



Mapping of soil degradation status on various land slope in Paranggupito, Wonogiri

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Abstract. *Soil degradation causes in loss of soil function in supporting living things. The slope of the land has the potential to cause soil degradation. This study aims to provide scientific information on soil degradation status in the form of a map and provide recommendations for improvement based on the determinant factor. Land map units were determined by an overlay of maps: soil type, rainfall, slope, and land use. The research area was divided into 12 LMU, and each was repeated by 3 site samplings. The soil degradation status is known by matching the condition of the soil with the criteria for soil degradation, which refers to the Government Regulation of the Republic of Indonesia Number 150 of 2 000. ANOVA was used to determine the effect of the land slope on the soil degradation status. Correlation analysis is used to know the relationship between the parameters with soil degradation. The result shows that soil degradation status is slightly degraded (R.I) in 6 032.44 ha with different limiting factors. Land slope 16-25% has the highest impact on soil degradation with the determinant parameters were bulk density and a total of porosity. Soil bulk density increases along with increasing steep slope. Efforts to improve the status of soil degradation are by giving organic matter and minimizing soil tillage.*

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INTRODUCTION

Soil is a place for various types of biota which can produce biomass to support human life and other living things. Amri *et al.* (2014) stated that biomass is the newest environmentally friendly energy source by the development of the times. It must be balanced with appropriate soil management. Land without proper management will suffer degradation and decrease its function (Rukmana *et al.*, 2016). Many factors caused soil degradation, there were natural factors (weather and environment) and human factors due to land-use changes (Bindraban *et al.*, 2012). Land degradation can occur in various places: one of them is in Paranggupito, Wonogiri, Indonesia.

Paranggupito is the only sub-district in Wonogiri Regency which has a coastal area in the Indian Ocean. It has a 6.475 hectare (ha) area (The Central Statistical Agency of Wonogiri District, 2017). Paranggupito is a mountainous area with a tropical climate. The land characteristic is dryland and only planted by certain plants. All type of soil is Mollisols with dark color, the soil structure is granular, the top layer of the soil is

crumbly, has a low solum depth ranging from 40-60 cm, and the land is planted by annual crops and perennial crops (Simanjuntak, 2003). Land slope ranges from 0% to 25% with 3 types of agricultural land use, namely paddy fields, plantation, and moorland. The paddy fields will change into moorland in the dry season (Nuraeni *et al.*, 2019).

Hilly land areas with a steep slope which is usually prone to erosion (Putra and Edwin, 2018). Erosion is the loss of soil from one area to another by water or wind (Rahman *et al.*, 2009). The erosion that occurs has resulted in soil degradation (Leh *et al.*, 2011), as well as sedimentation which can reduce water function (Quinton *et al.*, 2010). Land in the study area has the potential to suffer degradation if proper handling is not done. Handling heavy erosion later will require expensive and need a long time (Zuazo and Pleguezuelo, 2008).

Based on the description above, it is necessary to map the status of land degradation, especially in the relationship with land slope. This study aims to provide scientific information in the form of a map of the status of soil degradation and to identify the determinant degraded factor as a basis for improvement recommendation.

METHODS

Research Location

The research was carried out in Paranggupito District, Wonogiri Regency, Indonesia. The study area is an effective area for biomass production, namely paddy field, plantation, and moorland, with an area of 6 032.44 ha. Research design is a descriptive explorative which was carried out by the survey method, approach by observing and taking soil samples directly in the field supported by laboratory analysis. The soil physical, chemical, and biological characteristics analysis were carried out at the Laboratory of Soil Physics, Laboratory of Soil Chemistry and Fertility, and Laboratory of Biochemistry and Biotechnology in Department of Soil Science, Faculty of Agriculture, Universitas Sebelas Maret.

Data Collection and Soil Sampling

The materials used include disturbed and undisturbed soil samples, thematic map (administrative, slope, soil type, rainfall, and land use), and software ArcView GIS mapping. The map of site sampling was made by overlay the soil type and rainfall map obtained from the Center for Soil and Agro-climate Research, also the slope and land use map obtained from the National Survey and Mapping Coordinating Board (Bakosurtanal). There were 12 land map units (LMU) (Figure 1). For each LMU, 3 sampling points were taken, which were determined purposively therefore the number of site samplings was 36 (Figure 1).

Sampling stages started from collecting various kinds of data related to land characteristics (slope, drainage, vegetation, erosion levels, flood threats, solum thickness, and surface rocks) by observing the conditions around the location points. Soil sampling was done purposively according to Figure 1. Disturbed and undisturbed soil samples were taken from 0-30 cm depth.

Data Analysis

Soil analysis in the laboratory, based on the parameters in the standard criteria for soil degradation in Government Regulation of the Republic of Indonesia Number 150 of 2000, concerning Control of Soil Degradation for Biomass Production (The Government of Indonesia, 2000) (Table 1). Soil parameters measured include chemistry, physics, and biology properties. The parameters include solum thickness is measuring the thickness of each horizon of the soil (Pirenangingtyas *et al.*, 2020), surface rocks using the percentage of the number of stones on the soil surface, soil texture using the gravimetric method by measuring the weight of soil composition, bulk density using the gravimetric method in soil volume (Rosyidah and Wirosodarmo, 2013), a total of porosity is using the calculation of soil bulk density and

particle density, soil permeability is using a constant head permeameter, pH is using potentiometry, the electrical conductivity is using the electrical conductivity meters (Muliawan *et al.*, 2016), redox is using the electric voltage method, the number of microbes are using plating technique (Hamada *et al.*, 2015).

Table 1 Standard criteria for soil degradation

No.	Parameter	Critical Threshold
1.	Solum thickness	<20 cm
2.	Surface rocks	>40%
3.	Soil texture	<18% colloid ; >80% quartzite sand
4.	Bulk density	>1.4 g cm ⁻³
5.	Total porosity	<30% ; >70%
6.	Soil permeability	<0.7 cm hour ⁻¹ ; >8 cm hour ⁻¹
7.	pH	<4.5 ; >8.5
8.	Electrical conductivity	>4 mS cm ⁻¹
9.	Redox	<200 mV
10.	Number of Microbes	<102 cfu g ⁻¹ soil

Source: (The Government of Indonesia, 2000)

Mapping of soil degradation status was obtained by 2 methods, namely matching and scoring. Matching the parameter data obtained from survey and laboratory analysis with the standard criteria of soil degradation (Table 1). Matching is divided into two groups, namely, soil that is classified as degraded (R) and soil that is classified as not degraded (N). The scoring is done by calculating the relative frequency value (Table 2) of each soil degradation parameter. The relative frequency (%) is the percentage value of the ratio of the number of soil samples classified as degraded to the total number of observation points in each LMU. The scores for each parameter based on their relative frequency values are presented in Table 2. The accumulated scores obtained for each parameter were used to determine the soil degradation status (Table 3).

Table 2 Scores of soil degradation based on the relative frequency for each parameter

Relative Frequency of Soil Degradation (%)	Score
0-10	0
11-25	1
26-50	2
51-75	3
76-100	4

Source: (Indonesia Ministry of Environment, 2009)

Table 3 Soil degradation status based on the total of soil degradation scores

Symbol	Soil Degradation Status	Total Score
N	Not degraded	0
R.I	Slightly degraded	1-14
R.II	Medium degraded	15-24
R.III	Heavy degraded	25-34
R.IV	Very heavy degraded	35-40

Source: (Indonesia Ministry of Environment, 2009)

The data were displayed in tables and maps. ANOVA test was conducted to determine the effect of slope characteristics on soil degradation status. Further tests with Duncan were carried out if the results of the analysis showed a significant effect. Correlation analysis is used to determine the relationship between the parameters and the status of soil degradation.

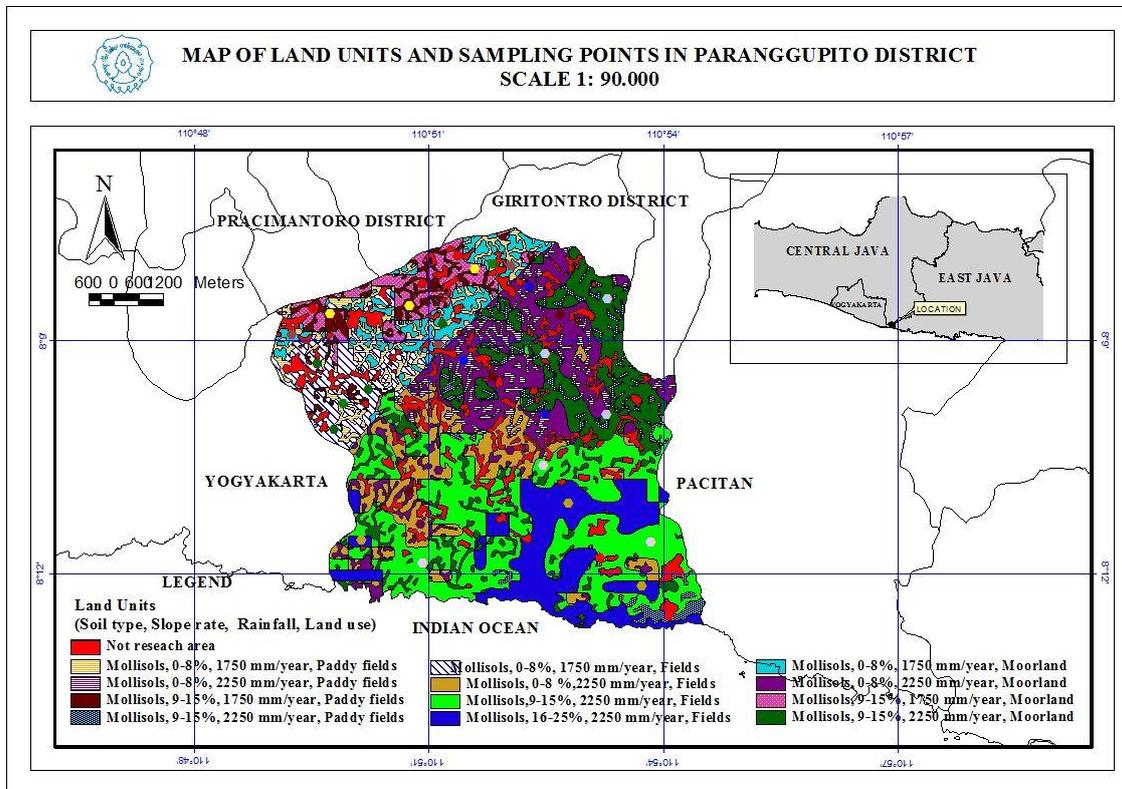


Figure 1 Land map unit and site sampling

RESULT AND DISCUSSION

Soil Characteristic

Soil degradation means changes in soil characteristics that exceed the standard criteria for soil degradation (Indonesia Ministry of Environment, 2006). The soil characteristics were matched with the critical threshold of soil degradation can be seen in Table 4. It shows there are parameters that have been degraded (less or exceed the critical threshold), including bulk density, a total of porosity, degree of water release, and redox. There are 18 sample points with a high value of soil bulk density ($>1.4 \text{ g cm}^{-3}$); therefore, it belongs to degraded. High bulk density is due to soil compaction by the soil processing system (Fuady, 2010), and high bulk density causes high soil particle density (Haridjaja *et al.*, 2010). The total porosity degraded at 16 sample points with a value of $<30\%$. Degraded porosity is due to the influence of bulk density and soil particle density. Sudaryono (2001) states that changes in soil particle density are followed by changes in the soil porosity.

Permeability at 5 sample points were degraded with a value of $<0.7 \text{ cm hour}^{-1}$ and $>8.0 \text{ cm hour}^{-1}$. Low permeability is not good for soil and plants on dry land because water is difficult to absorb into the soil (Widiatiningsih *et al.*, 2018a) and leads to increased soil erosion (Arisandi *et al.*, 2015). Redox parameters are degraded at all sampling points. According to Horbowicz *et al.* (2011), in their research showed high pH levels will make the H^+ content is low, so it is not able to exchange for dissolved hydrogen. It means potential redox conditions related to pH of the soil. Soil pH content affects the CEC (cation exchange capacity) and the availability of essential nutrients that need for crop growth (Dikinya and Mufwanzala, 2010).

Table 4 Matching between soil characteristics and critical threshold

No.	Site Sampling	Parameters									
		Solum Thickness (cm)	Surface Rocks (%)	Soil Texture (% colloid)	Bulk Density (g cm ⁻³)	Total Porosity (%)	Soil Permeability (cm hour ⁻¹)	pH	Electrical Conductivity (ms cm ⁻¹)	Redox (mV)	Number of Microbes (cfu g ⁻¹ soil)
1.	1A	60	0	51.81	1.25	46.67	2.25	6.78	0.19	4.21R	2 x 10 ⁶
2.	1B	50	1	64.61	1.35	30.12	0.80	6.87	0.13	4.62R	6 x 10 ⁶
3.	1C	50	3	44.74	1.38	31.31	4.16	6.89	0.19	4.58R	62 x 10 ⁶
4.	2A	26	1	61.49	1.47R	28.56R	1.38	6.63	0.12	4.35R	4 x 10 ⁶
5.	2B	37	1	48.09	1.14	39.75	1.00	5.85	0.10	4.28R	63 x 10 ⁶
6.	2C	25	1	45.46	1.56R	25.60R	1.66	6.50	0.09	4.58R	43 x 10 ⁶
7.	3A	60	0	41.61	1.13	52.69	3.32	6.99	0.18	4.62R	23 x 10 ⁶
8.	3B	70	1	60.24	1.18	40.54	3.65	6.49	0.12	4.40R	70 x 10 ⁶
9.	3C	80	0	36.74	1.56R	21.01R	2.65	7.01	0.14	4.61R	9 x 10 ⁶
10.	4A	40	3	57.54	1.29	38.08	0.66R	7.33	0.24	4.27R	5 x 10 ⁶
11.	4B	35	2	30.89	1.58R	21.45R	1.33	7.28	0.21	4.71R	13 x 10 ⁶
12.	4C	35	5	62.49	1.51R	18.62R	1.33	7.18	0.23	4.88R	55 x 10 ⁶
13.	5A	25	3	57.24	1.56R	30.15	1.07	6.02	0.14	2.10R	2.5 x 10 ⁶
14.	5B	22	2	34.51	1.39	48.40	3.19	6.65	0.17	2.48R	3.7 x 10 ⁶
15.	5C	30	5	34.34	1.30	37.67	4.27	7.23	0.17	2.50R	3.7 x 10 ⁶
16.	6A	24	7	58.61	1.54R	26.58R	5.64	7.01	0.19	3.04R	0.5 x 10 ⁶
17.	6B	33	15	56.14	1.01	55.85	1.33	6.75	0.20	3.39R	0.8 x 10 ⁶
18.	6C	21	20	57.66	1.59R	26.16R	5.22	6.72	0.17	3.33R	3.2 x 10 ⁶
19.	7A	24	10	60.99	1.37	36.43	8.50R	6.84	0.13	3.56R	9 x 10 ⁶
20.	7B	22	15	67.24	1.40	33.36	1.06	6.83	0.14	3.62R	10.5 x 10 ⁶
21.	7C	45	7	61.71	1.35	37.13	0.33R	6.08	0.12	3.72R	3.7 x 10 ⁶
22.	8A	53	3	41.64	1.52R	30.04	0.53R	6.96	0.28	3.78R	4.1 x 10 ⁶
23.	8B	40	3	60.21	1.54R	23.64R	1.86	7.12	0.28	4.26R	1.4 x 10 ⁶
24.	8C	47	5	38.26	1.57R	24.88R	1.88	7.27	0.31	4.15R	15.2 x 10 ⁶
25.	9A	40	15	32.31	1.52R	30.63	1.66	7.11	0.18	3.89R	5.5 x 10 ⁶
26.	9B	40	10	53.61	1.06	49.59	1.99	7.08	0.13	4.12R	13.9 x 10 ⁶
27.	9C	40	30	39.96	1.76R	6.3R	2.11	7.14	0.33	4.19R	8.8 x 10 ⁶
28.	10A	24	1	47.34	1.10	43.63	3.32	6.05	0.11	4.20R	0.2 x 10 ⁶
29.	10B	39	1	61.96	1.40	27.81R	3.45	6.29	0.12	4.35R	10.3 x 10 ⁶
30.	10C	36	1	52.86	1.55R	23.78R	1.00	6.91	0.17	4.32R	10.4 x 10 ⁶
31.	11A	80	30	54.81	1.49R	13.57R	1.99	7.20	0.28	3.99R	0.2 x 10 ⁶
32.	11B	40	30	71.41	1.52R	31.24	5.31	7.27	0.21	4.22R	1.5 x 10 ⁶
33.	11C	75	15	61.99	1.20	38.49	3.32	6.63	0.17	4.72R	2.5 x 10 ⁶
34.	12A	43	1	60.66	1.51R	23.63R	1.00	6.48	0.12	4.52R	0.3 x 10 ⁶
35.	12B	50	5	55.71	1.40	27.15R	2.65	7.31	0.16	4.77R	2.6 x 10 ⁶
36.	12C	40	3	44.99	1.47R	20.15R	0.66R	6.57	0.15	4.95R	9.3 x 10 ⁶

Remark: R = belongs to degraded criteria

Mapping of Soil Degradation

Map of soil degradation status is the final result containing status, distribution, symbols, and area information. Soil degradation status and the limiting factor in each LMU can be seen in Table 5.

Table 5 Status of soil degradation and limiting factors

LMU	Total Score	Soil Degradation Status	Symbol	Area (ha)	Limiting Factor
1.	4	Slightly degraded	R.1	268.82	Redox
2.	10	Slightly degraded	R.1	209.38	BD, Porosity, Redox
3.	8	Slightly degraded	R.1	175.68	BD, Porosity, Redox
4.	12	Slightly degraded	R.1	226.93	BD, Porosity, Permeability, Redox
5.	6	Slightly degraded	R.1	331.49	BD, Porosity, Redox
6.	10	Slightly degraded	R.1	470.25	BD, Porosity, Redox
7.	7	Slightly degraded	R.1	1,414.54	Permeability, Redox
8.	13	Slightly degraded	R.1	736.94	BD, Porosity, Permeability, Redox
9.	9	Slightly degraded	R.1	299.24	BD, Porosity, Redox
10.	9	Slightly degraded	R.1	787.38	BD, Porosity, Redox
11.	9	Slightly degraded	R.1	246.8	BD, Porosity, Redox
12.	13	Slightly degraded	R.1	864.99	BD, Porosity, Permeability, Redox

Map of soil degradation status was shown in Figure 2. All area research has slightly degraded (R.1) in 6 032.44 ha (100%). It was classified by an accumulated score between 1-14. The limiting factors were used to explain the parameters below or above the critical threshold. LMU 1 has limiting factors of redox, LMU 2, 3, 5, 6, 9, 10, and 11 were bulk density, porosity, and redox, LMU 4, 8 and LMU 12 were bulk density, porosity, permeability, and redox, and LMU 7 was permeability, and redox.

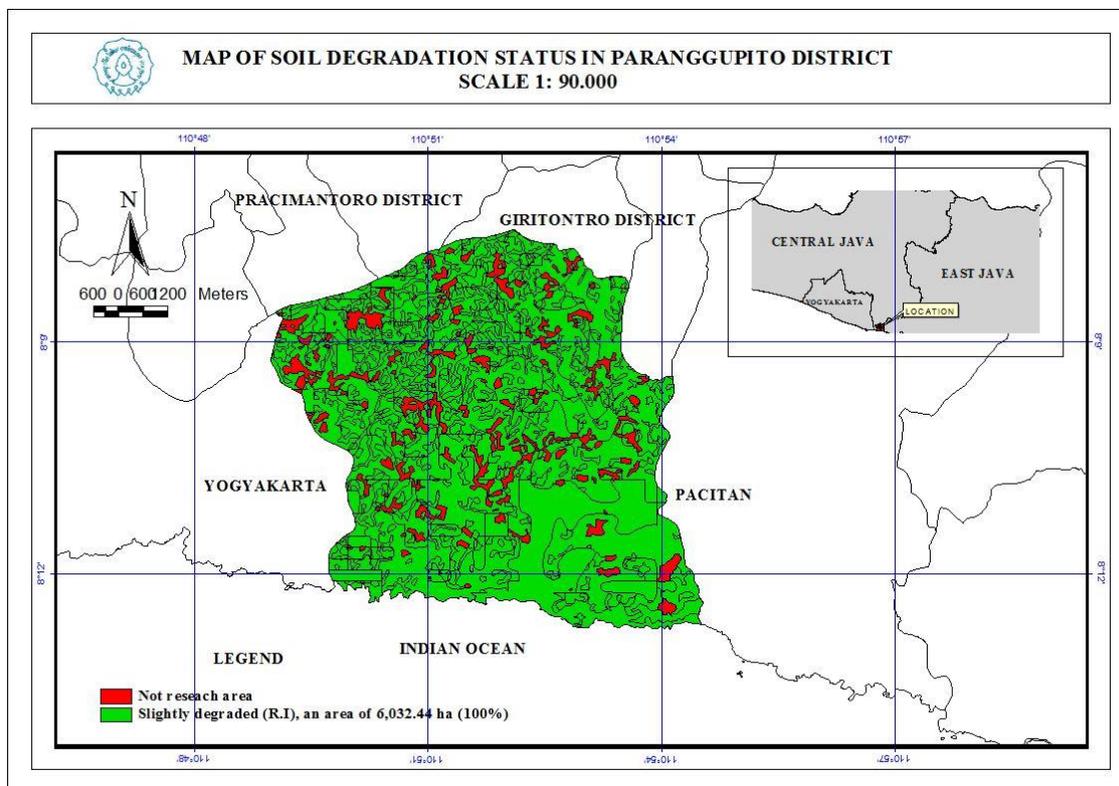


Figure 2 Map of soil degradation status

The Determinant Factor of Soil Degradation

The land slope in Paranggupito consists of 3 categories, namely flat (0-8%), sloping (9-15%), and rather steep (16-25%). ANOVA result showed the land slope had a very significant effect on the soil degradation (F Calc.= 7.224; P-Value = 0.003; n = 36). Results of the Duncan Multiple Range Test (DMRT) 5% were shown in Table 6.

Table 6 Effect of land slope on land degradation status

Land Slope	Soil Degradation Status
0-8%	8b
9-15%	9.8b
16-25%	13a

Remark: Soil degradation status accompanied by the same letters are not significantly different by DMRT 5%

Table 6 shows the land slope 16-25% has the significantly highest soil degradation score than the others. Suryanto and Wawan (2017) state higher slope of the land has a greater effect on erosion because the water of rain has kinetic energy and impact to degrades soil aggregates. This land slope 16-25% area has rainfall 2,250 mm year⁻¹ which is easier to lose the topsoil. It causes a decrease in solum thickness, effective root depth, and porosity (Nugroho, 2016). This area has the vegetation of sengon, teak, and mahogany crops, and those plants have large roots and require a deep solum thickness. Wahyuningrum and Basuki (2014) state that shallow soil solum limits plant growth.

The determinant factor of soil degradation was known by conducting a correlation test between all parameters and the status of soil degradation. It showed that bulk density has a very significant positive correlation (r= 0.782; P-Value= 0.000; n= 36) and total of porosity has a very significant negative correlation (r= -0.789; P-Value= 0.000; n= 36) with status of soil degradation. The bulk density affects the porosity. Lipiec *et al.* (2005) stated that bulk density is related to soil porosity. Higher bulk density makes lower soil porosity.

Land slope has no significant effect on soil bulk density (F Calc.= 1.055; P-Value= 0.360; n= 36). However, there is a tendency to increase soil bulk density and the increase in land slope. Land slope 16-25% has the highest bulk density 1.54 g cm⁻³, while land slope 0-8% and 9-15% have 1.38 g cm⁻³ and 1.39 g cm⁻³, respectively. The increased soil bulk density is due to the effect of gravity on the land slope 16-25% greater than the land slope 9-15% and the land slope 0-8% (Suryanto and Wawan, 2017).

Recommendation for Land Management

Improvement efforts are made based on the determinants of soil degradation. Improvement efforts that can be done include applying organic matter and minimal tillage to increase soil porosity and reduce bulk density. Adding organic matter (sugar factory waste and kettle ash) and minimum tillage be able to increase porosity on soil (Nita *et al.*, 2015). The use of organic matter, especially manure, can reduce soil compaction (Adijaya and Yasa, 2014). Land management in accordance with the land capability coupled with soil and water conservation also needs to be implemented to reduce and prevent erosion hazards (Widiatiningsih *et al.*, 2018b). Soil erosion can be reduced by applying organic fertilizers (Wati *et al.*, 2014) and planting along the contour on sloping land (Sukisno *et al.*, 2011).

CONCLUSION

All research points in Parangupito were slightly degraded (R.1), with the determining factors being bulk density and porosity. The land slope has a very significant effect on soil degradation. The highest land

degradation status is found on land with a slope of 16-25%. Efforts to improve that can be done are by giving organic matter and minimum tillage implementation.

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