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Spatial Distribution of Forest Cover for the Harmony and Sustainability of Watershed Ecosystem

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Abstract

The harmony and sustainability of the watershed ecosystem are vital to maintaining the conservation, protection, and production functions in line with the environment's carrying capacity. The spatial distribution of forest cover was linked to the sufficiency of forest area to analyze the harmony and sustainability of the watershed ecosystem. This research aims to analyze distribution patterns and forest cover areas supported by sufficient forest area so that the harmony and sustainability of the ecosystem in the watershed area are maintained. A descriptive spatial analysis using GIS was employed. The study was conducted in the Laa Watershed with an area of 318,494 Ha. The findings indicated that forest area and forest cover are 63.17% and 58.24% of the watershed area, respectively. Regarding the environmental carrying capacity for harmony and sustainability, the conservation function was in harmony with the watershed ecosystem. Meanwhile, the functional analysis of the protected and cultivated areas found that 16.08% of the protected areas were suitable for production function. In comparison 13.34% of the cultivated area was suitable for protective function. To realize the harmony and sustainability of the ecosystem in the watershed area, it is necessary to re-examine the directions for spatial allocation based on the environment's carrying capacity.

Keywords: Harmony, sustainability, ecosystem, forests, watershed.

1. Introduction

A forest is an ecosystem unit of landscape that contains inseparable biological natural resources. Forest, dominated by trees or woody vegetation, are generally managed for several aims, from producing timber, non-timber, and water to recreational purposes (Soekotjo, 2009). Principally, forests play significant roles in the survival of humans and other living creatures.

The forests are managed based on their functions. For instance, the wildlife sanctuary and nature preserve, aim to protect a variety of flora and fauna and their role as a source of germplasm. As protected forests, it is aimed to maintain the stability of the hydrological cycle and soil fertility. As production forests, it aims to maintain the availability of timber and non-timber forest products. Nevertheless, these functions have been disrupted due to the forest conversion to other purposes, such as plantations and agriculture, resulting in the loss of vegetation composition and biodiversity. Therefore, specific policies related to the preservation of primary forests are required, particularly to ensure the intactness of ecosystem services, including the biodiversity and the uniqueness of the ecosystem (Mackey et al., 2015; Austin et al., 2019; Heryandi et al., 2022).

Sustainable forest management is intended to ensure that forest products and services meet needs while upholding forest continuity and contributing to long-term development (Gamborg and Larsen, 2003). Moreover, population growth and cultural and technological advances urge proper management of natural resources in order to meet human needs (Hou et al., 2010; Zallé, 2019; Bana's et al., 2021).

In the implementation of regional spatial planning, the sufficiency of forest area with proportional distribution is one of the strategic directions in regional planning and development. It affirms the importance of determining the minimum threshold value to optimize the function of forest in realizing the harmony and sustainability of an ecosystem. In forest management strategies, planning forest cover at the water catchment scale is helpful to reduce the impact of land use (i.e., plantations) on the river runoff. Sustainable management of both forest resources and forest cover is vital to meet the social, economic, ecological, cultural, and spiritual needs of present and future generations (Brack, 2018; Garcia et al., 2018).

The Laa Watershed is located between two provinces; Central Sulawesi Province and South Sulawesi Province. It comprises forest and non-forest areas with land cover/use in the form of forest, shrubs, savanna, plantations, dryland farming, rice fields, embankments, settlements, mining land, lakes, swamps, and bare grounds. The agricultural activities in forest areas, however, potentially disrupt the harmony and

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sustainability of the ecosystem. Consequently, the impending changes in forest functions due to reduced forest cover and fires potentially decrease the air quality and increase carbon emissions (Sumarga, 2017; Syarif et al., 2023).

The concern regarding the role and function of forests leads to the necessity researching spatial distribution of forest area and forest cover in the Laa Watershed. It is expected that the results will be useful for realizing the harmony and sustainability of the ecosystem in the Laa Watershed, especially in the future.

2. Materials and Methods

This study was carried out from August to November 2023 in Laa Watershed. Materials and equipment included: (a) maps (forest area, topography, geology, slope classes, soil type, watershed, infrastructure, rainfall, and regional spatial plan); (b) SPOT 7 satellite imagery of 2022 for land cover/use mapping; (c) GPS, digital camera, tally sheet, and writing instrument; (d) related laws and regulations; (e) ArcGIS version 10.7 for data processing and spatial analysis of the distribution patterns and the extent of forest area and forest cover.

Remote sensing and a descriptive spatial analysis using GIS technology were employed to examine the distribution patterns and the extent of forest area and forest cover. Unsupervised classification was used for satellite imagery processed for land cover/use. The field surveys on biogeophysical conditions and land cover/use types were conducted. The spatial analysis examined: (a) natural forests (mangrove forests, swamp forests, dryland forests); (b) plantations (industrial plantations, rehabilitated land, replanted land); (c) non-forest area in the form of natural land covers (savanna, shrubs, bare ground, and karst), inseparable from their natural ecosystem.

The criteria of biogeophysical aspects, environmental carrying capacity, watershed characteristics, and biodiversity were examined. They are grouped into directions for conservation, protective, and production functions (Regulation of the Minister of Environment and Forestry, 2021).

(1) Conservation function - Biogeophysical aspects with indicators: (a) natural beauty and uniqueness; (b) eco-tourism; and/or (c) biosphere reserves. Diversity of flora and fauna with indicators: (a) endemic flora and fauna; (b) rare flora and fauna; (c) preservation of flora and fauna; and/or (d) protection and conservation of flora and fauna.

(2) Protective function - Biogeophysical aspects with indicators: (a) slope: ≥40%; (b) elevation: ≥2,000 m above sea level; (c) soil type: highly prone to erosion, slope class ≥15%; (d) part of coastal protection area; (f) distance from the river: ≥ 100 m; (g) distance from the coastline at the highest tide: ≥ 50 m; (h) mangrove forest; (j) the total score of slope class, soil type, and rain intensity multiplied by respective weighting factor: ≥175. These aspects reflect the land capability, namely the carrying capacity of the environment. They are combined with the watershed characteristics with indicators: the upstream area and the watershed criticality (erosion and land criticality).

(3) Production function - Biogeophysical aspects with indicators: (a) slope: <40%; (b) the total score of slope class, soil type, and rainfall intensity multiplied by respective weighting factor: <175, situated outside the protected area, nature reserve, conservation area (hunting park); (c) the total score of slope class, soil type, and rain intensity multiplied by respective weighting factor: 125-175, served as a buffer zone. These aspects indicate the land capability, namely the carrying capacity of the environment.

To calculate the forest function with a total score of ≥ 175 for the protective function and <175 for the production function, the following formula is used (Regulation of the Minister of Environment and Forestry, 2021; Akhbar et al., 2022):

$$\sum \text{SV ff} = (\text{SVsc} + \text{SVst} + \text{SVri}) \quad (1)$$

∑SVff: The sum of the forest function scores
SVsc: 20 x weight value for each slope class (5 classes)
SVst: Weight value 15 x each class of soil type (5 classes)
SVri: Weight value (10) x each class of rain intensity (5 classes)
Slope classes: 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%)
Soil type classes: 1 = not sensitive to erosion (alluvial, glei, planosol, gray hydromorphic); 2 = slightly erosion sensitive (latosol); 3 = less sensitive to erosion (brown forest soil, non-calcic brown, Mediterranean); 4 = sensitive to erosion (andosol, lateritic, grumusol, podsol, podzolic); 5 = very sensitive to erosion (regosol, lithosol, organosol, rendzina)
Rain intensity classes: 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 = high (27.7 - 34.8 mm/rainy day); 5 = very high (≥34.8 mm/rainy day.

The protection and production functions of an area can be assessed based on the standard criteria and score of topography, soil, vegetation, and regional rainfall distribution (Sudarmadji and Hartati, 2018). Planning products must reflect the uniqueness and biodiversity of the environment and prioritize the conservation and preservation purposes of natural resources (Poerwoningsih et al., 2016). Considering the variables used to analyze the spatial distribution and the sufficiency of forest area and forest cover in the Laa Watershed, a GIS-based multi-criteria approach with a map overlay system was employed. This approach is relatively flexible in the decision making process (Akhbar et al., 2022).

3. Results and Discussion

3.1. Geography, Area, and Characteristics of the Laa Watershed

Geographically, the Laa Watershed is located at coordinates 1˚36'28.70" - 2˚17'16.65"S and 120˚42'27.90" - 121˚30'34.09"E. The total area is 318,494 ha with Laa-Yaentu as the main river (264.94 km in long). Administratively, it is situated in Central Sulawesi Province (North Morowali Regency with 81.94% and Poso Regency with 16.07%) and South Sulawesi Province (East Luwu Regency with 1.99%).

The regional function map of the Laa Watershed demonstrates five types of area: conservation forest of 10,690 ha; protected forest of 77,131 ha; permanent production forest of 93,153 ha; convertible production forest of 20,229 ha; and non-forest area of 117,291 ha. Conservation forest consists of the Faruhumpenai Nature Preserve of 6,331 ha and the Buru Landusa Park of 4,359 ha (Ministerial Decree of Environment and Forestry, 2021). Parameters and their description used for analysis of Laa Watershed are presented in Table 1.

3.2. Spatial Pattern on Sufficiency of Forest Area

Laa Watershed, covering a total area of 318,494 ha, is divided into two classes: a protected area of 90,393 ha and a cultivated area of 228,101 ha. Protected areas consist of nature preserves (1.99%), hunting Park (1.37%), protected forests (24.22%), and non-forest protected areas (0.81%). Meanwhile, cultivated areas comprised permanent production forests (29.25%), convertible production forests (6.35%), and non-forest cultivated areas (36.02%).

Table 1. Length information of the roads in the study area

No.	Parameter	Description
1	Rainfall and rain intensity in 2018-2022	Rainfall of 2,297.54 mm/yr (moderate); rain intensity of 11.69 mm/day (very low)
2	River pattern and flow density	Dendritic and parallel patterns; Flow density of 0.08 km/km^2
3	Runoff coefficient (C)	0.41 (high)
4	Elevation	0 – 2,550 m.a.s.l.
5	Slope classes	Flat (<8%) of 55,938 ha; ramps (8-<15%) of 44,900 ha; rather steep (15-<25%) of 92,953 ha; steep (25-<40%) of 88,244 ha; very steep (≥40%) of 36,459 ha
6	Geology/types of rock	Alluvial and coastal deposits (Qal), Tomata formation (Tmpt), Lerea formation (Tpll), Matano formation (Kml), Malih limestone (MTmm), Pompangeo complex (MTmp), Ultramafic complex (MTosu), Tetambahu formation (Jtl), and karst ecosystem (27,297 ha)
7	Types of soil	Alluvial, gray hydromorph, organosol, latosol, red-yellow Mediterranean, red-yellow podzolic, lithosol, grumusol, rendzina, brown forest soil
8	Groundwater basin	Wasopote Basin of 45,208 Ha; Tomori Basin of 18,971 ha; Pindolo Basin of 160 ha
9	Morphology	Downstream of 176,957 ha; midstream of 79,474 ha; upstream of 62,064 ha
10	Soil erosion	Not sensitive (<15 ton/ha/yr) of 161,696 ha; slightly sensitive (15 - <60 ton/ha/yr) of 114,367 ha; less sensitive 60 - <180 ton/ha/yr) of 34,918 ha; sensitive (180 - <480 ton/ha/yr) of 5,284 ha; very sensitive (≥480 ton/ha/yr) of 2,228 ha
12	Sediment load	10.17 ton/ha/yr (moderate)
13	Criticality level	Not critical of 47,623 ha; potentially critical of 116,691 ha; slightly critical of 131,645 ha; critical of 13,909 ha; severely critical of 8,626 ha
14	Non-forest land cover	Plantations of 32,816 ha; dryland agriculture/mixed farming of 37,788 ha; rice field of 6,082 ha; shrub/shrub swamp/savanna of 51,139 ha; embankment of 393 ha; mining lands of 593 ha, bare ground of 1,051 ha; settlement/transmigration of 1,785 ha; swamp/body of water of 1,345 ha
15	Forest land cover	Primary dryland forest of 101,639 ha; secondary dryland forest of 82,011 ha; secondary swamp forest of 724 ha; secondary mangrove forest of 388 ha; plantation forest of 739 ha
16	Coverage of government administrative area	2 provinces; 3 districts; 10 sub-districts; 68 villages
17	Population and its condition in 2022	Total of 72,720 people; population density of 14 people/km^2; growth rate of 1.98%, ‘high’ population pressure on agricultural land

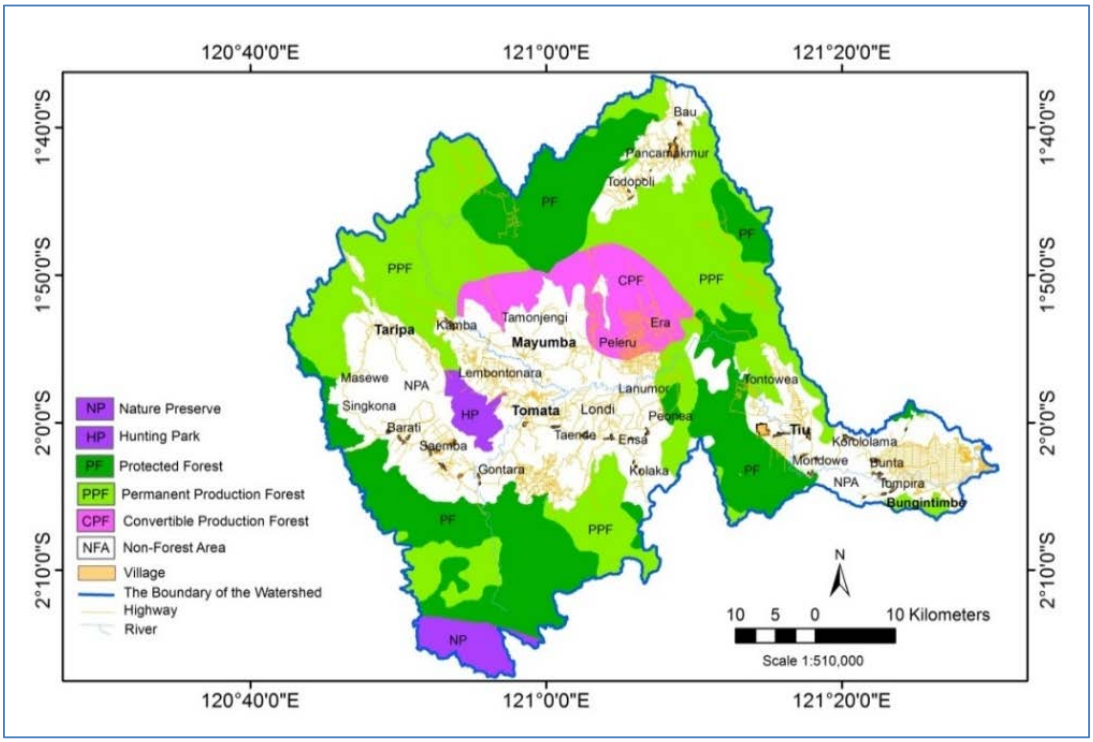


Figure 1. The road network map

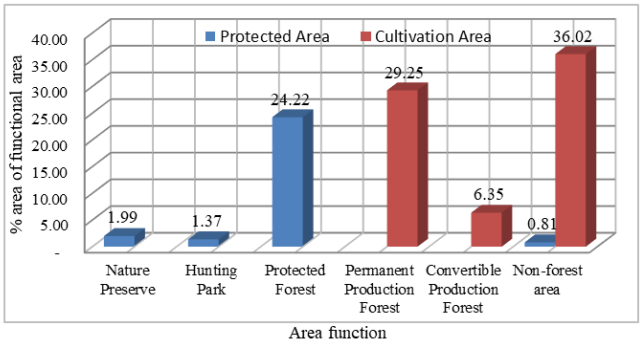


Figure 2. Percentage of functional areas in the Laa Watershed

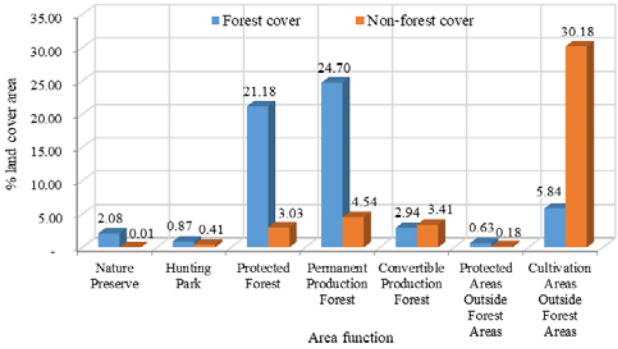


Figure 3. Percentage of functional areas in the Laa Watershed

The spatial distribution analysis shows that forests cover 63.17% of the Laa Watershed area, while the remaining 36.83% is others. Based on the status of the State Forest Area, the forest area in the Laa Watershed can maintain the conservation, protective, and production functions. The details are presented in Figure 2.

The extensive forest area in the Laa Watershed implies the capacity of forests to serve their conservation, protection, and production functions. The conservation function of forests involves its contribution to preserving the diversity of flora and fauna and their ecosystems and offering recreational activities. The protective function of forests includes its role in water regulation, flood prevention, erosion control, seawater intrusion prevention, and soil fertility maintenance. Meanwhile, the production function emphasizes the capacity of forests to provide economic products. This series of functions is fundamental for sustainable terrestrial systems (Krott, 2005; MEA, 2005; Sylviani, 2008; Chazdon et al., 2009; Abson et al., 2014; Reed et al., 2017).

3.3. Spatial Distribution of Forest Cover

The different land cover types in the Laa Watershed resulted from intensive development activities. Among nineteen types of land cover/use, forest cover (primary and secondary dryland forests, secondary swamp forest, secondary mangrove forest, plantations) dominated the area (58.24%), followed by shrubs and savanna (13.52%), plantations (10.30%), and mixed dryland agriculture (8.21%). Meanwhile, dryland agriculture, rice fields, settlements, bare ground, shrub swamps, embankments, mining lands, transmigration, swamps, and water bodies covered less than 4% of the area. The spatial distribution analysis confirmed that forest cover was distributed across all regional functions, dominated by protected and permanent production forests with coverage above 46%. Meanwhile, other functions covered less than 6% of the watershed area. The distribution patterns are presented in Figure 3.

The forest cover in the Laa Watershed was composed of primary natural forests (31.91%), secondary natural forests (26.10%), and plantations (0.23%). Primary natural forests still dominated protected forests,

permanent production forest, and nature preserve, while secondary natural forests dominated convertible production forests, hunting Park and non-forest cultivated areas. The dominance of natural forests has a positive impact on preserving of biodiversity. Old secondary forests harbored rich biodiversity, species with economic values, and tall trees with large trunk diameters (Otuoma et al., 2014; Karmini et al., 2021). The ability of primary forests to regenerate naturally with native species requires minimum intervention from human activities. Therefore, primary forest conservation must be a global concern, particularly considering its role as a carbon store and in maintaining the natural carbon cycle (Mackey et al., 2013).

3.4. Land Capacity and the Sustainability of Conservation Function

The conservation forests covered 3.36% of the Laa Watershed, including the Faruhumpenai Nature Reserve of 1.99% and the Buru Landusa Hunting Park of 1.37%. Based on the carrying capacity of the environment, conservation forests in the protected area are designated to preserve the conservation function. According to the regional spatial plan, the current locations of the Faruhumpenai Nature Preserve and the Buru Landusa Hunting Park are strategic to maintain the harmony and sustainability of the conservation forest ecosystem in the upstream and midstream of the watershed.

The role of nature preserve regarding the diversity of endemic and rare flora and fauna, is prominent. Freshwater swamp forests, primary grassland forests, and lower and upper montane tropical rainforests are among the ecosystems of nature preserves. They are flat to mountainous with rocky and cliffs, and the elevations range from 585 to 1,832 m (a.s.l). (Ashari, 2023). Approximately 0.32% of the Faruhumpenai Nature Preserve has steep slopes, while 1.15% of the Laa Watershed on land slopes >15% is extremely prone to soil erosion.

The Buru Landusa Park offers prospective sports tourism. Its ecosystem includes lowland forests, shrubs, savannas, and swamp with elevations ranging from 200 to 625 m (a.s.l). Among tourist attractions are deer and wild boar hunting tours, tracking tours, and historical tours (The Center for Natural Resources Conservation of Central Sulawesi, 2020). Approximately 0.04% of the area has a very steep slope.

3.5. Land Capacity and the Sustainability of Protective Function

The protected area consisting of protected forests and non-forest protected areas, is 24.22% and 0.81% of the Laa Watershed, respectively. Based on the carrying capacity of the environment, it aims to preserve protective functions, including water management regulator, flood prevention, erosion control, seawater intrusion prevention, and soil fertility maintenance. The spatial analysis showed that the carrying capacity of 22.27% of the watershed area maintains its protective function. It comprised protected areas (8.94%) and cultivated areas (13.34%). Furthermore, the protected area comprised protected forests (8.48%) and non-forest protected areas (0.46%). Meanwhile, the cultivated areas encompassed permanent production forest (4.96%), convertible production forests (2.30%), and non-forest cultivated areas (6.09%). Protected areas with very steep slopes, elevation ≥2,000 m (a.s.l), and karst ecosystems were the greatest contributors to protective function. Meanwhile, the protective function of the cultivated areas was upheld by very steep slopes and karst ecosystems, as well as swamp forests and mangrove forests in small quantities. The details are presented in Figure 4.

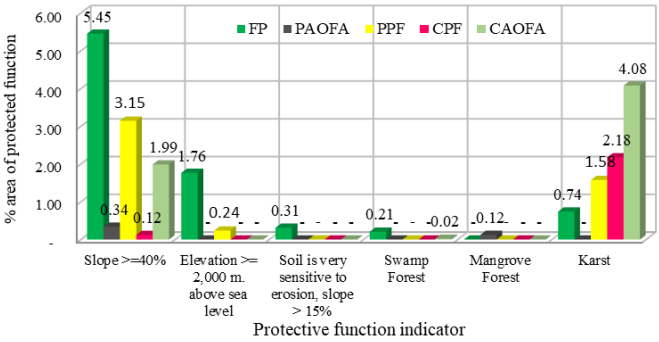


Figure 4. Areas of protective function in the Laa Watershed

The coverage of forest and non-forest protected areas reached 25.02% of the watershed, but the spatial analysis results showed that only 8.94% were capable of maintaining the protective function. Consequently, the remaining 16.08% did not fulfill the specified indicators of environmental carrying capacity. Instead, the total slope, soil, and rain intensity scores ranged from 65 to 150 (<175), indicating the suitability for production function. Areas with a total score for land and climate of less than 175 are potentially used as production forests (Akhbar et al., 2023).

3.6. Land Capacity and the Sustainability of Production Function

The cultivated areas in the Laa Watershed consisted of permanent production forests (29.25%), convertible production forests (6.35%), and non-forest cultivated areas (36.02%). Based on the environmental carrying capacity, the areas aim to preserve production functions, namely production of forest products and agricultural and non-agricultural products. The spatial analysis indicated the capacity of approximately 74.37% of the watershed area to maintain the sustainability of production function. It comprised cultivated areas (58.28%) and protected areas (16.09%). Land assessment requires land suitability to anticipate inefficient use of resources and potential decreasing production (Manna et al., 2009; Pilvere et al., 2014).

Furthermore, the cultivated areas (58.28% of the watershed) comprised permanent production forests

(24.29%), convertible production forests (4.06%), and non-forest cultivated areas (29.93%). Meanwhile, the protected areas (16.09% of the watershed) comprised of protected forests (15.74%) and non-forest protected areas (0.35%). The cultivated areas with flat to steep slopes, and total land and climate scores ranging from 65 to 150 (<175) were the most significant contributors for the production function. Also, the production function in protected areas was derived from those with total land and climate scores of <175. Furthermore, the cultivated area was also divided into a buffer for the protective function (13.29%) and the production function (44.99%). The details are presented in Figure 5.

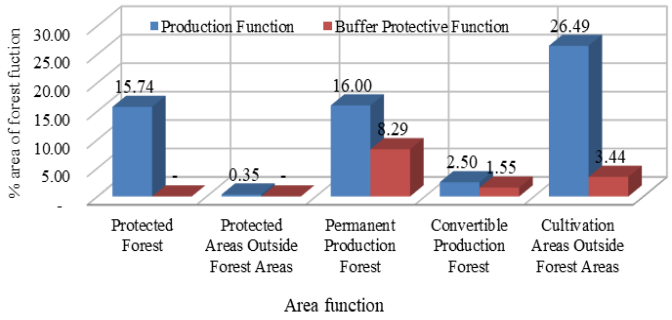


Figure 5. Areas of production function and a buffer of protection function in the Laa Watershed

3.7. Harmony and Sustainability of Watershed Ecosystem

Ecosystem harmony in a watershed is indicated by the distribution of spatial allocations, which is designated according to the environmental carrying capacity along with the conservation function, protective function, and production function. It is also related to the morphology of the watershed. Conservation forests and watersheds are relatively harmonious, with the former generally situated in the upstream and midstream of the watershed. Based on the functions, the protected forests and non-forest protected areas, as well as permanent production forests, convertible production forests, and non-forest cultivated areas in the Laa Watershed, can be claimed to be less harmonious with the environment since the locations are not in accordance by the carrying capacity of the watershed. The results of land suitability analysis are useful for determining land availability by considering the status of forest areas and land use in spatial planning (Tratnik et al., 2009; Widiatmaka et al., 2014; Widiatmaka et al., 2016).

The present study affirmed that the cultivated area (13.34% of the watershed area) did not fulfill the indicators of the environmental carrying capacity to maintain production function, but, instead, was suitable for preserving the protective function. Moreover, the protected area (16.08% of the watershed area) also did not fulfill the criteria of the environmental carrying capacity to maintain the protective function. However, it was appropriate for preserving the production function. The findings, however, indicated the need to re-examine the direction for determining regional functions in the regional spatial planning in accordance with the carrying capacity of the environment. Generally, spatial allocation failures are caused by the use of inconsistent maps, inaccurate projection systems and map coordinates, and incomplete and/or out-of-date spatial data sources. The quality of regional spatial planning is determined by evaluating the completeness and depth of indicators as well as the quality of data used in the planning process (Latif et al., 2022).

4. Conclusions

The watershed is composed of 63.17% forest area and 36.83% non-forest areas. Forest cover (58.24% of the watershed) dispersed across all functional areas is composed of 51.77% of forest area and 6.47% non-forest areas. The analysis of the environmental carrying capacity and the spatial planning in association with the harmony and sustainability of the ecosystem shows that the conservation function is suitable and harmonious with the watershed ecosystem. Furthermore, the functional analysis of the protected and cultivated areas also indicates that approximately 16.08% of the protected areas are suitable for production functions, while 13.34% of the cultivated areas are suitable for protective functions. To realize the harmony and sustainability of the watershed ecosystems, re-examining the directions for spatial allocation according to the ecosystem carrying capacity is required.

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