

GIS-based land suitability mapping for agroforestry development in Gunung Mas, Central Kalimantan, Indonesia

YAYAN HADIYAN¹, ANDY BHERMANA^{2,✉}, MUDJI SUSANTO^{3,✉✉}, ALIN FITHOR⁴

¹Research Center for Ecology, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor 16911, West Java, Indonesia

²Research Center for Food Crops, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor 16911, West Java, Indonesia. Tel.: +62-8110646799, ✉email: andy008@brin.go.id

³Research Center for Applied Botany, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor 16911, West Java, Indonesia. Tel.: +62-81119333605, ✉✉email: mudj003@brin.go.id

⁴Research Center for Hydrodynamic Technology, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor 16911, West Java, Indonesia

Manuscript received: 8 May 2025. Revision accepted: 4 March 2026.

Abstract. Hadiyan Y, Bhermana A, Susanto M, Fithor A. 2026. GIS-based land suitability mapping for agroforestry development in Gunung Mas, Central Kalimantan, Indonesia. *Asian J For* 10 (1): r100109. <https://doi.org/10.13057/asianjfor/r100109>. The expansion of agricultural land to support food security in Indonesia often leads to forest conversion, resulting in deforestation and land degradation. This study proposes agroforestry as a sustainable land-use alternative that integrates food crops with tree-based systems within forested landscapes. We developed a spatial planning framework to identify and allocate suitable agroforestry areas in Gunung Mas District, Central Kalimantan, Indonesia, using land resource assessments and GIS-based analysis. Slope classes were derived from a 30-m digital elevation model and integrated with land unit data to support planning at a 1:50,000 scale. Land suitability was then determined by matching specific land characteristics with crop growth requirements. The results show that agroforestry is primarily feasible on sloping lands within the 8-14% and 15-24% classes, covering a total of 202,874 hectares, or 18.71% of the district. Unlike monoculture systems, these areas were identified based on their capacity to maintain forest cover while remaining productive for food crops. These findings provide geospatial evidence to support location-specific land-use planning and policy-making. By utilizing this data, local authorities can better manage sustainable landscapes, ensuring that agricultural development does not come at the expense of forest conservation in Central Kalimantan.

Keywords: Agroforestry, integrated, planning, spatial, sustainability

INTRODUCTION

Agriculture development is among the primary drivers of land cover changes, some of which leading to deforestation and land degradation. The expansion stimulates tropical deforestation and land-use change globally which reached 6.4-8.8 million ha (Gibbs et al. 2010; FAO 2021; Pendrill et al. 2022). Both land cover and land use changes involving the conversion of forests into agricultural areas have become a significant pattern of land transformation in South Asia, including Indonesia (Appelt et al. 2022). In Indonesia, forest destruction has been occurring since the 1990s (FAO 2001), including peatlands conversion, which declined by approximately 34.90% from 2005 to 2021 (Hadiyan et al. 2022). For oil palm plantations, this crop was the largest single driver of deforestation over 2001-2016, resulting in 23% of deforestation nationwide (Austin et al. 2019)

Land use conversion is one of the contemporary problems in Indonesia as it leads to the loss of agricultural lands. Large extent of agricultural lands, especially in Java Island, have been converted to other uses, such as human settlements, road networks and industrial complexes. If this trend continues, the reduction of agricultural lands will have a major effect on food security (Ivanka et al. 2024). To resolve such problem, limited choices are available, one

of which is by converting forest for agricultural expansion particularly in regions outside Java including Kalimantan.

The Indonesian government launches the land extension program, which includes expanding agricultural land, to improve community welfare and to accelerate the development of local and national economy in the agricultural sector (Ilham et al. 2022). The strong emphasis in agriculture is because this sector is still considered as a key sector in accelerating economic development at the national and regional levels (Bhermana et al. 2024). In addition, agricultural expansion is intended to safeguard food security of the country to balance the growing population, increasing consumption and improving life quality. However, this strategy may also have negative environmental impacts on biodiversity, hydrology, biochemical processes, land degradation, and socioeconomic outcomes (van Vliet et al. 2016).

Since forest conversion into agricultural land can cause long-term ecological imbalance, agroforestry is promoted as sustainable land use systems. This system integrates woody shrubs, trees, and annual crops which can deliver win-win solutions by providing food security as well as ecological sustainability (Pendrill et al. 2022; Roy et al. 2025). The government also encourage community to implement agroforestry as a strategy to mitigate natural disasters, such as landslides and erosion, and the depletion

of biological resources (Susanto et al. 2024). Many parts of Indonesia have adopted agroforestry systems (Tropenbos 2023) as a form of integrated natural resource management (Pais et al. 2024). Such policy is strengthened by the issuance of Government Regulation Number 26/2020 and 23/2021 which provides a basis for agroforestry as a form of forest management that integrate food crop-forest systems as part of agricultural land expansion to support main program of food security.

Some argue that land conversion for particular purposes is unavoidable in response to political dynamics, economic development, and population growth (Dohong et al. 2017). However, before converting forest into agricultural lands, prudent planning is paramount. To guarantee the sustainability of land use and soils, opening forest for agricultural practice requires integrative spatial planning principle that addresses land allocation (González-Sánchez et al. 2016; Bhermana et al. 2021). The strength of the integrative spatial planning is its capacity to strategically envisage land use in a manner that strikes a balance between social justice, economic productivity, and environmental sustainability.

Proper land use management should be developed through spatial land use planning and design with suitable land management to achieve the sustainability principle. The planning will help protect natural resources over time and maintain soil fertility and productivity for agricultural production. This suggests that land resources should be planned according to their appropriateness and capacity for both forest and agricultural systems. In the face of land use changes for agricultural development, agroforestry system, which incorporates agriculture as a farming practice into forest environment, can be seen as a strategy and method rooted in nature and sustainability (Gassner and Dobie 2022; Carvalho et al. 2024).

Gunung Mas District is an upland area with slopping lands and mainly covered by forest where the agricultural sector significantly supports local livelihoods and contributes to the Gross Regional Domestic Product (GRDP) (BPS-Statistics of Gunung Mas District 2024). The sector produces economic value and provides essential food commodities that support regional food security. This corresponds to Indonesia's national food self-sufficiency initiative, which emphasizes enhancing domestic agricultural output, fostering rural economic growth, and promoting sustainable land management. In environmentally sensitive settings, agroforestry systems that combine trees with food crops provide a strategic method to improve agricultural productivity while promoting forest conservation.

This study was then aimed to spatially allocate areas for agroforestry in Gunung Mas District, Central Kalimantan Province, Indonesia. In this study, spatial planning is combined with government perspectives to achieve development objectives at the regional and district levels (Yudono 2018). The results of this study are expected to provide the concept of agricultural land use planning that integrate agriculture as a farming practice within forest environment.

MATERIALS AND METHODS

Study area

The selected study area that represents uplands and sloping lands was in Gunung Mas District, Central Kalimantan Province, Indonesia. The total area is 1,084,104 hectares and geographical position between 113° 00' 46.55" E to 114° 01' 59.98" E and 00° 17' 7.51" S to 01° 39' 46.64" S (Figure 1).

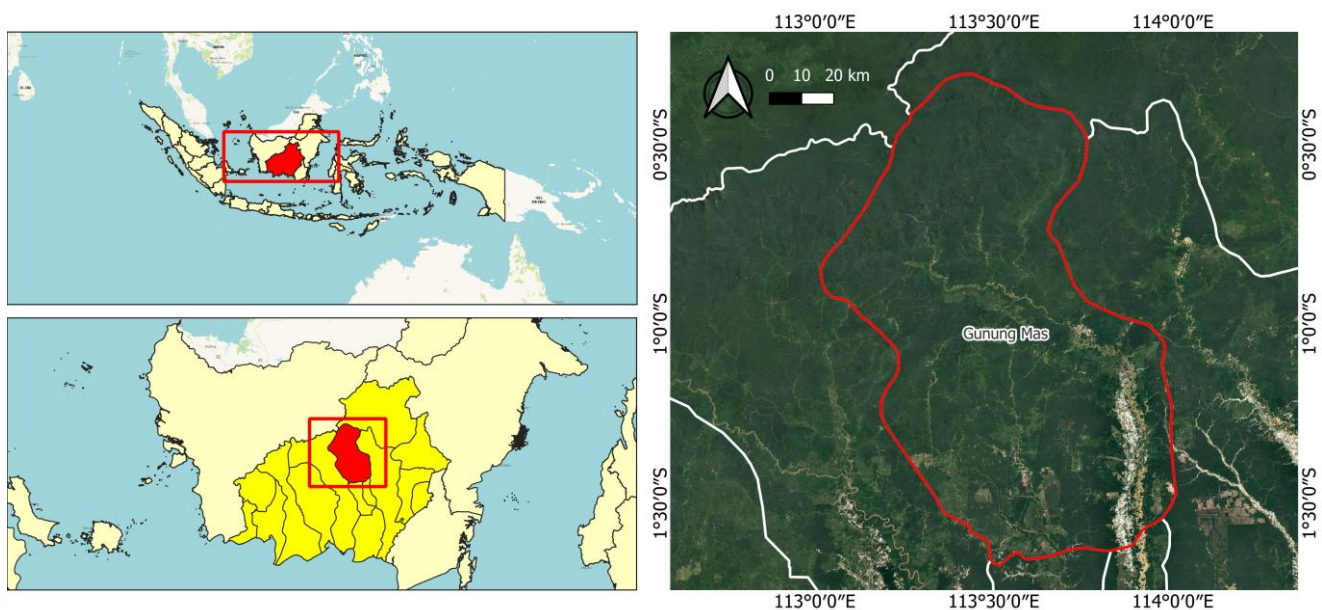


Figure 1. The maps showing the study location in Gunung Mas District, Central Kalimantan, Indonesia

The resulting data was then integrated into each land unit to provide information on land characteristics for further analysis using land evaluation procedures to determine land suitability for agricultural development areas. The matching process between land characteristics and crop growth requirements was used to establish land suitability for arable land suitable for food crops. The result of land suitability evaluation was then integrated within the GIS environment for further spatial analysis using ArcGIS.

RESULTS AND DISCUSSION

Environmental characteristics of the study area

Gunung Mas District, with a total area of 1,084,104 hectares, is administratively located in the northern part of Central Kalimantan Province despite geographically it is situated in the center of Kalimantan Island (Figure 1). This region is mainly dominated by upland areas with topography from hilly to mountainous (Amelia et al. 2016; Bhermana et al. 2021). The dominant soil orders include Ultisols (Tropudults), Inceptisols (Dystropepts, Tropaquepts), and Entisols (Tropopsamments and Ustipsamments) (Soil Survey Staff 2022). In sloping areas, these soil types are susceptible and are prone to erosion (Amelia et al. 2016).

This region has a tropical rainforest climate according to the Köppen-Geiger system. The climate condition is characterized by high precipitation, consistent temperature and daylight duration, and high ultraviolet index (Amelia et al. 2016; Andini et al. 2023). According to Oldeman's climate system criteria, this region is dominated by agroclimatic zone A, with more than nine consecutive wet

months and annual rainfall of 2500-3500 mm/year. Such climatic characteristics are suitable for food crop within agroecosystem (Susanti et al. 2021).

By the end of 2024, the result of Landsat imagery interpretation showed that the dominant land covers are forest and shrub, covered almost 1,058,127 hectares or 97.60% of the total area. Further spatial analysis showed that the remaining areas utilized for agriculture and human settlement are only 25,977 hectares (2.40%). Agricultural lands are mainly found in adjacent to human settlement located on riverbanks and scattered (Figure 3). This result suggests that the land is still widely available, especially for agricultural purposes. Appropriate land management, however, should be implemented to preserve the agroecosystem because this region has several important limiting factors that should be taken into account when opening the land for agriculture. The main limiting factor that should be considered involves topographical conditions dominated by sloping lands, which are prone to erosion, leading to land degradation.

Landform analysis

Physical characteristics of the land surface that characterize notable landforms were evaluated in order to comprehend the topography generally and perform a basic analysis to classify the slopes using DEM. The study area has elevation of 19 to 1,896 meters above sea level, with mountainous areas, hilly plains, moderately steep hills, and undulating plains with broad valleys. Area with the lowest elevation is in the southern part, especially in valleys located along the main river, while the highest location is in the northern parts of the study area (Figure 4).

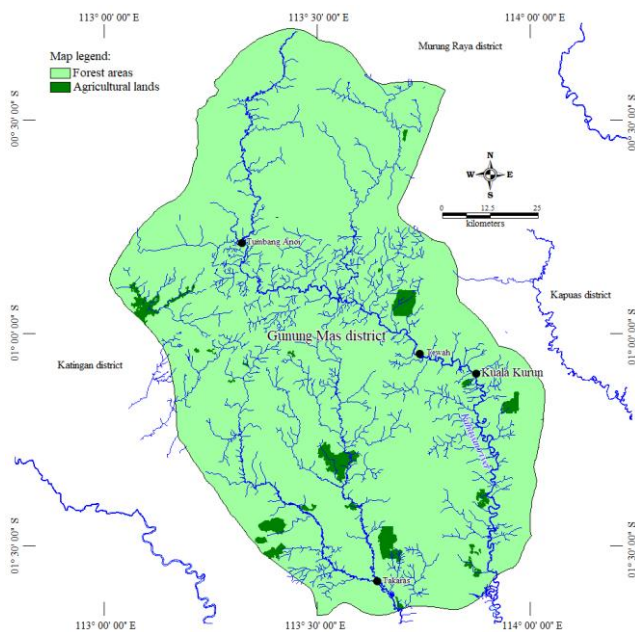


Figure 3. Land cover type in Gunung Mas District, Central Kalimantan, Indonesia

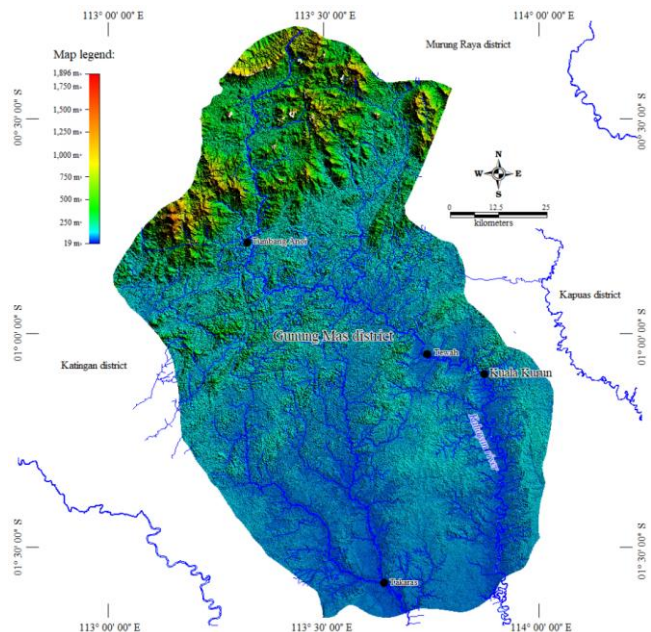


Figure 4. Elevation and topography of Gunung Mas District, Central Kalimantan, Indonesia

Slope is a crucial component of land evaluation as it acts as limiting factor for agriculture. The slope in Gunung Mas District can be classified into six classes, i.e., <3%; 3-7%; 8-14%; 15-24%; 25-40%; and >40% as presented in Table 1 and Figure 5. Slope of less than 15% is the most suitable for farming to make soil tillage, planting, and harvesting. It is still possible to cultivate on lands with steeper slope classes (15-25%), however, due to their vulnerability to soil erosion, these lands not advised for agricultural usage (Angima et al. 2003; Amelia et al. 2016; ICALRRD 2016; Bhermana et al. 2021). The result of analysis showed that slope class of 3-7% predominates with 58.07% of the entire area and is located in the central and southern regions. Such area can be developed for agriculture. On the other hand, slope class >40% has the smallest portion with only 23,694 hectares or just 2.19% and is located in the northern part which has steeper slopes composed by mountainous regions and hilly plains.

Land use planning for agroforestry

Identifying suitable areas for agroforestry in Gunung Mas requires a multi-criteria approach that goes beyond simple topographic classification. In this study, land suitability was determined by matching the biophysical characteristics of land units—such as soil depth, texture, and drainage—with the physiological requirements of both perennial trees and annual food crops. This "dual-component" matching is essential to ensure the selected land can support deep-rooted trees while providing sufficient topsoil fertility for annual crops like upland rice or maize.

Our spatial analysis identifies the most feasible zones within the undulating and hilly plains, specifically in the 8-14% and 15-24% slope classes, covering 202,874 hectares (18.71% of the district). Geographically, these suitable areas are distributed across the central to northern parts of the district, largely concentrated near the hilly northern regions that remain under forest cover and native vegetation. By overlaying these results with existing land cover data, it is evident that most of these identified areas have not yet been developed for intensive agriculture.

The lack of infrastructure, particularly road networks in these remote northern zones, makes them less ideal for intensive monoculture but highly suitable for less intensive systems like agroforestry. From a management perspective, prioritizing these sloping lands for agroforestry is a strategic move to prevent degradation. In these areas, the tree canopy mitigates the kinetic energy of rainfall while root systems stabilize the soil, allowing for food production on terrain that would otherwise be prone to erosion. This spatial planning framework provides a practical roadmap for local authorities to implement food security policies that are ecologically sound, infrastructure-appropriate, and location-specific, ensuring long-term landscape sustainability in Central Kalimantan.

This study focused on spatial planning to identify suitable area for agroforestry development. Based on previous research and the result of evaluation, hilly

plains with slope classes of 8-25% and undulating plains are among the landform appropriate for agroforestry (Khan et al. 2007; Amelia et al. 2016; ICALRRD 2016; Carvalho et al. 2024; Triwanto et al. 2024). Subsequent analysis revealed that region with slope classes between 8 and 25% are divided into classes 8-14% and 5-24%, which together account for 202,874 hectares, or 18.71% of the overall study area. Areas within these slope classes are recommended for agroforestry as shown in Figures 5 and 6.

Land management

Depending on the land's suitability and capacity, an integrated food crop-forest system can be introduced into an agroforestry setting. The result of land evaluation indicated that several crops, including upland rice, soybeans, and maize, are agricultural commodities of food crops. They can then be used as the primary crop in conjunction with trees. This model can be applied specifically to areas with land conditions such as open critical lands, traditional dryland farming, bushes or shrubs, and other places where local communities engage in farming activities in Gunung Mas District.

The implementation of agroforestry system refers to the regulation issued by the Ministry of Environment and Forestry Number P.105/2018, which concerns the management of agroforestry. The integrated food crops-forest system can be implemented with a composition of 75% of the land as perennial crops, such as trees that have economic value, and the remaining 25% is cultivated with food crops. Various species of tree include *warugunung* (*Hibiscus macrophyllus*), *segon* (*Paraserianthes moluccana*), durian (*Durio zibethinus*), cempedak (*Artocarpus integer*), *payait* (*Xerospermum* sp.), *gandis* (*Garcinia parvifolia*), *tampang* (*Cotylelobium* sp.), *sungkai* (*Peronema canescens*), and *paken* (*Durio kutejensis*). Research on *H. macrophyllus* agroforestry has been conducted by Susanto et al. (2024). Soil symbiosis with *P. moluccana* has been studied by Baskorowati et al. (2024), and interactions between the environment and *Gmelina arborea* have been carried out by Setiadi et al. (2021).

Table 1. Slope classification in Gunung Mas District, Central Kalimantan, Indonesia

Slope class (%)	Landform description	Total areas	
		Hectares	Percentage
<3	Undulating plains/flat	141,231	13.03
3-7	Undulating plains	629,511	58.07
8-14	Undulating plains/hilly plains	84,567	7.80
15-24	Undulating plains/hilly plains	118,307	10.91
25-40	Mountainous areas/hilly plains	86,794	8.01
>40	Mountainous areas/hilly plains	23,694	2.19
Total		1,084,104	100.00

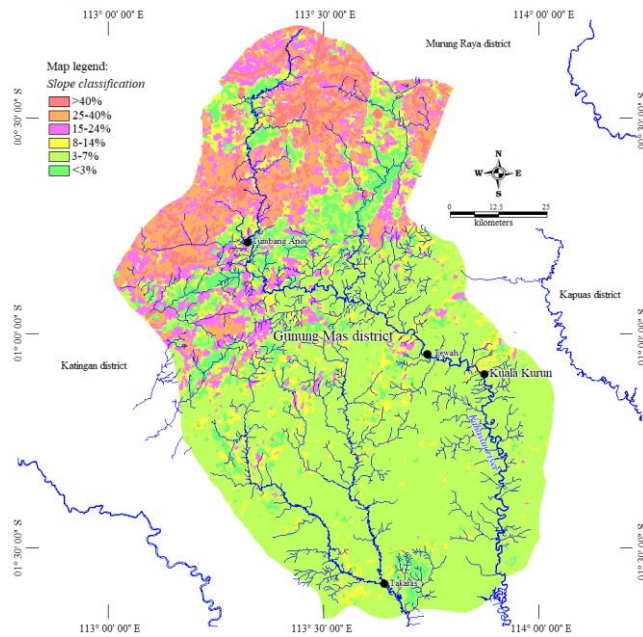


Figure 5. Slope classification in Gunung Mas District, Central Kalimantan, Indonesia

The planting system can use 5×5-meter spacing for trees while food crops can be applied between the trees. However, the planting distance can also be adjusted according to land conditions to manage the shade according to the canopy size. Because the agroforestry system mostly occupies sloping lands with topography conditions involving undulating plains and hilly plains, conservation should then be included in land management, to prevent soil erosion. On sloping lands characterized by hilly terrain features with gentle elevations and rolling slopes (Figure 3), the lands should be cultivated with trees according to contour lines. This is intended to prevent soil surface erosion while stabilizing the slopes. At the open areas in which erosion occurs, the planting system can be arranged with close spacing to obtain a soil-binding effect derived from plant roots (Khan et al. 2007; Forbes et al. 2013; Amelia et al. 2016). The simple intercropping of an integrated food crops-forest system can then be developed according to its scale, depending on the landform, ecological condition, and spatial distribution pattern within a region (Tropenbos 2023).

Although the map identifies suitable areas for agroforestry in Gunung Mas District, several challenges must be considered. The social and institutional context, particularly regarding farmer adoption levels, is often influenced by uncertain land rights, changing cultivation practices, and limited access to technology and markets (Maryudi and Myers 2018; Siscawati 2020), indicating a need for further research. The current practice of shifting cultivation presents notable challenges concerning land tenure in prospective agroforestry areas. Furthermore, insufficient road infrastructure in the proposed areas appears to limit the transportation of inputs and produce, while also obstructing future agroforestry extension or

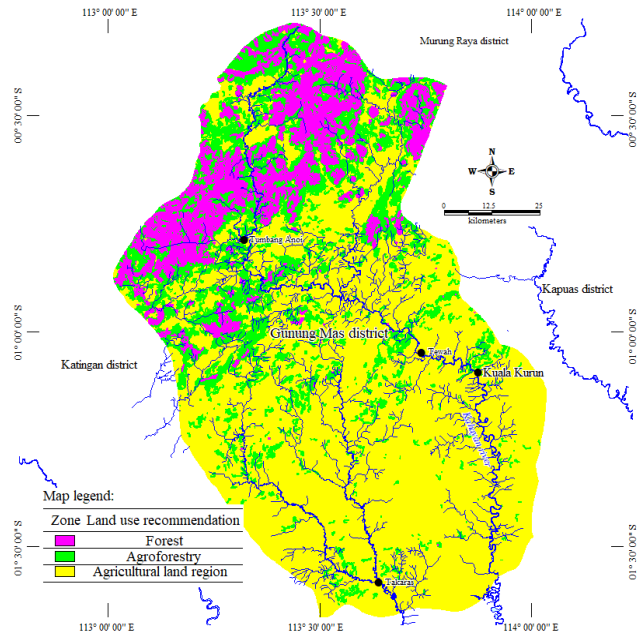


Figure 6. Area recommended for agroforestry in Gunung Mas District, Central Kalimantan, Indonesia

technical assistance. To enable effective implementation, policy instruments such as the Social Forestry scheme (Ministerial Regulation of the Environment and Forestry No. 9/2021) and the REDD+ program can be employed to strengthen community management rights, reduce deforestation, and sustainably increase the economic value of landscapes. The advancement of agroforestry in this region aligns with the Sustainable Development Goals (SDGs), particularly focusing on poverty alleviation (SDG 1), food security (SDG 2), and climate action (SDG 13). Furthermore, it can assist Indonesia in achieving its primary goals for forest landscape restoration (FAO and ICRAF 2019; Wijaya et al. 2020; Ministry of Environment and Forestry 2021).

In conclusion, the integrated food crops-forest system within an agroforestry environment can be implemented based on landform, ecological condition, and geographical setting, in addition to land suitability and capability. In light of spatial policy tools, this geospatial data can therefore be utilized in spatial land use planning and aid in the decision-making process. Geospatial tools, including DEM-based slope analysis and land use overlays, facilitate evidence-based planning. This approach is reinforced by a series of Ministerial Regulations of the Environment and Forestry: No. P.105/2018, which promotes agroforestry on sloped and degraded lands; No. 7/2021, which supports soil conservation in undulating terrain; No. 9/2021, which institutionalizes agroforestry as a legal land-use model within Indonesia's social forestry framework; No. 24/2020, which mandates geospatial mapping for social forestry areas; and No. 4/2023, which refines implementation procedures to strengthen agroforestry integration into community forest management plans. Additionally, Regulation of the Director General of Social Forestry and

Environmental Partnership No. P.02/PKPS/PP/PSKL.0/10/2016 further promotes agroforestry by integrating timber and food crops for ecological and livelihood benefits. Positioned within the broader frameworks of REDD+ and the SDGs, agroforestry contributes to deforestation mitigation, carbon stock enhancement, and improved food and livelihood security, serving as a key instrument in adaptive landscape governance through community-based forest utilization.

REFERENCES

- Abdelrahman MAE, Natarajan A, Hegde R. 2016. Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamaranagar District, Karnataka, India. *Egypt J Remote Sens Space Sci* 19 (1): 125-141. <https://doi.org/10.1016/j.ejrs.2016.02.001>.
- Alkan M, Sefercik UG, Marangoz AM, Karakış S. 2010. Updating objects for topographic map information using high resolution optical images of Zonguldak test field. In: Reuter R (eds.). 30th EARSeL Symposium: Remote Sensing for Science, Education, and Natural and Cultural Heritage. EARSeL, Paris.
- Amelia V, Kusuma Z, Sudarto, Syekhfani. 2016. Geographical distribution analysis of soil erosion risk for land use planning and sustainable agricultural system: a case study of Gunung Mas Regency, Central Kalimantan, Indonesia. *Intl J Agric Innov Res* 5 (3): 365-371.
- Anda M, Sarwani M, Nugroho K. 2012. Soil map information in Indonesia. In: Anda M, Shofiyati R, Nugroho K, Sulaeman Y, Mamat HS (eds.). *Proceeding of International Workshop on Global SoilMap.net Oceania Node 1-10*. Bogor, Indonesia, 7-9 February 2011. [Indonesian]
- Andini P, Nurlika R, Salma Y, Wicaksono A. 2023. Spatial-temporal analysis of land cover change and oil palm expansion in Gunung Mas. *Jurnal Agraria dan Pertanahan* 9 (2): 186-202. <https://doi.org/10.31292/bhumi.v9i2.784>.
- Angima SD, Stott DE, O'Neill MK, Ong CK, Weesies GA. 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agric Ecosyst Environ* 97 (1): 295-308. [https://doi.org/10.1016/S0167-8809\(03\)00011-2](https://doi.org/10.1016/S0167-8809(03)00011-2).
- Appelt JL, Garcia Rojas DC, Verburg PH, van Vliet J. 2022. Socioeconomic outcomes of agricultural land use change in Southeast Asia. *Ambio* 51 (5): 1094-1109. <https://doi.org/10.1007/s13280-022-01712-4>.
- Austin KG, Schwantes A, Gu Y, Kasibhatla PS. 2019. What causes deforestation in Indonesia? *Environ Res Lett* 14 (2): 24007. <https://doi.org/10.1088/1748-9326/aaf6db>.
- Baskorowati L, Wirabuana PYAP, Hendrati RL, Nurtjahjaningsih ILG, Setiadi D, Mashudi M, Susanto M, Pudjiono S, Sumardi S, Santoso Sulistiadi HB, Gunawan G. 2024. Early boosting of genetically improved *Falcataria moluccana* with mycorrhiza for better growth and disease tolerance. *For Sci Technol* 20 (2): 124-135. <https://doi.org/10.1080/21580103.2024.2314709>.
- Bhermana A, Amelia V, Sinaga S. 2024. Integrated spatial concept based on harmony in nature for sustainable agriculture in wetlands of Central Kalimantan. *E3S Web Conf* 595: 4-10. <https://doi.org/10.1051/e3sconf/202459504002>.
- Bhermana A, Suparman S, Tunisa H, Hendro Sunarminto B. 2021. Identification of land resource potential for agricultural landscape planning using land capability evaluation approach and GIS application: A case in Central Kalimantan Province, Indonesia. *Jurnal Lahan Suboptimal: J Suboptimal Lands* 10 (2): 170-177. <https://doi.org/10.36706/jlso.10.2.2021.549>.
- Bhermana A, Susilawati. 2019. Environmentally sound spatial management using conservation and land evaluation approach at sloping lands in humid tropic: A case study of Antang Kalang Sub-district, Central Kalimantan, Indonesia. *Sains Tanah* 16 (1): 76-89. <https://doi.org/10.20961/stjsa.v16i1.24004>.
- BPS-Statistics of Gunung Mas District. 2024. Kabupaten Gunung Mas dalam Angka 2024. BPS-Statistics of Gunung Mas District, Kuala Kurun. <https://gumaskab.bps.go.id>. [Indonesian]
- Carvalho PCF, da Silveira Pontes L, Barro RS, Simões VJLP, Dominschek R, dos Santos Cargnelutti C, Mauricio RM, de São José JFB, Bremm C. 2024. Integrated crop-livestock-forestry systems as a nature-based solution for sustainable agriculture. *Agrofor Syst* 98 (7): 2309-2323. <https://doi.org/10.1007/s10457-024-01057-9>.
- Darmawan M, Sutrisno D, Dewi C, Setiyawan IE. 2021. The integration of regional spatial planning (RTRW) and coastal spatial planning (RZWP3K) for the sustainable coastal area development. *IOP Conf Ser Earth Environ Sci* 750 (1): 012052. <https://doi.org/10.1088/1755-1315/750/1/012052>.
- Dibs H. 2013. Spatial analysis by using ArcGIS. [Research Report]. <https://www.researchgate.net/publication/272436631>.
- Dohong A, Aziz AA, Dargusch P. 2017. A review of the drivers of tropical peatland degradation in South-East Asia. *Land Use Policy* 69: 349-360. <https://doi.org/10.1016/j.landusepol.2017.09.035>.
- Drăguț L, Eisank C. 2012. Automated object-based classification of topography from SRTM data. *Geomorphology* 141-142: 21-33. <https://doi.org/10.1016/j.geomorph.2011.12.001>.
- Food and Agriculture Organization (FAO). 2001. *Global Forest Resources Assessment 2000*. Forest Resources Assessment. <https://www.fao.org>.
- Food and Agriculture Organization (FAO). 2021. COP26: Agricultural Expansion Drives almost 90 Percent of Global Deforestation. <https://www.fao.org>.
- Food and Agriculture Organization, International Centre for Research in Agroforestry (FAO and ICRAF). 2019. *Agroforestry and Tenure. Forestry Working Paper No. 8*. <https://openknowledge.fao.org>.
- Forbes K, Broadhead J, Bischetti GB. 2013. *Forests and Landslides: The Role of Trees and Forests in the Prevention of Landslides and Rehabilitation of Landslide-affected Areas in Asia*. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok.
- Gassner A, Dobie P. 2022. *Agroforestry: A primer. Design and Management Principles for People and The Environment*. CIFOR-ICRAF, Bogor. <https://doi.org/10.5716/cifor-icraf/bk.25114>.
- Gibbs HK, Ruesch AS, Achard F, Clayton MK, Holmgren P, Ramankutty N, Foley JA. 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proc Natl Acad Sci USA* 107 (38): 16732-16737. <https://doi.org/10.1073/pnas.0910275107>.
- González-Sánchez EJ, Kassam A, Basch G, Streit B, Holgado-Cabrera A, Triviño-Tarradas P. 2016. Conservation agriculture and its contribution to the achievement of agri-environmental and economic challenges in Europe. *AIMS Agric Food* 1 (4): 387-408. <https://doi.org/10.3934/agrfood.2016.4.387>.
- Hadiyan Y, Widiyatno, Nurtjahjaningsih I, Na'iem M, Herdyantara B, Isno. 2022. Genetic diversity and structure among four provenances of Gelam (*Melaleuca cajuputi* subsp. cumingiana) and implications for gene conservation and rehabilitation of degraded peat swamp forest in Indonesia. *For Sci Technol* 18 (4): 135-143. <https://doi.org/10.1080/21580103.2022.2115150>.
- Ilham N, Syahyuti, Sudaryanto T, Pasaribu SM, Irawan B, Gunawan E, Azis M, Suharyono S. 2022. Strategy for farmers corporation development to support food estate in Central Kalimantan. *Agro-Socioecon Newsletter* 15 (2): 1-8. <https://psekp.setjen.pertanian.go.id>.
- Indonesian Center for Agricultural Land Resources Research and Development (ICALRRD). 2016. *Technical Guidelines: Land Suitability Assessment for Strategic Agricultural Commodities at Semi Detail Level 1:50,000*. Indonesian Center for Agricultural Land Resources Research and Development, Bogor.
- Ivanka R, Muhammad FA, Dita LA, Simarmata T. 2024. Assessing the current state and future trends of land use conversion: Implications for food security in Indonesia. *IJLSAR* 3 (4): 284-290.
- Khan F, Waliulloh, Naem M, Bhatti A. 2007. Effect of slope steepness and wheat crop on soil, runoff and nutrient losses in eroded land of Malakand Agency, NWFP, Pakistan. *Sarhad J Agric* 23 (1): 101-106.
- Maryudi A, Myers R. 2018. Renting legality: How FLEGT is reinforcing power relations in Indonesian furniture production networks. *Geoforum* 97: 46-53. <https://doi.org/10.1016/j.geoforum.2018.10.008>.
- Ministry of Environment and Forestry. 2021. *Indonesia's FOLU Net Sink 2030: Operational Plan for Achieving Indonesia's Forestry and Land Use Climate Targets*. Ministry of Environment and Forestry, Jakarta. <https://planologi.kehutan.go.id>. [Indonesian]
- Pais CM, Salimath SK, Hegde R, Maheswarappa V, Deepthi DNL, Gooli M. 2024. Agrobiodiversity vis-à-vis agroforestry: Cultivating a sustainable future. *Intl J Res Agron* 7 (3 Suppl.): 176-186. <https://doi.org/10.33545/2618060x.2024.v7.i3sc.428>.

- Pendrill F, Gardner TA, Meyfroidt P et al. 2022. Disentangling the numbers behind agriculture-driven tropical deforestation. *Science* 377 (6611): eabm9267. <https://doi.org/10.1126/science.abm9267>.
- Roy MK, Fort MP, Kanter R, Montagnini F. 2025. Agroforestry: A key land use system for sustainable food production and public health. *Trees For People* 20: 100848. <https://doi.org/10.1016/j.tfp.2025.100848>.
- Setiadi D, Susanto M, Baskorowati L, Mashudi, Pudjiono S. 2021. Genetic variation of *Gmelina arborea* Roxb in Trenggalek, East Java. *IOP Conf Ser Earth Environ Sci* 914 (1): 012014. <https://doi.org/10.1088/1755-1315/914/1/012014>.
- Singh JK, Yadav KK, Gupta N, Kumar V. 2016. Remote sensing and Geographical Information System (GIS) and its application in various fields. In: Sohal R (eds.). *Energy and Environment: Threats and Remedies*. Department of Physics, RJIT.
- Siscawati M. 2020. Gender and forest tenure reform in Indonesia. Center for International Forestry Research (CIFOR), Bogor. <https://doi.org/10.17528/cifor/007572>.
- Soil Survey Staff. 2022. *Keys to Soil Taxonomy*. 13th ed. USDA-NRCS, Washington DC.
- Susanti E, Surmaini E, Pramudia A, Heryani N, Estiningtyas W, Suciantini S, Apriyana Y. 2021. Pemutakhiran peta sumberdaya agroklimat Indonesia untuk mendukung perencanaan pertanian. *Jurnal Tanah dan Iklim* 45 (1): 47-58. <https://doi.org/10.21082/jti.v45n1.2021.47-58>. [Indonesian]
- Susanto M, Baskorowati L, Hendrati RL, Nurtjahjaningsih ILG, Mashudi, Pudjiono S, Setiadi D, Sumardi, Santoso Sulistiadi HB, Fauzan YSA, Achmad B, Hadiyan Y, Haryjanto L. 2024. Growth of indigenous mountainous Indonesian *Hibiscus macrophyllus* in agroforestry system from various age, seed sources and slopes. *For Sci Technol* 20 (3): 300-308. <https://doi.org/10.1080/21580103.2024.2385181>.
- Triwanto J, Syarifuddin A, Aprilia L. 2024. The effect of land slope level on productivity of Pujon Agroforestry. *Agricobis* 7 (2): 89-97. <https://doi.org/10.22219/agricobis.v7i01.32918>.
- Tropenbos. 2023. *Scaling Agroforestry in Indonesia: Opportunities, Challenges and Solution Pathways in Scaling and Mainstreaming Agroforestry in Indonesia*. Tropenbos Indonesia and Tropenbos International, Bogor.
- van Vliet J, Magliocca NR, Büchner B, Cook E, Rey Benayas JM, Ellis EC, Heinemann A, Keys E, Lee TM, Liu J, Mertz O, Meyfroidt P, Moritz M, Poeplau C, Robinson BE, Seppelt R, Seto KC, Verburg PH. 2016. Meta-studies in land use science: Current coverage and prospects. *Ambio* 45 (1): 15-28. <https://doi.org/10.1007/s13280-015-0699-8>.
- Wahyutomo PK, Suprayogi A, Wijaya AP. 2016. Aplikasi sistem informasi geografis berbasis web untuk persebaran kantor pos di Kota Semarang dengan Google Maps API. *Jurnal Geodesi Undip* 5 (3): 70-80. [Indonesian]
- Wijaya A, Austin KG, Shevade VS, Stolle F, Hovani L, Beatrix K, Silva-Chavez GA. 2020. How can Indonesia Achieve its Climate Change Mitigation Goal? An Analysis of Potential Contributions from Forests and Land Use. World Resources Institute, Washington DC.
- Yudono A. 2018. Why do spatial data and information have a significant role in spatial planning process? The investigation of spatial data and information usage in Indonesian spatial planning policies. *Geoplanning: J Geomat Plan* 5 (1): 131-146. <https://doi.org/10.14710/geoplanning.5.1.131-146>.