JURNAL ILMU LINGKUNGAN
Volume 24 Issue 2 (2026) : 451-460 ISSN 1829-8907

Agroforestry-Based Land Rehabilitation in KHDTK UGM: Integration of Multipurpose Species and Renewable Energy Crops

Fitra K. Tegar[1], Louis B. R. Wijanarto[1], Muhammad A. Noor[1], Lutfiyyah Roihanah[1], Angelina N.[1], Helga Monica[1], and Hermudananto[1,2*]

[1]Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia; e-mail: hermudananto@ugm.ac.id
[2]CarbonNature Foundation, Depok, Jawa Barat, Indonesia

ABSTRAK

Saat ini terdapat masalah degradasi lahan di Indonesia yang membutuhkan rehabilitasi lebih dari 12,7 juta hektar. Agroforestri telah dianggap sebagai salah satu strategi paling efektif untuk memulihkan fungsi ekologis sekaligus memberikan manfaat sosial-ekonomi bagi masyarakat setempat. Tujuan penelitian ini adalah mengembangkan strategi rehabilitasi lahan berbasis agroforestri untuk Kompartemen 5 KHDTK di Universitas Gadjah Mada, yang terletak di Kabupaten Ngawi, Jawa Timur, Indonesia, menggunakan model CASM. Penelitian ini melibatkan penilaian aspek biofisik dan sosial-kelembagaan pada April 2025. Tiga Unit Pengelolaan Lahan (LMU) diidentifikasi melalui analisis overlay spasial terhadap tipe tanah, kemiringan, curah hujan, dan tutupan lahan. Kerja lapangan dilakukan di 18 petak lahan, sementara isu sosial ekonomi dan hak milik dikumpulkan melalui wawancara semi-terstruktur dengan penduduk setempat. Hasil penelitian menunjukkan bahwa LMU 1 termasuk dalam Kelas III Kemampuan Lahan. Namun, LMU 2 dan 3 ditetapkan ke Kelas IV, yang menunjukkan keterbatasan tanah yang parah akibat kedalaman tanah yang dangkal, kandungan tanah liat, serta kerentanan terhadap erosi. Analisis kesesuaian menunjukkan bahwa *Calliandra calothyrsus* dan *Arenga pinnata* memiliki kesesuaian marginal (S3) pada ketiga unit pengelolaan lahan. Sebaliknya, *Calophyllum inophyllum* beradaptasi lebih baik dengan kondisi lokal dan menghadapi lebih sedikit keterbatasan tanah maupun iklim. Penilaian ketersediaan dan pengelolaan mengidentifikasi masalah terkait penggunaan lahan informal, lembaga lokal yang tidak aktif, serta koordinasi yang buruk di antara para pemangku kepentingan. Faktor-faktor ini memungkinkan identifikasi potensi upaya bersama dalam rehabilitasi lahan melalui kerja sama dengan KHDTK UGM dan pihak lain. Hasil penelitian menunjukkan bahwa sistem agroforestri berbasis budidaya spesies pohon serbaguna dan tanaman energi terbarukan memiliki potensi besar untuk perencanaan rehabilitasi lahan di KHDTK UGM. Sebuah proyek percontohan disarankan.

Kata kunci: Agroforestri, Kerangka Kerja CASM, Rehabilitasi Lahan, KHDTK UGM, Spesies Pohon Serbaguna

ABSTRACT

There is currently a problem of land degradation in Indonesia, requiring the rehabilitation of over 12.7 million hectares. Agroforestry has been considered one of the most effective strategies for restoring ecological functions while providing socio-economic benefits to local people. The purpose of this study was to develop an agroforestry-based land rehabilitation strategy for Compartment 5 of KHDTK at Universitas Gadjah Mada, located in Ngawi Regency, East Java, Indonesia, using the CASM model. This study involved assessing both biophysical and socio-institutional aspects in April 2025. Three Land Management Units (LMUs) were identified using the spatial overlay analysis of soil type, slope, rainfall, and land cover. The fieldwork was conducted across 18 plots of land, while socio-economic and property rights issues were collected through semi-structured interviews with locals. The findings indicated that LMU 1 was assigned to Class III Land Capability. However, LMUs 2 and 3 were assigned to Class IV, indicating severe soil limitations due to shallow soil depth, clayey soil, and susceptibility to erosion. Analysis of suitability indicated that *Calliandra calothyrsus* and *Arenga pinnata* had marginal suitability (S3) across all three land management units. In contrast, *Calophyllum inophyllum* adapted better to local conditions and faced fewer soil and climatic limitations. The availability and manageability assessment identified problems with informal land use, inactive local institutions, and poor coordination among stakeholders. These factors allowed for the identification of potential for joint efforts in land rehabilitation through cooperation with KHDTK UGM and other parties. The research results indicate that an agroforestry system based on the cultivation of multipurpose tree species and renewable energy crops has great potential in land rehabilitation planning in KHDTK UGM. A pilot project is suggested.

Keywords: Agroforestry, CASM Framework, Land Rehabilitation, KHDTK UGM, Multipurpose Tree Species

Citation: Tegar, F. K., Wijanarto, L. B. R., Noor, M. A., Roihanah, L., Angelina, N, Monica, H., and Hermudananto. (2026). Agroforestry-Based Land Rehabilitation in KHDTK UGM: Integration of Multipurpose Species and Renewable Energy Crops. Jurnal Ilmu Lingkungan, 24(2), 451-460, doi:10.14710/jil.24.2.451-460

1. INTRODUCTION

Forest and land degradation have become serious ecological and socio-economic problems in Indonesia. The extent of critical land in the country exceeds 12.7 million hectares, largely due to land-use conversion, unsustainable agricultural practices, natural resource exploitation, and weak land-use governance (MoEF, 2022). This has resulted in significant declines in the ecological functions of many forest areas, including biodiversity loss, soil erosion, reduced land productivity, and disturbance of the hydrological system (Hakim, 2023; Ruslan et al., 2018).

To address these challenges, Forest and Land Rehabilitation (FLR), or Rehabilitasi Hutan dan Lahan (RHL) as it is known in the Indonesian regulatory framework, has become an important strategy for restoring the ecological and socio-economic functions of degraded forest lands. It should be noted that the acronym FLR is more commonly used internationally for Forest Landscape Restoration. This study refers to FLR in the context of Indonesia's forest and land rehabilitation programs as defined by national policies and regulations. Agroforestry, a land-use system that integrates woody perennials with crops, either simultaneously or in sequence (Nair, 2011), is increasingly adopted in these rehabilitation programs. Agroforestry improves land productivity, diversifies livelihood opportunities, increases ecosystem resilience through soil conservation, permanent vegetation cover, improved nutrient cycling, and improves local socio-economic conditions (Garrity, 2004; FAO, 2020). Therefore, agroforestry is widely recognized as a successful strategy for reconciling environmental restoration with community livelihood needs in degraded landscapes.

One of the areas facing pressure from land cover changes and the decline of forest functions is the Special Purpose Forest Area (KHDTK) managed by Universitas Gadjah Mada (UGM) in Getas, Central and East Java. The study site, KHDTK compartment 5, is generally used for seasonal crops such as maize and sugarcane. This intensive use of land has led to unstable productivity, increased erosion, and the loss of the area's protective functions.

Apart from the biophysical degradation, the area is confronted with the socio-tenure challenges that make it difficult to rehabilitate. Field observations and consultations with stakeholders show that local communities engage in informal cultivation of part of the KHDTK land under non-formal arrangements. These practices have offered livelihood opportunities to surrounding communities but have also raised uncertainties about access to land, responsibilities for its management, and long-term commitments to rehabilitation. In addition, local forest management institutions such as the Forest Village Community Institution (LMDH) and Forest Farmer Groups (KTH) are inactive or have limited involvement in forest management activities. This hampers coordination among stakeholders and institutional and governance issues that hinder the implementation of collective rehabilitation initiatives. These socio-tenure conditions are considered a major problem affecting the success of land rehabilitation in Compartment 5.

Land capability and land suitability assessments are traditional land evaluation methods applied in rehabilitation planning. These provide valuable information on soil characteristics, topography, climate, and species requirements. However, they mainly address biophysical aspects and do not sufficiently consider land availability, tenure conditions, stakeholder interests, institutional capacity, and implementation feasibility. Hence, rehabilitation programs based solely on biophysical suitability may face implementation barriers if socio-economic and governance factors are not adequately considered.

In this case, the CASM framework, comprising Capability, Availability, Suitability, and Manageability, is used to assess the potential for developing agroforestry in Compartment 5. The CASM framework provides a more holistic assessment of land capability and suitability than traditional approaches, as it includes the four interrelated components mentioned above. Capability measures the physical capability of the land; Availability refers to land status, accessibility, and ownership; Suitability refers to species and land-use compatibility; and Manageability includes institutional preparedness, stakeholder involvement, infrastructure, and management potential. It is very important in KHDTK UGM because the rehabilitation program depends not only on the biophysical aspect but also on socio-tenure and institutional issues.

This makes it possible to develop rehabilitation measures based on the particularities of the site, land tenure and availability, species suitability, and manageability (Chang, 2019; Eastman, 2006). Furthermore, participation and collaboration in the engagement process with local communities, such as Forest Village Community Institutions (LMDH), and private sector actors is very important.

The main objective of this research is to develop a land rehabilitation plan for Compartment 5 at KHDTK UGM using agroforestry approaches within the CASM framework. By analyzing biophysical, sociological, and institutional issues, this research aims to suggest viable land rehabilitation strategies. The results of this research will then serve as inputs for developing a forest management model that also offers socio-economic benefits.

2. METHODOLOGY

2.1. Study Sites

This research was carried out at Compartment 5 of Kawasan Hutan Dengan Tujuan Khusus (KHDTK) owned by Universitas Gadjah Mada and located in Gempol Village, Ngawi Regency, East Java, Indonesia (Figure 1). From a geographical perspective, the location is located between coordinates of 7°32' – 7°34'S latitude and 111°35'-111°36'E longitude. The topography of this location ranges from plain to slightly undulating, and the elevation is approximately 77 meters above mean sea level. The choice of this location was due to the extent of land degradation and the intensive agricultural use of the land. In these respects, this location can be considered a suitable test site for analyzing land rehabilitation through agroforestry techniques.

2.2. Research Design and Approach

The study adopted a mixed-methods case study design that included a biophysical quantitative assessment and a socio-institutional qualitative analysis. The study opted for the chosen methodology to achieve a comprehensive and detailed analysis of the biophysical, socio-economic, and land management practices in the area under study. The study used the CASM model (capability, availability, suitability, and manageability). The CASM model is used in integrated land rehabilitation planning and has proved useful for combining spatial analysis, community involvement, and the formulation of natural resource management strategies.

2.3. Land Mapping Unit Identification and Modeling

Spatial analysis in this study was conducted at the Level of Land Mapping Units (LMU). The LMUs were demarcated through spatial overlays of several geospatial layers, including soil type (soil map), land cover (land cover map), slope, and precipitation. This technique enables one to demarcate land units characterized by relatively uniform biophysical characteristics, which can then be subjected to more detailed analysis. The geospatial layers used in the spatial overlay analysis include: a Digital Elevation Model (DEM) at 30 m resolution; a Precipitation dataset from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station Data); a Soil map dataset from the FAO Soil Map database; and a Land cover dataset from Sentinel-2 satellite imagery (2024). In total, three different LMUs were demarcated based on distinct biophysical characteristics.

2.4. Data Collection

Data collection in the field was conducted using a method that integrated direct observations, biophysical measurements, and interviews with key informants. Eighteen sample plots in the form of circles, each with a diameter of 22.6 meters and an area of 0.04 hectares, were set up at a 2.5% sampling intensity, as prescribed by the Indonesian Ministry of Forestry Regulation No. P.37/Menhut-V/2010. In these sample plots, soil samples from 0–30 cm were collected for analysis of soil texture, effective depth, pH, drainage, and permeability. Slope was measured with a clinometer to assess landform condition for land rehabilitation planning. Moreover, land cover classification is supported by ground truthing in accordance with the Indonesian National Standard (SNI) 7645:2010. Social and economic, as well as land tenure, data were collected through interviews with key informants, including a smallholder farmer, a community representative (RT/RW), and the forest manager of KHDTK UGM. In total, 10 people served as key informants in the interviews: 6 local farmers involved in land cultivation in Compartment 5, 2 community representatives (RT/RW), and 2 forest managers from KHDTK UGM.

The interviews were conducted during fieldwork in April 2025, using a semi-structured questionnaire that covered land-use practices, tenure systems, perceptions of agroforestry, institutional settings, and willingness to participate in rehabilitation programs. Every interview lasted between 30 and 60 minutes and was recorded in field notes. To maintain confidentiality and respect the personal privacy of individual interviewees, their names were not used in the presentation of the results.

The application of these two methods helped develop an overall picture of the biophysical and socioeconomic features of the location in question.

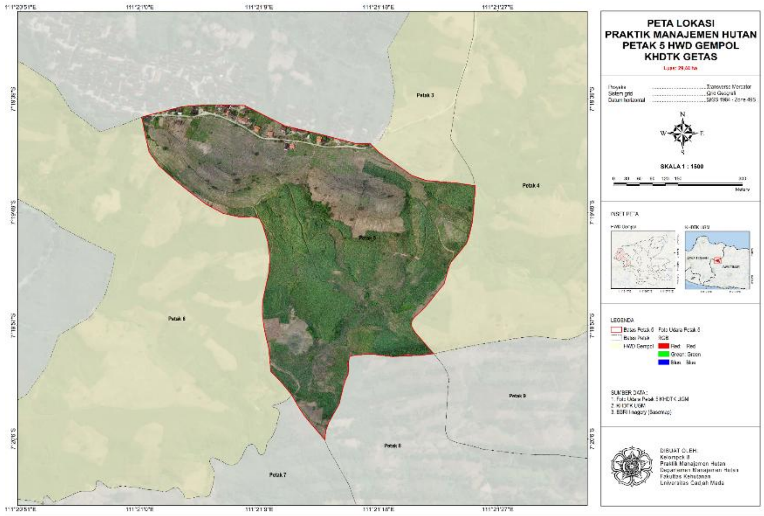

Figure 1. Compartment 5 of the Kawasan Hutan Dengan Tujuan Khusus (KHDTK) Managed by Universitas Gadjah Mada, Located in Gempol Village, Ngawi Regency, East Java, Indonesia

2.5. Data Analysis

The analyses were conducted using the CASM approach, which comprises four major elements: Capability, Availability, Suitability, and Manageability. The land capability assessment was carried out by considering biophysical factors such as soil texture, solum depth, drainage, and slope. The land capability assessment process used the land capability classification system by Arsyad (2010) and the Ministry of Environment regulation number 17 of 2009. The land availability assessment process involved analyzing the legality of the land, patterns of land ownership and utilization, and the community's willingness to participate in the land rehabilitation program. This information was gathered through interviews and field documentation. The land suitability analysis was conducted using the FAO (1976) land evaluation scheme, employing a matching approach to examine the compatibility between the growth needs of selected multipurpose tree species and the biophysical characteristics of the sites. The evaluated species include *Calliandra calothyrsus, Arenga pinnata, Calophyllum inophyllum, Tectona grandis (teak), Gliricidia sepium,* and *Bambusa spp*. Manageability was analyzed based on how easily an agroforestry system implementation could be done. The main indicators included infrastructure availability, site accessibility, the capability of the institutional organization, such as LMDH (Forest Village Community Institution) or KTH (Forest Farmer Group), the partnership organization (such as Pertamina Foundation), and financial feasibility. The information above was gathered through field observations, stakeholder interviews, and document review related to the institutions. The quantitative data were analyzed using descriptive statistics and visualized in QGIS and ArcGIS. ArcGIS was primarily used for spatial overlay analysis, LMU delineation, and land suitability mapping, whereas QGIS was primarily used for map visualization and cartographic design.

On the other hand, qualitative data gathered through interviews were coded into themes based on stakeholders' perceptions, roles, and barriers towards agroforestry. The interview results were grouped into the following themes: land tenure and access, institutional capacity, community participation, the benefits of agroforestry, and barriers to rehabilitation.

3. RESULT

3.1. Land Mapping Unit (LMU) Identification

Through spatial analysis and biophysical classification, three homogeneous Land Mapping Units (LMUs) were identified within compartment 5 of KHDTK UGM, which consist of different topographies, soil types, and land uses (Figure 2 and Table 1). LMU 1 consists of gentle slopes where maize is grown on Lithosol soils. LMU 2 comprises moderate slopes where sugarcane cultivation is practiced, and LMU 3 comprises the riparian buffer zone.

The LMU modeling for Plot 5 within the Gempol HWD region at KHDTK UGM has been done based on data sourced from different inputs like DEM, Soil Type of FAO, CHIRPS rainfall, and Sentinel-2 imagery (2024) to undergo spatial analysis and subsequent validation by field verification that encompasses the riparian zones, which have their unique topography, soil, and land use pattern. The developed model, as shown in Figure 2 and Table 1, distinguishes Compartment 5 into three separate LMUs (LMU 1, LMU 2, and LMU 3).

LMU 1 covers about 9.28 ha and is mainly used for maize cultivation. LMU 1 has a Lithosol soil type with a coarse texture and a shallow soil depth, and receives less than 1000 mm of rainfall annually, indicating a dry climate. The land slopes slightly (8-15%) and has a low erosion risk, making it suitable for mechanized cultivation and for drought-resistant crops such as maize.

LMU 2 covers a total area of 14.33 ha and is mainly used for sugarcane cultivation. Similar to LMU 1, the area has Lithosol soil type, receives less than 1000 mm of rainfall annually, and has a relatively lower elevation, with rolling slopes (15-25%). However, LMU 2 needs some form of conservation measures to protect it from erosion.

LMU 3 covers 3.84 ha and is mainly used for sugarcane cultivation. The area falls under the riparian buffer zone. Therefore, it is ecologically sensitive to any disturbance. The land has rolling slopes of (15-25%), receives less than 1000 mm of rainfall annually, and has Lithosol soil type.

All of the LMUs have low effective soil depth and high drainage rates. This implies that both features reduce water and nutrient-holding capacity, thereby creating difficulties for sustainable land management. Annual rainfall in the area under consideration does not exceed 1000mm, and the climate regime belongs to the D4 category of the Oldeman classification. Climate and soil constraints are of paramount importance in selecting the right tree species and designing the planting system.

3.2. Capability Analysis (C)

The capability analysis shows that LMU 1 belongs to class III land capability, whereas LMU 2 and LMU 3 belong to class IV. The classification of class III implies that land is suitable for cultivation with perennial crops, but under the condition that moderate soil and water management techniques will be used. In turn, class IV requires more elaborate conservation and can be used for certain land uses, such as forestry or pasture (Arsyad, 2010). The main limitations of the lands include shallow soil depth, clay soils, and moderate slopes.

Table 1. Biophysical Conditions of Each Land Mapping Unit.

LMU	Area (ha)	Land Use	Precipitation (mm/year)	Soil Type	Slope
1	9.28	Corn	<1,000	Lithosol	Gentle (8-15%)
2	14.33	Sugarcane	<1,000	Lithosol	Undulating (15–25%)
3	3.84	Sugarcane (Riparian Zone)	<1,000	Lithosol	Undulating (15–25%)

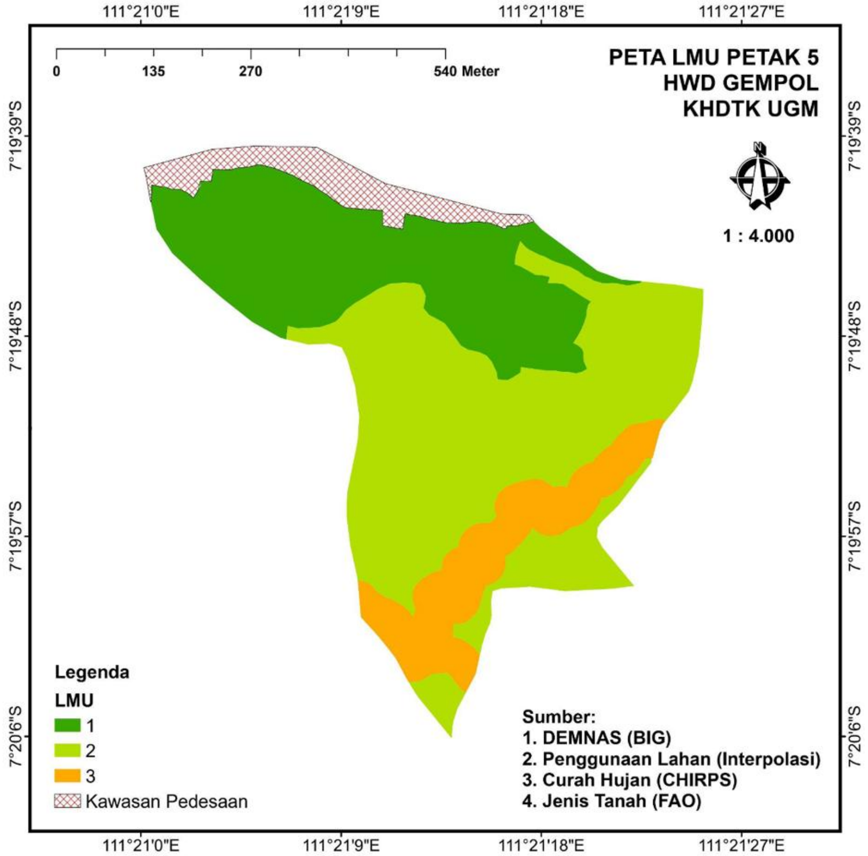

Figure 2 Land Mapping Unit Compartment 5 of KHDTK UGM.

3.3. Availability Analysis (A)

From an administrative perspective, the entire area in Compartment 5 falls under the jurisdiction of KHDTK UGM, as per the Decree of the Minister of Environment and Forestry No. 632/Menlhk/Setjen/PLA.0/8/2016. Nevertheless, field checks and interviews show that local communities manage some parts of the land through the cultivation of seasonal crops, and that local brokers can provide informal financial aid. Inactivity of local institutions such as LMDH (Institution of Village Forest Communities) and KTH (Forest Farmer Groups) over the past two years has led to poor coordination and a lack of common planning, which is important for realizing the community rehabilitation program. Availability issues are affected by uneven information and low community participation in the land management planning process.

3.4. Suitability Analysis (S)

Based on the suitability assessment results, both *Calliandra calothyrsus* and *Arenga pinnata* were found to be marginally suitable (S3) to the evaluated LMUs. On the other hand, *Calophyllum inophyllum* showed additional limitations regarding soil depth, water availability, and site suitability. However, each of these species possesses specific traits that can help in achieving rehabilitation goals with proper management.

Also, the selected species exhibit different growth rates, productivity cycles, and economic benefits. *Calliandra calothyrsus* is an example of a fast-growing, multipurpose tree that produces biomass quickly after planting. Thus, this species can be used for early rehabilitation and energy development purposes. *Arenga pinnata*, on the contrary, takes longer to grow and produces its products in the middle to later stages of its lifecycle. This species produces sugar, sap, fiber, and other non-timber forest products, offering the potential to generate income for several years after planting. *Calophyllum inophyllum* needs much more time to become mature enough to produce seeds for biofuel development.

The differences point to the necessity of species selection that considers not only biophysical suitability but also the timeliness of ecological and economic outcomes. Species with various production cycles could be used to reconcile short-term livelihood requirements with long-term rehabilitation goals.

Table 2. CASM Characteristic Analysis Matrix

PL	LMU	Cluster	Area (ha)	Capability (C)	Availability (A)	Suitability (S)	Managibility (M)
Corn	I	(Flat – Lowland Corn)	9.28	- Soil: Litosol - pH: 6.8–7.7 - Drainage: Fast - Depth: 47 cm - Texture: Clay - Land use: Corn farming	• Local communities depend on farming - Land owned by KHDTK UGM - Not individually owned, but used via collaboration - Ground checking confirmed usage by 3 farmers	• Suitable for corn, sorghum, energy crops - Supported by partnerships (KHDTK, Pertamina Foundation) - Community involved in sustainable projects	• Good access via footpath and vehicle - Existing infrastructure for agro-energy - Community familiar with farming practices
Sugarcane	II	(Moderate – Sugarcane Area)	14.33	- Soil: Litosol - pH: 6.5–7.7 - Drainage: Fast - Depth: >62.75 cm - Texture: Silty Clay - Land use: Sugarcane farming	• Local use of land without ownership rights - Land managed by KHDTK UGM - Identified 3 users	• Suitable for sugarcane, sorghum, energy crops - Strong potential for agroforestry projects - Good biophysical match for sustainable agriculture	• Access available for foot and small vehicles - Land relatively easy to manage - Supported by institutional collaboration
Sugarcane	III	(Flat– Moderate – Sugarcane)	3.84	- Soil: Litosol - pH: 6.8–7.6 - Drainage: Fast - Depth: >62.3 cm - Texture: Clay - Land use: Sugarcane farming	• Land under KHDTK UGM management - 3 users identified - No individual land rights	• Highly suitable for sugarcane and agro-energy - Located near conservation area - Collaboration with Pertamina Foundation	• Accessible by walking and river route - Familiar local users - Infrastructure limited but sufficient for management

3.5. Manageability Analysis (M)

Manageability includes technical (accessibility and infrastructures), institutional (social), and economic (financial and market access) considerations. LMU 1 has good road access, which will enable logistics for rehabilitation efforts. Conversely, LMUs 2 and 3 need improvements in transportation infrastructure to conduct efficient land management. The financial support from the Pertamina Foundation provides an opportunity for the sustainable development of energy forests. Nevertheless, this needs to be augmented by strengthening local institutions and the community's managerial capacity. A model of multi-stakeholder cooperation between KHDTK UGM as the land manager, the private sector as investors, the government as the regulator, and local communities as implementers of technical land management should be developed through collaboration within an agroforestry program.

Characteristic Analysis of CASM, as explained above, is made up of four elements – Capability, Availability, Suitability, and Manageability - to analyze the feasibility of land rehabilitation. This is evident in the matrix summary (Table 2) as follows.

3.6. CASM-Based Rehabilitation Priority Framework

To enhance the practicality of CASM assessment for rehabilitating degraded sites, the results were analyzed and prioritized into three levels: High, Medium, and Low (see Table 3). Such an analysis makes it easier for stakeholders to pinpoint intervention priorities and allocate resources to the most pressing needs. The priority classification was based on the level of constraints, rehabilitation options, and the feasibility of implementation for each CASM component. Analysis revealed that Capability, Availability, and Suitability represent high-priority areas that need immediate attention. For example, capability constraints on the lands in LMU 2 and LMU 3 would call for implementing soil and water conservation to mitigate erosion problems and increase site productivity. Land availability is another high-priority area that needs to be addressed, as informal land uses prevail and stakeholder coordination is needed to facilitate rehabilitation work. Another factor to consider is species suitability, with *Calliandra calothyrsus* and *Arenga pinnata* showing high potential for site rehabilitation.

Manageability, on the other hand, is categorized as a medium priority due to the availability of institutional support from KHDTK UGM and its partners. However, improvements can still be made to strengthen local institutions, enhance stakeholder involvement, and improve long-term governance arrangements. The prioritization model above offers a better, more practical way to assess the ecological and social feasibility of agroforestry-based rehabilitation programs and to make decisions.

3.7. Prioritization of Rehabilitation Interventions

With reference to the integrated CASM analysis, a priority ranking of rehabilitation strategies has been generated for the implementation of the plan in Compartment 5 of KHDTK UGM. This priority ranking considers biophysical limitations, ecological sensitivity, land availability, the species' suitability for rehabilitation, and the manageability of the intervention. Riparian ecosystem rehabilitation in LMU 3 is of the highest priority, as the land unit is ecologically sensitive, located along a river, and highly prone to land degradation and erosion. Rehabilitation efforts need to be focused on establishing vegetation cover, including bamboo and conservation species.

The establishment of multipurpose tree species in an agroforestry system is the second-priority intervention, as the two species, *Calliandra calothyrsus* and *Arenga pinnata*, were found to be the most suitable for the existing site conditions. The establishment of MPTS would benefit from an economic and ecological perspective. The next rehabilitation strategy is to revitalize local institutions such as LMDH and KTH, which have limited operational capacity.

Fourth on the list is the gradual implementation and expansion of agroforestry management systems, encompassing adaptive intercropping systems and land-use methods that integrate agricultural activities with rehabilitation aims. Such an undertaking will be facilitated through capacity-building, technical support, and partnership efforts among KHDTK UGM, local communities, the government, and other external parties. The systematic implementation of such intervention measures is anticipated to yield optimal rehabilitation outcomes.

4. DISCUSSION

4.1. Community Dependence on Agricultural Land and Stakeholder Coordination

KHDTK UGM relies heavily on maize and sugarcane production due to stable market demand and favorable ecological conditions for these crops. While maize is used as food and feed crops, sugarcane is used in the region's agroindustries (Bustam, 2021). Lithosol soil types, limited rainfall of less than 1000 mm per year, and gentle slopes support the growth of these crops. The long history of farmers in these areas and the lack of alternatives make their choices clear. There are many examples of similar decisions regarding land-capability-based cropping in Indonesia (Mujiyo et al., 2022).

The restoration of KHDTK UGM requires coordinated efforts from all stakeholders, including communities, UGM, Pertamina Foundation, the government, and private organizations. Good coordination enables balancing different interests and leveraging the capabilities of all stakeholders. Otherwise, the land restoration process may be disjointed. For this purpose, the Logical Framework Approach (LFA) may be helpful in participatory planning (Des Gasper, 1999; Virginia et al., 2018).

4.2. Governance and Forest Management

KHDTK UGM governance encompasses formal regulation and local practices. The challenges are land tenure uncertainty, poor capacity, and inadequate public participation. Technologies such as GIS and remote sensing, when employed in land suitability assessment and risk assessment, enhance informed decision-making (Nguyen et al., 2024; Fajeriana & Abd Kadir, 2020; Raharjo & Larosa, 2011). For instance, modeling of compartment 5 included DEM, CHIRPS rainfall data (Funk et al., 2015), and FAO soil maps to identify LMUs.

Present land use includes cultivation of maize and sugarcane, which provide economic benefits but may decrease ecological resilience. Transitioning to an integrated agroforestry system by planting fast-growing trees such as *Gliricidia sepium* can be a solution. *G. sepium* is well-suited for growing as low-input biomass and restoration of degraded landscapes (Elevitch & Francis, 2005; Bahri et al., 2023; Winata et al., 2012). Besides, its use in the production of wood pellets supports the development of bioenergy (Nugraha & Saputro, 2023; Setyawan et al., 2021).

Enhancing the capacity of the forest farmers group (KTH) is important for transitioning from a provider of labor to co-management of forest resources (Febryano et al., 2009).

Enhancements to governance should consider issues related to participatory land-use planning, policy implementation, and monitoring. The principles of forest governance include transparency, accountability, equity, and inclusion (Senawi, 2012; Suripin, 2002). These principles help improve sustainability and rural livelihoods (Syahputra et al., 20).

Table 3. CASM-Based Rehabilitation Priority Matrix

CASM Component	Key Findings	Priority Level	Management Implications
Capability	LMU 1 (Class III) suitable for agroforestry; LMU 2 and LMU 3 (Class IV) have erosion and soil limitations	High	Implement soil conservation measures and site-specific agroforestry systems
Availability	Land is available for rehabilitation, but informal cultivation and tenure-related issues exist	High	Strengthen land-use agreements and stakeholder coordination
Suitability	*Calliandra calothyrsus* and *Arenga pinnata* classified as S3 and suitable for rehabilitation objectives; *Calophyllum inophyllum* has additional limitations	High	Prioritize Calliandra and Arenga for initial rehabilitation activities
Manageability	Existing institutional support from KHDTK UGM and partners is available, but local organizations require strengthening	Medium	Improve capacity building, stakeholder engagement, and long-term governance mechanisms

4.3. Integrative Land Rehabilitation Strategy

Based on the CASM analysis, the following aspects form the suggested land rehabilitation strategy. First, agroforestry blocks combining multipurpose trees (MPTS) with renewable energy crops will be developed.

Incorporation of *Calliandra calothyrsus*, *Arenga pinnata*, and *Calophyllum inophyllum* gives different ecological and economic roles from different time horizons. *Calliandra calothyrsus* can deliver relatively rapid returns in the form of biomass, fuelwood, and soil regeneration, providing an opportunity to involve the community in the land rehabilitation process in the initial stage. At the same time, *Arenga pinnata* can provide medium- and long-term benefits through the production of palm sap, sugar, and other commercial products, while improving soil and water resources. In turn, *Calophyllum inophyllum* is more appropriate for long-term land rehabilitation.

The above differences in growth rates of the various plants pose significant challenges for rehabilitation plans. Species that grow quickly, like *Calliandra calothyrsus*, provide immediate motivation for locals to support rehabilitation efforts, while *Arenga pinnata* and *Calophyllum inophyllum* offer longer-lasting economic and ecological benefits. Therefore, an agroforestry scheme involving all three species is recommended over one involving only one species, as both short- and long-term rehabilitation goals can be achieved.

Based on the suitability analysis, the most suitable species for the site's current conditions are *Calliandra calothyrsus* and *Arenga pinnata*, both of which have been classified as marginally suitable (S3) across all LMUs and are more tolerant of shallow soils, limited water availability, and current management conditions. Secondly, it calls for establishing protected areas along the riverbanks, especially in LMU 3, by planting bamboo and other selected conservation species, such as *Calophyllum inophyllum*, depending on site conditions, to minimize erosion of riparian ecosystems. Even though *Calophyllum inophyllum* can be useful ecologically and economically, its implementation may be hindered by shallow soils and low rainfall, among other biophysical constraints identified in the suitability analysis. Thus, its implementation should be done with caution. Thirdly, the strategy involves capacity-building for community-based forest management organizations. Fourth, it involves adopting adaptive intercropping systems with specific planting schedules during the area's dry seasons to ensure crop productivity under low rainfall conditions. Lastly, the strategy emphasizes the importance of incorporating CSR funding, such as that from Pertamina Foundation, into the planning system of KHDTK UGM. The aforementioned integrated strategy aligns with the tenets of landscape-based rehabilitation, which emphasize ecological function, sustainable land use, and socioeconomic development (Garrity et al., 2010).

The use of the land in Gempol Village, KHDTK Getas, is an example of anthropogenic adaptation to environmental potential. Maize and sugarcane prevail, but the spatial assessment indicates varying suitability across LMUs. The use of GIS-assisted land assessment helps integrate land potential with suitable agroforestry schemes (Budiarta, 2014; Ritung et al., 2011), especially in areas where erosion is common and soil conservation is required.

The application of the CASM method would help achieve more accurate and relevant decision-making during the implementation of the land rehabilitation project. The power of this method lies in its ability to combine the following elements: biophysical assessment, land rights and legality, social capital, and management in one single method of site evaluation. Such a comprehensive approach enables more efficient planning and prioritization of interventions, while accounting for the ecological, legal, and socio-economic aspects of the issue. Nevertheless, the main obstacle remains the development of capacities and sustainable partnerships. As noted by Kusters et al. (2006), the success of agroforestry depends not only on ecological conditions but also on the availability of responsive, inclusive, and adaptive institutions.

However, certain limitations should be noted regarding this research. First, the fieldwork was conducted over a relatively short period in April 2025. The goal of such activities was the field verification, land condition evaluation, and consultations with stakeholders. Thus, the climatic conditions were not analyzed solely based on short-term fieldwork results. Instead, rainfall and climatic conditions were estimated from long-term secondary data, including CHIRPS precipitation data and regional climatological records. Such an approach provided a more representative description of local climatic conditions. Also, a socio-economic and institutional analysis was conducted using village profile information, document analysis, and interviews with local farmers, community representatives, and KHDTK managers. Though such information provides a good basis for developing a land rehabilitation plan, further research should be conducted to monitor ecological performance, socio-economic effects, and stakeholder involvement following the implementation of agroforestry interventions.

Before full-scale implementation, a pilot agroforestry demonstration plot is recommended to validate species performance, management arrangements, and stakeholder participation mechanisms under actual field conditions.

5. CONCLUSION

This study demonstrates the viability of CASM as an integrated platform for designing an agroforestry-based land rehabilitation strategy. Three LMUs were determined based on the area's capabilities and management traits. According to the suitability evaluation, *Calliandra calothyrsus* and *Arenga pinnata* are highly suitable plants for land rehabilitation at this time. Meanwhile, *Calophyllum inophyllum* is a potential choice, but it is subject to additional biophysical limitations.

An agroforestry rehabilitation strategy proposed for implementation in Compartment 5 of KHDTK UGM involves planting multipurpose tree species, growing renewable energy crops, protecting riparian areas, and instituting institutional reforms. Nonetheless, the outcomes of this research should be viewed as a platform for planning and prioritizing land rehabilitation rather than as proof of its success. The proposed interventions are based on findings from land capability, suitability, availability, and manageability evaluations, but have not yet been verified.

For this reason, pilot-scale implementation, adaptive management, and long-term ecological and socio-economic monitoring are necessary to assess the performance of the proposed agroforestry system. Future research must examine vegetation growth, improved soil conditions, erosion control, stakeholder involvement, and livelihood improvements to assess the long-term success of the rehabilitation program.

REFERENCES

Arsyad, S. (2010). Konservasi tanah dan air. IPB Press.

Bahri, S., Heriansyah, I., & Mulyana, Y. (2023). Analisis produktivitas dan potensi biomassa Gliricidia sepium pada lahan marginal. Jurnal Agroforestri Indonesia, 5(1), 23–32.

Bayrak, M. M., & Marafa, L. M. (2016). Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities. Sustainability, 8(7), 620. https://doi.org/10.3390/su8070620

Budiarta, K. (2014). Pemetaan kesesuaian lahan menggunakan sistem informasi geografis (SIG). Jurnal Ilmiah Teknik Sipil, 18(2), 75–84.

Bustam, M. A. (2021). Ekonomi pertanian: Dinamika komoditas jagung dan tebu dalam pembangunan pedesaan. Jurnal Sosial Ekonomi Pertanian, 20(3), 45–57.

Cerdan, C. R., Rebolledo, M. C., Soto, G., Rapidel, B., & Sinclair, F. L. (2012). Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. Agricultural Systems, 110, 119–130. https://doi.org/10.1016/j.agsy.2012.03.014

Chang, K. T. (2019). Introduction to Geographic Information Systems (9th ed.). McGraw-Hill Education.

Des Gasper. (1999). Logical Framework Analysis: A critical review. ISS Working Paper Series.

Eastman, J. R. (2006). IDRISI Andes: Guide to GIS and image processing. Clark Labs, Clark University.

Elevitch, C. R., & Francis, J. K. (2005). Gliricidia sepium (gliricidia). In C. R. Elevitch (Ed.), Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawaiʻi.

FAO. (1976). A framework for land evaluation (FAO Soils Bulletin No. 32). Food and Agriculture Organization of the United Nations.

FAO. (2020). Agroforestry and tenure. Forestry Working Paper 14. https://www.fao.org/documents/card/en/c/cb0564en

Fajeriana, F., & Abd Kadir, A. (2020). Pemanfaatan teknologi penginderaan jauh untuk mendukung rehabilitasi hutan dan lahan di Indonesia. Jurnal Sylva Lestari, 8(2), 187–198.

Febryano, I. G., Darusman, D., & Rachmat, M. (2009). Penguatan kapasitas kelembagaan kelompok tani hutan dalam pengelolaan hutan berbasis masyarakat. Jurnal Manusia dan Lingkungan, 16(3), 151–158.

Funk, C., et al. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Scientific Data, 2, 150066. https://doi.org/10.1038/sdata.2015.66

Garrity, D. P. (2004). Agroforestry and the achievement of the Millennium Development Goals. Agroforestry Systems, 61–62(1–3), 5–17. https://doi.org/10.1023/B:AGFO.0000028986.37502.7c

Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Sileshi, G., Mowo, J. G., Kalinganire, A., ... & Bayala, J. (2010). Evergreen agriculture: A robust approach to sustainable food security in Africa. Food Security, 2(3), 197–214. https://doi.org/10.1007/s12571-010-0070-7

Hakim, L. (2023). Landscape-level forest rehabilitation for biodiversity and rural livelihoods: A case from East Java, Indonesia. Environmental Management and Conservation, 14(2), 56–67.

Karyati, K., & Sarminah, S. (2018). Penilaian kesesuaian lahan untuk tanaman pertanian menggunakan metode matching di daerah tangkapan air. Jurnal Tanah dan Sumberdaya Lahan, 5(1), 643–651.

Kusters, K., Buck, L., de Graaf, M., Minang, P. A., van Noordwijk, M., & Wollenberg, E. (2006). Exploring the potential of agroforestry to enhance livelihood security in the tropics. CIFOR and ICRAF Policy Brief.

Ministry of Environment and Forestry of the Republic of Indonesia. (2016). Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number SK.632/Menlhk/Setjen/PLA.0/8/2016 concerning the Designation of Forest Area with Specific Purposes (KHDTK). Ministry of Environment and Forestry.

Ministry of Environment and Forestry. (2022). The state of the Indonesian environment 2022. Directorate General of Forestry Planning and Environmental Management, Ministry of Environment and Forestry.

Ministry of Forestry of the Republic of Indonesia. (2010). Regulation of the Minister of Forestry Number P.37/Menhut-V/2010 concerning Procedures for Compiling Forest and Land Rehabilitation Management Plans. Ministry of Forestry of the Republic of Indonesia.

Mujiyo, M., Pratiwi, R. D., & Kurniawan, H. D. (2022). Pengaruh pengelolaan lahan terhadap keberlanjutan usaha tani di lahan kering. Jurnal Pertanian Lahan Kering, 11(1), 33–39.

Nair, P. K. R. (2011). Agroforestry systems and environmental quality: Introduction. Journal of Environmental Quality, 40(3), 784–790. https://doi.org/10.2134/jeq2011.0076

National Standardization Agency. (2010). SNI 7645:2010 concerning Land Cover Classification. National Standardization Agency.

Nguyen, T. T., Mai, V. H., & Nguyen, D. V. (2024). Remote sensing and GIS for land suitability assessment in forest landscape restoration planning.

Environmental Monitoring and Assessment, 196(3), 120.
Nugraha, H., & Saputro, S. (2023). Potensi biomassa Gliricidia sepium sebagai bahan baku bioenergi di lahan marginal. Jurnal Energi Terbarukan, 12(2), 45–52.
PUPR. (2017). Peraturan Menteri PUPR Nomor 28/PRT/M/2015 tentang Penetapan Garis Sempadan Sungai dan Danau. Kementerian Pekerjaan Umum dan Perumahan Rakyat, Indonesia.
Raharjo, B., & Larosa, E. (2011). Penggunaan citra satelit untuk perencanaan rehabilitasi hutan dan lahan. Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, 1(1), 9–18.
Rahman, S. A., Jacobsen, J. B., Healey, J. R., Roshetko, J. M., & Sunderland, T. (2016). Finding alternatives to swidden agriculture: Does agroforestry improve livelihood options and reduce pressure on existing forest? Agroforestry Systems, 90(4), 715–731. https://doi.org/10.1007/s10457-015-9842-2
Republic of Indonesia. (2009). Regulation of the State Minister for the Environment Number 17 of 2009 concerning Guidelines for Determining Environmental Carrying Capacity in Regional Spatial Planning. State Ministry for the Environment.
Ritung, S., Wahyuningsih, T., & Subagyo, H. (2011). Petunjuk teknis evaluasi kesesuaian lahan untuk komoditas pertanian. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Litbang Pertanian.
Ruslan, M., Hermawan, H., & Wulandari, C. (2018). Model rehabilitasi hutan berbasis partisipasi masyarakat. Jurnal Rehabilitasi Hutan dan Konservasi Alam, 5(2), 139–148. https://doi.org/10.20886/jrh
Senawi. (2012). Fundamentals of spatial planning [Textbook]. Laboratory of Forest Management Information Systems, Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta.
Setyawan, E. Y., Lomi, A., & Saleh, C. (2021). The use of wood pellets for tofu production fuel in Kediri Regency SMEs. National Journal of Science and Technology Application, 2(02).
Suripin. (2002). Conservation of soil and water resources. Andi Yogyakarta.
Syahputra, O. H., Jamilah, M., & Saputra, S. (2022). Success rate of enrichment activities in the Forest and Land Rehabilitation Program at Pocut Meurah Intan Grand Forest Park, Aceh. Almuslim Environmental Journal, 1(2), 001–008.
Virginia, G., Susanto, B., Restiandito, & Proboyekti, U. (2018). Logical Framework Analysis and Appreciative Inquiry in Strategic Planning for Organizational Management Information Systems. Proceedings of the National Seminar on Community Service Results, 3(1). ISSN 2541-3805.