

Spatial modeling of Community Forestry (HKm) management options in Malang Regency

*Muhamad Syaikhu Alam, Nining Puspaningsih**, and *Leti Sundawati*

Forest Management Science, Department of Forest Management, Faculty of Forestry and Environment, IPB University, 16680, Indonesia

Abstract. Community Forestry (HKm) is a Social Forestry scheme that provides local communities with direct legal access to manage forest areas to improve community welfare, leveraging the forest's potential for NTFP, TFP, and environmental services. This study aims to formulate and map Community Forestry management options in Malang Regency using the Analytical Hierarchy Process (AHP) method and spatial modeling. The study was conducted across seven farmer groups in three districts of Malang Regency: Ngantang, Singosari, and Sumbermanjing Wetan. HKm management options are divided into 2 areas, protection areas and utilization areas. The results of this study show that in the low and medium vulnerability areas of the 3 sub-districts, the selected HKm management options are dominated by option 2B (forest MPTS with PLDT agricultural MPTS) in the protection area of 779,60 ha and the utilization area of 1607,78 ha. Meanwhile, in the high deforestation vulnerability areas, the selected management options in the 3 sub-districts in the protection area are dominated by option 2A (forest MPTS with honey) in the area of 1,37 ha and by option 1B (silvopasture) in the utilization area of 7,03 ha. The selected management, if implemented can reduce erosion relative to existing land conditions, making them feasible.

1 Introduction

Forests in Indonesia are tropical resources that have important benefits in ecosystem sustainability, biodiversity, climate change mitigation, and natural disaster mitigation [1, 2]. In addition, forests can support the local economy through social forestry, ecotourism, agroforestry, and environmental services [3, 4, 5]. However, the paradigm of land use from non-forested areas is shifting toward forested areas or natural forests, which could lead to massive deforestation. The concept of social forestry is among the solutions promoted by the Indonesian government to achieve more sustainable forest management. The issuance of the social forestry program through the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 9 of 2021 concerning Social Forestry Management aims to improve community welfare, maintain environmental balance, and socio-cultural dynamics. Community Forestry is the beginning of the evolution of social forestry that involves communities in forest management through the Decree of the Minister of Forestry: 622/1995.

* Corresponding author: n_puspaningsih@apps.ipb.ac.id

Community Forestry (HKm) is a form of forest management that prioritizes community welfare. HKm are granted rights/permits in the form of an IUPHKm (Cultivated Forest Management Permit) granted by the Minister of Environment and Forestry, located in production and protected forest areas. HKm applicants include individuals who join or form community groups, farmer groups, community cooperatives, or associations, with management rights for 35 years, extendable, with an approved area of ≤ 15 ha per household (KK) and ≤ 5000 ha per management unit. HKm management rights holders are obligated to prepare a forest management plan, business work plan, and annual work plan. HKm management rights holders are obligated to prepare a forest management plan, business work plan, and annual work plan. Effective forest management helps reduce high budgets by implementing gradual management. Therefore, it is crucial to determine priority management areas. This determination of priority management areas can be implemented through spatial modeling.

Spatial modeling is an explicit process that uses spatial references to understand and explain phenomena occurring on Earth's surface. Spatial modeling has been widely applied in forestry to monitor environmental conditions, analyze land and habitat suitability, understand wildlife distribution, and mitigate disasters [6, 7]. This approach provides significant benefits in land-use planning by considering various objectives, criteria, and indicators. Various methods have been developed to support spatial modeling, such as the Analytical Hierarchy Process (AHP). The AHP method is used to support decision-making in forest management by compiling and analyzing options against structured criteria [8]. This study integrates spatial modeling with AHP to develop a more effective and efficient model in determining Community Forestry (HKm) management options.

2 Materials and methods

2.1 Research area

This research was conducted from March to October 2025 in the Community Forestry (HKm) in Malang Regency, spread across three districts, covering an area of 3937 ha, including 614 ha of production forest and 3323 ha of protection forest managed by seven permit holders (Figure 1). The research locations in these districts were selected based on historical counts of deforestation incidents in Malang Regency.

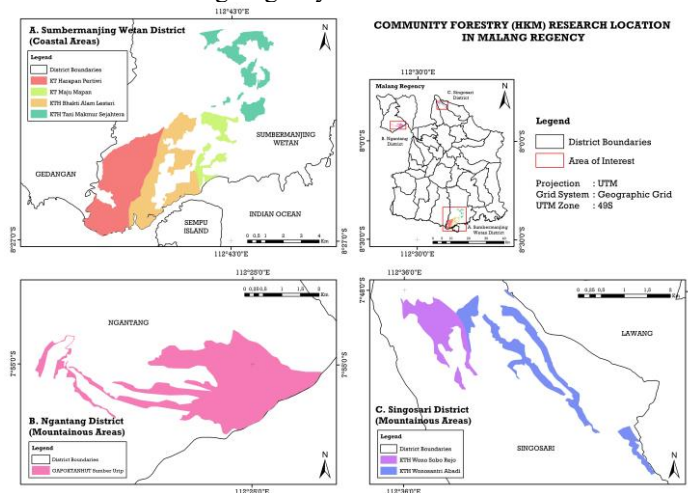


Fig. 1. Research location in Community Forestry (HKm) Malang Regency.

2.2 Determination of community forestry management areas

According to Ministerial Regulation No. 9 of 2021, Article 103 paragraph (4), the management area criteria distinguish between protection areas and utilization areas. The criteria for establishing protection areas in HKm Malang Regency include: riverbanks (< 50 m), coastal areas (< 100 m), areas with slopes > 40%, and areas with elevations > 2000 meters. Utilization areas are determined by criteria different from those used for protection areas. The management areas are divided into protection and utilization areas, as in Figure 2.

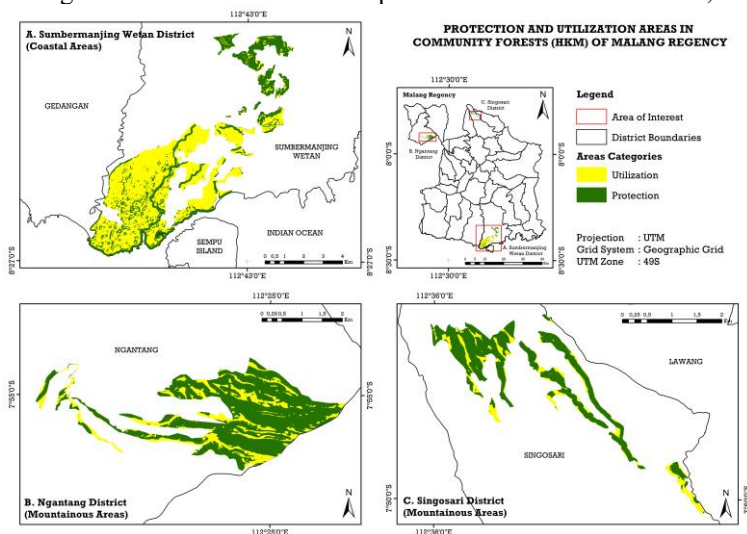


Fig. 2. Protection and utilization areas in HKm

2.3 Formulation of community forestry management option model

Management options for community forests are set for each protection and utilization area. Each option is refined based on its level of deforestation vulnerability: low, medium, or high. The formulation process relies on the Ministry of Environment and Forestry's Social Forestry Area Utilization Direction Map (PAPAPS) and insights from experts.

2.4 Development of community forestry management option

Model development was conducted using scores and weights for each criterion and indicator obtained via the Analytical Hierarchy Process (AHP). The criteria and indicators used in this study are presented in Table 1. The suitability classes for management options were divided into three categories using the equal-interval method: unsuitable, suitable, and highly suitable. Mathematically, the spatial modeling is formulated as follows:

$$Y = A_{i1}(a_1 \times x_1) + (a_2 \times x_2) + \dots + (a_n \times x_n) + B_{i1}(b_1 \times y_1) + (b_2 \times y_2) + \dots + (b_n \times y_n) \quad (1)$$

Description:

Y = HKm management option

A = environmental criteria weight

B = social criteria weight

a_1, a_2, a_n = environmental criteria indicator weight

b_1, b_2, b_n = social criteria indicator weight

x_1, x_2, x_n = environmental criteria indicator scores

y_1, y_2, y_n = social criteria indicator scores

Table 1. Criteria and indicators used.

Criteria	Indicators	Unit	Source
Environment	Slope	%	DEMNAS BIG
	Elevation	masl	DEMNAS BIG
	Soil type	-	OneMap BIG
	Erosion rate	tons/year/ha	OneMap BIG
	Land use	-	Sentinel-2
Social	Distance from road	m	Analysis result
	Distance from river	m	Analysis result
	Distance from settlements	m	Analysis result
	Population density	people/km ²	BPS
	Deforestation vulnerability	-	Analysis result

The data types for all criteria and indicators differ, so scoring is performed to standardize each variable's value, with an assessment on a scale of 1-3. The weighting process is carried out using the AHP method, with a scale of 1-9. The results of the weighting are then subjected to a consistency test to assess the extent to which the level of inconsistency is still acceptable. This measure uses the Consistency Ratio (CR) value, which must be less than 0.1 (10%) to be considered consistent.

$$IC = (\lambda \max - n) / (n - 1), \lambda \max = \Sigma \lambda / n \quad (1)$$

$$IR = [1.98 \times (n - 2)] / n \quad (2)$$

$$CR = IK / IA \quad (3)$$

Mapping of HKm management options is carried out by overlaying the suitability classes of management options (suitable and very suitable) and deforestation vulnerability zones (low, medium, high) within each management space (protection and utilization).

2.5 Erosion rate analysis for community forestry management options

Erosion rates are an indirect indicator of forest pressure and environmental degradation. Therefore, a scenario analysis using erosion rates was conducted to determine which community forest management options could reduce erosion. Erosion rates were predicted using the Universal Soil Loss Equation (USLE) method [9] with the following equation:

$$A = R \times K \times Ls \times Cp \quad (1)$$

Description:

A = annual soil loss (tons/ha/year)

R = rainfall erosivity factor

K = soil erodibility factor

L = field slope length

s = field slope factor

C = cover management factor

p = conservation practice management factor

3 Results and discussion

3.1 Community forestry management options

HKm management options are differentiated based on management areas and level of vulnerability to deforestation, as presented in Tables 2 and 3. In zones with high deforestation vulnerability, land use is prioritized with a primary focus on conservation efforts by

increasing forest cover and limiting forest management that has the potential to open new land. Meanwhile, in zones with low and medium deforestation vulnerability, land use is prioritized with a primary focus on economic improvement by maximizing the potential of forest products that can be developed in the area.

Table 2. HKm management options in protection areas.

Area	Option	Sub-option
Coastal	1. Utilization of areas (Production Forests)	A. Agrosilvopasture at low and medium deforestation vulnerability B. Silvopasture at high deforestation vulnerability
	2. Non-timber Forest Product (NTFP) collection	A. Forest Multipurpose Tree Species (MPTS) with honey at high deforestation vulnerability B. Forest MPTS with under-stand cropping system (PLDT) agricultural MPTS
	3. Utilization of environmental services	A. Riverbanks for riparian areas B. Coastal borders for tourism with casuarina trees
Mountains	2. NTFP collection	A. Forest MPTS with honey at high deforestation vulnerability B. Forest MPTS with under-stand cropping system (PLDT) agricultural MPTS
	3. Utilization of environmental services	A. Riverbanks for riparian

Table 3. HKm management options in utilization areas.

Area	Option	Sub-option
Coastal	1. Utilization of areas	A. Agrosilvopasture at low and medium deforestation vulnerability B. Silvopasture at high deforestation vulnerability C. Silvofishery on gentle slopes (0-8%) and low and medium deforestation vulnerability
	2. Collection and utilization of NTFP	A. Forest MPTS with honey on high deforestation vulnerability and gentle slopes (0-8%) B. Forest MPTS with PLDT agricultural MPTS on low and medium deforestation vulnerability C. Forest MPTS on high deforestation vulnerability D. Food diversification for national food security on gentle slopes (0-8%) (Production Forests)
	3. Utilization of environmental services	C. Mangrove ecosystem as blue carbon absorption and storage and ecotourism potential
	4. Collection and utilization of Timber Forest Products (TFP) (Production Forests)	A. Forest MPTS with agricultural MPTS at high deforestation vulnerability B. Forest timber with forest MPTS at low and medium deforestation vulnerability
Mountains	1. Utilization of areas	A. Agrosilvopasture at low and medium deforestation vulnerability B. Silvopasture at high deforestation vulnerability
	2. Utilization of NTFP	A. Forest MPTS with honey at high deforestation vulnerability and gentle slopes (0-8%) B. Forest MPTS with PLDT and agricultural MPTS at low and medium deforestation vulnerability C. Forest MPTS on high deforestation vulnerability
	3. Utilization of environmental services	D. Elevations > 1900 masl as ecotourism areas, such as trekking, birdwatching, and biodiversity exploration

3.2 Spatial model of hkm management options

The spatial model of HKm management options using the Analytical Hierarchy Process (AHP) weighting method produces weights for each criterion and indicator in both the protection and utilization areas, as presented in Tables 4 and 5. The weight values for each criterion and indicator determine their contribution to the suitability of HKm management options. The higher the weight value, the greater its influence on determining the suitability of HKm management options.

Table 4. Weighting of criteria and indicators for protection areas.

Criteria and Indicators	District		
	Ngantang	Singosari	Sumbermanjing Wetan
Macroweight			
Environment	0,44	0,26	0,39
Social	0,55	0,74	0,61
Environment microweight			
Slope	0,47	0,43	0,55
Elevation	0,21	0,21	0,21
Soil type	0,15	0,14	0,11
Erosion rate	0,12	0,11	0,07
Land use	0,05	0,05	0,05
Social microweight			
Distance from road	0,46	0,54	0,49
Distance from river	0,26	0,24	0,24
Distance from settlements	0,16	0,11	0,12
Population density	-	-	0,07
Deforestation vulnerability	0,10	0,07	0,06

Table 5. Weighting of criteria and indicators for utilization areas.

Criteria and Indicators	District		
	Ngantang	Singosari	Sumbermanjing Wetan
Macroweight			
Environment	0,85	0,86	0,84
Social	0,15	0,14	0,16
Environment microweight			
Slope	0,49	0,48	0,56
Elevation	0,19	0,18	0,19
Soil type	0,17	0,18	0,14
Erosion rate	0,11	0,12	0,07
Land use	0,04	0,05	0,05
Social microweight			
Distance from road	0,36	0,48	0,44
Distance from river	0,31	0,34	0,33
Distance from settlements	0,24	0,13	0,13
Population density	-	-	0,06
Deforestation vulnerability	0,09	0,05	0,05

The weighting results in Table 4 indicate that social criteria are the most influential factor in determining the suitability of management options in protection areas, while Table 5 shows that environmental criteria are the most influential factor in determining the suitability of management options in utilization areas. This is because utilization areas are optimized for higher forest productivity than protection areas, which focus on area protection. Therefore,

environmental criteria, including indicators such as slope, elevation, soil type, erosion level, and land use type, are the main factors in determining the suitability of management options.

Table 6. Consistency Ratio (CR) value.

District	Management Area	
	Protection	Utilization
Environment criteria		
Ngantang	0,09	0,10
Singosari	0,10	0,09
Sumbermanjing Wetan	0,09	0,09
Social criteria		
Ngantang	0,10	0,10
Singosari	0,10	0,10
Sumbermanjing Wetan	0,09	0,09

Table 6 presents the CR values for management areas (protection and utilization) across the selected districts. The results show that all CR values are consistently within the threshold of $CR \leq 0,10$. These results indicate that the pairwise comparisons from expert judgment exhibit a high degree of logical coherence. Therefore, the priority weights obtained for building HKm management option models in Ngantang, Singosari, and Sumbermanjing Wetan can be used with confidence.

3.3 Mapping of community forestry management options

3.3.1 Protection area

Protection areas are management areas designed to maintain forests' ecological functions. The primary focus of protection areas is to protect natural resources, maintain vegetation cover, and minimize disaster risk. Therefore, protection areas are oriented towards conserving forests and land use that does not damage the primary functions of forests. The results of mapping HKm management options in protection areas are presented in Figure 3.

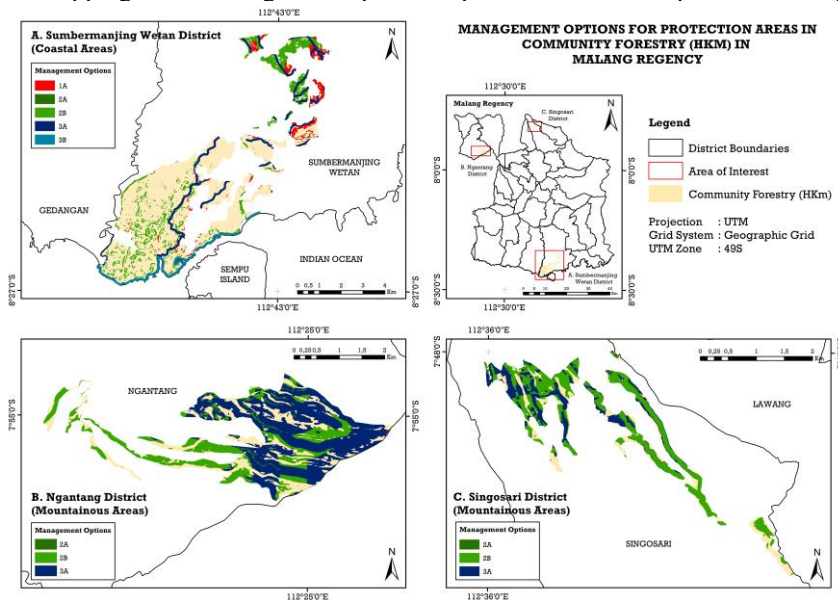


Fig. 3. HKm management options in protection areas.

Table 7. HKm management options in protection areas.

Option Code	Management Options	District			Total Areas (ha)
		Ngantang	Singosari	Sumbermanjing Wetan	
1A	Agrosilvopasture	-	-	123,33	123,33
2A	Forest MPTS with honey	1,27	0,01	0,10	1,37
2B	Forest MPTS with PLDT agricultural MPTS	185,27	122,40	471,92	779,60
3A	Riverbanks for riparian areas	341,35	54,40	252,60	648,35
3B	Coastal borders for tourism with casuarina trees	-	-	117,76	117,76

The results of the analysis of the mapping of protection area management options presented in Table 7 show a variety of options. There are three HKm management options in Ngantang and Singosari Districts: 2A, 2B, and 3A. There are five HKm management options in Sumbermanjing Wetan District: 1A, 2A, 2B, 3A, and 3B. Overall, the HKm management options in the three districts with low and medium deforestation vulnerability are dominated by option 2B, forest MPTS with PLDT MPTS agriculture, covering an area of 779,60 ha, while those with high deforestation vulnerability are dominated by option 2A, forest MPTS with honey, covering an area of 1,37 ha.

3.3.2 Utilization area

Utilization areas are management areas designed to optimize the potential of forest areas. The primary focus of utilization areas is to improve the community's economy through forest resources, whether from TFP, NTFP, or environmental services. The results of mapping HKm management options in protection areas are presented in Figure 4.

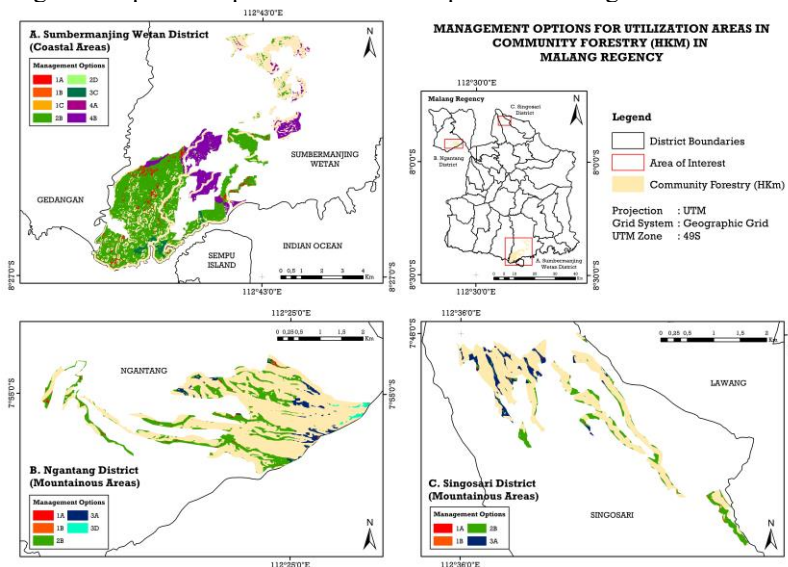


Fig. 4. HKm management options in utilization areas.

Table 8. HKm management options in utilization areas.

Option Code	Management Options	District			Total Areas (ha)
		Ngantang	Singosari	Sumbermanjing Wetan	
1A	Agrosilvopasture	5,58	0,48	72,32	78,38
1B	Silvopasture	0,19	0,94	5,90	7,03
1C	Silvofishery	-	-	5,28	5,28
2B	Forest MPTS with PLDT agricultural MPTS	143,33	32,71	1431,73	1607,78
2D	Food diversification	-	-	13,49	13,49
3A	Riverbanks for riparian	24,24	19,67	-	43,92
3C	Mangrove ecosystem	-	-	59,13	64,37
3D	Ecotourism areas	5,24	-	-	-
4A	Forest MPTS with PLDT agricultural MPTS	-	-	0,54	0,54
4B	Forest timber with forest MPTS	-	-	397,31	397,31

The results of the spatial utilization management options mapping analysis are presented in Table 8, highlighting various options. There are five community forest management options in Ngantang District: 1A, 1B, 2B, 3A, and 3D. There are four community forest management options in Singosari District: 1A, 1B, 2B, and 3A. There are eight community forest management options in Sumbermanjing Wetan District: 1A, 1B, 1C, 2B, 2D, 3C, 4A, and 4B. Overall, the community forest management options in the three districts with low and medium deforestation vulnerability are dominated by option 2B, forest MPTS with PLDT agricultural MPTS, covering 1607,78 ha. While those with high deforestation vulnerability are dominated by option 1B, silvopasture, covering 7,03 ha.

Option 1A, agrosilvopasture in areas with low to medium deforestation vulnerability, aims to optimize livestock productivity by integrating forestry, agriculture, and livestock production. Option 1B, silvopasture in areas with high deforestation vulnerability, aims to protect and restore forest vegetation as an ecological buffer while optimizing livestock productivity without increasing the risk of land degradation. Option 1C, silvofishery on slopes of 0-8% and low and medium deforestation vulnerability, aims to increase community economic productivity by integrating forestry and fisheries activities.

Most members of farmer groups and communities in the Ngantang and Singosari District, located in mountainous areas, are dairy farmers. Meanwhile, most members of farmer groups and communities in the Sumbermanjing Wetan District also own livestock, such as goats and cattle. The development of agrosilvopasture and silvopasture can help create integrated land management between forestry, agriculture, and livestock to increase livestock productivity and support the community's economy. Coastal areas also have the potential to develop silvofishery integrated with mangrove forests. This integrated approach not only supports community economic sustainability but also strengthens ecological functions.

Option 2A, forest MPTS with honey at high deforestation risk and slopes of 0-8%, focuses on protection efforts while considering potential economic value without creating additional pressure on forest land. Option 2B, forest MPTS with PLDT agricultural MPTS at low and medium deforestation risk, aims to maintain forest vegetation cover while increasing economic value through NTFP commodities. Option 2C, forest MPTS at high deforestation risk, aims to strengthen vegetation cover and increase environmental carrying capacity by considering biophysical conditions, economic potential, and the sustainability of forest ecological functions. Option 2D, food crop development commodities at slopes of 0-8% specifically in production forests, aims to support Indonesia's food diversification program to strengthen national food security.

Forest MPTS developed in the HKm of Malang Regency includes avocado and durian. These crops have economic potential through the utilization of non-timber forest products (NTFPs) while simultaneously strengthening forest vegetation cover. Avocado and durian are long-term productive crops that produce fruit with high market value [10, 11]. Agricultural MPTS developed include cocoa, cloves, coffee, citrus, sugar palm, and coconut. These crops support community income diversification, with harvests that can increase medium-term income. Integrating forest MPTS with agricultural MPTS is an investment for forest farmers to achieve a more stable income through a combination of medium-term income streams. Furthermore, a food diversification program for national food security through the forestry sector can be developed in production forest areas, with various agricultural crops such as rice, corn, and tubers.

Option 3A, riverbanks for riparian areas, aims to strengthen the protective function of riverbanks against erosion and sedimentation, and maintain water sources. Option 3B, coastal borders for tourism with casuarina trees, aims to provide natural protection against abrasion, strengthen coastal ecosystems, and increase the economic income of coastal communities through tourism. Option 3C, mangroves with carbon sequestration, ecotourism potential, and silvofishery development, focuses on integrated mangrove ecosystem management that combines ecological, economic, and social functions.

A farmer group in Ngantang District, GAPOKTANHUT Sumber Urip, is developing a drinking water business while preserving water sources through a local wisdom approach, deeming the water source area sacred. This activity focuses not only on using water sources as raw materials for drinking water production, but also on preserving community culture that maintains a balance between their use and protection. These water-source protection efforts can also support the sustainability of irrigation systems for plantations and agriculture, as well as water supply for settlements in mountainous and coastal areas.

Coastal areas have the potential to develop community economies through coastal ecotourism attractions, such as the CMC Tiga Warna ecotourism program run by KTH Bhakti Alam Lestari. Ecologically, mangrove forests can maintain soil stability, improve water quality, and provide natural habitats for various aquatic biota [12, 13]. Furthermore, mangrove forests play a crucial role in absorbing and storing blue carbon, contributing to climate change mitigation efforts [14]. Mangrove forests can also be integrated with silvofishery to support the development of option 1C. However, the development of casuarina vegetation in coastal areas is also crucial due to its crucial role in restoring ecological functions as a buffer and natural filter against wind erosion, contributing to agricultural stability, reducing the risk of crop failure, and increasing plant disease incidence due to high salinity in coastal areas [15]. This system not only maintains the balance of coastal ecosystems but also increases the economic resilience through diversified income sources.

Option 4A, forest MPTS with agricultural MPTS in production forests with high deforestation vulnerability, emphasizes the protection of areas with high deforestation vulnerability in production forests through the development of forest MPTS and agricultural MPTS without any efforts to utilize and collect TFP, but still possessing economic potential through the utilization and collection of NTFPs. Option 4B, forest timber with PLDT agricultural MPTS in production forests with low and medium deforestation vulnerability, emphasizes sustainable production forest management through forest timber commodities that integrate timber crops with agricultural MPTS.

Forest timber commodities developed in the coastal HKm production forest in Sumbermanjing Wetan District include sengon and mahogany. Forest timber in production forests serves to utilize and collect TFP and maintain the sustainability of forest production functions, while also serving as a long-term investment for forest farmers. Meanwhile, forest and agricultural MPTS plantations developed in production forests serve as medium-term investments. These efforts aim to ensure that farmers are not solely dependent on TFP

potential, which has a multi-year harvest rotation, but also have other medium-term income sources through the potential of NTFPs from forest MPTS and agricultural MPTS.

3.4 Erosion rate analysis for community forest management options

Selected management options are analyzed based on erosion rates to determine their potential for erosion reduction. This analysis is conducted by comparing erosion rates before and after implementation of the management options. The result of erosion value before and after implementation of management option using USLE method are presented in Table 9.

Table 9. Erosion values before and after implementation of management options.

District	R	K	Ls	Cp		A	
				Before	After	Before	After
Protection Area							
Ngantang	263,21	0,22	5,02	0,22	0,02	60,67	10,11
Singosari	225,57	0,10	5,65	0,12	0,00	16,08	0,16
Sumbermanjing Wetan	225,57	0,23	3,86	0,19	0,00	33,52	0,23
Total						110,27	10,49
Utilization Area							
Ngantang	259,371	0,223	9,25	0,27	0,00	134,81	0,62
Singosari	225,57	0,10	8,53	0,25	0,00	47,94	0,19
Sumbermanjing Wetan	225,57	0,23	8,32	0,14	0,12	52,71	34,33
Total						235,46	35,14

A = annual soil loss (tons/ha/year), R = rainfall erosivity factor, K = soil erodibility factor, L = field slope length, s = field slope factor, C = cover management factor, p = conservation practice management factor

Land use is used as a reference factor to determine the influence of existing land conditions and land conditions when the selected management option is implemented. Based on the results of the erosion value calculation in Table 9, the erosion value after implementation is lower than the pre-implementation value for the selected management option. Erosion levels are categorized into 5 classes, namely very low (<15 tons/ha/year), low (15-60 tons/ha/year), medium (60-180 tons/ha/year), high (180-480 tons/ha/year), and very high (>480 tons/ha/year). The erosion value after implementation of the protection area was categorized as very low, while that under existing land conditions was classified as moderate. The erosion value after implementation in the utilization area was categorized as low, while the erosion value under existing land conditions was categorized as high. These findings indicate that the selected HKm management option, if implemented in both protection and utilization areas, could potentially reduce erosion.

4 Conclusion

The results of this study show that the selected HKm management options in the protection and utilization areas in the 3 districts differ. Based on the level of deforestation vulnerability, in the low and medium vulnerability areas of the 3 sub-districts, the selected HKm management options are dominated by option 2B (forest MPTS with PLDT agricultural MPTS) in the protection area of 779,60 ha and the utilization area of 1607,78 ha. Meanwhile, in the high deforestation vulnerability areas, the selected management options in the 3 sub-districts in the protection area are dominated by option 2A (forest MPTS with honey) in the area of 1,37 ha and by option 1B (silvopasture) in the utilization area of 7,03 ha. The results of the erosion level analysis indicate that the selected management options, if implemented, can reduce erosion relative to existing land conditions, making them feasible.

This activity is supported by the Directorate General of Research and Development of the Ministry of Higher Education, Science, and Technology in accordance with the Research Program Implementation Contract for the 2025 Fiscal Year, Number: 006/C3/DT.05.00/PL/2025.

References

1. L.J.R. Nunes, C.I.R. Meireles, C.J.P. Gomes, NMCA Riberio, Forest contribution to climate change mitigation: Management oriented to carbon capture and storage. *Climate*. **8**, 21 (2020).
2. R.K. Dewi, P. Wijayanti, Nature-Based solutions for landslide risk reduction: A critical review of academic literature. *IOP Conference Series: Earth and Environmental Science*. **1180**, 012030 (2023).
3. M.M. Melani, W. Andayani, L.R.W. Faida, A. Maryudi, Ecotourism in Sebangau National Park: An avenue to enhance local community livelihoods while protecting the ecosystem. *IOP Conference Series: Earth and Environmental Science*. **399**, 012112 (2019).
4. H. Gunawan, I. Yeny, E. Karlina, *et al.*, Integrating Social Forestry and Biodiversity Conservation in Indonesia. *Forests*. **13**, 12 (2022).
5. N.D. Tien, T.N.L. Duyen, N.T.T. Huyen, *et al.*, Willingness of payment for forest environmental services: a systematic literature review for determinants. **29**, 5 (2024).
6. R. Virtriana, A. Riqqi, T.S. Anggraini, *et al.*, Development of spatial model for food security prediction using remote sensing data in West Java, Indonesia. *ISPRS Int. J. Geo-Inf*. **11**, 5 (2022).
7. A.N. Ikhsan, D.S. Hadmoko, P. Widayani, Spatial modeling of forest and land fire susceptibility using the information value method in Kotawaringin Barat Regency, Indonesia. *Fire*. **6**, 4 (2023).
8. T.L. Saaty, Decision making with the Analytic Hierarchy Process. *Int. J. Serv. Sci*. **1**, 1 (2008).
9. W.H. Wischmeier, D.D. Smith, *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning* (Department of Agriculture, United States, 1978).
10. FAO, *Adapting to climate change in the tropical fruit industry: a technical guide for avocadoproducers and exporters* (FAO, Rome, 2024).
11. N.A.W.A. Ali, Q.R. Wong, B.C. Tan, W.S. Lum, P. Mazumdar, Unleashing the potential of durian: challenges, opportunities, and the way forward. *J. Appl. Fruit. Sci*. **67**, 3 (2025).
12. Rahman, F.F. Lokollo, G.D. Manuputty, R.D. Hukubun, Krisye, Maryono, M. Wawo, Y. Wardianto, A review on the biodiversity and conservation of mangrove ecosystems in Indonesia. *Biodiv. Conserv*. **33**, 3 (2022).
13. T.S. Nam, P.T. Ha Nhung, D.T. Danh, *et al.*, Effects of mangrove age on water quality and deposit sediment layer in integrated mangrove-shrimp farming systems: a case study in Mekong Delta, Vietnam. *Ocean Coast. Manag*. **267**, 107734 (2025).
14. D.M. Alongi, Impacts of climate change on blue carbon stocks and fluxes in mangrove forests. *Forests*. **13**, 2 (2022).
15. S.H. Jeong, S.H. Lee, Effects of windbreak Forest according to tree species and planting methods based on wind tunnel experiments. *For. Sci. Technol*. **16**, 4 (2020).