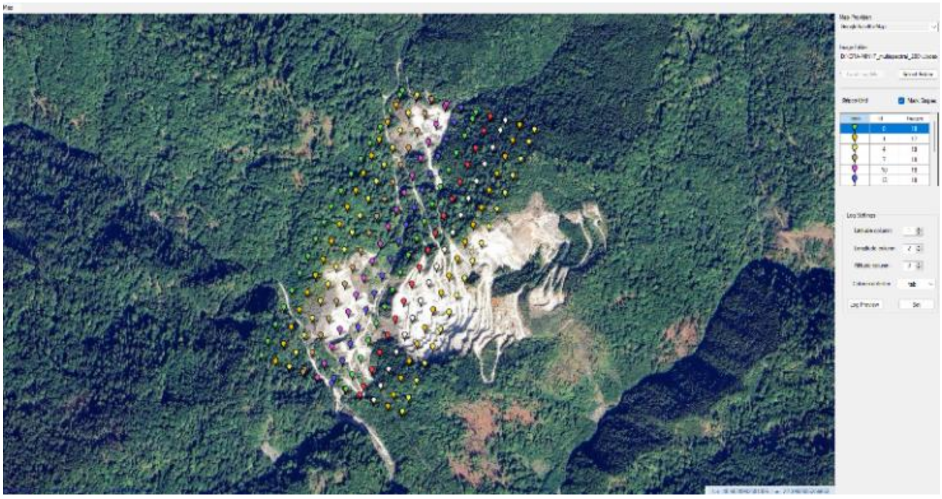

Fig.4. In-flight sensor positions for capturing images / data – focus on the quarry

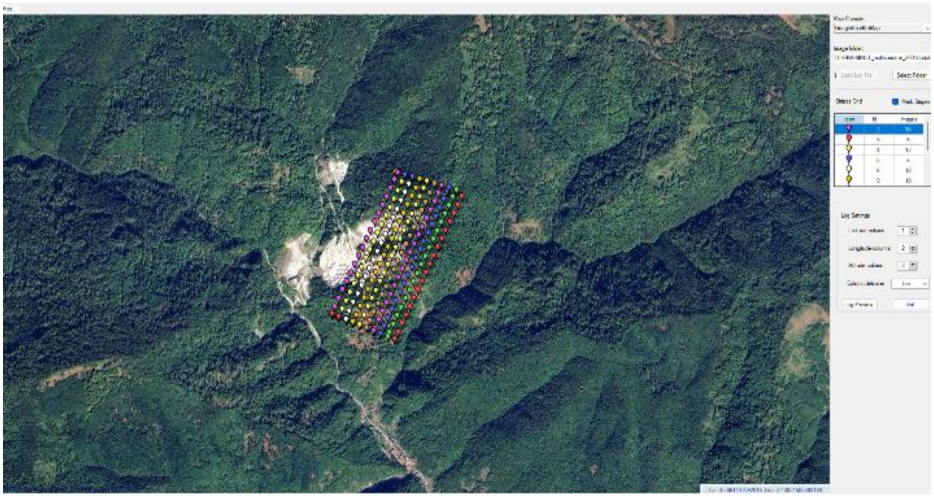

Fig.5. In-flight sensor positions for capturing images/ data – focus on the forest

Post-flight Data Handling

After each flight, the captured images were transferred from the drone's SD card to a secure storage device for processing. Metadata associated with each image, including GPS coordinates, altitude, and timestamp, were reviewed to ensure data integrity.

Fig.6. Selected locations for source images above the forest and quarry

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The dataset for each flight was organised systematically, with calibration images stored in separate folders for easy access during pre-processing.

Two locations were selected to compare Vegetation Indices (VI) – one above the forest, which will be compared to the location above the quarry, as presented in Fig. 6.

The source image, as it was captured by the multispectral camera (the visible parts), is shown in Fig. 7

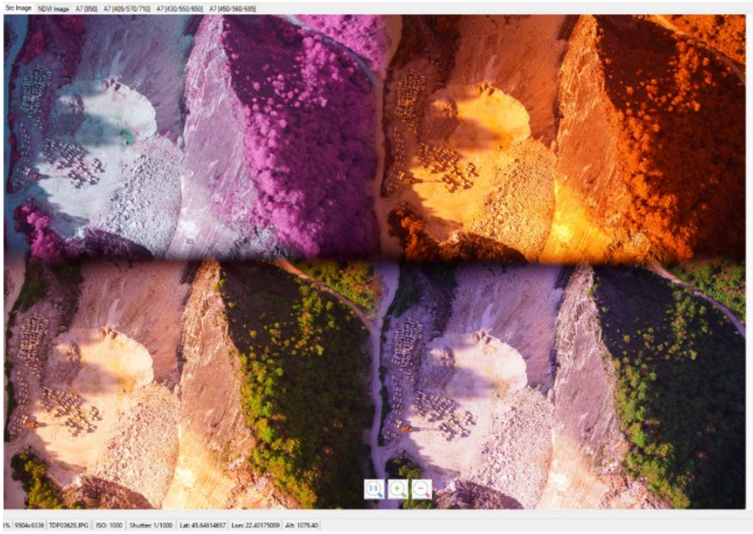

Fig.7. Source image from the multispectral camera

3.2. Image Processing and Vegetation Indices

The captured multispectral images were processed using Agrowing Basic Software, designed for multispectral drone imagery.

The workflow included radiometric correction to normalise light intensity variations and geometric correction to align the images.

Vegetation Indices (VI), such as the Normalised Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI), were calculated to assess vegetation health. [5]

Vegetation Indices (VI) are a remote sensing technique that can be used to measure vegetation's health and vitality, and they are based on the reflectance of plants.

Plants absorb some light through photosynthesis, and their leaves reflect some light. Vegetation Indices analyse the light that is not absorbed and evaluate their condition. Healthy plants reflect more Near-Infrared (NIR) and green light than those with stressed or dead leaves (Fig. 8).

Also, in Fig. 8 are presented the various VI that can be used for evaluation of plant health during its growing cycle, as follows:

- MSAVI – Modified Soil Adjusted Vegetation Index;
- NDVI – Normalised Difference Vegetation Index;
- NDRE – Normalised Difference Red Edge.

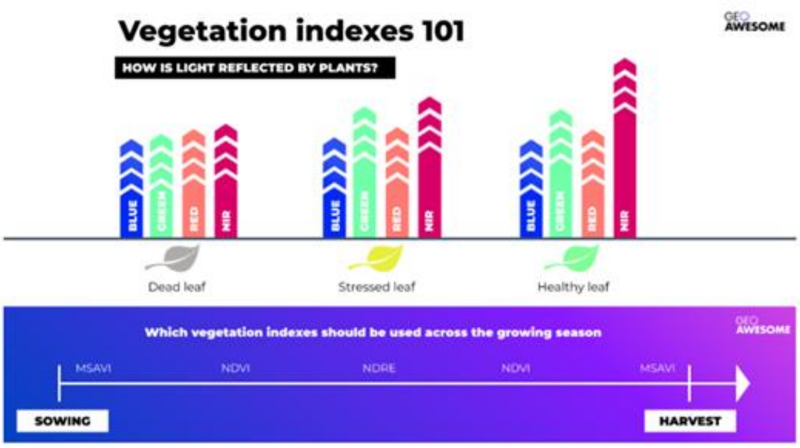

Fig.8. Light reflected by plants according to their health condition

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NDVI uses the difference between red and near-infrared reflectance to quantify chlorophyll content, while SAVI adjusts for soil reflectance, making it ideal for areas with sparse vegetation. These indices were mapped across the quarry to visualise and identify stressed areas.

Using Agrowing Basic, vegetation indices such as the Normalised Difference Vegetation Index (NDVI) and (Modified) Soil-Adjusted Vegetation Index (M/SAVI) were calculated.

NDVI was derived using the formula:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

Fig.9. NDVI and plant health

NDVI index is a reliable measure of vegetation chlorophyll activity and health, and its value ranges from -1 to 1 and shows the vigour of the plant – Fig. 9:

- Values close to 1 – the more intense the green, the more vigorous the plant and vegetation cover;
- Values close to 0 – areas with very little vegetation, bare soil or non-productive areas;
- Negative values – are usually associated with water, snow, or clouds

SAVI, which adjusts for soil background reflectance, was calculated using the formula:

$$SAVI = \frac{(1+L)(NIR - Red)}{NIR + Red + L} \quad (2)$$

where:

L - is a soil brightness correction factor

The vegetation indices were then visualised as images in Agrowing Basic Software, providing spatially explicit information on vegetation health across the quarry. These layers were further analysed to identify patterns of stress and areas of high vegetation coverage.

3.3. Analysis of Soil Conditions

Although the primary focus was on vegetation health, bare soil conditions were indirectly assessed through spectral analysis of bare soil areas.

Reflectance data in the red and NIR bands were used to estimate soil properties such as moisture content and organic matter.

While not validated through field sampling, these data offer preliminary indicators of soil quality and erosion risks and influence soil fertility and erosion risk, making them critical for restoration planning.

Agrowing Basic Software extracted and classified bare soil areas from the multispectral imagery. Spectral reflectance thresholds were applied to differentiate soil from vegetation.

While no field sampling was conducted in this study, the remote sensing data provided valuable soil quality and stability insights. [1]

3.4. Data Interpretation and Visualisation

The processed multispectral data were imported into Agrowing Basic Software for advanced analysis and visualisation.

Layers / images representing vegetation indices, bare soil areas, and terrain characteristics were generated to create composite maps highlighting the quarry's ecological conditions.

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Fig 10. Ruschita NDVI Index – above the forest

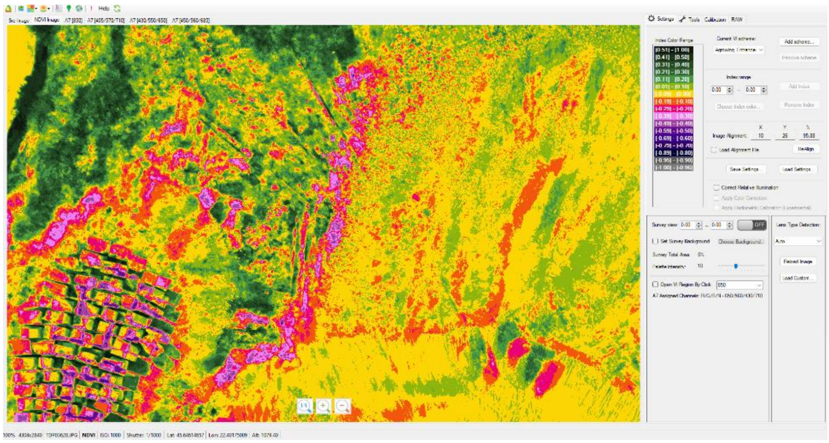

Fig.11. Ruschita NDVI Index - above the quarry

Fig.12. Ruschita MSAVI Index – above the forest

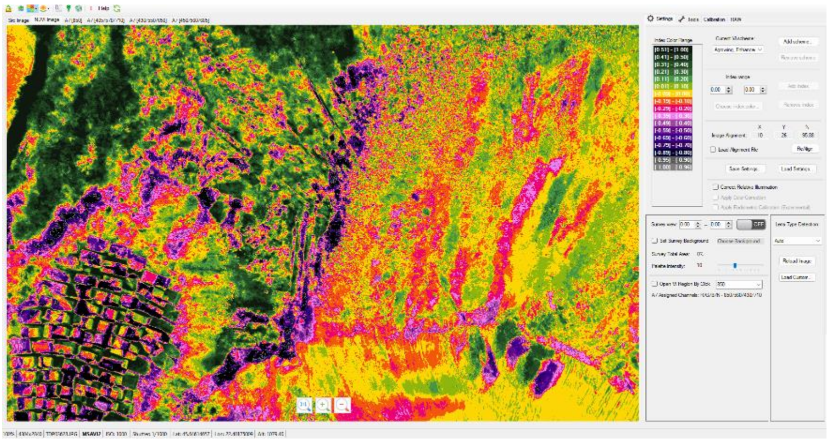

Fig. 13. Ruschita MSAVI Index – above the quarry

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Fig. 14. Ruschita NDRE – Index – above the forest

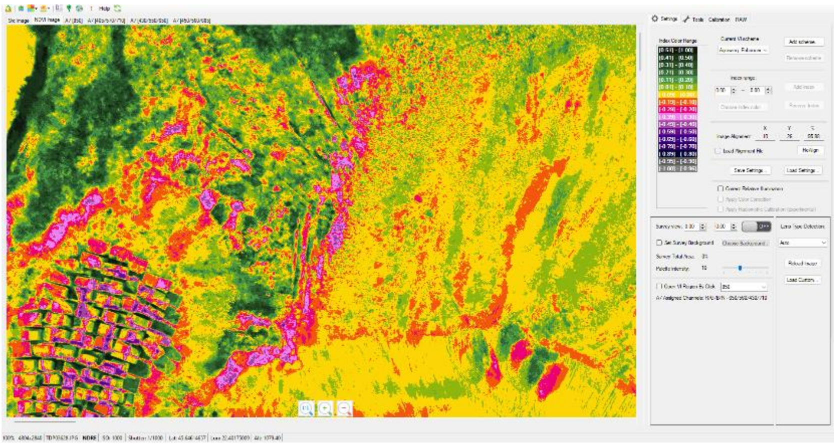

Fig. 15. Ruschita NDRE Index – above the quarry

Figures 10 to 15 show NDVI (Normalised Difference Vegetation Index), MSAVI (Modified Soil Adjusted Vegetation Index) and NDRE (Normalised Difference Red Edge) indices for the two selected locations – above the forest and quarry. The Index Colour Range for the respective data is on the right side of each image.

These tools could enable the generation of detailed thematic maps that illustrate vegetation coverage, stress zones, and potential erosion risks.

The maps will be analysed to identify areas requiring immediate intervention, such as replanting or soil stabilisation, and to prioritise resources for restoration efforts. [7]

A quantitative comparison of vegetation indices was done to enhance the comparative analysis between the forest and quarry areas. This approach provides concrete data to illustrate the differences in vegetation health and soil conditions between the two environments.

A comprehensive quantitative analysis of vegetation indices between the forest and quarry areas reveals significant disparities in plant health and soil conditions. By examining the Normalised Difference Vegetation Index (NDVI), Modified Soil Adjusted Vegetation Index (MSAVI), and Normalised Difference Red Edge (NDRE), we can objectively assess the ecological status of both regions. This comparison highlights the impact of quarrying activities on local vegetation and provides valuable insights for targeted restoration efforts.

As it can be seen from the Fig. 10, 12 and 14, the health status of the vegetation outside the quarry (forest area) is good to very good, with variations of NDVI, MSAVI and NDRE indices from 0.00 to 0.50, with lower values in certain parts of the canopy. Further investigations on the filed should be carried out, to identify the causes and areas of lower health.

On the other hand, Fig. 11, 13 and 15 show VI values starting for -1.00 to +0.50, representing a bare ground (in fact marble blocks or the rock mass), with patches of positive values of the indices – representing adjacent areas with some vegetation.

4. Conclusions

The methodology employed in this paper demonstrates the effectiveness and practicality of using drone-based multispectral remote sensing for assessing vegetation health and soil conditions in the Ruschita Marble Quarry. By leveraging advanced drone technology and high-resolution multispectral sensors, the research provides a comprehensive and efficient approach to environmental monitoring in quarry restoration. [3]

Using a multirotor drone equipped with an Agrowing A7CR 61MP QUAD Multispectral camera allowed for precisely capturing spectral reflectance data across critical bands (blue, green, red, red edge, and near-infrared). This data was instrumental in calculating vegetation indices such as NDVI, MSAVI, and NDRE, which are reliable indicators of plant health and stress levels. The drone's manoeuvrability and ability to operate at consistent altitudes ensured detailed coverage of the quarry's complex terrain, capturing high-resolution imagery suitable for rigorous analysis. [5]

The methodology highlights the advantages of using remote sensing technologies for environmental monitoring. Compared to traditional field-based methods, this approach offers significant efficiency gains by reducing time, labour, and costs while maintaining high levels of accuracy. The ability to repeatedly survey large areas with minimal environmental disturbance makes this method particularly suitable for ongoing monitoring and adaptive management in quarry landscapes. [2]

While this research focused on vegetation health and soil conditions using remote sensing data, it also acknowledges the importance of field validation to ensure accuracy and reliability. The lack of direct field sampling represents a limitation; however, the results provide a robust baseline for future studies incorporating ground-truthing techniques.

In conclusion, the methodology presented in this paper establishes a scalable framework for monitoring and managing the restoration of quarry landscapes. The integration of drone-based multispectral remote sensing not only supports the assessment of current ecological conditions but also offers valuable insights for developing sustainable restoration strategies. This approach can be adapted and applied to similar quarry environments, contributing to broader sustainable land management and environmental conservation efforts. [1, 7]

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