

Comparative study of land capability and land suitability for pepper plants (*Piper nigrum* L.) on karst and non-karst area in Pacitan Regency

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Abstract. Karst areas are often major challenges for agricultural development. Punung District in Pacitan Regency is included in the Gunung Sewu Karst Area, a UNESCO heritage geopark. Even as a center for pepper production, the production continues to decline. This study aims to determine the capability and suitability of land for pepper plants in the karst and non-karst areas of Punung District. This study is a field survey with purposive random sampling. The sampling points are based on the overlay of soil type, geology, and rainfall maps. The data variability of soil characteristics from the sampling was analyzed using ANOVA and resulted in a Land Map Unit (LMU). Data from the LMU were analyzed by matching the criteria for capability and land suitability with the results of observations. The results showed that the land capability of the karst and non-karst areas is the same class as II, III, and IV with limiting factors of surface, erosion rate, and soil depth. Land suitability for pepper is also the same, as marginal suitability (S3) with the limiting factors being the availability of water, very low available P nutrients, and the rate of erosion. The impact of this study is the Karst and non-karst do not significantly affect the class of land capability and land suitability for pepper plant development in this study area.

1 Introduction

Pacitan Regency is a small part of Mount Sewu Karst Area which extends from West Pacitan – East Pacitan [1]. Gunungsewu National Park has been designated as a network of world geoparks (Global Geopark Network) stretching from Gunungkidul, DIY; Wonogiri, Central Java; to Pacitan, East Java [2]. The Sewu Karst consists of the Wonosari Punung Formation from the Middle Miocene to the Pliocene [3]. Karst types are differentiated into exokarst, endokarst, merokarst, and holokarst [4]. Punung district located at 8° 02' 0" - 8° 18' 0" LS and 110° 96' 0" - 111° 1' 0" BT [5] includes karst with holokarst type with development that most perfect [6]. Punung district has sediment: clastic: medium: limestone and sediment:

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reef: limestone geological formations formed from sedimentation that produced limestone rocks. The soils formed from karst are generally latosols or loams having minimum soil depth (mean < 50 cm) [7]; red Mediterranean and renzina associations [8]; in the grumosol.

In addition to karst, Punung District also has other geological formations that fall under the non-karst zone. The geological formations are sediment: clastic: coarse: breccia, sediment: clastic: medium: sandstone, sediment: clastic: coarse: conglomerate, extrusive: intermediate: polymict, and intrusive: felsic. From the geological formation can be known that Punung is formed from the process of sedimentation and rock freezing extrusive (freezing on the earth's surface) and intrusive (freezing below the earth's surface) that produces breccia geology, sandstone (sandstone), conglomerate, polymict and felsic [9].

The pepper plant (*Piper nigrum* L.) is a widely cultivated plantation commodity in Indonesia because it has high economic value [10]. Punung was once a pepper producer, but since 2012 its existence tends to decline [11]. As a district that falls within the Sewu karst and is also a pepper producer, Punung District is considered as a potential pepper crop development area. Successful crop cultivation requires suitable land, therefore it is necessary to also conduct land suitability evaluation to determine whether a land has the potential to yield the production of a crop [12]. Land use that does not match its potential will lead to land degradation [13]. This study is important to conduct with the aim of knowing the potential of karst areas compared to non-karst through evaluation of land capability and land suitability for pepper crop in Punung District.

2 Material and Methods

This study is a field survey with purposive random sampling. The sampling points are based on the overlay of soil type, geology, and rainfall maps. Variables observed included physical, chemical, biological properties, and environmental conditions. The soil characteristics parameters analyzed in this study include soil depth, rough material, total nitrogen (N), phosphorus (P₂O₅), potassium (K₂O), cation exchange capacity (CEC), base saturation, pH H₂O, soil organic carbon, salinity, permeability, temperature, annual rainfall, length of dry season, flood depth, flood duration, surface stoniness, and rock outcrop. Soil samples were taken by purposive random sampling at a depth of 0-20 cm using the purposive sampling method, and then analyzed in the laboratory. The soil characteristics variability analysis results were further subjected to clustering using ANOVA test between each of the soil-forming factors with parameters – land characteristic parameters to obtain an LMU. The factors used here are rainfall factors, land use, geological formation, site elevation, and slope. Based on its geological conditions (Figure 1) the LMU is divided into karst and non-karst (Figure 2). The land characteristics in each SPL were determined using the matching method with the criteria of land capability classification based on Arsyad (2009) and the classification of land suitability for pepper growing requirements based on Ritung et al., (2011).

3 Result and Discussion

3. 1 Relationship of Soil Forming Factors for LMU Creation

Clustering uses the oneway ANOVA test between each soil forming factor and the results of land characteristic parameters. The factors used here are rainfall, land use, geological formation, altitude, and slope. The selection of these five factors is based on soil forming factors that will indirectly contribute to the characteristics of the land and its suitability for crops.

Table 1. Oneway ANOVA results of land use, elevation and geology formation influence on land characteristics

Parameters	Land use factor	Elevation Factor	Geology formation factor
	Sig.	Sig.	Sig.
Soil depth	0.469	0.260	0.237
Rough material	.	.	.
Total N	0.490	0.720	0.743
P ₂ O ₅	0.917	0.007*	0.114
K ₂ O	0.074	0.479	0.125
CEC	0.823	0.460	0.439
Base Saturation	0.622	0.059	0.884
pH H ₂ O	0.012*	0.753	0.562
Organic-C	0.486	0.727	0.696
Salinity	0.300	0.965	0.638
Flood depth	.	.	.
Flood duration	.	.	.
Surface stoniness	0.863	.	0.020*
Rock outcrop	.	.	.

Based on the results of the analysis show that land use has a significant influence on soil pH conditions (p-value = 0.012). soil pH is then classified and delineated for the basis of making LMU maps. The delineation results show that Punung sub-district is divided into 5 classes based on the relationship between land use and pH H₂O (Fig 1). Then based on the results of one-way Anova analysis shows that the height of the place has a significant influence on the condition of P₂O₅ (p-value = 0.007). The altitude of the place was then classified and delineated for the basis of making the LMU map. The delineation results show that the Punung sub-district is divided into 5 classes based on the relationship between altitude and P₂O₅ (Fig 2). Furthermore, the analysis shows that geological formation has a significant influence on surface rocks (p-value = 0.020). Geological formations were classified and delineated for the basis of making the LMU map. The delineation results show that the Punung sub-district is divided into two classes based on the relationship between geological formations and surface rocks (Fig 3).

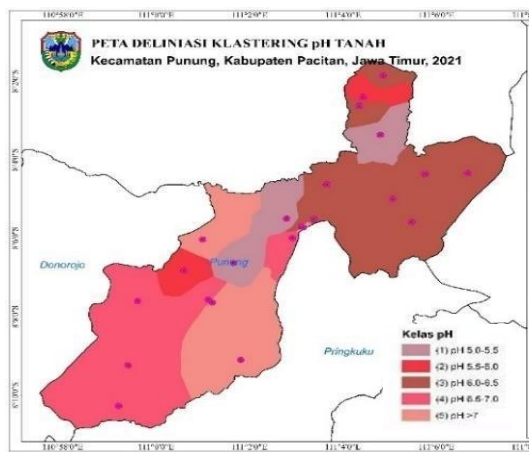


Fig 1. Soil pH Clustering Map (Land Use Significance)

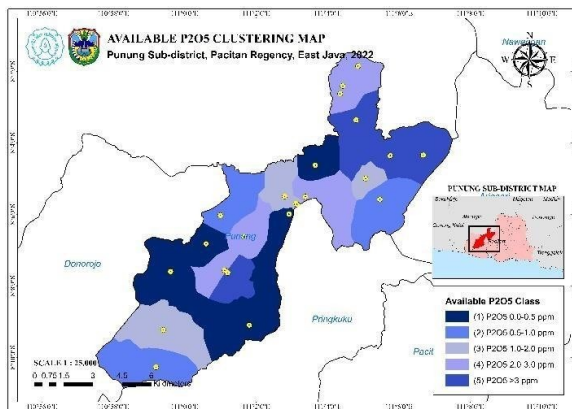


Fig. 2. Available P2O5 Clustering Map (Elevation Significance)

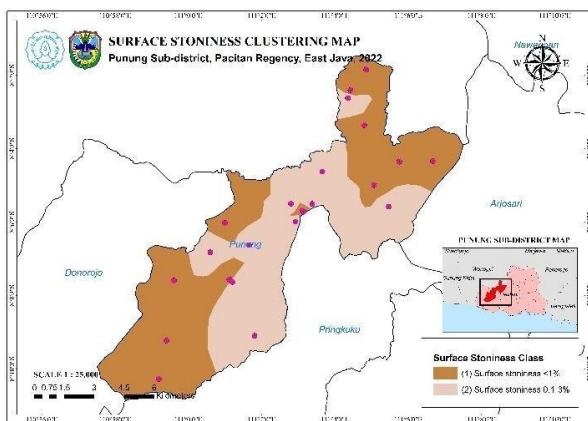


Fig. 3. Surface Rock Clustering Map (Geological Formation Significance)

Since slope and rainfall did not have a significant influence on land characteristics, the LMU was based on 3 significant maps (pH H₂O, P₂O₅, and surface rocks). The merging resulted in 20 Land Map Units (LMU). The LMUs are divided into karst (LMU 5,6,11, and 12) and non-karst (LMY 1,2,3,4,7,8,9,10,13,14,15,16,17,18,19, and 20). This map is the basis for determining the capability and suitability of land in karst and non-karst areas (Fig 4).

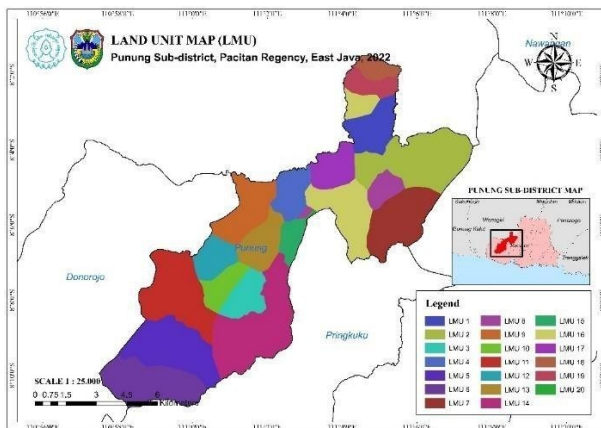


Fig. 4. Land Map Unit (LMU)

The distribution of geological formations in karst and non-karst areas can be divided into several, namely in karst areas, the existing formations consist of medium clastic sedimentary rocks and reef limestone. In contrast, in non-karst areas there are various formations, including coarse clastic sedimentary rocks such as breccias and conglomerates, medium clastic sandstones, intermediate extrusive polymictic rocks, and felsic intrusive rocks.

Table 2. Land Characteristics of the sampling sites

<i>Land Units</i>	<i>Class Lith Geology</i>	<i>Elevation (m dpl)</i>	<i>Permeai</i>	<i>Mean temperature (°C)</i>	<i>Annual rainfall (mm)</i>	<i>Length of dry season (month)</i>	
K A R S T	5 -Sed: clastic: medium: limestone	299	0.5-	24.506	2289	4	
	6 -Sed: clastic: medium: limestone	309	0.12:	24.446	2289	4	
	11 -Sed: clastic: medium: limestone	404.6	0.12:	23.872	2289	4	
	12 -Sed: clastic: medium: sandstone -Sed: reef: limestone	414	0.5-	23.816	2289	4	
N O N	1 -Sed: clastic: coarse: breccia	582	0.12:	22.808	2289	4	
	2 -Sed: clastic: coarse: breccia	406.5	0.12:	23.861	2289	4	
	3 -Sed: clastic: medium: sandstone	367	0.5-	24.098	2289	4	
	4 -Sed: clastic: coarse: breccia -Sed: clastic: coarse: conglomerate	321	0.12:	24.374	2289	4	
	7 -Sed: clastic: coarse: breccia	227	0.5-	24.938	2289	4	
	8 -Sed: clastic: coarse: breccia -Sed: clastic: coarse: conglomerate	197	0.5-	24.551	2289	4	
	K A R S T	9 -Sed: clastic: coarse: breccia -Sed: clastic: coarse: conglomerate	415	0.5-	23.810	2289	4
		10 -Sed: clastic: medium: sandstone	372	0.12:	24.068	2289	4
13 -Sed: clastic: coarse: breccia		474	0.12:	23.456	2289	4	
14 -Sed: clastic: coarse: breccia -Sed: clastic: medium: sandstone		366	0.5-	24.104	2289	4	
15 -Sed: clastic: coarse: breccia -Sed: clastic: coarse: conglomerate		414	0.5-	23.816	2289	4	
16 -Sed: clastic: coarse: breccia		390	0.5-	22.833	2289	4	

	-Ext: intermediate: polymict					
	-Sed: clastic: coarse: conglomerate					
17	-Sed: clastic: coarse: breccia	396.3	0.5-	23.922	2289	4
	-Sed: clastic: coarse: conglomerate					
18	-Int: felsic	786	0.5-	21.584	2289	4
	-Ext: intermediate: polymict					
	-Int: felsic					
19	-Sed: clastic: coarse: breccia	726	0.12:	21.944	2289	4
	-Ex: intermediate: polymict					
20	-Sed: clastic: coarse: conglomerate	388	0.12:	23.972	2289	4

Source : Data Analysis

Table 3. Land Characteristics of Punung Sub-District (Continued)

Land Units	Drainage	Root condition		Nutrient retention						
		Soil texture		Rough material (cm)	Soil depth (cm)	CEC (cmol/kg)	BS (%)	pH H ₂ O	Organic-C (%)	
K A R S T	5	well	Silty Clay Loam (SiCL)	slightly fine	<15	60	21.99	53.69	6.99	1.091
	6	well	Clay (C)	very fine	<15	81	11.28	86.09	6.75	4.172
	11	well	Clay (C)	very fine	<15	85	14.12	94.81	6.80	2.038
	12	well	Clay (C)	very fine	<15	70	10.72	99.90	5.80	3.384
	1	well	Silty Clay Loam (SiCL)	slightly fine	<15	78	9.98	50.32	5.28	1.194
	2	well	Clay Loam (CL)	slightly fine	<15	77	10.59	67.48	6.15	2.421
	3	well	Lempung berdebu (SiL)	moderately	<15	71	12.74	92.77	7.54	1.030
	4	well	Clay Loam (CL)	slightly fine	<15	84	17.61	51.40	5.31	2.027
	7	well	Silty Loam (SiL)	moderately	<15	88	13.66	78.74	6.48	0.325
N O N	8	well	Silty Loam (SiL)	moderately	<15	86.5	19.52	64.35	6.28	1.808
	9	well	Silty Loam (SiL)	moderately	<15	80	14.02	96.78	7.70	1.437
K A R S T	10	well	Silty Clay (SiC)	fine	<15	77	17.02	48.96	6.68	1.578
	13	well	Silty Clay (SiC)	fine	<15	80	17.20	61.38	5.45	1.515
	14	well	Silty Clay Loam (SiCL)	slightly fine	<15	89	29.75	65.65	7.41	1.428
	15	well	Silty Clay Loam (SiCL)	slightly fine	<15	66	16.19	97.52	6.91	1.443
	16	well	Silty Clay Loam (SiCL)	slightly fine	<15	77.5	10.73	47.39	6.28	0.891
	17	well	Loam (L)	moderately	<15	90	7.89	97.68	6.16	1.974
	18	well	Clay (C)	very fine	<15	78	19.52	40.86	6.48	5.834
	19	well	Clay (C)	very fine	<15	90	14.29	50.16	5.89	0.598

20 well Silty Clay (SiC) fine <15 80 19.57 95.66 7.07 1.965

Source : Data Analysis

Remarks : CEC = Cation Exchange Capacity. BS = Base Saturation

Table 4. Land Characteristics of Punung Sub-District (Continued)

Land Units	Nutrient availability (na)			Toxicity (xc)	Erosion hazard (eh)		Flood hazard (fh)		Land preparation (lp)		
	Total-N (%)	P ₂ O ₅ (ppm)	K ₂ O (cmol/kg)	Salinity (dS/m)	Slope (%)	Erosion hazard	Flood Depth (cm)	Flood Duration (day)	Surface stoniness (%)	Rock outcrops (%)	
K	5	0.147	1.233	1.313	0.092	3-8%	very low	0-25	<1	<0.1	0
A	6	0.505	2.569	0.800	0.092	8-15%	low-moderate	0-25	<1	<0.1	0
S	11	0.226	0.364	0.595	0.080	15-25%	moderate	0-25	<1	<0.1	0
T	12	0.416	0.310	0.698	0.054	8-15%	low-moderate	0-25	<1	0.1-3	0
N	1	0.106	7.415	0.331	0.087	15-25%	moderate	0-25	<1	<0.1	0
O	2	0.263	4.556	0.599	0.070	8-15%	low-moderate	0-25	<1	<0.1	0
N	3	0.207	4.227	1.195	0.111	8-15%	low-moderate	0-25	<1	0.1-3	0
O	4	0.167	1.609	0.317	0.059	3-8%	very low	0-25	<1	0.1-3	0
N	7	0.147	2.432	0.532	0.061	8-15%	low-moderate	0-25	<1	0.1-3	0
O	8	0.166	1.264	1.032	0.082	15-25%	moderate	0-25	<1	<0.1	0
N	9	0.406	2.512	1.052	0.142	3-8%	very low	0-25	<1	<0.1	0
K	10	0.281	0.901	0.950	0.093	8-15%	low-moderate	0-25	<1	<0.1	0
A	13	0.143	0.752	1.015	0.053	3-8%	very low	0-25	<1	0.1-3	0
S	14	0.264	0.315	0.565	0.117	8-15%	low-moderate	0-25	<1	0.1-3	0
T	15	0.239	0.333	0.377	0.123	15-25%	moderate	0-25	<1	0.1-3	0
	16	0.210	0.608	0.844	0.069	8-15%	low-moderate	0-25	<1	0.1-3	0
	17	0.038	0.335	1.090	0.060	15-25%	moderate	0-25	<1	0.1-3	0
	18	0.397	0.796	1.358	0.078	3-8%	very low	0-25	<1	<0.1	0
	19	0.226	0.766	0.811	0.087	3-8%	very low	0-25	<1	<0.1	0
	20	0.251	1.834	1.068	0.093	0-3%	very low	0-25	<1	<0.1	0

Source : Data Analysis

Based on Table 2, the location characteristics in Punung sub-district range from 197-786 meters above sea level, with an average annual rainfall of 2,289 mm and a dry period of about four months. Soil drainage in all 20 Land Mapping Units is good and suitable for various types of plants [14]. Karst soils have a very fine to-fine texture, while non-karst soils have a very fine to medium texture [15]. Soil depth varies between 60-90 cm, with higher slopes leading to shallower soils due to erosion [16]. Cation exchange capacity (CEC) ranges from 7.89-29.75 cmol/kg, positively correlated with soil organic carbon and base saturation which ranges from 40.861-99.902% [17,18]. Soil pH ranges from acidic to

slightly alkaline (5.28-7.70), which is influenced by land use and fertilization practices [19]. Organic carbon content ranges from 0.325-5.834%, influenced by different vegetation types [20].

Nitrogen content is low to moderate (0.038-0.505%), phosphorus is very low (0.310-7.415 ppm), and potassium ranges from low to very high (0.317-1.358 cmol+/kg), influenced by leaching and mineralization processes [21,22]. Salinity is low (0.053-0.142 dS/m), which is ideal for pepper cultivation [23]. Erosion hazards range from very mild to severe, with minimal risk of flooding, and rock outcrops cover less than 5% of the area. Geological formations show a clear division between karst areas, dominated by limestone, and non-karst areas with breccia, sandstone, and conglomerate [24].

3. 2 Land Capability and Land Suitability

Table 5. Land Capability and Land Suitability for Pepper (*Piper nigrum* L.) in Punung Subdistrict

Land Units	Land Capability			Land Suitability		Areas (Ha)
	Class	Limiting Factor	Conservation	Class	Limiting Factor	
K A R S T	5 II- I ₁ .e ₁ .k ₁	Surface slope, Erosion rate, - Soil depth	With conservation measures	S3; wa,na	Dry months (4), Very low P2O5	930
S T	6 III-I ₂	-Surface slope	Moderate	S3; wa,na	Dry months (4), Very low P2O5	866
	11 IV-I ₃	- Surface slope	Heavy	S3; wa,na,eh	Dry months (4), Very low P2O5, Erosion hazard (15-25%, heavy)	983
	12 III-I ₂	- Surface slope	Moderate	S3; wa,na	Dry months (4), Very low P2O5	327
N O N K A R S T	1 IV-I ₃	- Surface slope	Heavy	S3; wa,na,eh	Dry months (4), Very low P2O5, Erosion hazard (15-25%, heavy)	463
K A R S T	2 III-I ₂	- Surface slope	Moderate	S3; wa,na	Dry months (4), Very low P2O5	1.156
	3 III-I ₂ .e ₂	- Surface slope, - Erosion rate	Moderate	S3; wa,na	Dry months (4), Very low P2O5	355
S T	4 II- I ₁ .e ₁ .k ₁	- Surface slope, Erosion rate - Soil depth	With conservation measures	S3; wa,na	Dry months (4), Very low P2O5	366
	7 III-I ₂	- Surface slope	Moderate	S3; wa,na	Dry months (4), Very low P2O5	757
S T	8 IV-I ₃	- Surface slope	Heavy	S3; wa,na,eh	Dry months (4), Very low P2O5, Erosion hazard (15-25%, heavy)	238
	9 II- I ₁ .e ₁ .k ₁	- Surface slope, Erosion rate - Soil depth	With conservation measures	S3; wa,na	Dry months (4), Very low P2O5	583
S T	10 III-I ₂	- Surface slope	Moderate	S3; wa,na	Dry months (4), Very low P2O5	279
	13 II-I ₁ .k ₁	- Surface slope, - Soil depth	Heavy	S3; wa,na	Dry months (4), Very low P2O5, Erosion hazard (15-25%, heavy)	426
S T	14 III-I ₂	- Surface slope	Moderate	S3; wa,na	Dry months (4), Very low P2O5	1.246
	15 IV-I ₃	- Surface slope	Moderate	S3; wa,na,eh	Dry months (4), Very low P2O5	203
S T	16 III-I ₂ .e ₂	- Surface slope, - Erosion rate	With conservation measures	S3; wa,na	Dry months (4), Very low P2O5	845

17	IV-I ₃	- Surface slope	With conservation measures	S3; wa,na,eh	Dry months (4), Very low P2O ₅	380
18	III-e ₂	- Erosion rate	Moderate	S3; wa,na	Dry months (4), Very low P2O ₅ , Erosion hazard (15-25%, heavy)	181
19	II-I _{1.e1.k1}	- Surface slope	Heavy	S3; wa,na	Dry months (4), Very low P2O ₅	245
20	II-e _{1.k1}	- Erosion rate, Soil depth	Moderate	S3; wa,na	Dry months (4), Very low P2O ₅	9

Source: Data analysis

Table 2 indicates that the karst areas (LMU 5, 6, 11, and 12) possess land capability classes II, III, and IV. LMU 5 is classified as land capability class II, limited by surface slope (l), erosion rate (e), and soil depth (k) = II-I_{1.e1.k1}. LMU 6 and 12 are classified as class III, with surface slope (l) as the limiting factor = III-I₂. Conversely, LMU 11 is the only area in the Punung karst region classified as class IV, also limited by surface slope (l) = IV-I₃. The karst region in Punung has a dominant land capability class III (1,193.95 ha) compared to class II (930.05 ha) and IV (983.42 ha), with surface slope being a limiting factor across all karst LMUs (Figure 5).

The non-karst areas (LMU 1, 2, 3, 4, 7, 8, 9, 10, 13, 14, 15, 16, 17, 18, 19, and 20) also exhibit land capability classes II, III, and IV. Class II, limited by surface slope (l), erosion rate (e), and soil depth (k) = II-I_{1.e1.k1}, is found in LMU 4, 9, and 19. Class II, constrained by surface slope (l) and soil depth (k) = II-I_{1.k1}, is present in LMU 13, while class II limited by erosion hazard (e) and soil depth (k) = II-e_{1.k1} is found in LMU 20. The total area for class II capability is 1,205.04 ha. Class III, limited by surface slope, erosion rate, and soil depth (III-I₂), is observed in LMU 2, 7, 10, and 14. Class III, limited by surface slope and erosion rate (III-I_{2.e2}), appears in LMU 3 and 16, while class III limited by erosion rate (III-I₂) is in LMU 18, with a total area of 4,640.94 ha. The research location has one class IV land capability type, limited by surface slope (IV-I₃), found in LMU 1, 8, 15, and 17, totaling 1,285.98 ha. This illustrates that the non-karst region of Punung has a more dominant class III land capability (4,640.94 ha) than classes II and IV (Figure 5). Higher land capability classes indicate worsening quality¹⁸, which corresponds to increased threats of degradation and limiting factors. Classes I to IV are designated based on their suitability for various land uses, including annual and perennial crops, pasture, fodder grass, or forests, while classes V to VIII are unsuitable for agriculture and are intended for natural vegetation, grasslands, and tree crops.

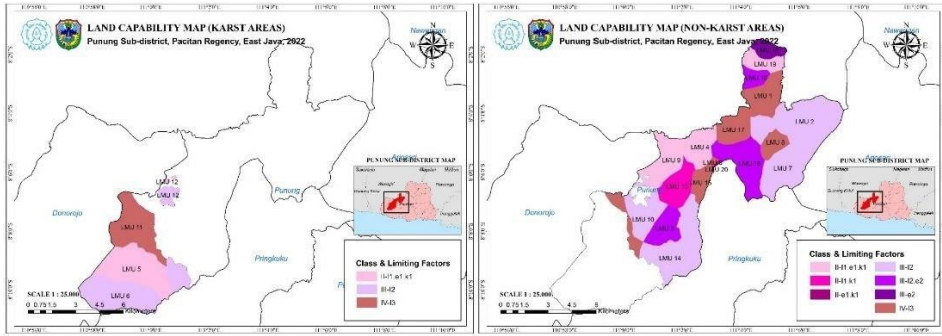
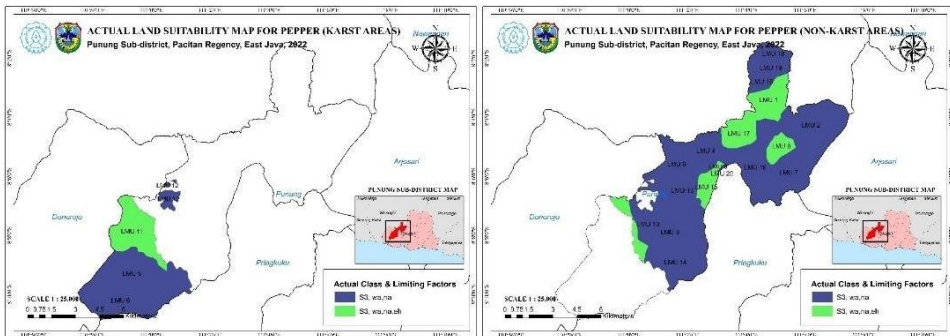


Fig. 5. Land capability map of Punung Sub-district Karst and Non Karst area
Note: wa; water availability, na: Nutrient availability; eh; erosion hazard

Table 3 presents the analysis results of the actual land suitability for pepper cultivation in the Punung District, both in karst and non-karst areas, which is classified as marginally suitable (S3) due to limiting factors: water availability (wa), nutrient availability (na), and erosion hazard (eh). The karst areas (LMU 5, 6, 11, and 12) are categorized into two groups based on their limiting factors (Figure 7): S3; wa, na (LMU 5, 6, and 12) and S3; wa, na, eh (LMU 11). The limiting factors for pepper suitability in these areas include insufficient dry months (wa), extremely low available P2O5 (na), and high erosion hazard potential (eh).

In the non-karst areas of Punung, there are also two groups of land suitability based on limiting factors (Figure 8): S3; wa, na (LMU 2, 3, 4, 7, 9, 10, 13, 14, 16, 18, 19, and 20) and S3; wa, na, eh (LMU 1, 8, 15, and 17). Similar limiting factors affect pepper cultivation in these regions, including insufficient dry months (wa), very low available P2O5 (na), and high erosion hazard potential (eh). The primary issue concerning water availability (wa) in both karst and non-karst areas is that the average number of dry months over the last ten years is only four, whereas pepper plants require less than two dry months for optimal growth. Nutrient availability (na) is a constraint due to the very low levels of available P2O5 in the soil, which hinders pepper growth. Additionally, the erosion hazard (eh), characterized by slopes greater than 8%, is a limiting factor; steeper slopes lead to



greater nutrient loss and surface runoff [23].

Fig. 6. Land suitability map for pepper cultivation Punung Sub-district Karst and Non Karst Areas
Note: wa; water availability, na: Nutrient availability; eh; erosion hazard

3. 3 Relationship between Land Capability and Land Suitability for Pepper Crops in Karst and Non-Karst Areas

Table 2 shows that all karst areas with geological formations sediment: clastic: medium: limestone and sediment: reef: limestone have land capability II, III and IV. All of these land capabilities can be utilised for agricultural cultivation. The results of the evaluation of land suitability for pepper plants in karst areas are S3 (marginally suitable). Where class S3 with limiting factors of water availability, and available nutrients (S3; wa,na) is found on land capability II and III. Then the S3 class with limiting factors of water availability, available nutrients, and erosion hazard (S3; wa,na,eh) is found on land capability IV.

The same condition is also found in non-karst areas. Non-karst areas with geological formations of sediment: clastic: coarse: breccia, sediment: clastic: medium: sandstone, sediment: clastic: coarse: conglomerate, extrusive: intermediate: polymict, and intrusive: felsic have land capabilities II, III, and IV that can still be pursued for agricultural cultivation. The results of the evaluation of land suitability for pepper plants in non-karst areas are S3 (marginally suitable). Where the S3 class with limiting factors of water availability, and available nutrients (S3; wa,na) is found on land capability II and III. Then the S3 class with limiting factors of water availability, available nutrients, and erosion hazard (S3; wa,na,eh) is found on land capability IV.

Overall the analytical results in table 3 show that both karst and non-karst areas in Punung sub-district exhibit marginal suitability (S3) for pepper cultivation, mainly constrained by water availability, low nutrient levels, and high erosion hazard, which highlights the need for improved land management practices to increase agricultural productivity in this diverse landscape.

Table 6. Relationship between Land Capability and Land Suitability for Pepper Crops in karst and non-karst areas

<i>Class Lith Geology</i>	<i>Land Units</i>	<i>Land Capability</i>	<i>Land Suitability for Pepper (Piper nigrum L.)</i>
K - Sediment: clastic: medium: limestone	5	II	S3; wa,na
R	6	III	S3; wa,na
S	11	IV	S3; wa,na,eh
T - Sediment: reef: limestone	12	III	S3; wa,na
- Sediment: clastic: coarse: breccia	4, 13, 14	II	S3; wa,na
N	2, 7, 14, 16	III	S3; wa,na
O	1, 8, 15, 17	IV	S3; wa,na,eh
N - Sediment: clastic: medium: sandstone	3, 10, 12, 14	III	S3; wa,na
K - Sediment: clastic: coarse: conglomerate	4, 9, 20	II	S3; wa,na
A	16	III	S3; wa,na
R	8, 15, 17	IV	S3; wa,na,eh
S - Extrusive: intermediate: polymict	16, 18, 19	III	S3; wa,na
T - Intrusive: felsic	19	II	S3; wa,na
	18	III	S3; wa,na

4 Conclusion

In Punung sub-district land use affects on soil pH, elevation affects on P₂O₅, and geology formation affects on surface stoniness. Punung sub-district has 7 geological formations which are divided into karst and non-karst areas. Both karst and non-karst geological formations produce 3 classes of land capability, class II, III, IV which can still be pursued for agricultural cultivation. Karst areas have land capability with limiting factors of surface slope (I), erosion rate (e), and soil depth (k) = II-I1.e1.k1, III-I2, and IV-I3. Non-karst areas have land capability with limiting factors of surface slope (I), erosion rate (e), and soil depth (k) = II-I1.k1, II-e1.k1, II-I1.e1.k1, III-I2, III-e2, III-I2.e2, IV-I3. Karst areas have land suitability for pepper plants that is marginally suitable (S3) with the limiting factors are water availability (wa), available nutrients (na), and erosion hazard (eh) = S3; wa,na, S3;wa,na,eh. Non-karst areas have a land suitability for pepper plants that is marginally suitable (S3) with the limiting factors being the availability of water (wa), available nutrients (na), and erosion hazard (eh) = S3; wa,na, S3; wa,na,eh.

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