Geomatics for Monitoring Rehabilitation Status in Aruwakkalu Limestone Quarry, Sri Lanka

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Abstract

Aruwakkalu limestone quarry in Sri Lanka, owned and operated by Siam City Cement (Lanka) Limited, is one of the largest limestone deposits in Sri Lanka. Since the limestone deposit is seated in a shallow depth, it is being excavated by utilising opencast mining methods. The target main product from the extracted limestone is to produce cement. As the first step of rehabilitation, the land restoration is carried out by backfilling the mined-out areas with the previously stripped overburden material. To achieve the final landform, replantation of vegetation cover is formed by planting native trees on top of the re-filled land area. This study aims to evaluate UAV suitability for monitoring rehabilitation in the Aruwakkalu limestone quarry, geomatics-based vegetation analysis in rehabilitated areas, and the assessment of the drainage system of the study area. Aerial images were acquired from an UAV equipped with a multispectral sensor and the data was post processed by utilising Pix4D, ENVI, and ArcGIS software. The processed data was classified into different regions according to the rehabilitated year and further analyses revealed that there were certain areas which had poor vegetation cover which requires revegetation measures. Analyses of the terrain models of the study area revealed irregular drainage patterns, which need to be rectified by grading and forming better landforms. The findings provide valuable insights for monitoring and improving rehabilitation efforts in similar mining sites, contributing to sustainable mining operations.

Keywords: Hydrogeological analysis, Multispectral image analysis, Sustainable mining, Unmanned aerial vehicle, Vegetation analysis

1 Introduction

Mining activities can significantly impact the Earth's surface, leaving lasting scars that can have adverse environmental consequences. In light of this, it is of utmost importance to acknowledge the debt we owe to nature for the resources it has provided us. Consequently, it becomes imperative to undertake substantial efforts and initiatives aimed at restoring and replenishing the natural environment. Therefore, rehabilitating the mine site is a paramount endeavour, driven by the objective of mitigating the environmental consequences associated with mining operations, while concurrently revitalizing the land to a state that aligns with its intended purpose [1].

Aruwakkalu Limestone Quarry is an open pit mine located in Puttalam District, Northwestern Province, Sri Lanka. This quarry has been in operation since the early 1990s and can be considered one of the largest limestone deposits in the country. The primary use of the extracted limestone is to produce cement, while also finding applications in diverse industries including construction and agriculture. The process of rehabilitating decommissioned lands entails a systematic approach comprising three essential steps. Firstly, the quarried region is restored by replenishing it with the overburdened low-grade red soil, which is a byproduct of mining operations. Secondly, these filled areas are then layered with topsoil, characterized by its high organic content and natural seed bank, sourced from newly mined regions. Lastly, during the northeast monsoon period, appropriate native plant species such as *Limonia acidissima, Millettia pinnata, Madhuca longifolia,* etc. are deliberately cultivated in the refilled areas, fostering ecological restoration, and enhancing the re-establishment of a sustainable ecosystem [2]. This methodical rehabilitation process aims to mitigate the adverse effects of mining activities and promote the recovery and rejuvenation of the affected land, ultimately contributing to the preservation and preservation of the natural environment.

Conventional methods of revegetation monitoring involve the selection of multiple sample locations to quantitatively assess parameters such as density for evaluating the growth, height, and girth of the trees [2]. While these techniques may prove efficient for monitoring small quarries, they become impractical and labour-intensive when applied to larger areas[3]. In contrast, the utilisation of geomatics for monitoring rehabilitation status emerges as a significantly more efficient alternative compared to the conventional approach. The use of UAV (unmanned/unpiloted aerial vehicle) surveying techniques in geomatics for evaluating the rehabilitation status at open pit mines is a relatively new approach that has the potential to greatly improve the efficiency and accuracy of rehabilitation assessments. [1], [3–8]

2 Methodology

2.1 Study area

Aruwakkalu Limestone Quarry is encapsulated by the coordinates of 8°15'4.14"N latitude and 79°49'10.45"E longitude. The study area Shown in Fig. 1 covers an extensive land expanse, comprising a total area of 1.024 km^2 (102.44 hectares).

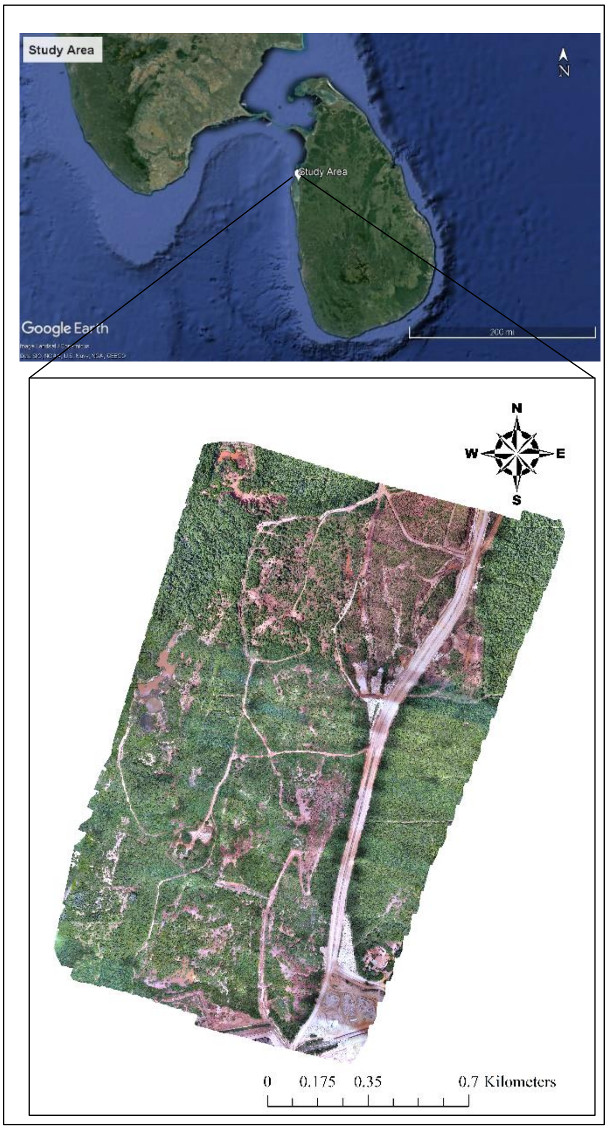

Figure 1: Study area

Different sections of the study region have experienced reforestation activities in different years Shown in Fig. 2. It is important to emphasize that this study only covers the areas that underwent reforestation between the years 2002 and 2021.

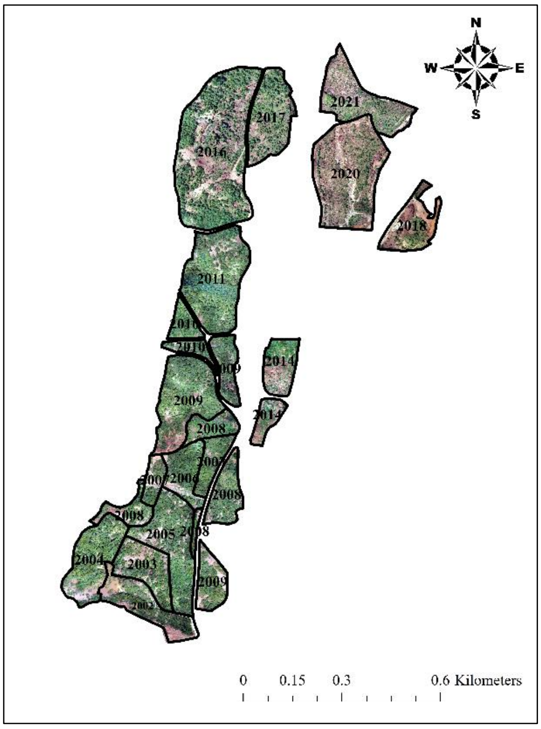

Figure 2: Map showing different areas that are planted in different years

2.2 Data collection

The missions conducted for this study involved using a DJI Phantom 4 UAV equipped with a multispectral camera. The drone survey and image acquisition parameters are detailed in Table 1. During the survey, 12,258 images were captured in 6 spectral bands (red edge, near- infrared, green, red, blue, and visible light) using the multispectral camera. The drone was programmed to fly at a height of 120 meters, ensuring a balance between image resolution and coverage area. A 60% side overlap ratio and 70% front overlap ratio were employed to ensure comprehensive data coverage and accuracy. These efforts aimed to monitor and assess the rehabilitation of the quarry site effectively.

Table 1: Parameters of the drone when acquiring images

Parameter	Description
Waypoints	96
Flight length	52650 m
Course count	48 lines
Cover area	203.68 Ha
Camera model	P4 multispectral camera
Shooting angle	Course aligned
Capture mode	Capture at an equal distance interval
Speed	12.4 m/s
Flight time	85 minutes
Front overlap ratio	70%
Side overlap ratio	60%

2.3 Data processing

The processing of UAV images using Pix4D involves several key steps, including importing images, initial processing, generating a dense point cloud and digital surface model (DSM), performing quality control, and extracting valuable information. The results can be exported for further analysis or integration into geographic information system (GIS) software. Colour correction was applied to address colour variation in the maps using ENVI software.

In the project, UAV ortho image maps were georeferenced using ArcMap, involving preparation, loading, and strategic selection of control points. The incorporation of reference data improved the accuracy of georeferencing results, making the orthoimages suitable for spatial analysis and integration. The successful georeferencing process enhances the overall applicability of the data for subsequent research.

Both the Pix4D and ArcMap methods help to align the UAV orthoimages with real-world geographic coordinates, improving spatial accuracy and enabling seamless integration with other geospatial datasets.

Based on the replantation year, NDVI (normalised difference vegetation index) maps were created in this research study to quantify vegetation density in different vegetated areas shown in Fig. 3. The orthophotos were corrected as needed, and NDVI values were computed pixel by pixel, yielding a series of NDVI maps exhibiting vegetation distribution and dynamics within the research region. Furthermore, NDVI maps for each replanted area were developed, providing insights into vegetation changes from 2002-2021 and aiding the evaluation of rehabilitation operations. This comprehensive approach aided in gaining a better knowledge of the efficacy of replanting activities as well as the general vegetation conditions across the area.

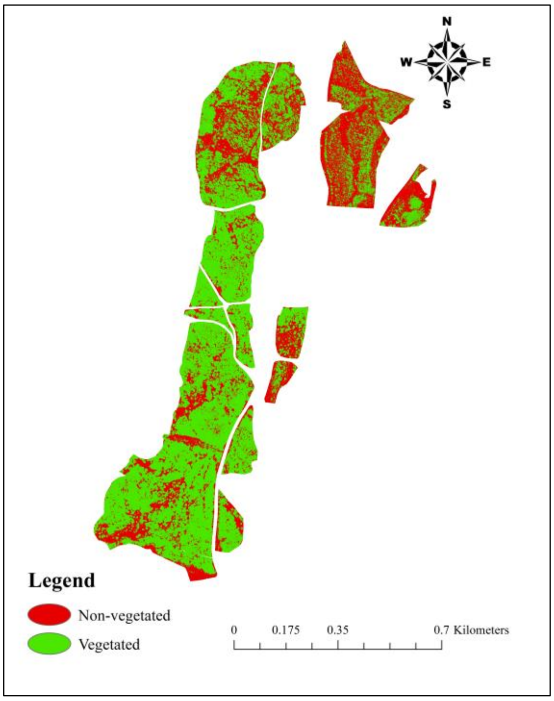

Figure 3: Classified NDVI map into two classes vegetated and non-vegetated in the year 2023

To generate the threshold values for the NDVI map, each year's NDVI readings were compared to the corresponding RGB (red-green-blue) photos. The purpose of this investigation was to determine the relationship between NDVI values, which measure plant density, and the visual look of vegetation in RGB images. By examining the correlation between these datasets, appropriate threshold values were identified to distinguish and classify different vegetation conditions, aiding in the interpretation and analysis of the NDVI maps for each year.

Finally, the digital terrain model (DTM) was employed to generate drainage path maps of both the rehabilitated areas and the surrounding regions. These drainage path maps were instrumental in revealing the hydrogeological characteristics of the area under study. By utilising the DTM, the flow direction of surface water could be identified, offering valuable insights into the hydrological processes at play within the rehabilitated and neighbouring landscapes. This information holds significance in understanding the overall hydrogeological dynamics and plays a crucial role in evaluating the effectiveness of rehabilitation efforts concerning water flow in the area.

3 Results

Given that the various areas under consideration were planted in different years, an analysis of their growth progress can be conducted by evaluating their respective advancements up to the date of image acquisition. Subsequently, the present extent of vegetation coverage and the mean NDVI values can be determined, as delineated in the subsequent Table 2.

A map was created (Fig. 4) to understand the hydrogeology of the rehabilitated area and the surrounding region using the acquired images. This map aids in the interpretation of water flow patterns, and overall hydrological conditions as of the day the images were acquired.

Table 2: Vegetation cover and the mean NDVI values of the study area in 2023

Replanted Year	Replanted Area (ha)	Current (2023) Vegetation Cover %	Mean NDVI
2002	2.73	61.27	0.46
2003	2.21	74.02	0.43
2004	3.07	79.09	0.42
2005	3.77	84.34	0.42
2006	1.71	82.50	0.38
2007	1.91	80.95	0.44
2008	10.38	76.09	0.43
2009	11.22	77.70	0.44
2010	8.03	90.03	0.47
2011	4.57	86.58	0.42
2014	2.35	46.35	0.41
2016	2.10	62.02	0.43
2017	3.04	59.46	0.38
2018	2.04	36.04	0.37
2020	6.09	35.78	0.38
2021	3.37	40.44	0.35

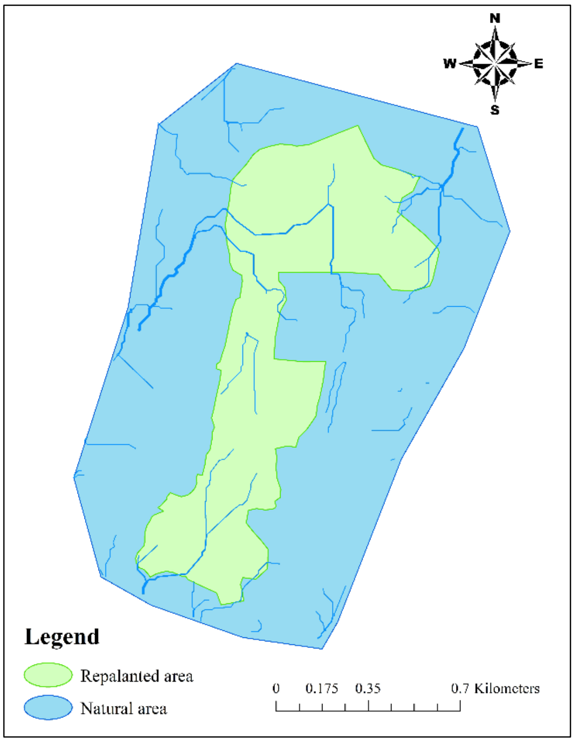

Figure 4: Drainage path map of the study area and the surrounding area

4 Discussion

This study encompasses the rehabilitation period spanning from 2002 to 2021, during which significant changes in vegetation cover, ranging from 35% to 90%, were observed. Among the replanted areas, the maximum vegetation covers of 90% is evident in the region planted in the year 2010, enclosing an 8.03 ha area (Table 2). Notably, this area displays favourable hydrogeological conditions, contributing to its robust vegetation growth. Conversely, the minimum vegetation covers of 35% is found in the area replanted in 2014, covering 2.35 hectares. This region exhibits signs of erosion profile, potentially attributed to its lower vegetation cover.

The findings from this study provide valuable insights into the dynamics of vegetation cover and its correlation with hydrogeological factors, contributing to a better understanding of the rehabilitation outcomes and guiding future efforts to optimise vegetation recovery and ecosystem restoration in the Aruwakkalu limestone quarry.

In this study, variations in hydrogeological conditions were observed across different areas within the rehabilitated site, characterized by an irregular drainage pattern. Notably, a significant number of streams were observed to be directed into the rehabilitated area. This phenomenon may be attributed to the decommissioned land having a lower profile compared to its original state. As a result, there is a likelihood of water accumulation in certain parts of the rehabilitated area. The potential convergence of streams towards the rehabilitated site highlights the impact of topographical changes caused by decommissioning, which may have influenced the water drainage dynamics and distribution across the landscape. These findings provide valuable insights into the hydrogeological implications of the rehabilitation process and contribute to a deeper understanding of water movement patterns in the study area.

The application of UAVs in assessing the rehabilitation of opencast mining areas has demonstrated encouraging outcomes, particularly for larger rehabilitated regions. Conventional methods, while effective for smaller areas, tend to be less efficient when dealing with larger areas. In contrast, the use of UAVs offers several advantages, as it provides more detailed information regarding the rehabilitation status and proves highly beneficial for monitoring purposes. The advantage of utilising multispectral images in monitoring mine sites is their ability to capture diverse spectral bands, providing valuable insights into various aspects of the site's conditions and environmental changes.

5 Conclusion

The analysis of vegetation cover in the rehabilitated areas of the Aruwakkalu limestone quarry reveals significant differences based on the plantation year. The highest vegetation cover is observed in the area planted in 2010, where the hydrogeology is well-distributed and there is minimum erosion. There may be a possibility of the effect of hydrogeology on vegetation cover and these findings need to be confirmed by examining the rainfall data specific to the area. This information highlights the need for further gap-filling and intervention in specific areas to enhance the rehabilitation process effectively.

The successful use of UAVs for monitoring the rehabilitation of the Aruwakkalu limestone quarry has proven to be highly efficient. The UAV technology provides more detailed and extensive information, particularly beneficial for monitoring larger areas. Through UAV-based monitoring, a comprehensive understanding of the rehabilitation progress can be achieved, facilitating better decision-making and adaptive strategies to improve overall rehabilitation outcomes.

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