Utilization of Aerial Mapping Using Unmanned Aerial Vehicle for Watershed and Forest Rehabilitation Planning

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Abstract
This study demonstrated the use of Unmanned Aerial Vehicles (UAVs) and photogrammetry to produce baseline watershed imagery and support forest rehabilitation planning in the Kaliwa Watershed Area of Brgy. Mamuyao, Tanay, Rizal, Philippines. A geospatial survey was conducted using a DJI Mavic 3 Enterprise drone, capturing 1,411 high-resolution images across more than 1.2 million square meters. These images were processed using Agisoft Metashape to generate orthomosaics and Digital Elevation Models (DEMs) for terrain, slope, and land cover analysis. The assessment focused on Parcel 3, a 108.92-hectare region characterized as a secondary forest and tropical semi-evergreen rainforest. Land cover analysis revealed that 31% (34.024 hectares) of this parcel is barren, while 69% (74.948 hectares) remains vegetated. The generated DEMs and orthophotos identified precise terrain profiles and exposed soil areas. Ultimately, this high-resolution spatial mapping delivered critical baseline data to prioritize reforestation efforts and ensure the long-term ecological sustainability of the watershed.

Keywords: Agisoft Metashape, Drones, Ecological Sustainability, Geospatial Analysis, Land Cover Analysis, Spatial Mapping, Tanay Philippines,

Introduction

1.1 Unmanned Aerial Vehicle

The use and development of Unmanned Aerial Vehicles (UAVs), commonly known as ‘drones’, have been crucial on various occasions, such as but not limited to agriculture, surveillance and monitoring, transportation, building systems, delivery systems, and inspections (Ahmed et al, 2022). In this modern era, UAVs have diverse applications ranging from commercial use to military use and disaster risk management (Ali et al, 2022). These UAVs are also used in environmental monitoring via remote sensing and taking airborne photographs (Frater et al, 2015). Some examples of utilizing drones in environmental monitoring are the surveillance of natural reserve areas and wetlands, and pollutant measurement and mapping, such as in the event of an oil spill (Frater et al, 2015). Visible imagery data obtained by UAV platforms has seen an increasing demand for estimating the within-season variations in vegetation cover (Noonan, et al., 2025).

In the Philippines, the Department of Environment and Natural Resources’ (DENR) banner reforestation program is the National Greening Program (NGP) pursuant to Executive Order (EO) 26, Series of 2011, and EO 193, Series of 2015. The NGP adapted the use of UAVs or drones to support the inventory, monitoring, and evaluation of sample sites and plots (DAO 2023-09). This is to generate efficient maps to reinforce the NGP forest management activities. Moreover, the DENR Forest Management Bureau (FMB) uses the Quadcopter Remotely Piloted Aircraft (RPA) technology. Based on FMB Technical Bulletin No. 35 (2021), RPAs can capture high-resolution images/videos in a single flight covering large areas, resulting in more efficient and cost-effective forest monitoring and assessment.

1.2 Study Area

The study was performed at Brgy. Mamuyao, Tanay, Rizal, which is located at approximately 14.6831^{0}N, 121.3829^{0}E on the main island of Luzon, Philippines. The area is generally mountainous with an elevation of about 655.9 meters above sea level (PhilAtlas, 2021). Figure 1.1 illustrates the location of the study area.

Brgy. Mamuyao is part of the Kaliwa Watershed Area. By topography, this area generally has a very steep slope. But patches of flat land can be found in areas along the banks of the Lanatin River. The Lanatin River drains the watershed towards the Pacific Ocean in the east. The steep slope of the general area and the presence of this major river system make the barangays highly susceptible to two natural hazards: rain-induced landslides and flooding (Tanay CLUP, 2023).

The majority of the local population is engaged in farming and in the harvest of minor forest products. Among their produce are rice, corn, cash crops, vegetables, fruits and bamboo.

The project area, being part of the Kaliwa Watershed Area, is considered a critical area that needs nature-based strategies to ensure long-term ecological sustainability and protection of the community. In 2020, the Municipality of Tanay had 18,000 Ha of natural forest extending over 69% of its land. In 2024, it lost 69 Ha of natural forest, equivalent to 34 kt of carbon dioxide emissions (GFW, 2026). According to the Climate Change Commission (2024), continued deforestation and uncontrolled anthropogenic activities lead to worsen environmental stresses, such as soil erosion, flooding, and pollution, among others. As these stressors persist, the gradual weakening of ecosystem resilience and decline of environmental quality will follow (Forster, Bhandary, & Gallagher, 2026).

The need for science-based planning and rehabilitation is one of the key proactive approaches to restoring the ecological functions of the watershed and enhancing its capacity to provide essential ecosystem benefits. Furthermore, forest restoration is globally acknowledged as key strategies to mitigate biodiversity loss and ecological function (Feng, Tu, Zhang, Luo, & Xueyong Pang, 2026). One key important tool for reforestation planning and rehabilitation is the utilization of Geographical Information Systems (GIS). This application is a crucial approach for identifying and assessing the current condition of the area and aids in the decision-making in identifying priority areas for reforestation based on various considerations such as slope, elevation, and land cover.

Figure 1.1. Location of the Study Area

This study aimed to utilize unmanned aerial vehicles combined with the Agisoft software application for watershed imagery baseline assessment and planning for the forest rehabilitation program of a 180-hectare forest reserve in Brgy. Mamuyao, Tanay, Rizal, Philippines. The proponents conducted topographic mapping and 3D modeling to create Digital Elevation Models (DEMs) and Digital Surface Models (DSMs) for analyzing the slope, terrain, and vegetation cover determined the slope and elevation through Digital Elevation Model slope values and created imagery of the terrain and vegetation cover of the project area.

Material and Methods

2.1 Drone Specification

For the initial assessment of the surface of the study area, a DJI Mavic 3 Enterprise drone was used. Figure 2.1 below illustrates the drone utilized in the study. The Aerial Drone Survey was conducted on 19th May 2024, and the take-off point was at Latitude 14° 40' 19.8" and Longitude 121° 21' 18.8", Brgy. Mamuyao, Tanay, Rizal.

Figure 2.1. DJI Mavic 3 Enterprise Drone (Unmanned Aerial Vehicle (UAV)

2.2 Overall Project Workflow

The study adopted a geospatial research design using the UAV-based aerial survey combined with photogrammetric and GIS analysis techniques through the Agisoft Software. The flight route altitude was set at about 100 meters Above Take Off (ATO). The total flight path of the study was 31,302 meters covering an area of 1,213,921 sq. m. The take-off point is set at Latitude 14° 40' 19.8" and Longitude 121° 21' 18.8". A total of 1,411 images were processed during the conduct of the survey.

The UAV's images were assessed for their quality and spatial coverage. They are then processed in photogrammetric software using the Agisoft Methashape Professional Version 1.5.3 build 8407 (64-bit). Agisoft Metashape Professional is a software that maximizes the potential of photogrammetry. It utilizes machine learning technologies for assessment, analysis, and post-processing to deliver the highest accuracy results and imagery. Metashape processes images obtained with red, green, and blue wavelengths (RGB) or multispectral cameras, including multi-camera systems. It converts photographs into dense point clouds, textured polygonal models, georeferenced orthophotography maps, and digital elevation/terrain models (DEM/DTM).

This software application processed the captured digital images from the project site to create 3D spatial data and transformed them into precise, high-resolution models with Digital Elevation Models (DEMs).

The following workflow parameters and results are shown based on the processed capture images using the Agisoft Metashape Professional:

● Align Photos
a. Cameras (Captured Images) – 1,411
b. Aligned Cameras – 1,383
c. Coordinate System – WGS 84 (EPSG: 4326)
● Point Cloud
a. Points – 892,107 of 941,082
b. Accuracy – High
● Dense Point Cloud
a. Points 14,644,432
b. Quality – Low
● Model
a. Source – Dense Cloud
b. Faces – 2,836,370
c. Quality – Low
● DEM
a. Size – 4,536 x 6,175
b. Source – Mesh
● Orthomosaic

a. Size – 24,184 x 37, 024
b. Coordinate system – WGS 84 /UTM Zone 51N (EPSG: 32651)

Results and Discussion

The result of the image processing based on the UAV and photogrammetric process created the digital orthophotos and Digital Elevation Model (DEM) Slope Values. The digital orthophoto captured the visual detail of the photograph with an accurate and uniform scale of a map, creating a direct measurement of distances, angles, and areas. The DEM Slope Values created a profile identifying the highest and lowest elevations of the study area. Figure 3.1 shows the actual drone shot of the ridge taken using the UAV.

Figure 3.2 below shows the 4 Parcels of land identified for the watershed rehabilitation, with focus on Parcel 3 as the primary area of consideration. Figure 3.4 shows the Digital terrain of Parcel 3 of Barangay Mamuyao, Tanay, Rizal. There is the visible terrain and vegetation showing areas with brown patches exposing the soil surface and indicating sparse or potential alteration of vegetation cover. The imagery generated is a valuable illustration of the current condition of the area, which can be the basis for the tree rehabilitation program and monitoring of the watershed.

Figure 3.1 Photograph of the Ridge Taken by DJI Mavic 3 Enterprise Drone

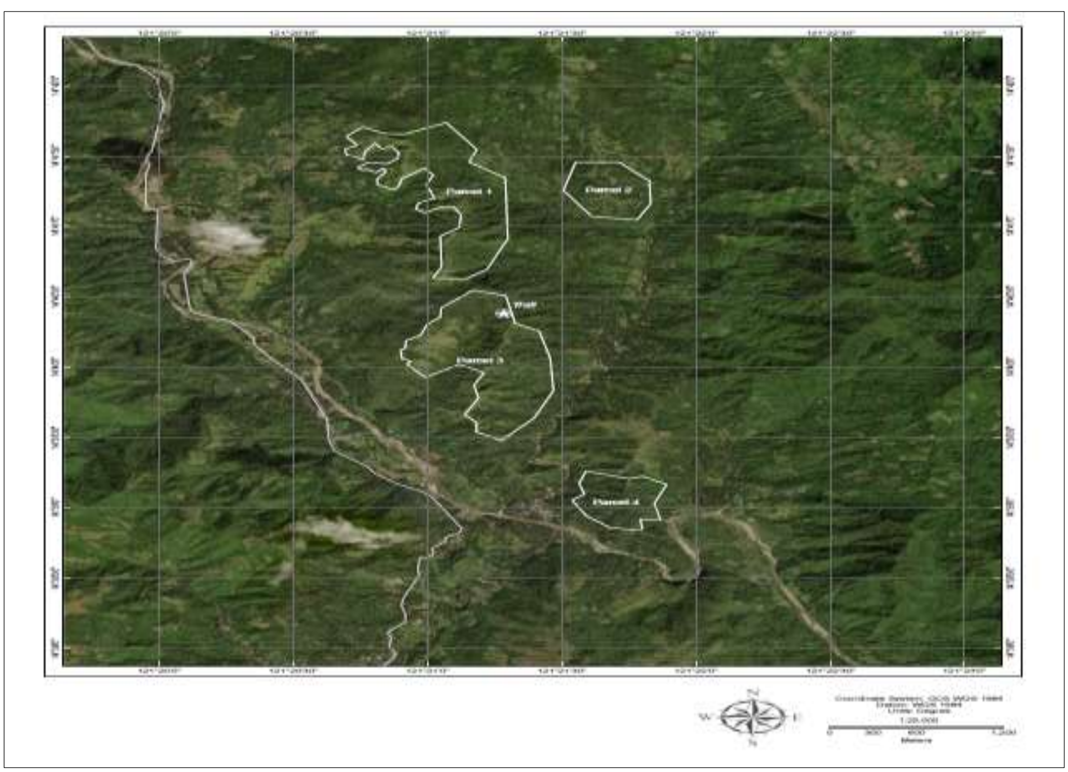


Figure 3.2 Photograph of the four (4) parcels of land Taken by DJI Mavic 3 Enterprise Drone

Figure 3.3 Photograph of the Ridge Taken by DJI Mavic 3 Enterprise Drone

Figure 3.4. Digital Terrain Model of the Parcel 3 of Brgy. Mamuyao, Tanay, Rizal

For the assessment of the general terrain of Parcel 3, an aerial view with isolation on section lines 1 and 2 for the preparation of DEM slope values (Figure 3.5). Aerial Photo Showing Section Lines 1 and 2

Figure 3.5 Aerial View of the Identified Section Lines 1 and 2

Line Section 1

The survey shows the Digital Elevation Model (DEM) Slope Values with the highest elevation at about 570 m down to about 425 m above sea level for Line Section 1(see Figure 3.5 below). The Line Section 1 has the following data results:

a. Start – 1622393.703 N/322242.849 E
b. End – 1622278.138 N/322513.705 E
c. Maximum Slope (Degrees) – 51.8°
d. Average Slope (Degrees) – 29.9°

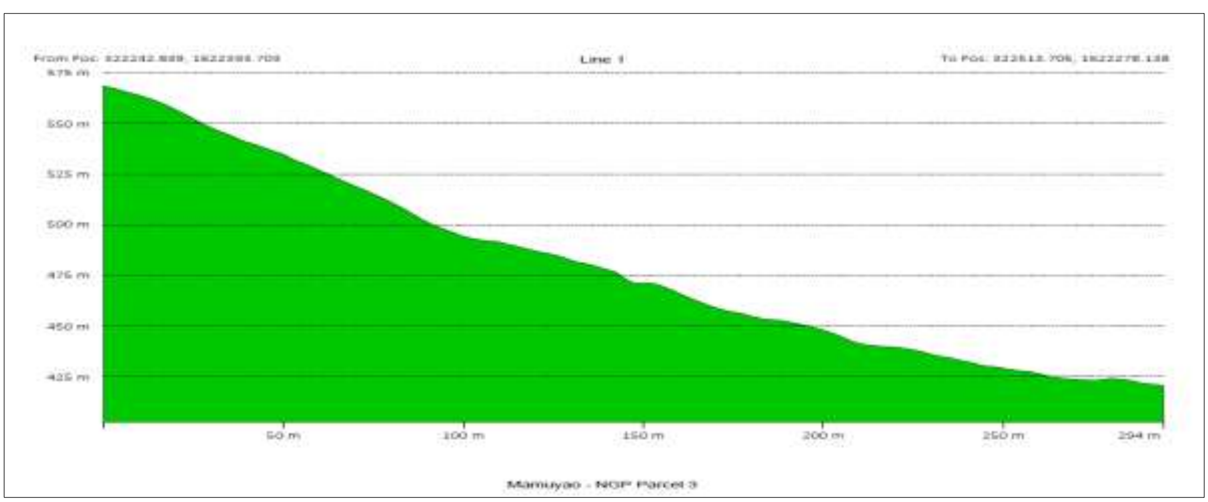


Figure 3.6. Digital Elevation Model (DEM) Slope Values for Line Section 1

Line Section 2

The survey shows the Digital Elevation Model (DEM) Slope Values with the highest elevation at about 475 m down to about 325 m above sea level for Line Section 2(see Figure 3.6 below). The Line Section 2 has the following data results:

a. Start – 1621714.756 N/322434.254 E
b. End – 1621599.191 N/322997.636 E
c. Maximum Slope (Degrees) – 53.5°
d. Average Slope (Degrees) – 21.6°

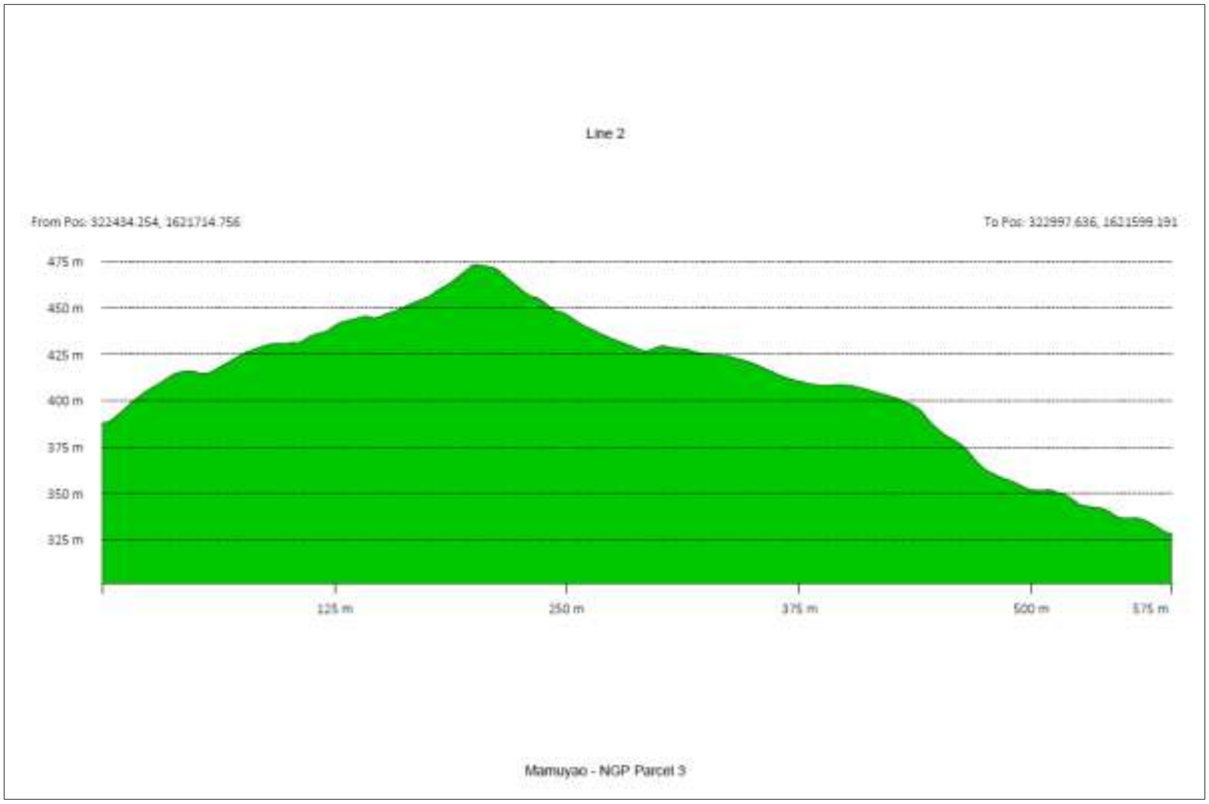


Figure 3.7. Digital Elevation Model (DEM) Slope Values for Line Section 2

General Vegetation

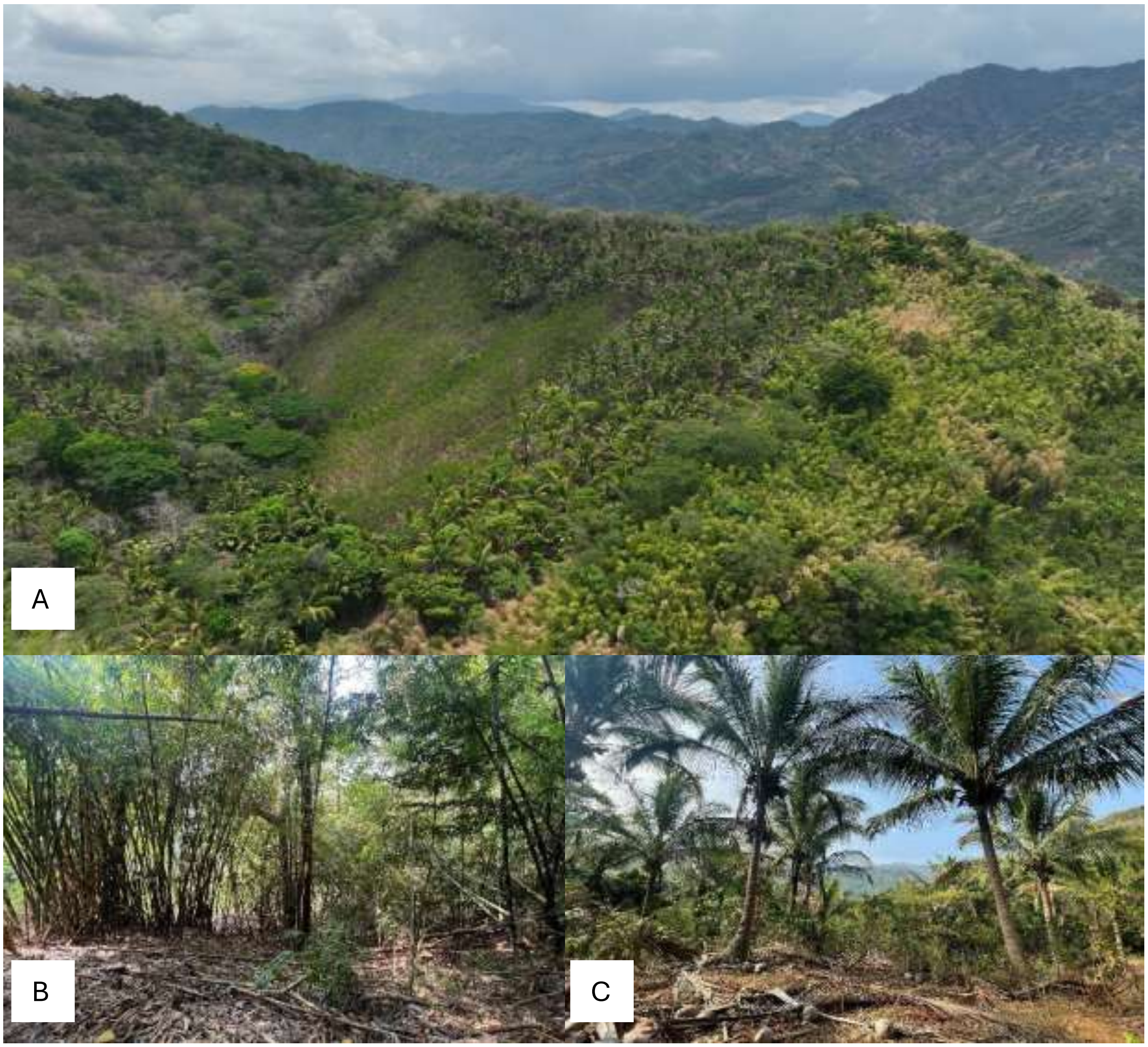
The general vegetation and the type of forest formation of Parcel 3 of the study area at Brgy. Mamuyao, Tanay, Rizal can be classified as secondary forest and a tropical semi-evergreen rainforest, respectively. Secondary forests typically arise in areas that have experienced disturbance, such as logging, shifting cultivation, and natural events, and are characterized by a mix of pioneer species, regenerating native trees, and scattered remnants of primary forest vegetation.

According to (Fernando et al., 2008; Lillo, Fernando, & Lillo, 2019), tropical semi-evergreen rainforests are commonly found in regions with a distinct dry season, which aligns with the climatic type of the study area, classified as Climate Type III. This climate is marked by a pronounced dry period from November to January, followed by wetter months. The vegetation responds to this seasonal rhythm, with certain deciduous species shedding their leaves early in the dry season to conserve water and reduce physiological stress. Such phenological patterns are evident in Parcel 3, where leaf fall and canopy thinning occur during the onset of the dry months, subtly altering the forest's microclimate and light penetration.

During the site reconnaissance, several notable tree species were observed, representing both emergent and canopy layers. Emergent trees included Balinghasai (Buchanania arborescens), Akleng parang (Albizia procera), Smooth Narra (Pterocarpus indicus forma indicus), Rain Tree (Samanea saman), and Taluto (Pterocymbium tinctorium). These species rise above the general canopy, providing structural diversity and habitat for various fauna. Canopy trees, which were observed as frequently occurring species, were Ipil-ipil (Leucaena leucocephala), Alangas (Ficus heteropoda), Dita (Alstonia scholaris), and Niyog (Cocos nucifera). The presence of Kawayan killing (Bambusa vulgaris) and Bunga (Areca catechu) further enriches the vegetation profile, reflecting both natural regeneration and possible anthropogenic influences, as these species are often associated with human settlements and traditional land use.

The presence of both deciduous and evergreen species in Parcel 3 is an indication of the transitional characteristics of semi-evergreen rainforests. While evergreen trees dominate, there are a few deciduous trees, which implies an adaptation to seasonal drought stress. This patchwork of vegetation types promotes biodiversity, as it hosts diverse ecological niches.

Besides, the structural complexity afforded by emergent trees, bamboo clumps, and palms is important for broader ecological functions such as soil stabilization, watershed integrity, and biodiversity of micro-habitats, which are especially needed in the rugged terrain of Tanay, Rizal. According to (Saharudin, Jeswani, & Azapagic, 2024) tropical forest formations, such as this one, are acknowledged for their substantial carbon sequestration potential, strengthening their functions in climate change mitigation.



Assessment of the Current Vegetation and Exposed Soil Coverage in Parcel 3

In analyzing the land cover, a Global Mapper was applied to estimate the vegetation coverage and exposed soil area of Parcel 3. The Global Mapper aids in mapping the terrain into color-coded maps illustrating the location and area of patches of trees and exposed soil. Figure 3.9 shows the estimated vegetated and barren areas and the corresponding ranges computed through Global Mapper. Parcel 3 has an estimated area of 108.92 hectares, about 31 percent or 34.024 hectares is identified as barren area, while the remaining 69% or 74.948 hectares constitutes the vegetated area. Figure 3.10 shows the actual condition of the area taken through aerial photography.

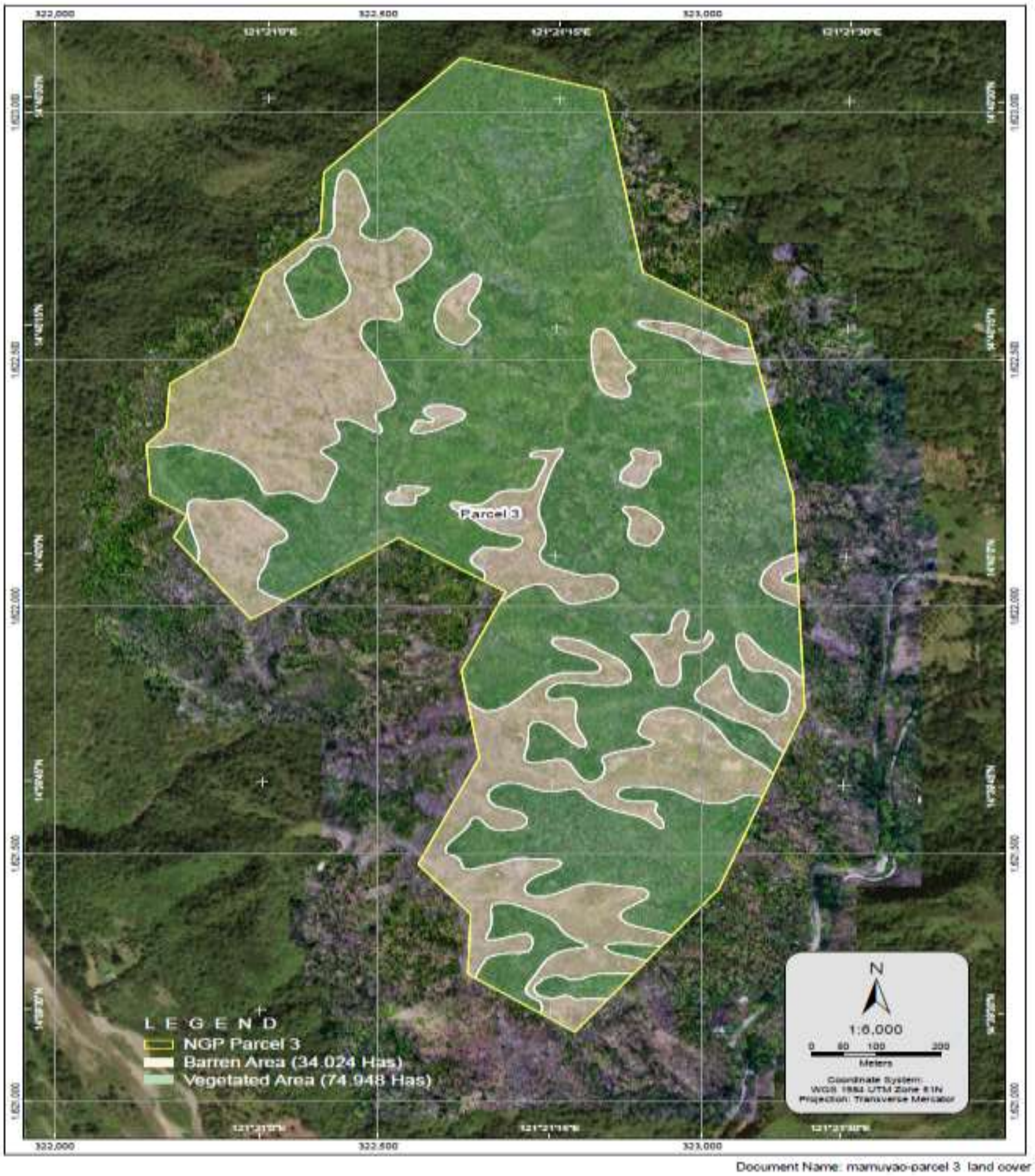


Figure 3.9. Land Cover Assessment of Parcel 3

The close match of the mapped percentage of vegetated and barren areas from Global Mappers (figure 3.9) and the aerial photograph of parcel 3 from DJI Mavic 3 Enterprise (figure 3.10) indicates consistency between the digital analysis and direct observation. This confirms the reliability of both the drone and the software.

Conclusion

The utilization of Unmanned Aerial Vehicles (UAVs) combined with photogrammetry software has proven to be a highly effective approach for generating baseline watershed imagery and supporting forest rehabilitation planning. By deploying a DJI Mavic 3 Enterprise drone and processing the data through Agisoft Metashape, this study successfully produced high-resolution 3D models, orthomosaics, and Digital Elevation Models (DEMs) for Parcel 3 in the Kaliwa Watershed Area. The geospatial analysis provided critical insights into the area's topography, revealing steep slopes reaching up to 53.5 degrees. Furthermore, land cover assessment determined that 31% (34.024 hectares) of the 108.92-hectare parcel is currently barren and exposed, while 69% (74.948 hectares) remains covered by a mix of secondary forest and tropical semi-evergreen rainforest vegetation.

Given that Brgy. Mamuyao is highly susceptible to rain-induced landslides and flooding, alongside recent threats from deforestation. Proactive restoration of this critical area is imperative. The high-resolution spatial data and visual mapping generated by this study deliver the crucial baseline information needed to identify highly vulnerable areas with exposed soil and strategically prioritize reforestation efforts. Ultimately, integrating UAV technology and Geographic Information Systems (GIS) into initiatives like the National Greening Program will enhance the efficiency of forest monitoring, foster biodiversity, and ensure the long-term ecological sustainability and disaster resilience of the watershed.

Recommendations

To enhance forest rehabilitation and watershed management in the Kaliwa Watershed, the following three recommendations for further studies are proposed based on the provided sources:

To create a complete rehabilitation master plan for the entire 180-hectare forest reserve, future studies should expand the high-resolution geospatial mapping to include Parcels 1, 2, and 4. While this study provided critical baseline data for the 108.92 hectares of Parcel 3, a comprehensive understanding of the surrounding areas is essential to ensure long-term ecological sustainability across the entire site. Applying the established UAV-based photogrammetry workflow to these remaining parcels will enable a unified strategy to address the region's environmental stresses.

Future research should integrate the high-resolution Digital Elevation Models (DEMs) and slope data into predictive hydrological and soil erosion models to mitigate the area's high susceptibility to rain-induced landslides and flooding. The study identified extremely steep slopes, reaching up to 53.5 degrees, particularly in areas where soil is exposed, posing a direct threat to the safety and livelihoods of the local community. By modeling how different reforestation strategies might impact these high-risk zones, researchers can prioritize interventions that maximize disaster resilience and stabilize the rugged terrain of Tanay, Rizal.

A longitudinal monitoring program should be established to conduct periodic UAV surveys to track the progress of rehabilitation efforts within the 34.024 hectares identified as barren land. This multi-year study would utilize the current research as a baseline to monitor the survival rates of planted species and the rate of natural regeneration in the secondary forest. Continuous assessment of vegetation health and canopy density will provide the necessary feedback to refine management practices and ensure the restoration of essential ecosystem benefits to the watershed.

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