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Sustainable forest strategy based on land capability evaluation in Muna regency, Indonesia

Mukrimin Mukrimin[1,2*], La Ode Sumahir[2], Baharuddin[1,2], Sitti Marwah[3], Hasanuddin[4]

[1] Department of Forestry, Faculty of Forestry, Hasanuddin University, Makassar, Tamalanrea Campus, Jalan Perintis Kemerdekaan Km. 10, Makassar 90245, Indonesia
[2] Master Program of Forestry, Faculty of Forestry, Tamalanrea Campus, Hasanuddin University, Makassar, Jalan Perintis Kemerdekaan Km. 10, Makassar 90245, Indonesia
[3] Faculty of Forestry and Environment, Halu Oleo University, Green Campus Bumi Tridharma, Anduonohu, Kambu District, Kendari, Southeast Sulawesi 93232, Indonesia
[4] Forestry Study Program, Faculty of Agriculture, Muhammadiyah University of Makassar, Makassar, 90221, Indonesia
* Corresponding author's email: mukrimin@unhas.ac.id

ABSTRACT

Changes in land use in Muna regency, including the Jompi Watershed, have become the main factor that causes ecosystem damage. This damage impacts drought, decreases land productivity, and disrupts the watershed's hydrological system. To overcome this problem, the management of the Jompi watershed needs to be carried out by combining the interests of soil and water conservation with efforts to increase agricultural production in order to realize sustainable watershed conditions. One of the first steps that can be taken is to evaluate land capabilities. The study seeks to evaluate the land capacity of the Jompi watershed by analyzing data according to land capacity classification criteria. The study results indicated that the land in the Jompi watershed is divided into three classes of ability, namely Class IV, which is primarily constrained by moderate surface rock presence, steep slopes, and poor soil drainage. Class V faces limitations due to slow soil permeability and very poor drainage. Meanwhile, Class VIII is restricted by coarse soil texture and rapid soil permeability. The recommended land use direction is in forest areas, land use areas, and production forests for classes IV and V; it is recommended to implement agroforestry systems with conservation actions by creating terraces and adding organic matter. For class VIII, it is recommended that the land be left naturally. In protected forest areas for classes IV, V, and VIII, the land is recommended to be maintained as a protected forest or left in nature. This approach is expected to support more sustainable forest management.

Keywords: sustainable forest management, land capacity, land units, GIS.

INTRODUCTION

A watershed is an area with topography (ridge) as a natural barrier and functions to receive, accommodate, and drain water from upstream to downstream [Asdak, 2010; Pambudi, 2019; Yu and Duffy, 2018]. The dynamics of land use change that occur are factors that cause damage to watershed ecosystems, which significantly impact drought, decreased land productivity, and disruption of watershed hydrological systems both *in situ* (in the watershed) and ex-situ (outside the watershed) [Araújo Costa *et al.*, 2019; Aygün, *et al*, 2021; Dance *et al.*, 2021]. Likewise, it causes an increase in the rate of erosion, surface flow, an increase in the weight of soil volume, a decrease in porosity, a decrease in organic matter, the potential for interception, and a decrease in surface roughness [Alwi and Marwah, 2015; Bettoni *et al.*, 2023].

The Jompi watershed is one of the watersheds in Muna Regency that has experienced significant ecosystem degradation. This condition is influenced by two main factors, namely human activities and natural disasters, which cause changes in land cover, a decrease in vegetation density, and the conversion of forested area into non-forest land that continues to increase and is uncontrollable [Laughs *et al.,* 2016], so that it has great implications for fluctuations in river discharge, decreased land productivity, and, of course, dramatically impacts the level of community welfare.

The Jompi watershed requires intensive management efforts that combine the interests of soil and water conservation with the interests of increasing agricultural production and community income to realize sustainable watershed conditions [Caković *et al*., 2024].

Watershed management and development can be carried out with the right land use method. In realizing this, it is necessary to evaluate land capabilities through a land capability classification approach by determining land use by its carrying capacity [Ayalew and Yilak, 2014]. Land capability evaluation systematically assesses land and its components, grouping it into various categories based on characteristics that indicate both its potential and limitations for sustainable utilization. Meanwhile, land capability classification is an approach used to evaluate land in order to determine the appropriate land use [Abd-Elazem *et al*., 2024; Arsyad, 2010].

Land use efforts to achieve maximum production and sustainable sustainability must be based on the right land capabilities. Therefore, land capacity is one of the important inputs to determine the planning of land use directions in an area [Ippolito *et al*., 2021]. The ability of land in an area can vary due to differences in topographic factors, relief, soil type, slope, and land use [Blackburn *et al*., 2022].

Research on evaluation of land capacity for land use direction in the Jompi watershed area of Muna regency. It is important to support the development of various sustainable sectors and sustainable watershed areas. Research on the study has never been conducted in the Jompi watershed area of Muna regency. To date, no research on this topic has been conducted in the region. This study assesses land feasibility and establishes appropriate land use directions within the Jompi watershed. The findings will provide valuable insights into land capability classifications and recommend suitable land uses.

METHODOLOGY

This study was conducted from January to March 2024 and consisted of two main parts: fieldwork and laboratory work. The fieldwork involved the creation of land unit maps and field observations, while the laboratory work focused on soil sample analysis carried out at the Silviculture and Tree Physiology Laboratory, Faculty of Agriculture, Hasanuddin University (UNHAS).

The tools used in the field consist of a global positioning system (GPS), meters, machetes, hoes, shovels, beams (beaters), soil drills, sample rings, samples plastic, label paper, writing stationery, and mobile phone cameras. Tools used for analysis in the laboratory include analytical scales, weighing bottles, shakers, conductivity meters, gauze, rubber, measuring cups, paralon pipes, ovens, glass weighing bottles, 500 ml measuring cups, soil hydrometers, thermometers, mixers, sieve nets, erlenmeyers, bulps, scale pipettes, and drip pipettes.

The materials used in this study are slope maps (terrain maps on a scale of 1:50,000), geological maps of southeast Sulawesi on a scale of 1:250,000, land maps of the review of southeast Sulawesi on a scale of 1:250,000 and land cover maps of southeast Sulawesi province on a scale of 1:250,000 which are used to make land units (LU) and determine the point of soil samples that are disturbed and undisturbed. The materials used for laboratory analysis include Aquadest, Calgon solution (analysis of soil texture, permeability, and salinity), H_2SO_4, $K_2Cr_2O_7$, diphenylamine indicator, and ammonium persulfate (C-organic analysis).

The methodology used in this study is descriptive-exploratory, with a field survey approach supported by laboratory analysis. In the first stage, land unit (LU) maps are created by combining soil type maps, slope maps, and land use maps to determine the compatibility among these factors in the studied area. Then, The LUs that do not meet the criteria of size and map accuracy scale are excluded, resulting in 22 representative LUs (Figure 1). This stage aims to generate LU maps depicting the research location's physical condition and land use.

Next, the sampling points are determined using a purposive sampling method, which involves selecting points representing each land unit based on relevant criteria. Soil samples are taken at depths of 0–30 cm, 30–60 cm, and 60–90 cm to analyze parameters such as soil texture,

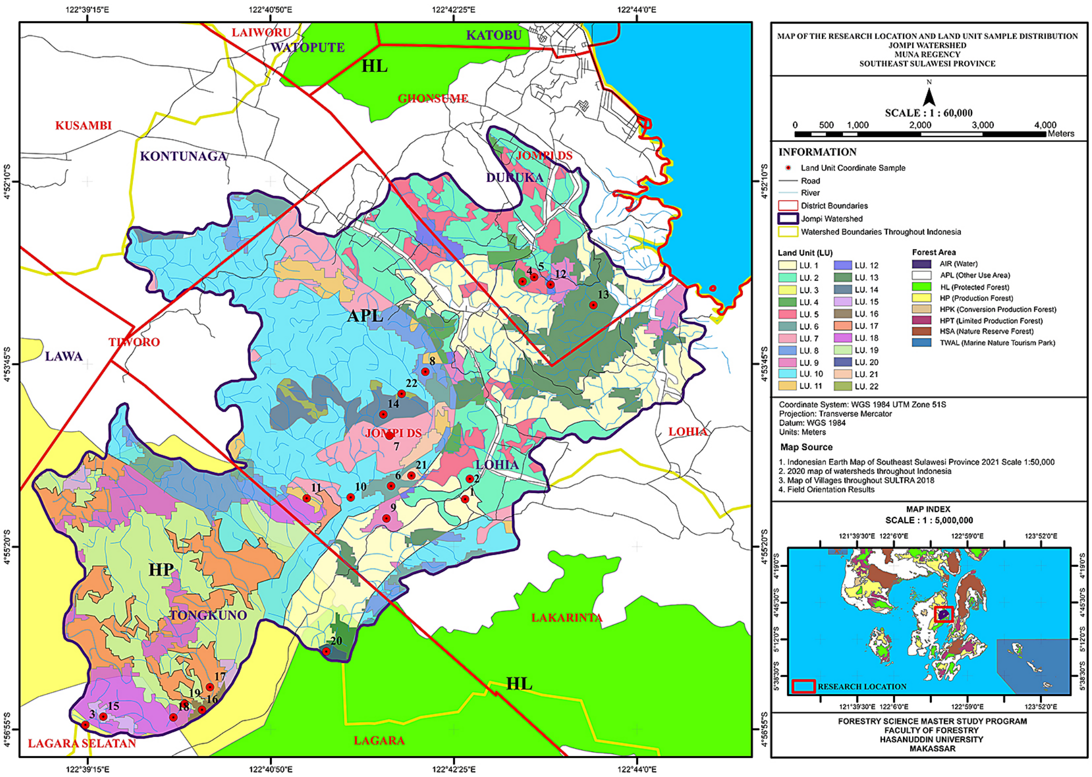

Figure 1. Map of the LU of watershed of Jompi, Muna regency (ArcGIS Analysis, 2024)

permeability, organic matter, and salinity (Figure 2). This stage aims to ensure that the samples taken represent the conditions of each land unit and provide accurate data for further analysis.

During the survey, field observations are also conducted on several parameters, including soil depth and effective drainage, assessed through soil cores to examine soil depth and color. Additionally, observations on potential erosion, flood hazards, and surface rocks are qualitatively made in the field. The goal of these field observations is to identify and document the physical conditions of the soil and potential hazards, which will be used for further analysis and land suitability determination.

Soil samples collected from the field are then analyzed in the laboratory for several key parameters: soil texture, permeability, salinity, and organic matter. Soil texture is analyzed using the soil texture triangle method (USDA, 1972), permeability is calculated based on Darcy's law (1856), salinity is measured using Electrical Conductivity (EC), and organic matter is determined using $K_2Cr_2O_7$ and ferrous ammonium sulphate solution according to the method published by Hammer (1978). This analysis aims to obtain the quantitative data required to assess land suitability and further hazard potential.

Erosion sensitivity (ES) was calculated using the following formula:

$$KE = \begin{Bmatrix} 2.7 \times 10^{-4}(12 - OM)M^{1.14} + \\ + 3.25(S - 2) + \dfrac{2.5(P - 3)}{100} \end{Bmatrix} \quad (1)$$

where: *OM* – percentage of organic matter, *S* – soil classification code, *P* – soil permeability, and *M* – percentage of silt × (100 - the percentage of clay). This calculation aims to determine the erosion potential that may affect the land quality and its sustainable use.

In the land suitability evaluation stage, the results from field observations and laboratory analysis were used to classify the land based on the main limiting factors. This classification refers to the land suitability classification table (Arsyad, 2010b), shown in Table 1, and each land unit was evaluated to determine the appropriate land suitability class. Based on this classification, recommendations for land use were made to ensure that the land is used according to its capacity. This evaluation aims to determine the potential land use and provide appropriate land use recommendations based on the physical characteristics and potential hazards present.

After the land suitability class is determined, the final step is to determine the direction of land

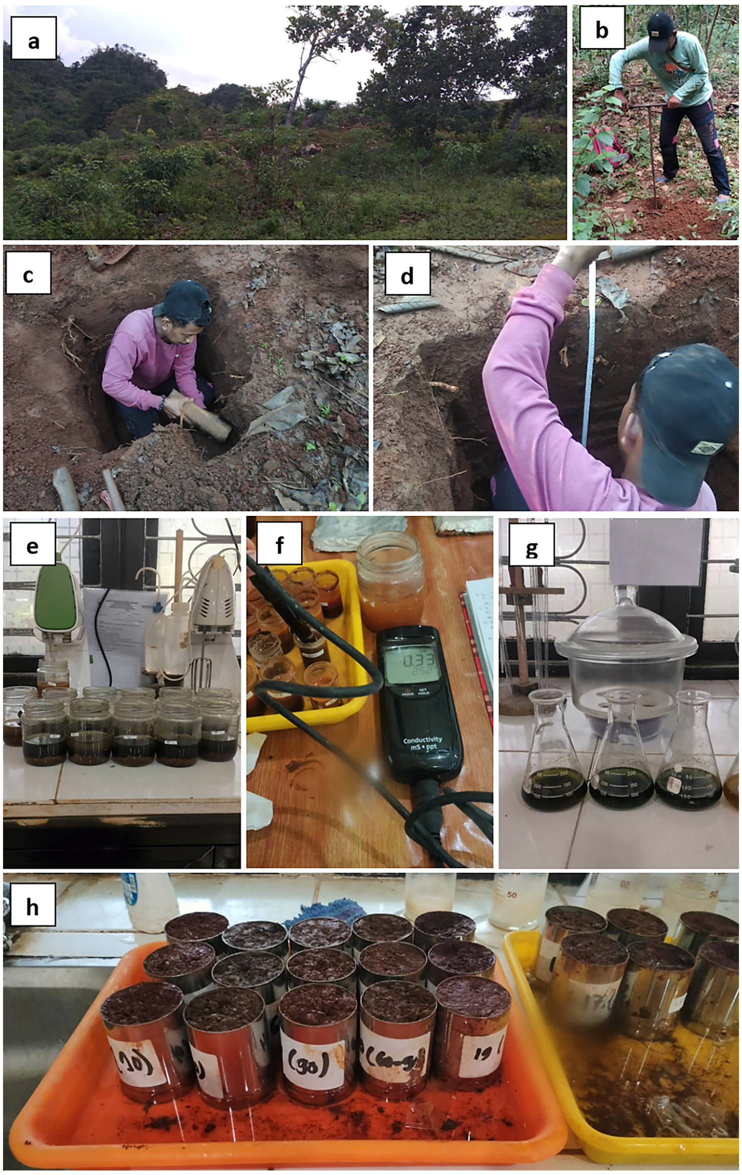

Figure 2. The research process involves several stages, beginning with field surveys at the initial stage, which include: a) Identifying the location for soil sampling in the Jompi watershed; b) collecting soil samples using a soil drill; c) employing the ring method for sample collection; d) measuring the depth of the soil; and proceeding to the laboratory analysis stage, which encompasses; e) analysis of soil texture; f) testing for soil salinity; g) analysis of soil C-organic; h) conducting soil permeability tests.

use based on the results of overlaying forest area maps and land suitability evaluation maps. The purpose of this stage is to guide sustainable land use according to the ecological potential of each land unit. Thus, the most suitable type of land use for each land unit's physical conditions and potential can be determined.

RESULTS AND DISCUSSION

The Jompi watershed is one of the largest watersheds in Muna regency, where the area covers four sub-districts, namely Duruka District, Lohia District, Kontunaga District, and Tongkuno District. Based on the land map reviewed by the Jompi watershed, there are two types of soil, namely Kambisol (2,166.11 ha) and Mediteran (2,975.51 ha). The topography of the Jompi watershed is quite varied; namely flat slopes (2,235.56 ha), sloping (1,609.25 ha) and slightly sloping/undulating (1001.89 ha), hilly slopes (284.21 ha) and slightly steep (10.71 ha). The land use consists of secondary dryland forests or former logging (1,194.22 ha), settlements/built lands (109.86 ha), secondary

Table 1. Land capability criteria and its inhibiting factors based on (Arsyad, 2010b)

No	Inhibiting factors	Land capability class							
		I	II	III	IV	V	VI	VII	VIII
1	Soil texture (T)	T2-T3	T1-T3	T1-T4	T1-T4	(*)	T1-T4	T1-T4	Q5
2	Permeability (P)	P2-P3	P2-P3	P2-P4	P2-P4	P1	(*)	(*)	P5
3	Erosion sensitivity (KE)	KE1-KE2	KE3	KE4-KE5	KE6	(*)	(*)	(*)	(*)
4	Effective depth (K)	K0	K1	K2	K2	(*)	K3	(*)	(*)
5	Slope slope (I)	A	B	C	D	A	E	F	G
6	Soil drainage (D)	D1	D2	D3	D4	D5	(**)	(**)	D0
7	Salinity (G)	G0	G1	G2	(**)	G3	G3	(*)	(*)
8	Potential hazards erosion (B) flood (O)	E0 O0	E1 O1	E2 O2	E3 O3	(**) O4	E4 (*)	E5 (*)	(*) (*)
9	Surface rock (B)	B0	B0	B1	B2	B3	(*)	(*)	B4

Note: A = flat; B = sloping/undulating; C = slightly skewed/wavy; D = hilly slope; E = a bit steep; F = steep; G = very steep; KE1 = very low; KE2 = low; KE3 = medium; KE4 = relatively high; KE5 = high; KE6 = very high; E0 = no erosion; E1 = lightweight; E2 = medium; E3 = somewhat heavy; E4 = weight; E5 = very heavy; K0 = in; K1 = medium; K2 = shallow; K3 = very shallow; T1 = fine; T2 = relatively fine; T3 = medium; T4 = somewhat coarse; T5 = coarse; P1 = slow; P2 = a bit slow; P3 = moderate; P4 = relatively fast; P5 = fast; D0 = excessive; D1 = good; D2 = quite good; D3 = somewhat bad; D4 = bad; D5 = very bad; B0 = none; B1 = medium; B2 = lot; B3 = very much; G0 = free; G1 = Slightly affected; G2 = moderately affected; G3 = strongly affected; O0 = never; O1 = sometimes – sometimes; O2 = for one month in a year flooded for more than 24 hours; O3 = 2–5 months of the year regularly suffer from flooding for more than 24 hours; O4 = 6 months or more flooded for more than 24 hours. (*) – can have any inhibiting factor properties, (**) – not valid.

mangrove forests (36.86 ha), dryland agriculture (75.48 ha), mixed dryland agriculture (1,163.11 ha), and shrubs (2,562.08 ha).

Characteristics of land capability

The characteristics of land formation in the Jompi watershed area are 3 factors, namely soil type, land use, and slope. Land characteristics assessment was carried out on LU samples formed from the results of overlaying on land-forming factors. The description of the characteristics of each land unit is the result of observation, measurement, and laboratory tests (Table 2).

Classification of land ability class

The results of the study showed that the land ability class in the Jompi watershed area of Muna regency consisted of 3 classes, namely Class IV covering an area of 2429.27 ha (48.65%), class V covering an area of 1014.08 ha (20.31%), and class VIII covering an area of 1550.10 ha (31.04%), with limiting factors for all land ability classes being surface rocks (medium and very many), slope (steep), drainage (poor and very poor), permeability (slow and fast), and soil texture (rough) (Table 2).

Land capability evaluation

Land ability class IV at the research site has three main inhibiting factors, namely surface rocks (moderate), slope (steep), and drainage (poor) in different LU (presented in Table 3 and Figure 3). The limiting factor in the form of surface rocks greatly affects plant growth and whether or not it is easy to cultivate land [Pg 100] *et al.*, 2022]. In addition, the limiting factor in the form of drainage also has an important influence on class IV. Drainage is a determining factor for plant fertility levels and good soil permeability. Poorly drained soils have low nutrient content. One of the causes is the presence of bacteria *Actinobacteria.* The abundance of bacterial *Actinobacteria* is significantly higher in areas with good drainage (Graça et al., 2021). In addition, rapid drainage occurs in soils with high sand fractions, while soils with high clay fractions have slow drainage (De Feudis et al., 2021). Likewise, the limiting factor in the form of slope slope has a great influence on the loss of soil and nutrients. The rate of soil loss, total nitrogen, and total phosphate in the soil will increase as slope slope increases (Fang, 2021). Slopes are one of the factors that encourage and increase soil erosion. The slope affects the level of surface flow, leaching, and soil transportation

Table 2. Land characteristics in each land unit in the Jompi basin area, Muna regency

UL	KTT	KPT	KKR	KKE	KS	KKT	KDT	KBB	KBE	KBP	KKL
1	T1	P1	B	KE1	G0	K0	D5	O0	E1	B0	V-P1,D5
2	T2	P2	A	KE1	G0	K1	D4	O0	E0	B1	IV-D4
3	T2	P3	D	KE2	G0	K1	D3	O0	E2	B2	IV-D,B2
4	T2	P1	D	KE1	G0	K1	D4	O0	E2	B2	V-P1
5	T2	P1	B	KE1	G0	K0	D4	O0	E1	B0	V-P1
6	Q4	P3	C	KE2	G0	K0	D3	O0	E2	B2	IV-B2
7	Q4	P5	A	KE4	G0	K0	D2	O0	E0	B2	VIII-P5
8	Q4	P4	D	KE3	G0	K1	D2	O0	E2	B2	IV-D,B2
9	Q5	P4	C	KE3	G0	K1	D2	O0	E2	B1	VIII-T5
10	T2	P2	A	KE1	G0	K0	D4	O0	E0	B1	IV-D4
11	T2	P2	D	KE1	G0	K1	D4	O0	E2	B2	IV-D,D4,B2
12	Q4	P5	C	KE5	G1	K1	D2	O0	E2	B0	VIII-P5
13	Q4	P3	D	KE2	G0	K1	D2	O0	E2	B2	IV-D,B2
14	T2	P3	A	KE2	G0	K0	D4	O0	E0	B2	IV-D4,B2
15	T2	P2	C	KE1	G0	K1	D4	O0	E2	B0	IV-D4
16	T2	P3	E	KE2	G0	K2	D2	O0	E2	B4	VIII-B4
17	Q4	P5	B	KE5	G0	K1	D2	O0	E1	B0	VIII-P5
18	Q4	P5	D	KE4	G0	K1	D2	O0	E2	B2	VIII-P5
19	T3	P5	A	KE6	G0	K0	D3	O0	E0	B0	VIII-P5
20	Q4	P5	C	KE3	G1	K1	D2	O0	E2	B0	VIII-P5
21	Q5	P5	C	KE5	G1	K1	D1	O0	E2	B0	VIII-T5,P5
22	Q5	P5	B	KE5	G1	K0	D1	O0	E1	B0	VIII-T5,P5

Note: Results match between land characteristics and land ability class criteria. UL (land unit), KTT (soil texture class), KPT (soil permeability class), KKR (slope class), KKE (erosion sensitivity class), KS (salinity class, KKT (soil effective depth class), KDT (soil drainage class), KBB (flood hazard class), KBE (erosion hazard class), KBB (surface rock class), KKL (land ability class).

and affects soil organic matter levels due to surface erosion (Mujiyo et al., 2020).

This grade of land is suitable for a variety of agricultural uses, ranging from annuals (and agricultural crops in general), grass crops, meadows, production forests, and nature reserves (Arsyad, 2010b). Land capability class IV requires special conservation measures such as planting perennial crops, creating terraces, improving drainage, planting cover crops/livestock feed for 3–5 years [Ayobami Ogunsola *et al.*, 2021; Suzuki, 2024].

Land ability class V has two limiting factors, namely soil permeability (slow) and soil drainage (very poor), which are identified in several LUs (presented in Table 3 and Figure 3). The height and low permeability of the soil were influenced by the texture of the soil at the research site. In addition to soil texture factors, soil chemical properties, especially organic matter content, also significantly contribute to the low level of soil permeability in the research area. Low organic matter content impacts poor soil permeability [Hidayat *et al.*, 2022]. The texture of clay soil dominates the land in this class. The soil's clay content significantly determines the permeability value and affects the soil's ability to absorb water [Henrique Novotny *et al.*, 2023; Suharyatun *et al.*, 2023]. Low permeability values and the dominance of clay soil texture affect the soil drainage level, which is very poor [Li *et al.*, 2021].

According to [Arsyad, 2010] that land ability class V should always be covered with vegetation such as forests or shrubs. However, class V land can still be used for other purposes that are more suitable for these conditions. Some common uses for class V capability land include pasture, plantation or forestry forests, recreational or conservation uses, wildlife habitat maintenance, and biomass production for energy (Fanish & Priya, 2013; Yenibehit et al., 2024).

Land ability class VIII has three limiting factors, namely surface rocks (very many), soil permeability (very fast), and soil texture (very rough), which are identified in several LU (presented in Table 3 and Figure 3). This class of land ability has

Table 3. Land ability class and its limiting factors in each land unit in the Jompi basin area, Muna regency

Land units	Land capability class	Area	
		(Ha)	(%)
6	IV-B2	97.94	1.96
3, 8, 13	IV-D, B2	569.21	11.40
11	IV-D, D4, B2	73.35	1.47
2, 10, 15	IV-D4	1,580.47	31.65
14	IV-D4, B2	108.30	2.17
4, 5	V-P1	269.14	5.39
1	V-P1, D5	744.94	14.92
16	VIII-B4	10.41	0.21
7, 12, 17, 18, 19, 20	VIII-P5	1,417.87	28.39
9	VIII-T5	81.53	1.63
21, 22	VIII-T5, P5	40.29	0.81
Total		4,993.45	100.00

Note: Matching results between the analysis results and the land ability class criteria.

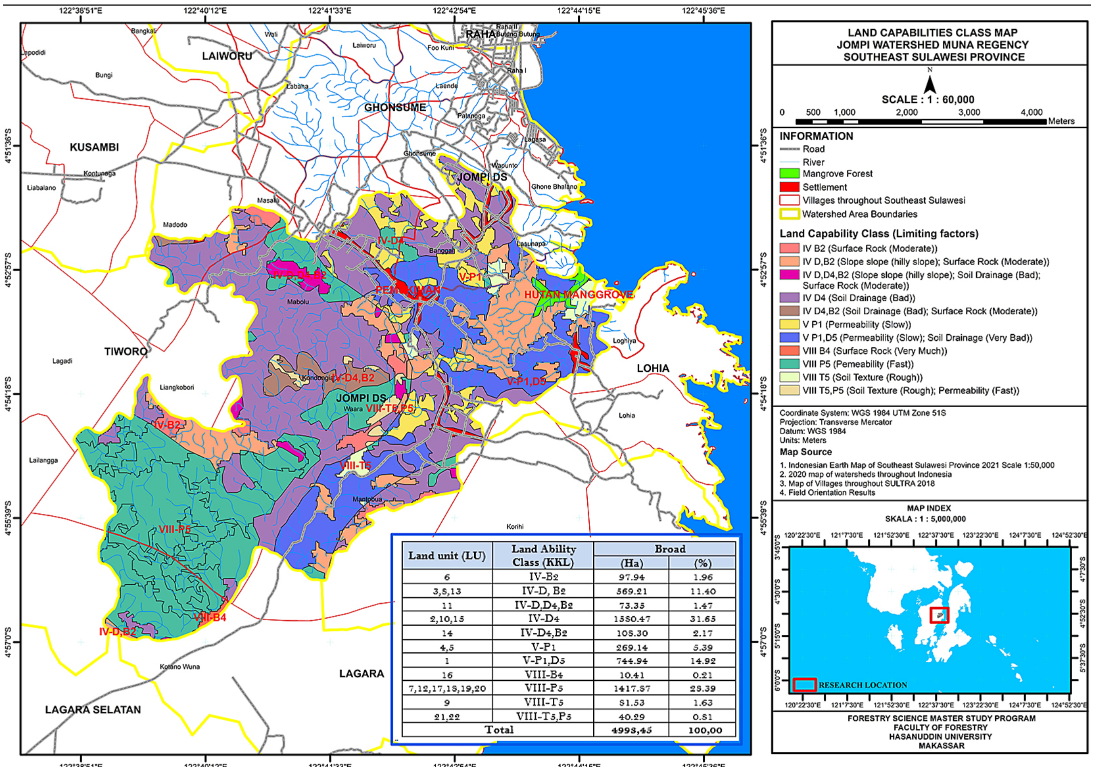

Figure 3. Map of land ability class in the Jompi watershed area of Muna regency (ArcGIS Analysis, 2024

a limiting factor in the form of a large number of surface rocks, so it affects planning and agricultural practices in the area of the research location (Bitew and Alemayehu, 2017). In addition, this class of land ability has a very fast soil permeability limiting factor and a very rough soil texture that affects the ability to store water (Permata et al., 2022), vulnerability to erosion, nutrient limitations, and limited plants that can be grown (Abu-Hashim et al., 2021). According to [Arsyad, 2010] explained that land ability class VIII is unsuitable for cultivation or should be left naturally.

Land use directions in the Jompi basin area, Muna regency

Based on the results of this study, the appropriate land use direction can be determined

Table 4. Land use directions in the Jompi watershed area, Muna regency

ST	KKL	Sub-KKL	LU	Land use instructions	Land management	Area	
						(Ha)	(%)
APL	IV	IV B2	6	Agroforestry	Addition of organic matter	73.57	1.47
		IV D, B2	3,8,13	Agroforestry	Terraces and addition of organic matter	475.16	9.52
		IV D, D4, B2	11	Agroforestry	Terraces and addition of organic matter	73.35	1.47
		IV D4	2,10,15	Agroforestry	Addition of organic matter	1467.21	29.38
		IV D4,B2	14	Agroforestry	Addition of organic matter	108.30	2.17
	V	V-P1	4,5	Agroforestry	Addition of organic matter	269.14	5.39
		V P1,D5	1	Agroforestry	Addition of organic matter	666.84	13.35
	VIII	VIII P5	7,12,17,18,19	Left naturally	-	448.67	8.99
		VIII T5	9	Left naturally	-	81.53	1.63
		VIII T5,P5	21,22	Left naturally	-	40.29	0.81
HP	IV	IV B2	6	Agroforestry	Addition of organic matter	24.37	0.49
		IV D,B2	8	Agroforestry	Terraces and addition of organic matter	73.89	1.48
		IV D4	10,15	Agroforestry	Addition of organic matter	112.65	2.26
	V	V P1,D5	1	Agroforestry	Addition of organic matter	47.83	0.96
	VIII	VIII B4	16	Left naturally	-	10.41	0.21
		VIII P5	7,17,18,19	Left naturally	-	960.69	19.24
HL	IV	IV D,B2	8,13	HL	-	20.17	0.40
		IV D4	10	HL	-	0.61	0.01
	V	V P1,D5	1	HL	-	30.27	0.61
	VIII	VIII P5	20	HL	-	8.51	0.17

Note: Results of forest area overley with land ability class criteria. Description: KKL (land capability class), SUB-KKL (sub-land capability class), APL (other use area), HP (production forest), HL (protected forest).

based on the results of the overlay of forest area maps and land ability class evaluation maps so that two land use directions can be formulated, namely Agroforestry and protected forests (PF) (presented in Table 4).

Land with land ability classes IV and V in other use areas and production forests are recommended for agroforestry systems accompanied by soil and water conservation measures to create terraces for slope restriction factors. The advantages of making a terrace include reducing surface flow, controlling erosion, and increasing crop yields [Deng *et al.*, 2021]. The addition of organic matter for limiting factors in the form of soil drainage, surface rocks, soil permeability, and soil texture can improve soil structure, increase water storage capacity, improve soil drainage, and fertilize soil [Al-Shammary *et al.*, 2024; Ma *et al.*, 2023]. Land in land ability class VIII in the status of other use area and production forest is recommended to remain in nature. Land with land ability classes IV, V, and VIII in protected forest areas is still maintained as a protected forest area or left naturally.

The Jompi watershed has a variety of commodities, including agricultural crops in the form of corn, pumpkin, watermelon, peanuts, and annual crops in the form of buttermilk, local teak, Jabon (*Nauclea cadamba* Roxb.), and coconut, as well as quite a lot of livestock in the form of chickens and cows. Therefore, agroforestry can be developed in the Jompi watershed area by combining annual crops with agricultural crops and livestock (Figure 4). The implementation of agroforestry systems has a positive impact on the environment in the form of water conservation and hydrological balance, soil erosion control, improving soil quality and fertility, increasing biodiversity, and reducing carbon emissions, as well as social and economic impacts on the form of increased productivity and income diversification, food security, marginal land utilization, and reducing the risk of crop failure [Castle *et al.*, 2022; Kaur *et al.*, 2023; Panther *et al.*, 2021].

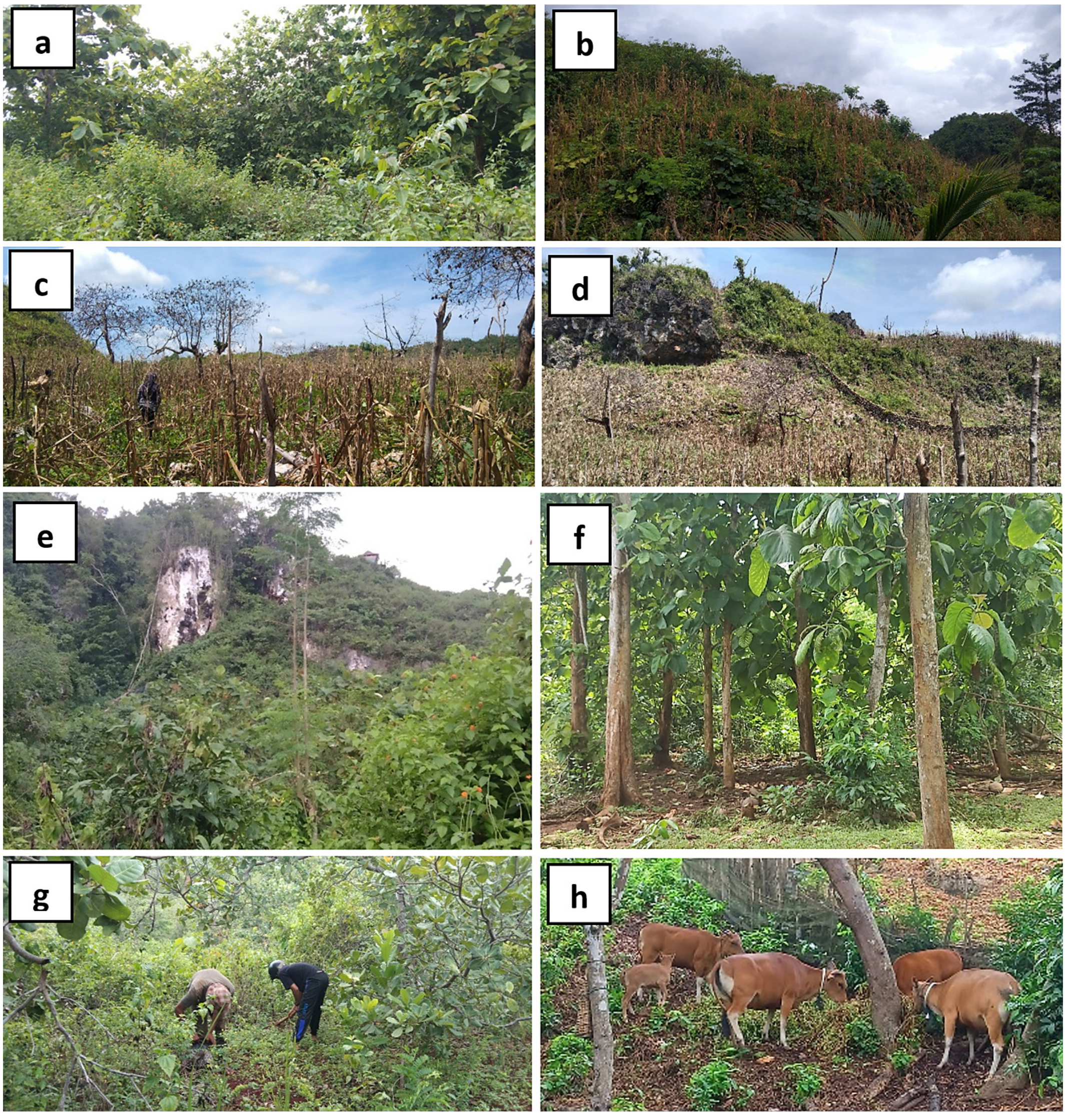

Figure 4. Random sampling was conducted at the research site across various land units with different types of land cover, including a) shrubs and teak trees; b) corn fields situated on hilltops; c) corn fields on flat terrain; d) corn cultivated among karst rocks; e) Jabon (*Nauclea cadamba* Roxb.) trees planted on flat land between karst cliffs; f) teak stands thriving in flat areas and valleys; h) cashew plants; and i) silvopastoral systems integrating cattle as part of the agroforestry framework

CONCLUSIONS

It can be concluded that this study has succeeded in achieving its goal of identifying land ability classes and formulating appropriate land use directions. This research revealed that the area consists of three land capabilities classes, namely IV, V, and VIII, each with specific limiting factors that affect its management potential. The analysis of the overlay between the forest area map and the land ability class evaluation map resulted in two main directions for land use, namely the agroforestry system with conservation actions, such as the creation of terraces and the addition of organic matter, applied to the land use area and production forest area for classes IV and V and protected forest, recommended for the land use area and production forest area in class VIII and all protected forest areas. These findings provide an integrated approach to forest and land management in the Jompi watershed, fill information gaps related to land ability-based land use directions, and provide a scientific basis for sustainable regional management. Future research prospects include evaluating the impact of implementing these recommendations on land productivity, community welfare, and watershed ecosystem sustainability.

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