Land Suitability and Capability Analysis for Evaluating the Land Use in Achieving Sustainable Land Management in Banyumanik, Gunungkidul

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Abstract. Banyumanik is an area that has been geomorphologically shaped by the solutional process of karst rock, and it features various land uses. Improper land management based on these characteristics can lead to land degradation, primarily through erosion and sedimentation. This study aims to assess the current land uses, analyze land reserves and capabilities, and provide recommendations for land use aligned with these capabilities and reserves. The research employs survey techniques and map overlay using ArcGIS software. Sampling points were determined through random sampling. Analysis of land capability and suitability utilized the guidelines from the Indonesian Minister of Environment Regulation Number 17 of 2009. The analysis revealed five types of land use in Banyumanik, covering a total area of 177.22 hectares. The land capability was classified into three categories: Forest (Class V), Residence (Class I), Rained Rice (Class III), Field Land (Class V), and Shrub (Class III). Based on this classification, the use of Forest Land, Residence, Rained Rice, and Shrub is appropriate. However, the use of Field Land is deemed unsuitable as it falls under Class V. To improve land usage in Banyumanik, Field Land should be integrated with tree species, such as Teak (*Tectona grandis*), within an agroforestry system.

1 Introduction

The increasing population, especially in Indonesia, is putting increasing pressure on natural resources and forests. To meet the living needs of the growing population, an increase in food supply is required, which results in pressure on forest areas for food production. Increasing population and urbanization processes have also increased pressure on existing forest resources. In many cases, especially in critical areas such as Gunungkidul, the limited availability of agricultural land is a factor that supports changes in land use. Increased pressure on available land resources can result in land degradation [1]. Therefore, a reliable, effective, and accurate land evaluation is necessary for the decision-making process. Making

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appropriate land use policies can support sustainable rural development. Land evaluation techniques are important for developing models and predicting land suitability for various types of land use.

Land evaluation is the basis for rescheduling and sustainable management of land resources because it can determine whether these resources have experienced degradation or increased quality [2], [3]. Land capability was determined by different land characteristics, such as soil type, which are very important for productivity, basic geology, topography, and hydrology. This characteristic limits the area of land that utilized for various purposes. The ultimate goal of land capability classification is to predict the agricultural land development unit's ability to utilize land resources. Evaluation of land suitability depends on land capability as well as other factors such as land quality, proximity to different accesses, land ownership, customer demand, and economic value.

Land use that is not in accordance with the ability of the land will encourage land degradation caused by the development of erosion and sedimentation processes. Erosion will leave soil that is poor in nutrients and soil solum that is decreasing, so that critical land occurs. In karst and semi-arid regions, such as parts of Gunungkidul, this mismatch often leads to severe topsoil loss and subsurface degradation, which significantly reduces the soil's water retention capability [4]. In many areas, soil degradation and erosion reduce the quality and nutrient content of the soil in the longrun. The result of this degradation is the creation of various environmental, cultural, economic, social, and political problems on a local, national, and even global scale. Critical land restoration is very expensive and takes a long time. For example, it takes up to one hundred years to form 4 cm-thick soil.

Economic development in Gunungkidul, especially in Banyumanik Hamlet, Pancarejo Village, is very dependent on agricultural activities because agriculture is the main occupation of the majority of the community. Expansion of cultivation areas to compensate for low yields on degraded land and soil exploitation without restoration of soil fertility is a challenge in sustainable development in this hamlet. Land suitability functions as an alternative to sustainable resource management, predicting the potential and limitations of land for crop production [5]. Geographic Information System (GIS) techniques have been used to spatially identify and evaluate the physical capabilities and suitability of land. GIS is proven to be a helpful and successful tool in studying, mapping, processing, and presenting certain problems effectively. By integrating Multi-Criteria Decision Analysis (MCDA) with GIS, researchers can weigh various biophysical and socio-economic parameters more objectively to produce highly accurate spatial suitability maps [6]. For this reason, it is necessary to study the characteristics of the land for current and potential capabilities and the suitability of crop production. Field survey data is needed to examine soil properties, drainage, slope, and other supporting data for land suitability and capability analysis.

Departing from the description of the condition of the community, the characteristics of the study location, and the degradation of the land, it is deemed necessary to carry out this research immediately, bearing in mind that land use that is not in accordance with land capability and land suitability classes will reduce land quality. This study aims to:

1. Examine current forms of land use;
2. Analyze land suitability and land capability;
3. Formulate suggestions for land use according to land suitability and suitability classes.

The results of land suitability analysis can be used as a guide in making strategic land use decisions. This study will benefit the community in managing sustainable and sustainable land resources so that they can be passed on to the next generation. Moreover, the research results are intended to formulate preventive measures so that land degradation can be suppressed.

2 Material and methods

2.1 Research site

This research was conducted in Banyumanik Hamlet, Pacarejo Village, Semanu District, Gunung Kidul, which is included in the Baron Underground River Catchment Area. The Baron Underground River flows through Banyumanik Village, Semanu District, Gunung Kidul Regency (Figure 1). The research area is included in the karst landscape of the origin of the solution process. Some of the location points are clearly visible as the constituent parent rocks in the form of carbonate rocks. Physiographically, the study area is included in the Southern Mountains Zone.

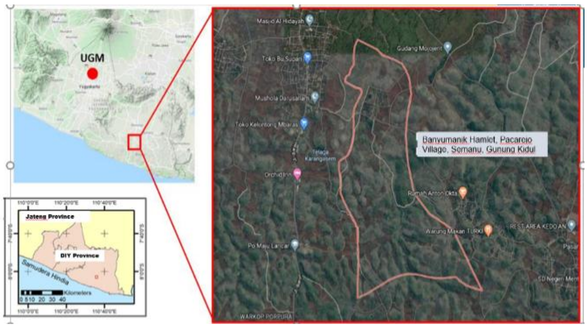


Fig 1. Study area at Banyumanik Hamlet, Pacarejo Village, Semanu, Gunung Kidul, Java island, Indonesia.

2.2 Data Collecting Method

Before data collection, a field survey (ground check) was conducted to determine the data collection locations. Data collection locations were located across various land use types: forests, fields, shrubs, rice fields, and residential areas. Data collection points were located based on land units formed by overlaying land use maps and slope maps using a purposive sampling method.

At each observation point, using random sampling, a representative area was obtained for each land use type, thus representing field conditions. To obtain representative data, soil data collection was conducted with a breakdown of three forest land use samples, three fields, three settlements, three rice fields, three food crops, and three shrubs.

Slope gradient was measured using a survey using a clinometer for each land use. Slope gradients were categorized according to land capability classification as follows:
A = 0 to 3%
B = 3 to 8% (gentle or undulating)
C = 8 to 15% (slightly sloping or undulating)
D = 15 to 30% (sloping or hilly)
E = 10 to 45% (slightly steep).

Soil erodibility was determined by collecting soil samples at the study site. The purpose of soil sampling was to determine the physical and chemical properties of the soil. These physical and chemical properties include structure, texture, specific gravity (SG), bulk density (BV), organic matter (OM), porosity, and permeability. Soil sampling was performed using a soil ring for undisturbed soil and using a plastic bag for disturbed soil.

Soil erodibility was analyzed using a nomograph and the equation proposed by [7]. To calculate the value of erodibility using a nomograph, the erodibility value is obtained from the results of plotting between soil texture data (total percentage of sand and total percentage of fine sand + dust), soil structure type data, soil permeability speed data (cm/hour), and soil organic matter percentage data on the nomograph.

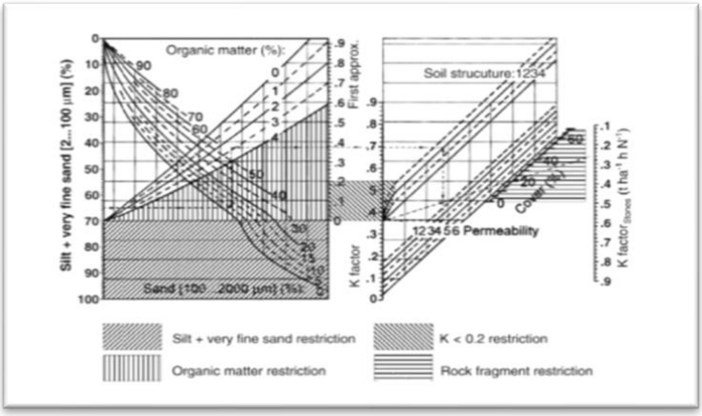


Fig. 2. Nomograph for erodibility [8].

In using a nomograph, soil erodibility was calculated using the equation proposed by [7], if the % sand and silt content is >70%, use the following formula:

$$K = (2.173\mathbf{M}^{\wedge}1.14\ (10)^{\wedge}(-4))(12-\mathbf{a})+3.25(\mathbf{b}-2)+2.5(\mathbf{c}-3))/100 \qquad (1)$$

Note:
M = (% very fine sand + % silt content) x (100 - % clay)
a = % soil organic matter
b = soil structure code used in soil classification
c = permeability class code
The % very fine sand content was estimated as 1/3 x % sand.

Soil texture indicates the ratio of sand, silt, and clay grains [9]. Soil texture is measured in the laboratory using the pipette method. Soil organic matter has a fairly complex structure, but its composition is relatively constant. The Walkley and Black method is used to determine the percentage of organic matter in the soil.

Soil permeability is the ability of water or air to pass through saturated soil per unit time. Soil permeability was analysed in the laboratory using a soil permeameter. Effective soil depth is the depth of soil favorable for plant root growth, reaching a layer impermeable to plant roots. The Effective soil depth was classified as follows:
K0 = more than 90 cm (deep)
K1 = 90 to 50 cm (medium)
K2 = 50 to 25 cm (shallow)
K3 = less than 25 cm (very shallow)

The appearance (forms) of erosion, namely sheet erosion, gully erosion, and gully erosion, will determine the level of erosion hazard. Erosion hazard is a condition that suggests soil erosion will occur in the relatively near future, or if soil erosion has already occurred, the erosion hazard is the level of soil erosion that will occur in the future. The following is a classification of erosion features:
e0 = no erosion;
e1 = light: less than 25% of the topsoil is lost;
e2 = moderate: 25 to 75% of the topsoil is lost;
e3 = moderately severe: more than 75% of the topsoil to less than 25% of the subsoil is lost;
e4 = severe: more than 25% of the subsoil is lost; e5 = very severe: gully erosion

Soil drainage is the property of excessive drying of water in the soil, including the distribution and diversion of water both in the soil profile and on the surface of the soil.
do = excessive (excessively drained), water comes out of the soil more quickly, and very little water is retained by the soil, so that plants will soon experience water shortages
d1 = good, the soil has good air circulation. The entire soil profile from top to bottom (around 150 cm) is a uniform light color, and there are no yellow, brown, or gray spots.
d2 = quite good, the soil has good air circulation in the root area; There are no yellow, brown, or gray spots in the top soil layer and the top of the subsoil layer (up to about 60 cm from the soil surface).
d3 = quite poor, the top soil layer has good air circulation; There are no yellow, gray, or brown spots. Spots are found throughout the lower soil layer (around 40 cm from the soil surface).
d4 = bad, the bottom of the soil layer, above (near the surface), there are gray, brown, and yellow colors or spots.
d5 = very bad, the entire soil layer up to the surface of the soil is gray, and the lower soil layer is gray or has bluish spots, or there is water that stagnates on the surface of the soil for a long time, thereby inhibiting plant growth.

The threat of flooding or inundation is categorized as follows:
bo = never: the land is never flooded for more than 24 hours in one year.
bi = sometimes: flooding that covers the land for more than 24 hours occurs irregularly in periods of less than one year.
b2 = the land is regularly flooded for more than 24 hours during one month of the year.
b3 = the land is regularly flooded for more than 24 hours during two to five months of the year.
b4 = the land is regularly flooded for more than 24 hours during six months or more.

Soil salinity is expressed in terms of soluble salt content or electrical resistance of soil extracts as follows:
go = free, 0 to 0.15% soluble salts; 0 to 4 (EC x 103) mmhos per cm at 25°;
g1 = slightly affected, 0.15 to 0.35% soluble salts; 4 to 8 (EC x 103) mmhos/Cam at 25°;
g2 = moderately affected: 0.35 sa, pao 0.65% soluble salts, 8 to 15 (EC x 103) mmhos/Cam at 25°;
g3 = severely affected: more than 0.65% soluble salts; more than 15 (EC x 103) mmhos/Cam at 25°.

Coarse materials can be found within the soil layer or on the surface. Coarse materials found within the 20 cm layer or in the upper part of the soil that are larger than 2 cm are classified as follows: Gravel: Coarse material with a diameter greater than 2 mm and up to 7.5 cm if round or up to 15 cm long axis if flat. Gravel within the 20 cm layer and the surface of the soil is classified as follows:
bo = none or little: 0 to 15% of the soil volume;
b1 = moderate: 15% to 50% of the soil volume;
b2 = abundant: 50% to 90% of the soil volume;
b3 = very abundant: more than 90% of the soil volume.
Gravel: Coarse material or rocks with a diameter of 7.5 cm to 25 cm if round or with a long axis of 15 cm to 40 cm if flat. The amount of gravel is classified as follows:
bo = none or little: 0 to 15% of the soil volume;
b1 = moderate: 15% to 50% of the soil volume; tillage begins to be somewhat difficult, and plant growth is somewhat impaired;

b2 = extensive: 50% to 90% of the soil volume; tillage is very difficult, and plant growth is somewhat impaired;
b3 = very extensive: more than 90% of the soil volume; tillage is impossible, and plant growth is impaired.

Rocks on the surface of the soil are divided into two types:
Loose rocks: Loose rocks are rocks scattered on the surface of the soil and have a diameter greater than 25 cm (round) or an elongated axis of more than 40 cm (flattened). The distribution of loose rocks on the surface of the soil is classified as follows:
bo = no less than 0.01% of the area;
b1 = slight: 0.01% to 3% of the soil surface is covered; tillage is still somewhat disturbed but does not interfere with plants;
b2 = moderate: 3% to 15% of the surface is covered; tillage begins to be somewhat difficult, and production area is reduced;
b3 = extensive: 15% to 90% of the land surface is covered; tillage and planting become very difficult.
b4 = very extensive: more than 90% of the land surface is covered; the land is completely unusable for agricultural production.
Rock: The distribution of exposed rock is grouped as follows:
bo = no, less than 2% of the land surface is covered;
bi = little: 2% to 10% of the land surface is covered; soil cultivation and planting are somewhat disturbed;
b2 = moderate: 10% to 50% of the land surface is covered; soil cultivation and planting are disturbed;
b3 = extensive: 50% to 90% of the land surface is covered; soil cultivation and planting are severely disturbed;
b4 = very extensive: more than 90% of the land surface is covered; the land cannot be cultivated at all.

2.3 Land capability classification

Land capability classification is the systematic assessment of land components, which, according to [10], is a systematic assessment of land components and grouping them into various categories based on characteristics that represent potential and constraints to land use. Land is classified into three main categories: class, subclass, and land capability unit. The land capability classification structure is based on inhibiting factors, as shown in Table 1.

Table 1. Land capability classification [11]

Division	Land Capability Class	Land Capability Sub-class	Management Unit	Soil Mapping Unit
Arable (Can be cultivated)	I II III IV	 IIIe (erosion) IIIw (flooding) IIIs (soil limitations, etc.)	 IIIe1, 1 IIIe2, 2 IIIe3, 3	 Series x Series y Series z

Division	Land Capability Class	Land Capability Sub-class	Management Unit	Soil Mapping Unit
Non-arable (Cannot be cultivated)	V VI VII VIII			

Land capability classification is applied as a method for land-use planning. Furthermore, the relationship between land capability class and land use intensity and type is presented in Figure 3.

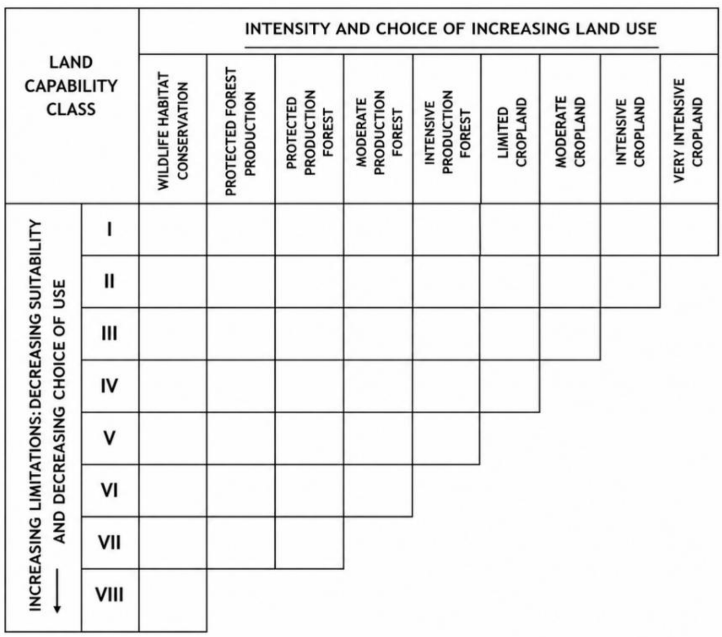


Fig. 3. Land capability classification [11].

Figure 3 shows the schematic relationship between land capability classes and land use based on the definition of land capability classes and subclasses, and the grouping of land properties or qualities. The relationship between capability classes and classification criteria is matched in Table 2.

Table 2. Land capability classification criteria

Inhibiting Factors / Limitations	I	II	III	IV	V	VI	VII	VIII
1. Surface slope	A	B	C	D	A	E	F	G
2. Erosion susceptibility	KE_1	KE_3	KE_4, KE_5	KE_5	(*)	(*)	(*)	(*)
3. Erosion level	E_0	E_1	E_2	E_2	(**)	E_4	E_5	(*)
4. Soil depth	t_1, t_2	K_1	K_2	K_2	(*)	K_3	(*)	(*)
5. Topsoil texture	t_3, t_3	t_1, t_2, t_3	t_1, t_2, t_3, t_4	t_1, t_2, t_3, t_4	(*)	t_1, t_2, t_3, t_4	t_1, t_2, t_3, t_4	t_5
6. Subsoil texture	t_3, t_3	t_1, t_2, t_3	t_1, t_2, t_3, t_4	t_1, t_2, t_3, t_4	(*)	t_1, t_2, t_3, t_4	t_1, t_2, t_3, t_4	t_5

7. Permeability	P_2, P_3	P_2, P_3	P_2, P_3, P_4	P_2, P_3, P_4	P_1	(*)	(*)	P_5
8. Drainage	d_1	d_2	d_3	d_4	d_5	(*)	(*)	d_0
9. Gravel/Stoniness	b_0	b_1	B_1	b_2	b_3	(*)	(*)	b_4
10. Flood threat	O_0	O_1	O_0	O_3	O_4	(**)	(*)	(*)
11. Salinity/Salt	g_0	g_1	G_2	g_3	(**)	G_3	(*)	(*)

3 Result and discussion

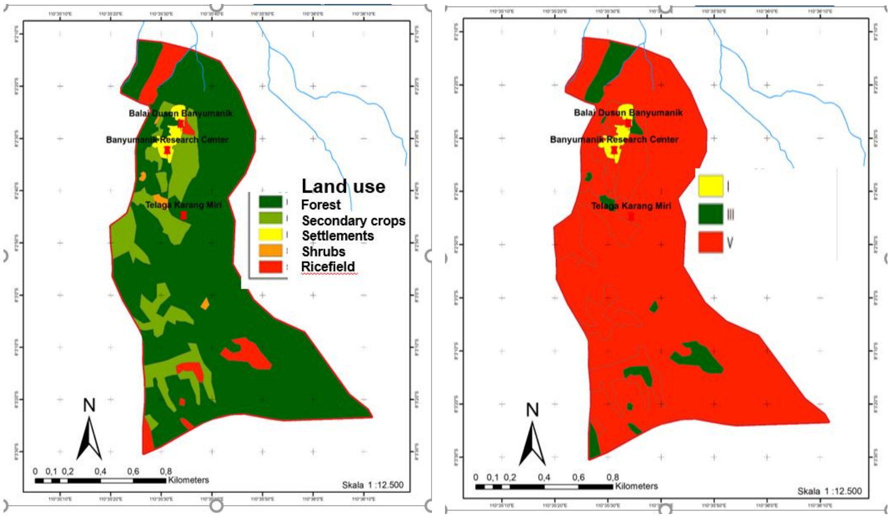
Classification of land capability is a process of systematically assessing land and grouping it into several categories based on the potential and obstacles to its sustainable use. An ability class is a group of ability subclasses that have the same relative level of limitation or hazard. Ability classes are denoted by a Roman letter symbol, and the boundaries for land use and management are increasing from class I to class VIII. The ability class category is divided into two groups, namely the first group, which is class I to IV, which are considered to be used for farming land or as land that can be cultivated, and the second group, which is class V to class VIII, which is determined as land that cannot be cultivated for farming. The results of the analysis are presented in Table 3.

Table 3. Land capability class.

Land use	**Tek**	**Per**	**Sol**	**Ler**	**Dra**	**Ero**	**Ker**	**Bkc**	**Blp**	**Btp**	**Gen**	**KL**
Forest	t2	p1	k3	i3	d2	e0	b1	b2	b1	b0	o0	V
Settlements	t2	p2	k3	i0	d1	e0	b1	b0	b0	b1	o1	I
Rainfed paddy field	t1	p2	k2	i0	d2	e1	b1	b0	b0	b1	o2	III
Herbs	t1	p2	k2	i0	d2	e1	b1	b0	b0	b1	o0	V
Shrubs	t1	p2	k2	i3	d1	e0	b1	b1	b1	b0	o1	III

Note
PL : Land use
Tek : Soil texture
Per : Permeability
Sol : Soil solum
Ler : Slopes
Dra : Drainage
Ero : Erosion
Ker : Small polder
Bkc : Polder
Blp : Loose stone
Btp : open stone
Gen : Floods
KL : Land capability class

Classification of land capability was calculated through several parameters of the Land Capability Class. This research examines the area of Banyumanik Hamlet, Semanu District, Gunungkidul. The area of Banyumanik Hamlet is 177.22 Ha, with the use of forest land, settlements, rainfed rice fields, crops, and shrubs, as in Table 4. Rainfed 0.99 Ha, and 9.73 Ha Shrubs. Geomorphologically, Banyumanik is a karst (solutional) landscape formed due to the dissolving process of carbonate rocks. Figure 4 shows the Banyumanik Hamlet area with hills (cockpit), which reflects that the classification in this Hamlet has developed.



A B

Fig. 4. Land use map (A) and land capability class (B) of the Banyumanik area.

The analysis results indicate that forest land use falls into land capability class V. This land is characterized by a sandy clay loam texture (t2), with slow soil permeability (p1). Very shallow soil depth (k3) with a hilly, sloping slope (i3). Forest land use has relatively poor drainage (d2), but no erosion (e0). Limiting factors include a moderate gravel proportion (d1), a high proportion of small rocks (b2), and a low proportion of loose rocks (b1). No exposed rocks were found (b0), and the threat of flooding never existed (o0).

Residential land use falls into land capability class I. This land is characterized by a sandy clay loam texture (t2), with moderate soil permeability (p2). Very shallow soil depth (k3) with a flat slope (i0). Residential land use has relatively good drainage (d1), but no erosion (e0). The inhibiting factors include the proportion of gravel, which is moderate (d1), but the proportion of small rocks was not found (b0), and the proportion of loose rocks was not found (b0). Exposed rocks are small (b1), and the threat of flooding is occasional (o1).

Rainfed rice field land use falls into land capability class III. This land is characterized by a clay texture (t1), moderately slow soil permeability (p2), shallow soil depth (k2), with a flat slope (i0). Residential land use has relatively poor drainage (d2) and mild erosion (e1). The limiting factor is the moderate proportion of gravel (d1), but no small rocks (b0), and no loose rocks (b0). Exposed rock is low (b1), and the risk of flooding is high, with the land regularly covered by water for one month a year (o2).

Secondary crops (secondary crops) fall into land capability class V. This land is characterized by a sandy clay loam texture (t2), moderately slow soil permeability (p2), very shallow soil depth (k3), with a flat slope (i0). Secondary crops (secondary crops) have relatively poor drainage (d2) and mild erosion (e1). The inhibiting factors in the form of gravel proportion are moderate (d1), but the proportion of small rocks is not found (b0), and the proportion of loose rocks is not found (b0). Exposed rocks are small (b1), and threats never exist (o0).

Shrubland land use is included in land capability class III. The characteristics of this land have a sandy clay loam texture (t2), and the soil permeability is included in the class of rather slow (p2). The soil depth is shallow (k2) with a hilly sloping land slope (i3). The drainage of forest land use is quite good (d1), but there is no erosion (e0). The inhibiting factors are the proportion of gravel, including moderate (d1), the proportion of small rocks, including moderate (b1), and the proportion of loose rocks, including small (b1). Exposed rocks are not found (b0), and the threat of flooding is sometimes (o1).

Land Capability Class V is generally not suitable for agricultural activities, but in Banyumanik Hamlet, the land is used for secondary crops such as corn, cassava, and peanuts. This land has constraints that limit the choice of uses and crops due to its shallow soil depth of 50-25 cm. Land with Land Capability Class V is recommended for grasslands, pastures, production forests, protected forests, and nature reserves. Utilizing Class V land for intensive seasonal agriculture without adequate conservation practices can trigger high runoff and accelerate the formation of critical lands [12]. Land Capability Class III in Banyumanik Hamlet is suitable for its intended use, namely for rain-fed rice farming activities. Land with Land Capability Class III is recommended for annual crops, crops that require soil cultivation, grasses, grasslands, production forests, protected forests, and nature reserves. This aligns with the principle that Class III land has moderate limitations that restrict the choice of plants and require careful soil management, such as terracing and specific drainage control, to prevent erosion and sustain productivity [13], [10]. Land Capability Class I in Banyumanik Hamlet is suitable for residential purposes. Land Capability Class I can also be used for annual crops, grasses, forests, and nature reserves.

Table 4. Land suitability of Banyumanik

Land use	**Land class**	**Constraints factor**	**Area (Ha)**	**Evaluation**
Forest	V	Slope and soil solum	138,11	Suitable
Settlements	I	Floods	2,7	Suitable
Rainfed paddy fields	III	Slope and floods	0,99	Suitable
Herbs	V	Slope and soil solum	26,03	Not suitable
Shrubs	III	Slope and soil solum	9,73	Suitable

Land suitability can be seen in Figure 4 and Table 4, the results of the map overlay and data analysis. Land suitability is a description of the level of suitability of a plot of land for a particular use [14]. Land suitability classification is the process of interpreting or grouping land areas into more detailed sections according to their level of suitability for a particular use. Land suitability classification is more specific for a particular crop or land use, while land capability classification is more general for a sustainable use.

Field surveys show that areas that are actually classified as Land Capability Class V have largely been used for forestry. The majority of forest land in Banyumanik Hamlet is used for production forest owned by PT. Lintang Jati Kencana and community forests. Teak plantations belonging to the Yogyakarta Forestry Service are also located in Banyumanik Hamlet. Some areas in Land Capability Class V are still used for secondary crops, so based on data analysis, the current land use is not in accordance with its intended use. The current land use, which consists of rain-fed rice paddies and shrubs, is appropriate, according to the Land Capability Class analysis and map overlay. Rain-fed rice paddies in Banyumanik Hamlet are not always planted with rice; during the dry season, they are used for secondary crops. Some rain-fed rice paddies have been abandoned for agriculture and are left to grow grass for livestock feed.

Settlements in Banyumanik Hamlet are concentrated, with a smaller proportion of residential areas than non-residential areas. Settlements are only located on the northern side of Banyumanik Hamlet. The community chose settlements in the northern region due to the availability of water and the land's slopes, which are easy to live on. Residential land use in Banyumanik Hamlet is in accordance with the land capability class. Shrubland land use is also appropriate because it is located in a sloping area prone to flooding. Maintaining shrubs or natural vegetation on these vulnerable terrains acts as a critical biological barrier that enhances water infiltration, minimizes surface runoff, and prevents severe mass wasting or flash floods downstream [15].

4 Conclusions

The land capability and suitability analysis study in Banyumanik Hamlet yielded the following conclusions:

1. Banyumanik Hamlet covers an area of 177.22 hectares, divided into five land uses: Forest, Residential, Rainfed Rice Fields, Secondary Crops, and Shrubland.
2. The Land Capability Classes of Forest (V), Residential (I), Rainfed Rice Fields (III), and Shrubland (III) are appropriate for their intended use. The use of Secondary Crops is less appropriate for its intended use, with Land Capability Class V.
3. The use of Secondary Crops in Banyumanik Hamlet should be combined with tree species such as teak. The karst landscape, water scarcity, and socio-economic conditions of communities like those in Banyumanik Hamlet would be better served by implementing an agroforestry system combining teak and secondary crops. This would maintain ecological function and socio-economically support the income of residents, as teak can be used as long-term savings with good commercial value.

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