

Unravelling Soil Degraded Patterns in the Alas Bromo Education Forest

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Abstract. Land degradation is crucial for maintaining soil resilience and carbon storage, as key components in addressing the impacts of climate change. Soil degradation can reduce the function of soil as a biomass producer through the degradation of soil physical, chemical and biological properties. Alas Bromo Education Forest is a type of dry land that has several types of land cover with varying ages and has varying slopes. This study aims to determine the potential for soil degradation and the actual soil degradation status in the Alas Bromo Education Forest, determine the parameters that are limiting factors for soil degradation, and determine the effect of slope and tree stands with different ages on soil degradation status. The method used in this research is descriptive exploratory through survey approach and laboratory analysis. Alas Bromo Education Forest has the potential for moderate and high soil degradation. However, actual degradation does not indicate moderate and high degradation, but rather no degradation and minor degradation. Soils with non-degraded and lightly degraded classes have a fraction composition in the form of colloids <18%, bulk density >1.4 gr/cm³, porosity <30%, and degree of water passing <0.7 cm/hour. The greater the slope, the higher the soil degradation score. Rosewood with 5 years of age has the greatest influence on soil degradation. Maintaining low actual degradation rates is crucial for maintaining soil carbon storage and thus supporting climate change mitigation.

1 Introduction

Agriculture is not only defined as the cultivation of food crops; agriculture also broadly includes forestry crops. Land resources are included in one of the agricultural production factors that are closely related to the level of fertility and suitability of land for stranded commodities. Utilization of land resources is often done without paying attention to conservation measures that should be taken, so this allows soil degradation which is part of land resources. This soil degradation can reduce the function of soil as a biomass producer

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through a decrease in soil physical, chemical and biological properties. Soil degradation is possible in all types of land use, including forests. Indonesia has 34.3% production forest area, 34.7% protected forest area, and 30.9% conservation area [1].

Alas Bromo Education Forest includes a type of dry land that has the potential for agroforestry crop cultivation. Alas Bromo Education Forest has several types of land cover with varying ages and has varying slopes. Soils with steep slopes have the potential for greater soil degradation because soils with steep slopes will be more prone to erosion [2]. Stands with dense canopies have a role in providing organic matter to the soil in the form of litter and bark [3]. This soil degradation can affect the function of the forest in producing biomass. Maintaining soil quality in this area is therefore essential, as soil degradation can reduce ecosystem carbon sequestration capacity and consequently hinder climate-change mitigation efforts aligned with SDG 13 (Climate Action).

Alas Bromo Education Forest has an important role in carbon sequestration due to global warming. Tree growth is supported by the process of photosynthesis which can absorb and bind carbon in the air and then convert the substance into organic compounds stored in stand biomass. This biomass includes leaves, branches, stems and roots. The level of tree biomass in each land cover in the Alas Bromo Education Forest is 171.72 - 385.36 tons/ha [4]. The role Alas Bromo Education Forest in carbon sequestration must be maintained by optimizing the role of soil in producing biomass. Several studies have been conducted in relation to carbon and biomass, but there are still few that discuss soil conditions, especially none that discuss their relationship to land degradation. This study aims to identify and map land degradation patterns in Alas Bromo Educational Forest and determine the biophysical factors of the land that influence the level of land degradation in the area.

2 Materials and Methods

2.1 Research area description

The research was conducted at the Alas Bromo Education Forest, which is located on Karanganyar, Central Java, Indonesia whereas geographically at 7°34' 21.93" - 7°35'38.90" S and 110°59'40.39"- 111°0'49.36" E. The soil ordo at location is Alfisols with undulating and hilly topography with altitude of 200-337.5 m asl and has 3,225 mm/year rainfall [4]. Vegetation in Alas Bromo Education Forest is dominated by pine and mahogany stands. The decrease in land cover area will affect the status of land capability, the less land cover area, the status of land capability in supporting stand productivity will also decrease. This is followed by a decrease in the ability of land to store water, a decrease in the ability of land to reduce erosion and run-off rates and degradation of soil fertility [5]. The types of tree vegetation in Alas Bromo Education Forest are further described in Table 1. Because the research location is dominated by pine trees, so pine trees are grouped into several types of classes. Pine tree age classification depends on physiological conditions and management practices in each region. Generally, pine trees over 40 years old are no longer tapped due to low resin productivity. Pine trees aged 20–40 years are in their optimal production phase and are still actively tapped. Pine trees aged 10–20 years old can be tapped but have not yet reached maximum production, while pine trees under 10 years old are not yet suitable for tapping [6].

Alas Bromo Education Forest has a hilly and undulating topography with varying slopes. The amount of slope is directly proportional to erosion, the more sloping a land is, the greater the potential for erosion. The slope can affect the availability of water in the soil, this is because the steeper the land, the lower the infiltration rate. Soil with a steep slope will be

more easily degraded and disturbed, so this will affect stand growth and development and have an impact on reducing production yields.

Table 1. Tree vegetation type in Alas Bromo Education Forest

No	Vegetation type	Planting year
1	Annual crops	-
2	Mahogany 74 years old	1949
3	Mahogany 50 years old	1973
4	Old pine (> 40 years) old	1973, 1977
5	Old Tapping Pine (20-40 years old)	1994, 1996, 2000
6	Young tapper pine (10-20 years old)	2001, 2002, 2003, 2006, 2007
7	Young pine (< 10 years old)	2018, 2016
8	Rosewood 5 years old	2018

2.2 Research design

This research was conducted using a descriptive exploratory method through a field survey approach and laboratory analysis results. The activities were carried out in several stages in accordance with technical instructions based on the Minister of Environment Regulation number 7 of 2006 as an explanatory derivative of Government Regulation number 150 of 2000 concerning Control of Land Damage for Biomass Production. The first stage was the collection of secondary data in the form of maps of soil type, climate or rainfall, land use and land slope.

The next stage was the overlay of the map data to produce a Land Map Unit (LMU) or polygon area with the same land characteristics from the data. Each polygon was assessed according to the standard threshold of damage in the above ministerial regulation. The assessment results were used to generate a Potential Degraded Land Map, which served as the basis for determining field verification points by observing land conditions and taking soil samples. For each LMU, three field verification points were determined as a relative frequency for land degraded assessment.

The subsequent stage involved analyzing the field verification based on observation parameters according to the standard threshold of land damage to produce a spatial Land Degraded Status, which was presented in the form of a Land Degraded Status Map. This research identified 27 LMUs. In addition to the four types of secondary data used, stand types were also considered, as the study area was a forest area where land use was similar but management practices differed. The LMUs used in this study are presented in Table 2.

Table 2. Land Map Unit Alas Bromo Education Forest

LMU	Stand	Slope %	LMU	Stand	Slope %
1	Annual crops	9-15	15	Old Tapping Pine	26-40
2	Annual crops	16-25	16	Old Tapping Pine	>40
3	Annual crops	26-40	17	Young tapper pine	0-8
4	Mahogany 74 years old	0-8	18	Young tapper pine	9-15
5	Mahogany 74 years old	9-15	19	Young tapper pine	16-25
6	Mahogany 74 years old	16-25	20	Young tapper pine	26-40
7	Mahogany 74 years old	26-40	21	Young tapper pine	>40
8	Mahogany 50 years old	9-15	22	Young pine	9-15
9	Old pine	9-15	23	Young pine	16-25
10	Old pine	16-25	24	Young pine	26-40
11	Old pine	26-40	25	Rosewood 5 years old	9-15

12	Old Tapping Pine	0-8	26	Rosewood 5 years old	16-25
13	Old Tapping Pine	9-15	27	Rosewood 5 years old	26-40
14	Old Tapping Pine	16-25			

2.3 Statistical analysis

Conducting matching and scoring to determine the status of soil degradation and determine the parameters that become limiting factors. Performing erosion calculations using the USLE method. Conducting Analysis of Variance (ANOVA) statistical testing between actual soil degradation scores and slope and vegetation type. The ANOVA test was conducted to determine the effect of slope and land cover type on the actual soil degradation score. Conduct Duncan's Multiple Range Test (DMRT) to determine the real difference in effect. Conduct a correlation test between soil degradation parameters and actual degradation scores.

3 Results and Discussion

3.1 Potential Soil Degradation in Alas Bromo Education Forest

The land degradation potential score in Table 3 is obtained by multiplying the rating value by the values of each thematic map, including slope, rainfall, soil type, and land cover, although slope is the most variable. This variable determines land degradation potential, consistent with the soil erosion modeling concept in USLE and other formula variations such as RUSLE, where erosivity (rainfall) and topography (slope) significantly influence the initial sensitivity of the land to degradation [7]. The Alas Bromo Educational Forest has two degradation potential classes: moderate degradation potential and high degradation potential based on (Figure 1).

Table 3. Estimation of Soil Degradation Potential in Alas Bromo Education Forest

LMU	Slope (%)	Score	Total Score	Classification*
1	9-15	6	30	Moderate
2	16-2	9	33	Moderate
3	26-40	12	36	High
4	0-8	3	27	Moderate
5	9-15	6	30	Moderate
6	16-25	9	33	Moderate
7	26-40	12	36	High
8	9-15	6	30	Moderate
9	9-15	6	30	Moderate
10	16-25	9	33	Moderate
11	26-40	12	36	High
12	0-8	3	27	Moderate
13	9-15	6	30	Moderate
14	16-25	9	33	Moderate
15	26-40	12	36	High
16	>40	15	39	High
17	0-8	3	27	Moderate
18	9-15	6	30	Moderate
19	16-25	9	33	Moderate
20	26-40	12	36	High
21	>40	15	39	High
22	9-15	6	30	Moderate
23	16-25	9	33	Moderate

24	26-40	12	36	High
25	9-15	6	30	Moderate
26	16-25	9	33	Moderate
27	26-40	12	36	High

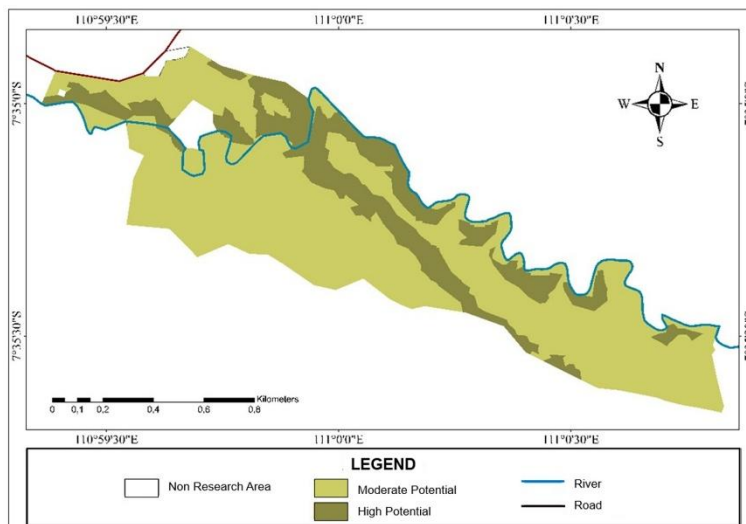


Fig. 1. Map of Soil Degraded Potential of Alas Bromo Education Forest

3.2 Actual Soil Degradation Status

Analysis result shown five parameters that are included in the degradation class, these are surface rock, fraction composition or particle size composition, bulk density, total porosity, and water permeability or infiltration. These five parameters are the limiting factors for soil degradation, as also reported in previous studies on soil degradation assessment in forest areas [8]. Based on the results of matching and scoring that have been carried out as in Table 4 and Figure 2, it can be seen that two soil degraded statuses are classified in the Alas Bromo Education Forest, namely the class of not degraded and low. A total of 10 LMU were categorized as not degraded and 17 LMU were categorized as moderately degraded. The lowest score is 0 and the highest score is 7 which has degradation to 3 parameters, these are bulk density, porosity, and infiltration.

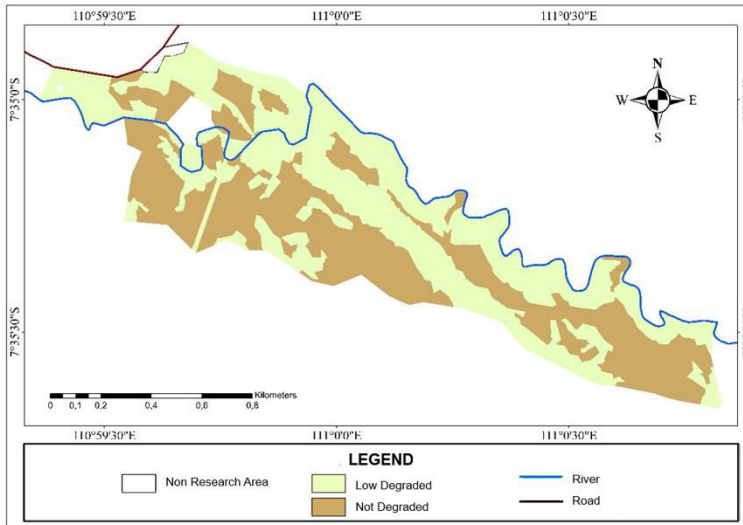


Fig. 2. Map of Actual Soil Degradation Status in Alas Bromo Education Forest

Table 4. Results of Matching and Scoring of Soil Degradation Parameters

LMU	Sd	Sr	Psc	Bd	Tp	Ir	pH	Ec	Rh	Tmc	Total	Status	Limited Factor
1	0	0	0	0	2	0	0	0	0	0	2	Low	Tp
2	0	0	0	0	2	0	0	0	0	0	2	Low	Tp
3	0	0	0	2	2	0	0	0	0	0	4	Low	Bd, Tmc
4	0	0	2	0	0	2	0	0	0	0	4	Low	Psc, Ir
5	0	2	0	0	2	0	0	0	0	0	4	Low	Sr, Tp
6	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
7	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
8	0	0	0	0	0	2	0	0	0	0	2	Low	Ir
9	0	0	0	0	2	0	0	0	0	0	2	Low	Tp
10	0	0	0	0	0	2	0	0	0	0	2	Low	Ir
11	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
12	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
13	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
14	0	0	0	2	0	0	0	0	0	0	2	Low	Bd
15	0	2	0	2	0	0	0	0	0	0	4	Low	Sr, Bd
16	0	2	2	0	0	0	0	0	0	0	4	Low	Sr, Psc
17	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
18	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
19	0	0	0	0	2	0	0	0	0	0	2	Low	Tp
20	0	0	0	0	0	2	0	0	0	0	2	Low	Ir
21	0	0	2	0	0	0	0	0	0	0	2	Low	Psc
22	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
23	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
24	0	2	0	0	0	0	0	0	0	0	2	Low	Sr
25	0	0	0	0	0	0	0	0	0	0	0	Not degraded	-
26	0	0	0	2	2	3	0	0	0	0	7	Low	Bd, Tp, Ir
27	0	0	0	2	2	0	0	0	0	0	4	Low	Bd, Ir

Description: Sd: Solum deep; Sr: Surface rockiness; Psc: Particle size composition; Bd: Bulk Density; Tp= Total porosity; Ir= Infiltration rate; Ec= Electrical conductivity; Rh= Redox; Tmc= Total microbial count

Table 5. Correlation of Soil Degraded Parameters with Actual Soil Degraded Score

	Sd	Sr	Sp	Cp	Bd	Tp	Ir	pH	EC	Rh	Tmc
ASD	-.033	.271*	.137	-.057	.335**	-.296**	-.204	.18	-.134	-.19	-.014

Description: ASD: Actual soil degraded; Sd: Solum deep; Sr: Surface rockiness; Sp: Sand particle; Cp: Coloid particle; Bd: Bulk Density; Tp: Total porosity; Ir: Infiltration rate; Ec: Electrical conductivity; Rh: Redox; Tmc: Total microbial count

Based on Table 5, the correlation test results show that the soil degradation score is positively correlated with surface rock (0.271*). The higher the percent of surface rock, the higher the soil degradation score, indicating that the soil in the area is more degraded. Sandy soils have low water holding capacity and organic matter content so that they are not widely used for agricultural activities. The soil degradation score is positively correlated with bulk density (0.335**), and negatively correlated with total porosity (-0.296*). The higher the porosity value, the lower the soil degradation score, and likewise the higher the bulk density value, the higher the soil degradation score. Porosity affects the movement of water and air, and influences the storage and availability of water to the stand. Low bulk density indicates that the pore space in the soil tends to be large so that the permeability and infiltration rate of the soil will be high [9].

3.3 Effects of slope and vegetation type on actual soil degradation status

The effect of diversity type in the form of slope and vegetation type on soil degradation status can be seen in Table 6. The Anova test results show that slope and vegetation type have a real effect on the actual soil degradation status, so a further test is carried out in the form of the DMRT test to determine the real difference between the two types of diversity as shown in Figure 3 and Figure 4.

Table 6. ANOVA Test of Slope and Stand type on Actual Soil Degraded

ANOVA	Source of diversity	
	Stand type	Slope
P-value (sig.)	.002**	.022*
N	84	84

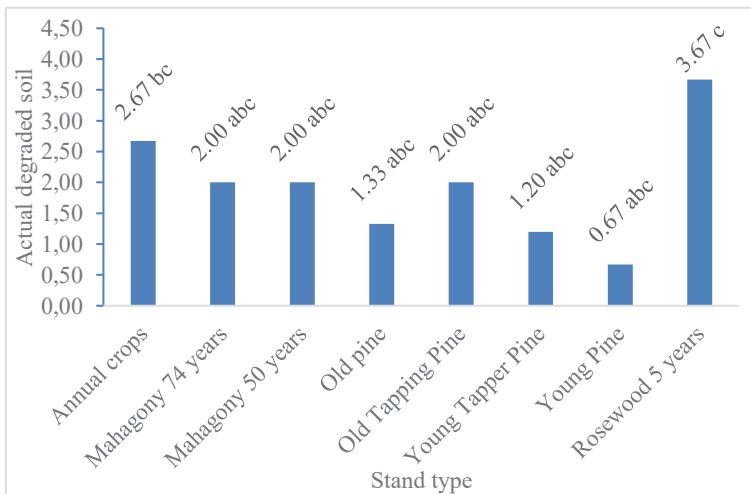


Fig. 3. DMRT of Stand Type on Actual degraded soil

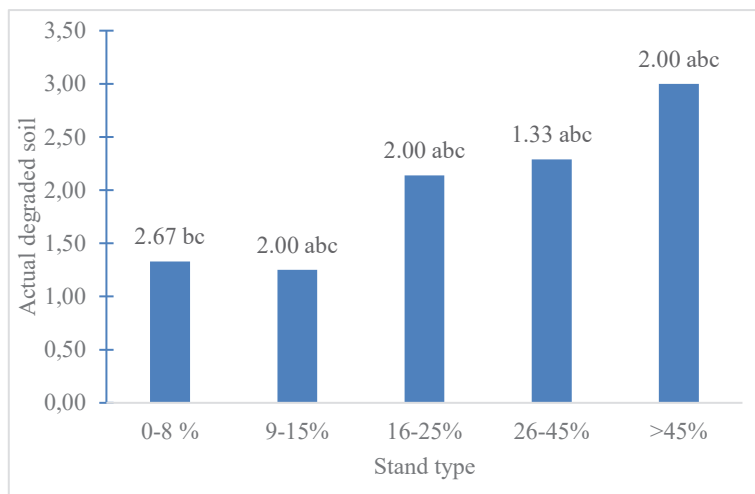


Fig. 4. DMRT of Slope on Actual degraded soil

3.4 Discussion

There is a difference between potential soil degradation and actual soil degradation status in Alas Bromo Education Forest, this may occur because potential soil degraded only uses secondary data in the form of slope, rainfall, soil type, and land use type. While the actual erosion soil degraded status uses primary data from 10 parameters in the form of solum depth, surface rocks, particle size composition, bulk density, porosity, infiltration rate, pH, electronic conductivity, redox, and total microbial count. Based on existing sources, the scoring used in determining potential soil degraded is higher than the scoring of actual soil de degraded gradation status. potential soil degraded has a score on each factor with a range of 2-15 while the actual soil degraded score on each parameter is 1-4. Alas Bromo Education Forest is a forest area with a fairly dense canopy, cool air, and lots of leaf litter on the soil surface. Leaf litter is an organic material that can improve soil aggregates and increase the total number of pores in the soil so that the weight of the soil content becomes low. This allows the soil to be included in the class of not degraded and low degraded. Land cover will affect the redox value, the higher the land cover, the higher the redox value. The redox value is high because of the lack of sunlight that can penetrate into the soil. An example of a redox reaction is the process of photosynthesis in stands [10]. Organic matter can make the soil structure crumbly so that it has a relatively small weight because the soil with this structure has a lot of pore space.

Soil with a high percent of surface rock indicates that the land has been eroded so that it loses a lot of fertile soil particles and only leaves rocks. Soil surfaces that have a high percent of surface rocks indicate that the land area has experienced high erosion, so the soil is also experiencing a nutrient deficit [10]. Surface rocks will affect the amount of effort that will be made in land processing, the less rocks on the surface, the easier land processing will be done. The steeper the slope of a land, the course the soil and the loss of clay fraction. Soil with a sufficient percent of the sand fraction makes the soil less prone to runoff and erosion because it has large soil pores, so water is easily infiltrated and percolation can occur more quickly [11]. Soil bulk density shows an inverse relationship with porosity. As depth increases, the soil bulk density tends to increase because deeper layers are generally denser. Therefore, the greater the soil bulk density, the lower the porosity [12]. Soil with clay texture has a high total porosity but low permeability rate because it is dominated by micro pores The low

permeability rate can indicate that root movement activity is also disturbed because the soil has a dense structure [10]. The greater the porosity, the greater the ability of the soil to pass water [11]. The amount of permeability rate in the soil is directly proportional to the amount of porosity and infiltration.

Based on Figure 3, it is known that 5-year-old rosewood stands have the highest average level of degradation. Rosewood with 5 years of age is significantly different from young pine, old pine, young tapping pine, and is not significantly different from other stands. Differences in stand types result in differences in the speed of decomposition of leaves. Tree age will affect the biomass that can be produced and the number of piles of debris on the ground. The age factor affects the volume of the tree because of the increase in the number of cells, cell volume, and cell mass. Based on Figure 4, it is known that slopes >40% have the highest average degradation. Slope >40% was significantly different from 0-8% and 9-15%, but not significantly different from the other 2 slopes. The higher the slope, the greater the potential for soil degradation. Land with a high slope level will be more easily disturbed or degraded [13]. The steeper the land, the greater the likelihood of erosion and loss of organic carbon. Erosion removes fertile topsoil and reduces the groundwater's water retention capacity, increasing soil permeability [14].

4 Conclusion

Based on the results of the research, it can be concluded that the Alas Bromo Education Forest has the potential to experience moderate to high levels of soil degradation. However, the actual condition indicates that soil degradation is generally absent or occurs at a low level. Soils classified as not degraded or slightly degraded are characterized by a low proportion of colloidal fractions, high bulk density, low porosity, and slow infiltration rates. An increase in slope is associated with higher levels of actual soil degradation. Rosewood stands have the greatest influence on soil degradation compared to other vegetation types. Low levels of actual soil degradation contribute positively to climate change mitigation, as dense canopy cover and abundant litter reflect high biomass production and enhanced carbon sequestration.

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References

- [1] Pusat Data dan Informasi, *Statistik 2022 Kementerian Lingkungan Hidup dan Kehutanan*. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan, 2023.
- [2] A. Suzana, "Penyusunan Status Kerusakan Tanah untuk Produksi Biomassa di Kabupaten Bandung," *Unbari Civronlit Journal*, vol. 4, no. 1, pp. 1–9, 2019.
- [3] F. A. Siahaan, Rony Irawanto, Apriyono Rahadiantoro, and Ilham Kurnia Abiwijaya, "Sifat Tanah Lapisan Atas di Bawah Pengaruh Tegakan Vegetasi Berbeda di Kebun Raya Purwodadi. Jurnal Tanah dan Iklim Vol. 42 No. 2, Desember 2018: 91-98," pp. 91–98, 2018.
- [4] T. A. Drupadi, D. P. Ariyanto, and S. Sudadi, "Pendugaan Kadar Biomassa dan Karbon Tersimpan pada Berbagai Kemiringan dan Tutupan Lahan di KHDTK Gunung Bromo UNS," *Agrikultura*, vol. 32, no. 2, p. 112, 2021, doi: 10.24198/agrikultura.v32i2.32344.

- [5] D. P. Ariyanto, A. R. Wijayanti, and J. Suyana, “Kesesuaian Lahan Tanaman Jahe, Kencur, Kunyit, dan Serai Wangi sebagai Komoditas Agroforestri di KHDTK Gunung Bromo, Kabupaten Karanganyar,” *Jurnal Penelitian Hutan Tanaman*, vol. 19, no. 2, pp. 75–89, Dec. 2022, doi: 10.59465/jpht.v19i2.785.
- [6] H. Bowo Woesono, Sushardi, and M. B. Pamungkas, “Pengaruh Kelas Umur dan Metode Sadapan Terhadap Produksi Sadapan Getah Pinus,” *Jurnal Wana Tropika*, vol. 12, no. 1, pp. 1–7, Jul. 2022, doi: 10.55180/jwt.v12i1.214.
- [7] I. Andriyani, Indarto, S. Soekarno, and M. P. Pradana, “Analysis of rainfall erosivity factor (R) on prediction of erosion yield using USLE and RUSLE Model’s; A case study in Mayang Watershed, Jember Regency, Indonesia,” *Sains Tanah*, vol. 21, no. 1, pp. 64–73, 2024, doi: 10.20961/stjssa.v21i1.63641.
- [8] T. M. Hartati, A. Teapon, I. Wati, U. S. Y. Vitri Indrawati, and K. Aji, “Analisis Kapasitas Infiltrasi pada Beberapa Tipe Lahan Tegalan di Kelurahan Sasa Kecamatan Ternate Selatan,” *Agrikultura*, vol. 34, no. 3, p. 401, 2023, doi: 10.24198/agrikultura.v34i3.47021.
- [9] S. S. Harahap, M. Manfarizah, and T. Alvisyahrin, “Analisis Sifat-Sifat Fisika Tanah pada Beberapa Kelas Lereng di Kecamatan Lembah Seulawah Kabupaten Aceh Besar,” *Jurnal Ilmiah Mahasiswa Pertanian*, vol. 9, no. 1, pp. 554–562, 2024.
- [10] A. A. G. Al-Shammery, A. Z. Kouzani, A. Kaynak, S. Y. Khoo, M. Norton, and W. Gates, “Soil bulk density estimation methods: A review,” *Pedosphere*, vol. 28, no. 4, pp. 581–596, 2018.
- [11] Roisatul Ainayah, Amang Fathurrama, Mulyono Wibisono, Fafit Rahmat Aj, and Diyono Yusuf, “Pengaruh Jenis Tegakan terhadap Komposisi dan Keanekaragaman Tumbuhan Bawah di Hutan Sapen Kecamatan Prigen Kabupaten Pasuruan,” *Agromix*, vol. 8, no. 1, 2017, doi: 10.35891/agx.v8i1.564.
- [12] S. Soltanpur and M. Jourgholami, “Soil Bulk Density and Porosity Changes due to Ground-based Timber Extraction in the Hyrcanian Forest,” *Not. Sci. Biol.*, vol. 5, no. 2, pp. 263–269, May 2013, doi: 10.15835/nsb528951.
- [13] D. P. Ariyanto, M. P. Solekha, J. Suyana, S. Maro’ah, Komariah, and M. Senge, “Erosion Prediction Based on Musle Method in Various Land Covers in Gunung Bromo Education Forest,” 2025.
- [14] T. Li *et al.*, “Soil erosion affects variations of soil organic carbon and soil respiration along a slope in Northeast China,” *Ecol. Process.*, vol. 8, no. 1, p. 28, Dec. 2019, doi: 10.1186/s13717-019-0184-6.