



Research article

Spatial model of forest area utilization in integration of production forest functions, Central Sulawesi, Indonesia

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Abstract

Importance of the work: The determination of the function of limited and permanent production forests has different land- and climate-limiting factors. Therefore, environmental damage is feared when using integrated production forest areas as stipulated in a Government Regulation of the Republic of Indonesia.

Objectives: To identify models applicable to dryland ecosystems for the utilization of forest areas in the spatial integration of producing good functions.

Materials & Methods: A limited production forest study area covering 500.28 ha was investigated using a descriptive method with a spatial data simulation approach utilizing GIS technology.

Results: The spatial models of forest area utilization in the integration of forest functions were: Model 1 (local protected area); Model 2 (utilization of timber forest products in a natural forest with delayed selective logging); Model 3 (utilization of timber forest products in a natural forest with selective logging); Model 4 (reforestation/plantation forest pattern rehabilitation); and Model 5 (rehabilitation of agroforestry patterns), with areas of 374.48 ha, 74.59 ha, 0.35 ha, 50.11 ha, and 0.75 ha, respectively.

Main finding: The delineation of the five spatial models of forest area utilization in the integration of production forest functions needs to be followed up with testing at the site level.

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Introduction

In Indonesia, after the enactment of Government Regulation of the Republic of Indonesia Number 23 (2021) concerning forestry administration, production areas with the main function of producing products were required to be managed under an integrated utilization system. Before this regulation, there were functions of limited and permanent production forests with the application of different silvicultural regimes in the utilization of timber forest products, such as selective logging, strip cutting, or clear-cutting. Soekotjo (2009) stated that the silvicultural system or regime is also known as the regeneration system, which collects forest products from mature trees.

Sustainable forest management is a complex task because it is faced with increasing demand for timber forest products. On the other hand, developing sustainable forest areas with guaranteed ecosystem sustainability is necessary. Forest resource management aims to meet social, economic, ecological, cultural and spiritual needs (Hou et al., 2019; Banaś et al., 2021).

As regulated in the Minister of Environment and Forestry Number 8 (2021), the use of areas, timber, non-timber forest products and environmental services can be conducted in production forest areas. Utilization of the area can be in the form of activities such as plant cultivation, agroforestry and agrosilvopasture. The utilization of timber forest products in natural forests begins with harvesting followed by planting, with the utilization of products in plantation forests begins with planting followed by harvesting. Soenarno et al. (2019) stated that natural forest management has improved, especially in the efficiency of timber harvesting, which has a positive impact on increasing log production and saving natural forest resources.

The current review aims to provide direction for forest area functions while aligning the interests of effective, efficient and compact management. Assessment of forest area functions is based on criteria and standard values covering topography, soil and vegetation conditions, as well as regional rainfall distribution (Sudarmadji and Hartati, 2018; Akhbar et al., 2022).

Product planning should reflect the character of the environment with a variety of uniqueness and diversity. Sustainable planning is reflected in the process, starting from the exploration stage of the planning vision to the decision-making stage. Furthermore, it prioritizes the interests of conservation

and preservation of natural resources (Poerwoningsih et al., 2016). Forest cover area planning at the catchment scale can be used in management strategies to reduce land use impacts (Garcia et al., 2018).

Geographic Information System (GIS) technology has the capability of multi-criteria-based spatial planning and modeling to support decision-making. The multi-criteria-based decision-making approach is a very complex data usage category but is widely used in site selection analysis and specific problems. These conditions require effective models and analytical techniques to handle the complexity and intensity of data in identifying the best alternative. Multi-criteria-based spatial analysis on changes in forest area designation and function is quite flexible in decision-making (Drobne and Lisec, 2009; Zhang et al., 2012; Rikalović et al., 2013; Fataei et al., 2015). GIS-based multi-criteria decision analysis is a collection of methods and tools for transforming and combining geographic data to obtain decision-making information. Multi-criteria-based spatial analysis on changes in the allocation and function of forest areas is quite flexible in decision-making (Malczewski and Rinner, 2015; Akhbar et al., 2022).

The incorporation of limited productivity forest functions is mandated in Indonesia Government Regulation of the Republic of Indonesia Number 23 (2021), which could lead to erroneous interpretations of silvicultural regimes/systems which will threaten the sustainability of timber forest product production. It is necessary to look for models of approaches to area utilization and harvesting of timber forest products considering the carrying capacity of the physical environment, the climate and forest vegetation cover. This study aimed to identify models for using areas in the spatial integration of production forest functions that are feasible to be applied to dryland forest ecosystems.

Materials and Methods

The study occurred in a limited production forest area of 500.28 ha in the Dolago Tanggunung Forest Management Unit (FMU), Central Sulawesi province, Indonesia. It is located in Toboli Barat and Avolua villages, North Parigi sub-district, Parigi Moutong regency, in the Salubai River Basin at 120°2'9.41"E–120°3'42.17"E and 0°41'44.05"S–0°43'34.86"S. The study was conducted during May–July 2022. A map of the location is provided in Fig. 1.

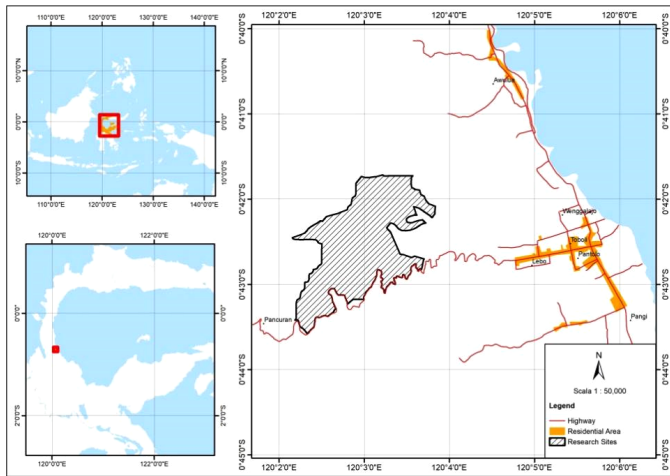


Fig. 1 Location of Dolago Tanggunung Forest Management Unit research site

Work materials and equipment consisted of 1) information on forest area, topography, geology, slope class, soil type, watershed, infrastructure and regional spatial plans; 2) satellite imagery (Landsat-8 imagery dated 2021) for land cover/land use mapping; 3) climatic (annual rainfall and rainy days) and socioeconomic data; 4) GPS unit, digital cameras, tally sheets and stationery; (e) relevant laws and regulations; and 6) Arc-GIS software version 10.4.1 (ESRI; Redlands, CA, USA). The ArcGIS software was used to analyze the spatial factors (Phankamolsil et al., 2021).

Study activities consisted of collecting and processing data, analyzing data and maps, simulating spatial models and compiling reports and layout maps for spatial models of area utilization and forest products. The descriptive method used a spatial data simulation analysis approach with GIS technology for spatial data collection on area utilization and forest products to integrate production based on silvicultural regimes. The study location was selected purposively.

Observations were made on the slope class, soil type, climate, forest vegetation cover, and land use. Interviews and coordination with related agencies were conducted, namely the Dolago Tanggunung KPH Manager. Furthermore, interviews were held related to the motivations and expectations for each planned location.

Making spatial models of areas and forest products on the integration of limited and permanent production forest functions uses spatial data (land criteria: physical, climate, vegetation) and non-spatial data (criteria for natural forest silvicultural regimes for the use of forest products wood). Spatial modeling was carried out through a system simulation process. GIS analysis included

attribute data analysis (tabular), layer overlay (spatial data query), distance analysis, network analysis and non-parametric techniques. Decision analysis on problems in the modeling process was classified into a multi-attribute approach of certainty and uncertainty (Akhbar et al., 2022). Developments in decision-making have led to an increase in GIS capabilities in location analysis. Multi-object and multi-criteria are two procedures that need to be fulfilled in GIS (Rikalovic et al., 2014).

The decision-making process was carried out in Stage I with a location scoring technique to produce the function of the production forest area in the form of the total land scoring value. Stage II used spatial data simulation analysis techniques between the results of land scoring and the type of vegetation cover/potential for timber forest products, the level of vulnerability to landslides and the government's policy to stop granting new permits. The scoring value of forest area land derived from the land and climatic factors was obtained from the result of multiplying and summing both parameters using Equation 1:

$$\Sigma SV_{ff} = (SV_{sc} + SV_{st} + SV_{ri}) \quad (1)$$

where

ΣSV_{ff}	sum of the forest function scores.
SV_{sc}	20 x weight value for each slope class (5 classes)
SV_{st}	weight value 15 x each class of soil type (5 classes)
SV_{ri}	weight value (10) x each class of rain intensity (5 classes)
Slope class	1 = flat (slope <8%) 2 = ramps (slope 8–15%) 3 = rather steep (slope 15–<25%) 4 = steep (slope 25–<45%) 5 = very steep (slope 45% and above)
Soil type class	1 = not sensitive to erosion (alluvial, glei, planosol, gray hydromof) 2 = slighty erosion sensitive (latosol) 3 = less sensitive to erosion (brown forest soil, non-calsic brown, mediteran) 4 = sensitive to erosion (andosol, lateritic, grumusol, podsol, podzolic) 5 = very sensitive to erosion (regosol, litosol, organosol, renzina).

Rainfall intensity class 1 = very low (1–<13.6 mm/rainy day)
 2 = low (13.6–<20.7 mm/rainy day)
 3 = moderate (20.7–<27.7 mm/rainy day)
 4 = height (27.7–<34.8 mm/rainy day)
 5 = very high (≥34.8 mm/rainy day).

Source: Government Regulation of the Republic of Indonesia Number 23 (2021); Akhbar et al. (2022).

The decision-making process used the criteria as shown in Table 1.

Table 1 provides the criteria of the assessment of landslide vulnerability level that was analyzed using the spatial multi-criteria evaluation (SMCE) method with weighted overlay tools in ArcGIS.

The analytical model used to determine the level of landslide vulnerability was an estimation referring to the results of the [Research Center for Research and Development (Puslittanak), 2004] using Equation 2:

$$\Sigma TSVIs = [(0.3 \times rf) + (0.2 \times sf) + (0.2 \times rtf) + (0.2 \times luf) + (0.1 \times stf)] \quad (2)$$

where:

$\Sigma TSVIs$	total score value of landslide vulnerability
rf	rainfall factor
sf	slope factor
rtf	rock type factor
luf	land use factor
stf	soil type factor
Rainfall class (mm/yr) with weight of 30%	(1) very wet: >3,000 mm/yr (score 5) (2) wet: 2,501–3,000 mm/yr (score 4) (3) medium: 2,001–2,500 mm/yr (score 3) (4) dry: 1,501–2,000 mm/yr (score 2) (5) very dry: <1500 mm/yr (score 1)
Slope grade with	(1) very steep: slope 45% and above (score 5) (2) steep: slope 25–<45% (score 4) (3) rather steep: slope 15–<25% (score 3) (4) ramps: slope 8–<15% (score 2) (5) flat; slope <8% (score 1) (slope percentage modified according to research needs)
Rock type class with weight of 20%	(1) volcanic rock (score 3) (2) sedimentary rock (score 2) (3) alluvial rock (score 1).

Table 1 Decision-making matrix for spatial model of area utilization and forest products in integration of production forest functions

Recommendation/ Decision	Existing condition of forest function	Post GR 23/ 2021 status/ function	Location conditions
Utilization of TFP in natural forest by postponed selective logging	LPF	PPF	Land and climate score 150–<175 Natural forest vegetation is covered with a predominance of commercially valuable timber and a trunk diameter of 60 cm (≤10 stems/ha)*. Landslide vulnerability level (medium–very high) Not included in the IMPGNP (LOA) policy.
Utilization of TFP in natural forest based on selective logging	LPF	PPF	Land and climate score 124–<150 The vegetation cover of natural forest with dominance of commercially valuable wood and trunk diameter of 40 cm (>10 stems/ha)*. Landslide vulnerability level (low–moderate) Not included in the IMPGNP (LOA) policy.
Local protected area	LPF	PPF	Field slope class ≥45% and with an altitude of ≥2,000 m above sea level and body of water (lake/river) or included in the IMPGNP policy.
Rehabilitation of plantation forest patterns (reforestation)	LPF	PPF	Land and climate score 150–<175 Land cover is mixed dry land agriculture, dry land agriculture, shrubs; savanna; open ground. Landslide vulnerability level (moderate–very high)
Rehabilitation of agroforestry patterns	LPF	PPF	Land and climate score 124–<150 Land cover is mixed dry land agriculture, dry land agriculture, shrubs; savanna; open ground. Landslide vulnerability level (low–moderate)

GR = Government regulation; LPF = limited production forest; PPF = permanent production forest; IMPGNP = indicative map of postponement of granting new permits; LOA = logged over area; TFP = timber forest products.

* = results of inventory of TFP by BPKH (Forest Area Stabilization Center, Region XVI, Palu (2016)) in KPHP (Production Forest Management Unit) V area of Central Sulawesi (SD = 6.75–7.79).

Land cover/land use class with weight of 20%	<ul style="list-style-type: none"> (1) upland, paddy fields, dry land agriculture, open land, savanna (score 5) (2) shrubs, mixed dry land agriculture (score 4) (3) forest, plantation (score 3) (4) settlements (score 2); ponds, reservoirs, waters (body of water) (score 1). <p>(type of land cover/use modified according to research needs).</p>
Soil type class with score of 10%	<ul style="list-style-type: none"> (1) regosol (score 5) (2) andosol, podzolic including red yellow podzolic (score 4) (3) brown latosol (score 3) (4) yellowish brown latosol association (score 2) (5) alluvial (score 1) <p>(soil type modified according to research needs).</p>

Source: Research Center for Research and Development (Puslittanak, 2004)

The final results were classified based on score analysis using four landslide vulnerability classes: low, moderate, high and very high. Furthermore, class intervals were used to classify the overlay results into levels of landslide vulnerability based on the Sturgess formula: $C_i = (X_t - X_r) / k$, where C_i = class interval, X_t = largest data, X_r = smallest data, k = number of classes, $k = 1 + 3.3 \log n$ and n = amount of data).

Results and Discussion

Physical land, climatic and socio-economic conditions

The area with limited production forest covered 500.28 ha in the West Toboli and Avolua villages, North Parigi sub-district, Parigi Moutong regency, Central Sulawesi province, Indonesia. The forest area in the Salubai River Basin had a moderately steep slopes (slope 15–< 25%, slope 25–< 45% and slope \geq 45%) covering 1.10 ha, 81.57 ha and 417.61 ha, respectively. All areas had sedimentary rock, red, yellow podzolic soil, 953.90 mm/year of rainfall with 251 rainy days and a very low rainfall intensity (3.79 mm/rainy day). This forest area with mountainous and

hilly geomorphology extending from north to south had an altitude of 225–660 m above sea level. The location has good accessibility and is easy to reach by four-wheeled vehicles because it is located on the axis of the Palu-Parigi Highway.

Key components of the socioeconomic conditions around the forest area were: 1) Toboli Barat village had a population of 1,346 people, 341 families, a gender ratio of 106, and a population density of 68 people/km²; 2) Avolua village had a population of 1,154 people, 319 families, a gender ratio of 111 and a population density of 37 people/km². About 65.75% of the population in the villages were farmers, while the others were traders, employed in fishing, general employees, breeders, industrial workers, laborers, transportation workers, entrepreneurs and retirees (BPS Parigi Moutong, 2022).

Forest land scoring

The forest areas with limited production functions covered 500.28 ha, with scores for the forest land of 130, 150 and 170, in the moderately steep, steep, and very steep slope classes, respectively. Score variations were largely determined by the slope class at each location; namely, very steep (score 100), steep (score 80) and rather steep (score 60), while the soil type and rainfall intensity consisted of only one class each, namely erosion sensitive with a red, yellow podzolic soil type (score value 60) and very low rainfall intensity class with a value of 3.79 mm/hr (score 10). The scores of 170, 150, and 130 covered areas of 417.61 ha (83.48%), 81.57 ha (16.30%) and 1.10 ha (0.22%), respectively.

The results showed that consistent with the mandate in Government Regulation of the Republic of Indonesia Number 23 (2021) concerning forest management, the function of limited production was integrated with the permanent production function. Before this regulation, limited production forest was determined with scores of 125–174 and <125 for the respective categories—Government Regulation of the Republic of Indonesia Number 44 (2004) on forestry planning. Therefore, the land score was the main determinant in assessing the suitability of areas in production forests. Akhbar et al. (2022) stated that a scoring technique is needed in determining new forest functions. To achieve the target of efficient and effective change in the allocation of forest areas, the scoring technique was considered as an initial stage in evaluating/assessing changes. The results of the land scoring analysis in production forest areas are presented in Fig. 2.

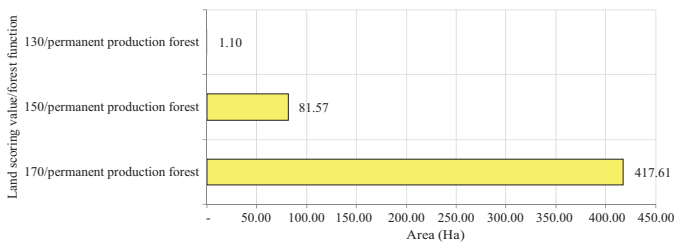


Fig. 2 Graph of land scoring results for production forest areas

Analysis of vegetation cover and land use types

The condition of forest vegetation cover/land use was based on the manual interpretation and analysis results from the satellite imagery (Landsat 8), the 2021 annual records and the results of field checks in May 2022. The type land cover in the function of limited production forest covering 500.28 ha consisted of 1) secondary dry land forest (88.52%); 2) dry land agriculture, shrubs, savanna, open land (10.17%); and 3) waterbody or river (1.31%). Dry land agriculture in production forest areas is managed and used by the community to plant seasonal and annual crops, usually to grow rice, vegetables and fruits (Usup et al., 2021).

The condition of the cover provides an overview of the biophysical and socioeconomic conditions, especially those related to land use activities by communities in forest areas. Biophysical and socioeconomic variables are also the basis for understanding the structure and biodiversity of tropical secondary forests (McClellan et al., 2018).

The area of each type of land cover/land use is provided in Fig. 3.

In the limited production forest area of 500.28 ha, timber forest vegetation was known to the public for species with high commercial value, such as Maraula (*Diospyros macrophylla*), Meranti (*Shorea* sp.), Palapi (*Herriteria* sp.), Nyatoh (*Palaquium* sp.), Rau (*Dracontamelon mangiferum*), Bintangur (*Calophyllum inophyllum*), Matoa (*Pometia pinnata*), Dao (*Dracontamelon dao*), Forest mango (*Mangifera foetida*)

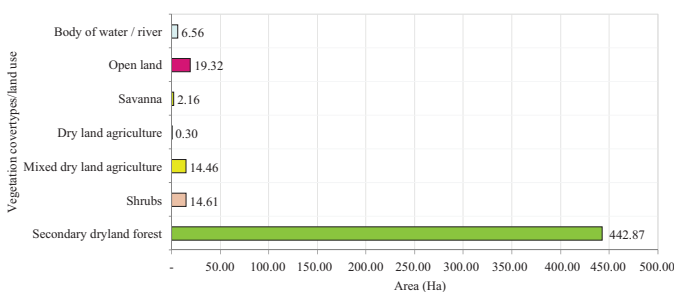


Fig. 3 Graph of vegetation cover/land use types in production forest areas

and Binuang (*Octomeles sumatrana*). Non-timber forest product vegetation types included Rattan (*Calamus* spp.), Bamboo (*Schizostachyum* sp., *Dendrocalamus* sp., *Bambusa* sp. *Gigantochloa* sp.) and Sugar palm (*Arenga pinnata*). Cultivated plants on the community forest land included Cocoa (*Theobroma cacao*), Coffee (*Coffee* sp.) and other cultivated plants.

The potential for timber forest products based on diameter class and commercial stand volume consisted of: 1) secondary dryland forest cover with a trunk diameter class of 60 cm, an average volume of 62.16 m³/ha and stocking of 10 trees/ha; and 2) secondary dryland forest cover with a trunk diameter class of ≥40 cm with an average volume of 34.74 m³/ha and 19 trees/ha (Forest Area Stabilization Center, Region XVI, Palu, 2016)). The potential timber forest products in natural forests consisted of average numbers of commercial wood species of ≤10 trees/ha in the ≥60 cm diameter class and > 10 trees/ha in the ≥40 cm diameter class.

Analysis of landslide vulnerability

Following the analysis of the vulnerability level to landslides as described previously, the following criteria were determined: low (score <1.90); moderate (score 1.90–<2.80); high (score 2.80–<3.70); and very high (score >3.70). The scoring of landslide vulnerability level in the production forest area of 500.28 ha was dominated by the moderate level, with an area of 453.19 ha (90.59%), and the high vulnerability level, with an area of 47.09 ha (9.41%). The results are as shown in Fig. 4.

The vulnerability to landslides in production forest functions in the moderate and high classes resulted from the accumulation of rainfall conditions, slopes, land cover/land use, rock types and soil types. However, landslide hazard can further exacerbated by climatic and meteorological factors, with the overall risk of landslides occurring in a certain area and period that can cause harm to the community (Segoni and Calea, 2021).

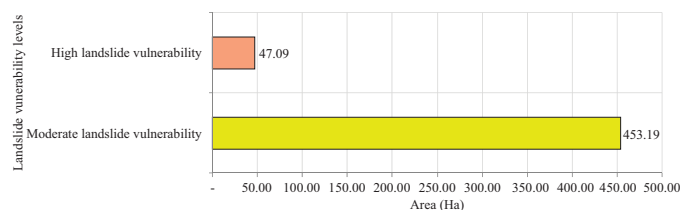


Fig. 4 Graph of scoring for landslide vulnerability levels

Landslide hazard assessment aims to prevent and predict hazardous areas to provide local land management and security services whose assessment is also based on the spatial and temporal probability following three main steps: 1) the creation of a phenomenon inventory, 2) erosion susceptibility analysis; and 3) erosion hazard analysis (Corominas et al., 2014; Winter et al., 2016; Vandromme et al., 2020).

Government policy analysis

Analysis of government policies related to the existence of the IMPGNP in limited production forest area of 500.28 ha was based on the Decree of the Minister of Environment and Forestry Number 5446/MenLHK-PKTL/IPSDH/PLA.1/8/2021 August 26, 2021. This forest area with limited production function was entirely excluded from the IMPGNP policy because of its cover being secondary dry land forest or LOA.

Spatial model of area utilization for integration of production forest functions

Referring to the results of the scoring analysis of forest area land, the physical condition, type of vegetation cover/land use, the potential for commercially valuable timber forest products to maturity, the level of landslide susceptibility and government policies related to the cessation of granting new permits, a spatial model simulation of utilization was conducted on the integration of production forest functions. This was carried out to obtain the best silvicultural regime/system to apply in each area. In this spatial model simulation, limiting factors in planning the use of timber forest products were also considered, such as physical land factors (slope class $\geq 45\%$) and the presence of forest locations at an altitude of $\geq 2,000$ m above sea level.

The results are shown in [Table 2](#).

[Table 2](#) contains five spatial models of area utilization in the integration of production forest functions covering 500.28 ha, namely: Model 1 (local protected area); Model 2 (utilization of timber forest products in a natural forest with delayed selective logging); Model 3 (utilization of timber forest products in a natural forest with selective logging); Model 4 (reforestation/plantation forest pattern rehabilitation); and Model 5 (rehabilitation of agroforestry patterns) covering areas of 74.85%, 14.91%, 0.07%, 10.02%, and 0.15%, respectively. The area of each spatial model and its location distribution are presented graphically in [Fig. 5](#) and [Fig. 6](#), respectively.

Table 2 Spatial model analysis of area utilization for integration of production forest functions

Land and climate score	Area (ha)	Status/ Function post GR 23/2021	Vegetation cover / Land use		Landslide susceptibility level	IMPGNP	NON IMPGNP	Slope class	Height $\geq 2,000$ m above sea level	Spatial model	
			Type	Area (ha)							
170	417.61	Production forest	Dryland natural forest	367.93	Moderate	-	Secondary dryland forest	Slope $\geq 45\%$	-	Local protected area	
150	81.57	Production forest	Mixed dry land agriculture, dry land agriculture, Scrub; savanna; Open ground	45.73	High	-	-	Slope $\geq 45\%$	-	Rehabilitation of plantation forest patterns (reforestation)	
			Body of water (river)	3.95	Moderate	-	-	-	-	Local protected area	
			Dry land natural forest: Commercial timber potential: trunk diameter ≥ 60 cm with average of 46.09 m ³ /ha (7.57 trees/ha).	74.59	Moderate	-	-	Secondary dryland forest	-	-	Utilization of timber forest products in natural forests by postponing selective logging
130	1.10	Production forest	Mixed dry land agriculture; Shrubs.	3.02	Moderate	-	-	-	-	Rehabilitation of plantation forest patterns (reforestation)	
			Open ground	1.36	High	-	-	-	-	Rehabilitation of plantation forest patterns (reforestation)	
			Body of water (river)	2.60	Moderate	-	-	-	-	-	Local protected area
			Dryland natural forest: Commercial timber potential: trunk diameter ≥ 40 cm with an average of 35.10 m ³ /ha (18.43 stems/ha).	0.35	Moderate	-	-	Secondary dryland forest	-	-	Utilization of timber forest products in the natural forests by selective logging
			Mixed dry land farming	0.75	Moderate	-	-	-	-	-	Rehabilitation of agroforestry patterns
				500.28							

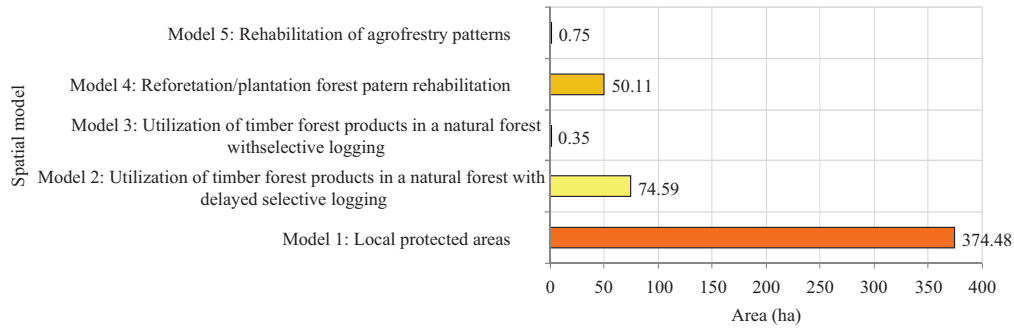


Fig. 5 Graph of area utilization spatial model for integration of production forest functions

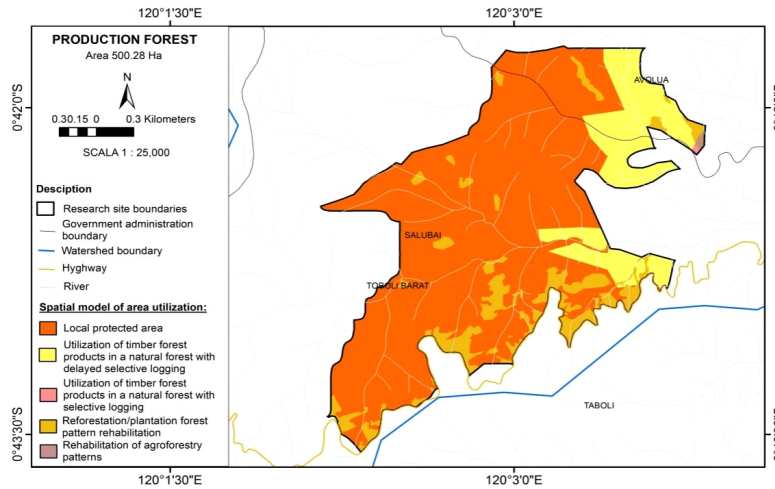


Fig. 6 Distribution map of spatial model of area utilization for integration of production forest functions

Soekotjo (2009) commenting on the use of forests, especially the production function, prioritized the selection of silvicultural regimes, known as the regeneration system, which collected forest products from mature trees. It was designed to address all the complexities of biological, physical and economic considerations, including problems of logging, manipulation and protection of stands, forest land fertility, water management, animal conservation and forest management administration.

The spatial models of the area used in the integration of production forest functions are described as follows:

Model 1: Local protected area

In the production forest area, Model 1 is used for local protected areas that have a steep slope class (>45%). Even though the land scoring results with a value of 170 (in the function of production forest) and the level of vulnerability to landslides is in the medium category, the very steep slopes will endanger the area below when

timber forest products are harvested. The forests growing on mountain slopes play an important role in soil and water conservation, as well as water and climate regulation. Furthermore, proper landslide hazard management and saving human lives can minimize socioeconomic impacts (Winter et al., 2016).

Model 1, with an area of 374.48 ha, has a vegetation cover of secondary dry land forest (LOA). Furthermore, there is a body of water covering 6.56 ha, namely the Salubai River, which needs to be protected for sustainability. The vegetation cover should be preserved because the forest can regenerate naturally with native plant species without disturbance from human activities. Forest conservation should be a concern, given its supporting role as a store and maintaining the natural carbon cycle. During the regeneration process in tropical secondary natural forests, changes occur between trade-offs and the provision of ecosystem services. Therefore, special policies are needed in forest management and protection. Without policies, the ecosystem services

provided by the forests will be eroded, such as the values of biodiversity and unique ecosystems (Mackey et al., 2013, 2015; Naime et al., 2020).

Model 2: Utilization of timber forest products in natural forests with delayed selective logging

Model 2 covers the utilization of timber forest products in a natural forest with delayed selective logging. Thus, in production forest areas this allows harvesting of timber products by selective logging but this needs to be postponed because it has a land score of 150.

Model 2, with an area of 74.59 ha, has a vegetation cover of secondary dry land forest (LOA), with 10 commercial trees/ha having a trunk diameter ≥ 60 cm. The 50-year-old secondary forest has biodiversity, especially trees with economic value. Therefore, this needs to be preserved, with its predominant use being for maintaining and increasing biodiversity (Karmini et al., 2021). Excessive extraction of resources to obtain higher income and more jobs will ultimately lead to unsustainable forest management, resulting in rapid and dangerous degradation and deforestation (Darusman, 2012).

Model 3: Utilization of timber forest products in natural forests based on selective logging

Model 3 applies to the utilization of timber forest products in the natural forest based on selective logging, specifically in production forest areas where harvesting of timber products has been authorized because it has a score of 130. Furthermore, it is consistent with the targets of having commercial tree species with a trunk diameter ≥ 40 cm and an average number of trees >10 trees/ha.

Model 3, with an area of 0.35 ha, has a vegetation cover of secondary dry land forest (LOA), and the average number of commercial trees with a trunk diameter ≥ 40 cm is 19 trees/ha. The potential benefit from harvesting timber forest products in this area supports selective harvesting. Although the tree size and regeneration in the secondary forest are smaller than in the primary forest, the richness of woody and non-timber species is higher. Succession in secondary forests forms tree canopy with palm species through the successful growth of seedlings, saplings and young trees from the mature forests (Norden et al., 2009; Chen et al., 2020). Most of the species succession is due to late growing in the old secondary forests. However, the regeneration can grow long enough to reach an average trunk diameter equal to or greater than trees in older plantations (Otuoma et al., 2014).

Model 4: Reforestation/plantation forest pattern rehabilitation

Model 4 describes reforestation/plantation forest pattern rehabilitation and deserves consideration because residents have cleared forests to plant crops as dry land and mixed dry land agriculture. Furthermore, the study area also contains open land, savanna and shrubs.

Model 4, with an area of 50.11 ha, is in the class of steep to very steep slopes, with erosion-sensitive soil types. Although the intensity of rain is very low, the location score (150–170) places it in the erosion category of medium-high. Under these conditions, it is impossible to carry out intensive land management. Therefore, only timber species can be planted for forest rehabilitation.

Deforestation in Indonesia during 2001–2016 increased due to the conversion of forest into agricultural land and smallholder plantations, which resulted in the loss of trees and biodiversity (Austin et al., 2019; Heryandi et al., 2022).

Tropical rainforests are vulnerable to disturbances in complex ecosystem processes caused by interactions between natural abiotic elements and high biodiversity. Therefore, such ecosystems will continue to be under threat of deforestation as a result of human pressure, with deforestation and degradation of tropical rainforests increasing vulnerability via various damaging effects on billions of people, as well as the loss of vegetation diversity and accelerated runoff and erosion (Brandon, 2014; Lewis et al., 2015; Miller and Spoolman, 2016; Turubanova et al., 2018; Naharuddin et al., 2023).

Model 5: Rehabilitation of agroforestry patterns

Model 5 covers the rehabilitation of agroforestry patterns and needs to be addressed because residents have cleared forests to cultivate crops involved in mixed dry land agriculture. It has an area of 0.75 ha, and it is located in the steep slope class. Although the soil type is sensitive to erosion and the rain intensity is very low, the land score is only 130, while the location is prone to landslides in the moderate category. These conditions makes it possible to carry out intensive land management with an agroforestry pattern rehabilitation activity approach. The agroforestry system can reforest critical land using tree vegetation and commercial crops, such as coffee, cloves and ‘iles-iles’ (*Amorphophallus muelleri* Bl.). Therefore, it is socially acceptable, economically feasible and ecologically suitable for increasing humidity and biomass (Asfaw and Zewudie, 2021; Hasannudin et al., 2022).

The agroforestry pattern applied is agrisilviculture with a combination of secondary crops, plantations and forest trees that are dominated by coffee, pepper, rubber and banana plantings. Coffee plants that dominate agroforestry have a lower average carbon stock value than other plants because their diversity index is lower and can increase the rate of soil loss (erosion). Increasing biodiversity is needed to optimize growing space on farmland through species enrichment among existing plants (Naharuddin et al., 2021, 2022; Heryandi et al., 2022). From the perspective of conservation, local communities have the opportunity to be parties who can protect forests. Therefore, reasonable efforts and regulations are needed to empower local communities in forest conservation (Rangga et al., 2020).

Conclusion

This study developed five spatial models of forest area utilization which were considered appropriate for the integration of production forest functions in the study area as stipulated in Government Regulation of the Republic of Indonesia Number 23 (2021), namely: Model 1 (local protected area); Model 2 (utilization of timber forest products in a natural forest with delayed selective logging); Model 3 (utilization of timber forest products in a natural forest with selective logging); Model 4 (reforestation/ plantation forest pattern rehabilitation); and Model 5 (rehabilitation of agroforestry patterns) with areas of 374.48 ha, 74.59 ha, 0.35 ha, 50.11 ha, and 0.75 ha, respectively. The spatial model of forest area utilization in the integration of production forest functions needs to be followed up with testing at the site level. The implications of the results of this research should be very useful for forestry development policies, especially the integration of sustainable production forest management development.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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