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Article

Evaluating Forest and Land Rehabilitation Using Remote Sensing: A Case Study in Maros Regency

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Abstract. Remote sensing technology has become crucial in vegetation monitoring, particularly for assessing vegetation density. Despite its broad application, its use in evaluating land rehabilitation efforts remains limited. The increasing extent of degraded lands has underscored the importance of effective forest and land rehabilitation activities. Traditionally, evaluating these efforts involves direct site visits to monitor plant growth annually for three years post-planting, which is time-consuming, labor-intensive, and costly. According to rehabilitation standards, a program is successful if 75% of the planted vegetation survives until the end of the third year. This study presents an efficient alternative by evaluating a rehabilitation site in Maros Regency, using remote sensing technology to monitor planting success over periods of 15 years (2007), nine years (2013), and three years (2019). The evaluation utilizes multispectral drone imagery and Normalized Difference Vegetation Index (NDVI) analysis to assess vegetation density through multi-temporal analysis across wide areas. The findings reveal that the percentage of forested areas after three, nine, and fifteen years of rehabilitation activities was 24.6%, 3.1%, and 23.5%, respectively. This research demonstrates the potential for further application of Unmanned Aerial Vehicle imagery in monitoring the success of land rehabilitation projects.

Keywords: Remote Sensing, Forest Rehabilitation, Vegetation Monitoring, NDVI Analysis, Unmanned Aerial Vehicles (UAVs)

INTRODUCTION

Deforestation, characterized by permanently converting forested areas into non-forest land, has emerged as one of the most pressing environmental issues over the past decade (Food and Agriculture Organization, 2005; Margono et al., 2012). Indonesia's deforestation rate is particularly alarming, surpassing the Southeast Asian average of 1% between 1990–2000 and 0.4% from 2000–2010 (Sulistiyono et al., 2015). Globally, Indonesia ranks third among tropical countries with the highest deforestation rates, following Brazil, Congo, and Bolivia (Forest Watch Indonesia, 2020). The cumulative effects of deforestation lead to severe forest and land degradation, posing significant threats to biodiversity, food security, and environmental sustainability (Batistella et al., 2000; Olson et al., 2004; Foley, 2005).

To combat deforestation and mitigate its adverse effects, Indonesia has prioritized Forest and Land Rehabilitation as a key strategy (Nawir et al., 2008). Rehabilitation activities are critical for restoring forest functions and productivity on degraded lands and reducing the mounting pressure on remaining forested areas (Foley, 2005). Furthermore, rehabilitation activities contribute to improved biophysical conditions, such as water management and disaster prevention, and support community empowerment by providing direct and indirect benefits to those living near forest areas (Nugroho et al., 2013; Wibawa, 2014; Indrawati et al., 2016; Sudarsono et al., 2016).

Despite its importance, the success of rehabilitation activities initiatives in Indonesia remains debated. Rehabilitation efforts are complex, involving multiple interconnected factors influencing their effectiveness and sustainability. Not all rehabilitation projects achieve their intended outcomes (Nawir et al., 2008). Traditionally, the success of rehabilitation activities is assessed through direct field visits to monitor vegetation regrowth, a time-consuming and expensive process. Current rehabilitation standards deem a program successful if 75% of the planted vegetation survives until the third year.

Given these challenges, there is a pressing need for more efficient and cost-effective evaluation methods, such as those offered by remote sensing technology (Liu et al., 2019). Remote sensing allows for accurate and economical forest monitoring, offering a valuable tool for assessing the progress of rehabilitation activities (Albuquerque et al., 2021; Ding et al., 2021). It provides a framework for analyzing global trends in forest restoration and integrates geospatial methods to enhance the success of rehabilitation efforts (Kinoti, 2019).

In recent years, Unmanned Aerial Vehicles (UAVs) have gained significant attention in remote sensing, particularly for vegetation monitoring, vegetation index (VI) mapping, and precision agriculture (Lu et al., 2020). UAVs controlled remotely or via programmed devices, offer a low-cost, high-resolution option for monitoring, with advantages including rapid data acquisition, ease of operation, and independence from cloud cover (Matese et al., 2015; Iizuka et al., 2018). The study evaluated the effectiveness of rehabilitation activities in Maros Regency, a region with critical watersheds that supply water to Makassar City. By leveraging UAV-based remote sensing technology, this research seeks to assess rehabilitation activities efforts in this area comprehensively. The findings are expected to serve as a foundational framework for evaluating rehabilitation activities' success on a broader scale, contributing to more effective rehabilitation strategies in Indonesia and beyond.

MATERIAL AND METHODS

Research Location

This study was conducted at a forest and land rehabilitation site in Maros Regency, South Sulawesi Province, as shown in Fig. 1. Maros Regency features diverse forest ecosystems, including mangrove forests, pine forests, karst forests, natural forests, plantation forests, and community plantation forests. The region also encompasses Bantimurung Bulusaraung National Park, a conservation area for endemic flora and fauna. The forest and land rehabilitation activities are focused on protected forest areas, aiming to enhance water management, prevent flooding, control erosion, deter seawater intrusion, and maintain soil fertility. Hydrologically, Maros Regency is located upstream of the Walanae and Maros watersheds, which are crucial for water distribution to the Bone, Soppeng, and Wajo Regencies, as well as Makassar City, thus necessitating restoration efforts (Indrawati et al., 2016).

Data Collection

Remote sensing technology and Geographic Information Systems (GIS) were employed to evaluate the success of forest and land rehabilitation activities, specifically by analyzing vegetation indices obtained from multispectral drone imagery. Data were collected using a DJI Phantom 4 (P4) Multispectral UAV in 2022, covering rehabilitation sites with planting periods of 15 years (2007), nine years (2013), and three years (2019). The Jeneberang Saddang Watershed Management Center, under the Ministry of Environment and Forestry, obtained spatial data on rehabilitation sites. The DJI P4 Multispectral UAV has an RGB camera and a multispectral camera array that captures images in the blue, green, red, near-infrared (NIR), and infrared bands. These images were processed using the Agisoft Metashape application, following a workflow that included photo alignment, dense cloud construction, mesh generation, texture mapping, and the Normalized Difference Vegetation Index (NDVI) calculation, as shown in Fig. 2.

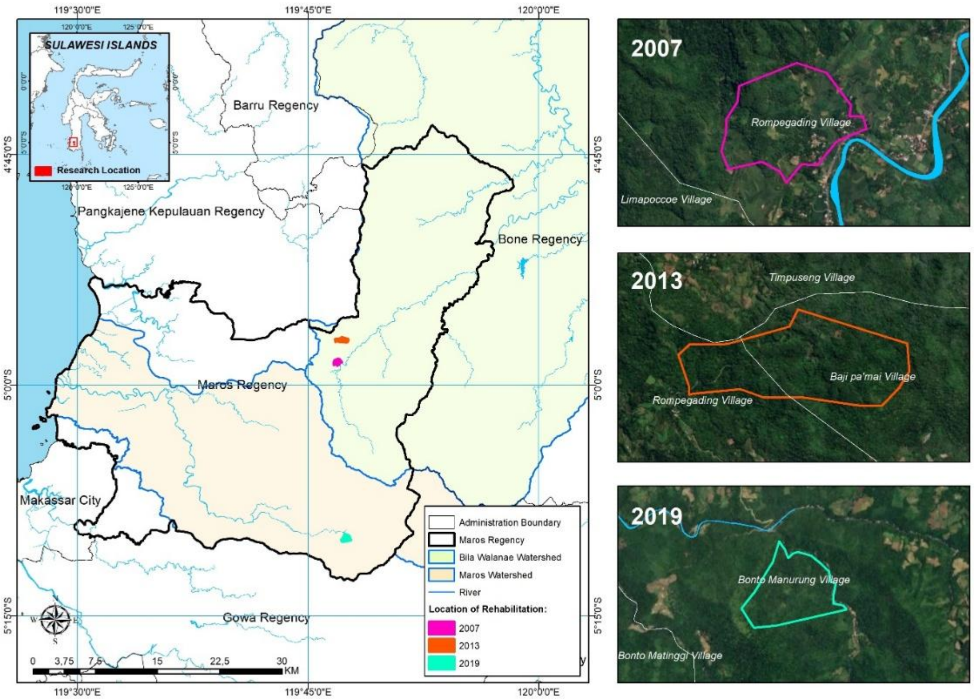

Figure 1. Research location map

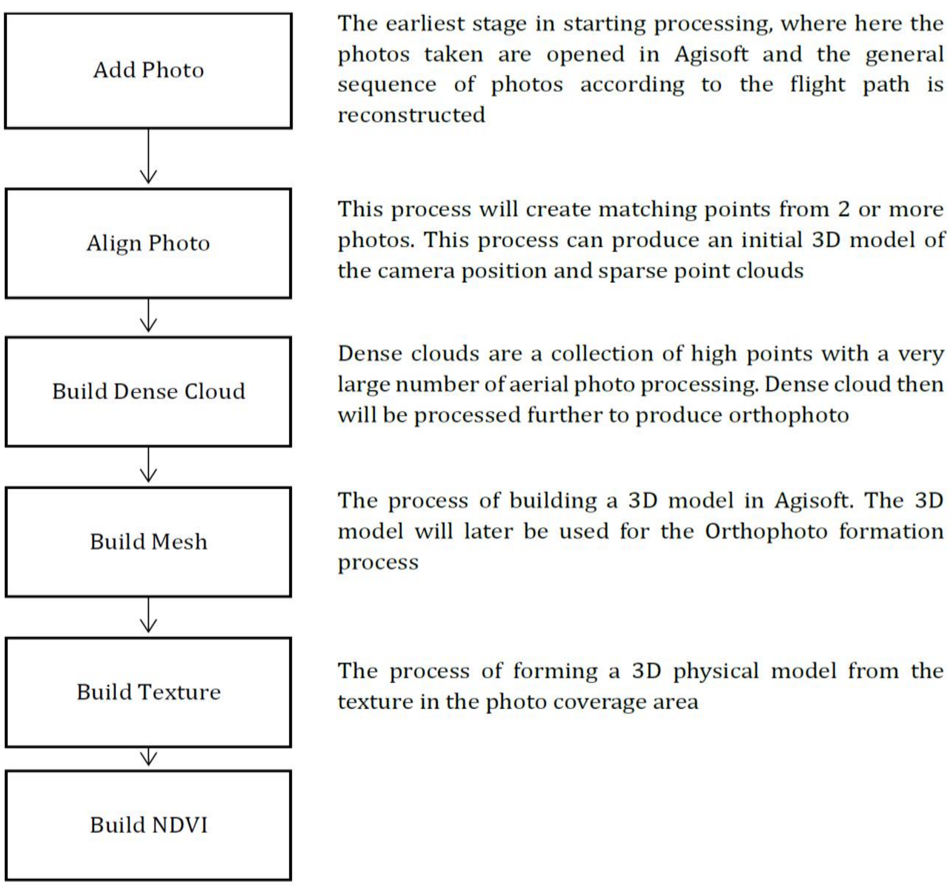

Figure 2. DJI P4 multispectral data processing flow

Data Analysis

The data analysis in this study focused on evaluating vegetation conditions in the forest and land rehabilitation areas using the Normalized Difference Vegetation Index (NDVI). NDVI is one of the most widely used vegetation indices in satellite image processing and global vegetation cover monitoring, having been well-established over the past two decades (Huete & Liu, 1994; Leprieur et al., 2000). This index provides insight into vegetation density and health by comparing reflectance values in the red and near-infrared (NIR) bands. Healthy vegetation tends to absorb most visible light and reflect a significant portion of NIR light, while unhealthy or sparse vegetation exhibits different reflectance patterns.

In this study, NDVI was calculated using the following equation:

$$NDVI = \frac{\rho\, NIR - \rho\, RED}{\rho\, NIR + \rho\, RED} \qquad (1)$$

Where ρ NIR represents the NIR band reflectance value, and ρ RED represents the red band reflectance value. The resulting NDVI values range from -1 to 1, with higher values indicating denser and healthier vegetation. For this study, the NDVI values were classified into specific categories to determine the vegetation density and greenness levels in the study area, as summarized in Table 1. This classification allows for a detailed evaluation of the ongoing success of forest and land rehabilitation efforts.

Table 1. Vegetation index class classification

No.	Index	Class
1	-1–0.1	Not Vegetated
2	0.1–0.3	Low-Density Vegetation
3	0.3–0.5	Vegetation with Slightly Low Density
4	0.5–0.6	Medium Density Vegetation
5	0.6–0.7	Vegetation with Quite High Density
6	0.7–0.9	High-Density Vegetation
7	0.9–1.00	Very High-Density Vegetation

Sumber: Nursaputra et al., 2021

RESULTS

This study analyzed vegetation density at three distinct forest and land rehabilitation sites, representing three different planting periods: 2007, 2013, and 2019. Each site was selected to assess the success of forest rehabilitation over time using NDVI analysis. The results indicate significant variations in the effectiveness of rehabilitation across the different sites, as observed through the distribution of vegetation density.

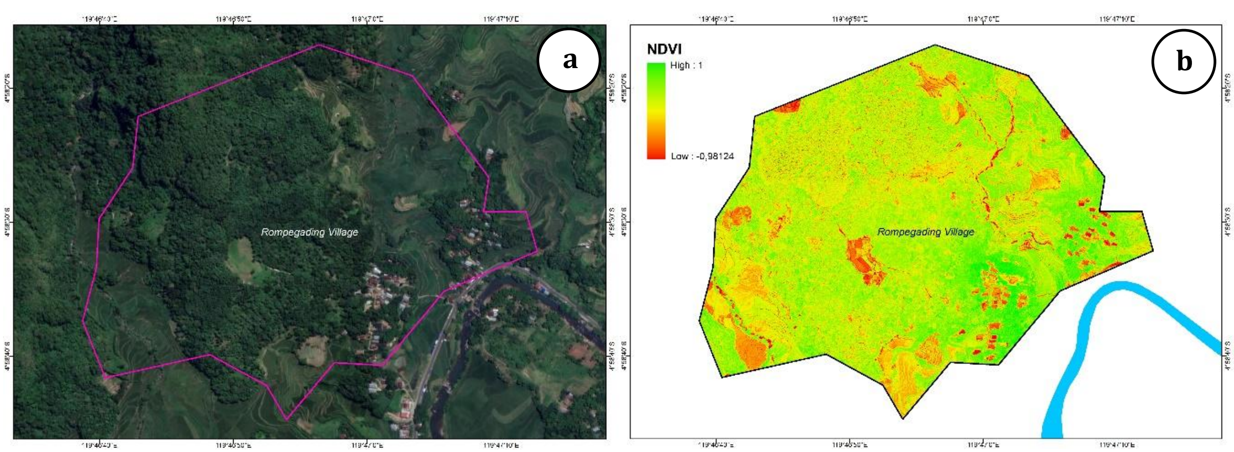

Figure 3. Land and forest rehabilitation sites in (a) 2007 and (b) NDVI Index from UAV Aerial Photography

Fig. 3 presents the NDVI values for the 2007 rehabilitation site, ranging from -0.98 to 1. Approximately 24.6% of the total area is medium to high-density vegetation (NDVI 0.3 to 0.7). These results suggest that the rehabilitation efforts during this period were relatively successful in certain key areas, with a reasonably even distribution of vegetation. However, some sections still exhibit low NDVI values, indicating that not all parts of the site have developed into optimal forest cover. These findings align with literature emphasizing the importance of consistent management practices for effective reforestation outcomes (Adidharma, 2023; Putri, 2023).

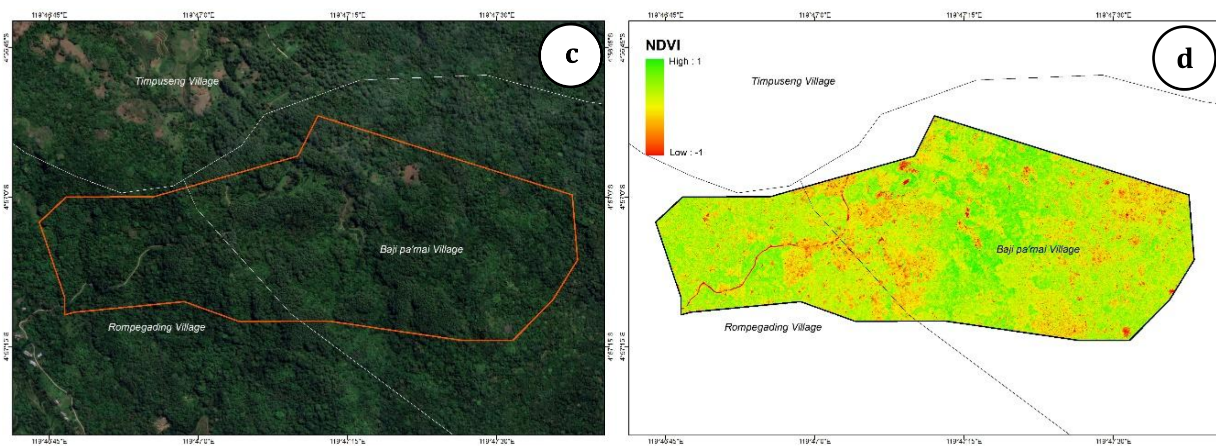

Figure 4. Land and forest rehabilitation sites in (c) 2013 and (d) NDVI Index from UAV Aerial Photography

At the 2013 rehabilitation site, visualized in Fig. 4, the NDVI values range from -1 to 1. Only 3.1% of the total area is medium to high-density vegetation. Most of the area is dominated by open land and shrub vegetation, indicating a failure to maintain the planted vegetation. This suggests that maintenance and management activities were ineffective, leading to significant vegetation degradation. Similar challenges in maintaining vegetation cover have been reported in other reforestation efforts, particularly in regions with insufficient post-planting care and monitoring (Yasin et al., 2022; Gandri et al., 2023).

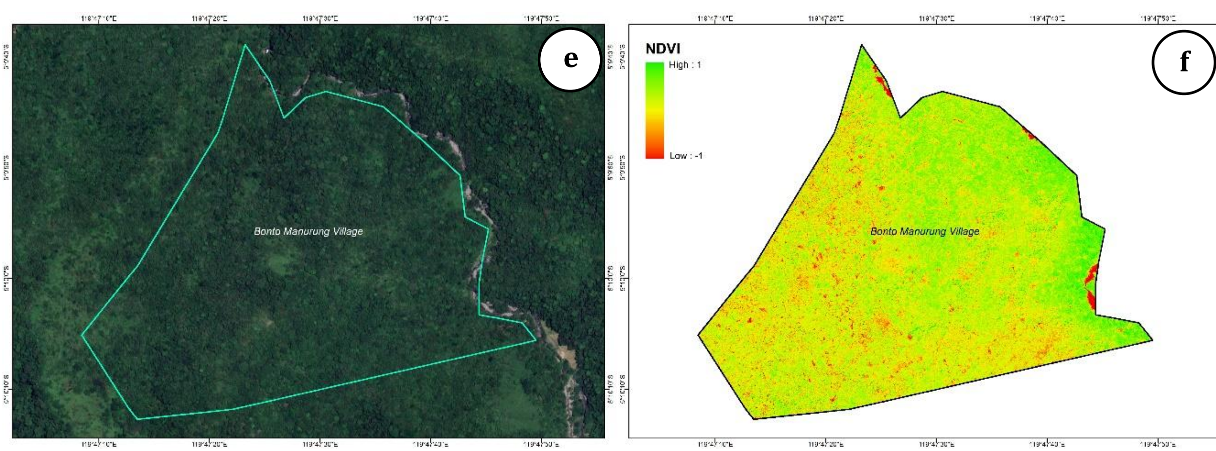

Figure 5. Land and forest rehabilitation sites in (e) 2019 and (f) NDVI Index from UAV Aerial Photography

The analysis for the 2019 rehabilitation site, as shown in Fig. 5, reveals some improvement, with 23.5% of the area classified as medium to high-density vegetation. Although there is an increase in vegetation density compared to the 2013 site, the distribution remains uneven. Some areas show better vegetation growth, while others exhibit low-density vegetation. These findings are consistent with studies by Kinyanjui (2010), which note that uneven vegetation recovery is expected in areas where post-rehabilitation interventions are not uniformly applied.

Fig. 6 and 7 present vegetation density maps for each planting period. The 2007 rehabilitation site shows medium to high-density vegetation distributed across several key areas, while the 2013 site is predominantly characterized by low-density vegetation. At the 2019 site, although there are improvements in certain areas, medium to high-density vegetation remains concentrated in limited spots. This pattern underscores the importance of sustained management efforts to achieve more comprehensive rehabilitation success, as supported by studies on long-term vegetation dynamics and land-use practices (Traoré et al., 2014; Kalisa et al., 2019). The findings indicate that rehabilitation efforts across these three sites and different years have not fully met the expected outcomes. The most significant shortfall occurred at the 2013 site, where vegetation degradation was most evident. Although the 2019 site shows some improvements, it still falls far short of the 75% vegetation cover target required for a successful rehabilitation program.

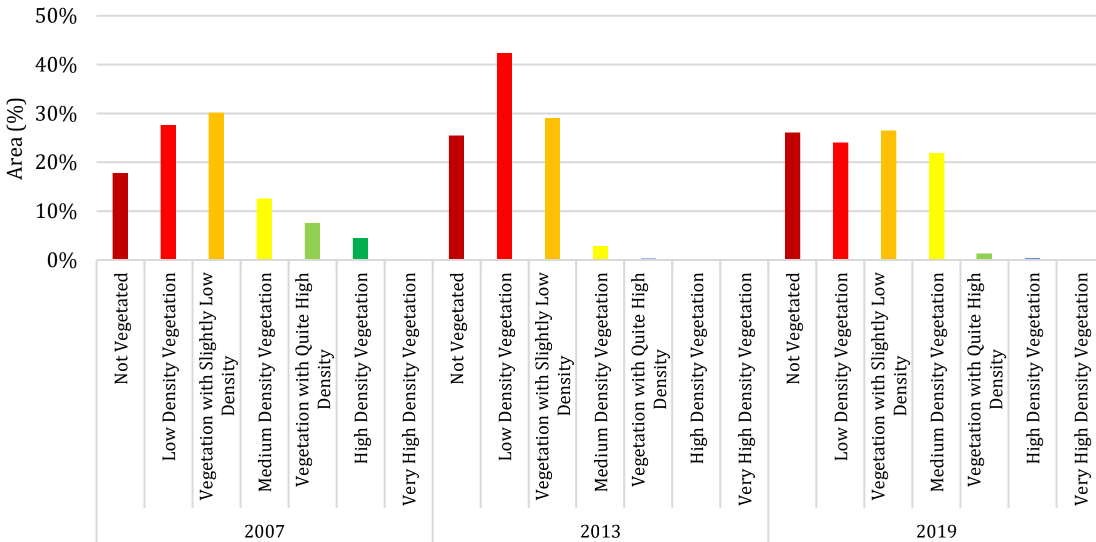

Figure 6. Percentage of study area by level of vegetation density

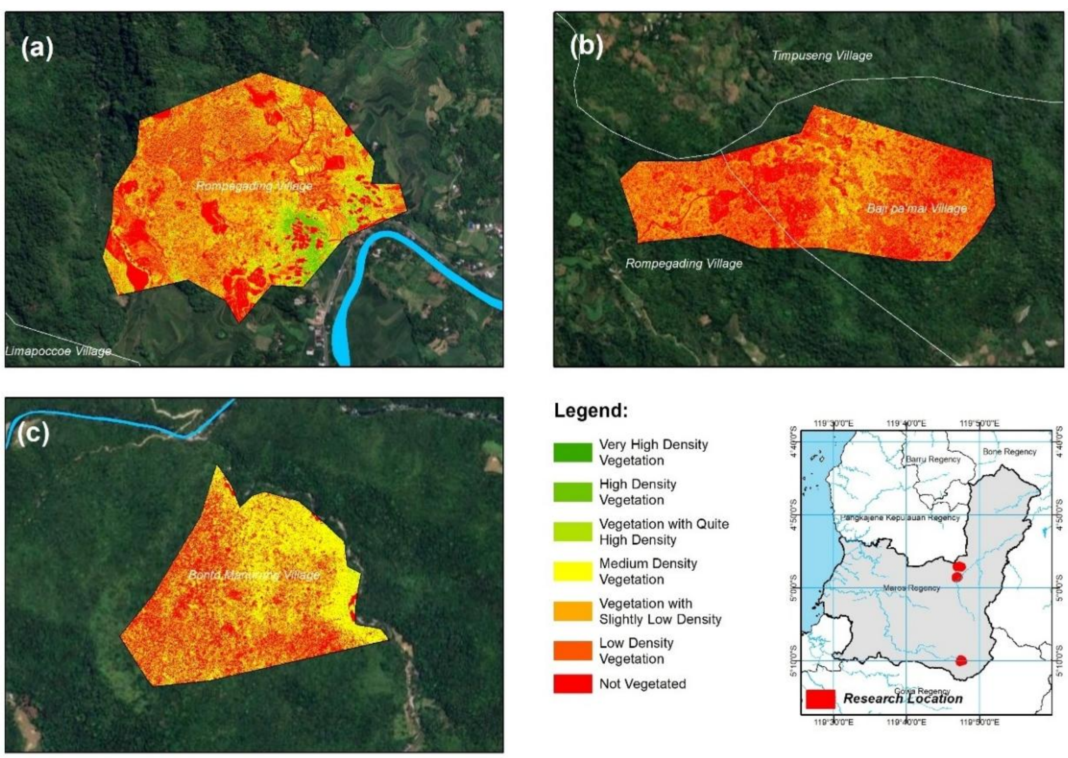

Figure 7. Vegetation density map of land and forest rehabilitation sites in (a) 2007, (b) 2013, and (c) 2019

DISCUSSION

The NDVI analysis across the three forest and land rehabilitation sites (2007, 2013, and 2019) reveals substantial variability in vegetation density, indicating differing success levels in the rehabilitation efforts. As reflected in Fig. 3, 4, and 5, the NDVI values show that the vegetation conditions at these sites remain suboptimal even after 15, 9, and 3 years of rehabilitation. For example, as shown in Fig. 6 and 7, only 24.6% of the 2007 site and a mere 3.1% of the 2013 site achieved medium to high-density vegetation. Although there was a modest improvement at the 2019 site, where 23.5% of the area showed medium to high-density vegetation, these figures are still significantly below the 75% target.

The dominance of low-density or non-vegetated areas, particularly at the 2013 site, underscores the challenges of maintaining vegetation post-planting. As shown in Fig. 4, the failure to achieve substantial vegetation cover at this site suggests that the management and maintenance practices needed to be improved, leading to widespread degradation. Similarly, Fig. 7 highlights that while the 2019 site shows some vegetation recovery, the distribution is uneven, with large sections still classified as low-density vegetation. This points to the need for more effective post-planting interventions to ensure the success of rehabilitation efforts.

The results of this study are consistent with previous research, such as Kamble et al. (2013) and Nursaputra et al. (2021), which have demonstrated the accuracy of NDVI in assessing vegetation density. NDVI, as a widely used metric, effectively differentiates between various vegetation densities, making it invaluable for monitoring rehabilitation efforts. However, as this study illustrates, the success of such efforts depends not only on the technology used but also on the consistency and sustainability of management practices.

The implications of these findings are significant for forest rehabilitation policies and management practices in Indonesia. The observed failure at the 2013 site, where low NDVI values predominate, highlights the necessity for adaptive management strategies that can respond to the specific challenges encountered during the critical post-planting years. More robust policies may include enhancing silvicultural techniques or employing real-time monitoring systems to identify areas that require additional intervention.

Several limitations of this study should also be acknowledged. The resolution of the UAV imagery and the temporal variability in data collection could affect the accuracy of the results. For instance, differing weather conditions during image acquisition may influence data quality, a concern highlighted in studies by Matese et al. (2015) and Iizuka et al. (2018). Despite these challenges, the study demonstrates the significant potential of UAV technology in monitoring forest rehabilitation activities. However, the findings underscore that technology alone is insufficient; effective and sustained management remains the key to successful rehabilitation.

NDVI's utility extends beyond simple vegetation monitoring. As Adidharma (2023) and Putri (2023) noted, NDVI is instrumental in assessing changes in land cover and vegetation health, especially in response to environmental changes and land-use practices. Its application in this study reaffirms its value in ecological studies and resource management, particularly in tracking the impacts of anthropogenic activities on vegetation dynamics.

Moreover, the challenges faced in forest rehabilitation, such as stakeholder conflicts, institutional capacity, and the effects of climate change, complicate restoration efforts. These challenges require integrated approaches that consider ecological, social, and economic factors to enhance the success of rehabilitation initiatives (Dang et al., 2017; Damayanti et al., 2020; Kassa et al., 2022). Addressing these challenges is critical for the long-term sustainability of forest and land rehabilitation projects in Indonesia and similar contexts globally.

While UAV-based NDVI analysis provides a valuable tool for monitoring vegetation density and rehabilitation success, the results of this study emphasize the need for comprehensive management strategies that go beyond initial planting efforts. Only through such integrated approaches can the long-term goals of forest rehabilitation be fully realized.

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AUTHOR CONTRIBUTIONS

Syamsu Rijal: research conceptualization, research coordinator, data analysis, data interpretation, manuscript writing; Munajat Nursaputra: member contributor, research implementer, data analysis, map making, manuscript writing; Chairil A: member contributor, research implementer, data collection, manuscript writing.

CONFLICTS OF INTEREST

The authors declare no conflict of interest related to financial funding and authorship order for this article.

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