Soil physicochemical properties to evaluate soil degradation under different land use types in a high rainfall tropical region: A case study from South Sulawesi, Indonesia

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Abstract. Intensive cropping in the tropical region always becomes one of important driving forces of soil degradation. The primary aim of this study is to analyze the states and the dynamics of soil physicochemical properties to evaluate soil degradation in the tropical region a high rainfall on agricultural areas in South Sulawesi. A number of soil characteristics were analyzed for physical and chemical properties, and clay minerals with X-ray diffractometer. The degree of soil degradation is determined using Wischmeier and Smith equation. This study reveals that mean annual precipitation in 1979-2016 ranged from 1853.15 to 2981.30 mm/year. For land used for paddy field, palm oil, cacao and coffee plantation, the texture dominated with silt loam-clay loam, cation exchange capacity was 18.63-26.32 cmol+ kg⁻¹, 0.98-2.91% of C-organic, 32-55% of base saturation, 0.1-3.5 cm h⁻¹ of permeability, soil clay minerals were montmorillonite-kaolinite-halloysite, and the index erodibility was 0.3-0.5. Land used for mixed plants and shrubs, the texture dominated with silt loam-sandy clay loam, cation exchange capacity was 18.63-27.12 cmol+ kg⁻¹, 1.09-2.89% of C-organic, 32-55% of base saturation, 0.2-4.9 cm/h of permeability, soil clay minerals were kaolinite-halloysite, and index erodibility was 0.1-0.3. Land use for cultivated in the high intensity of rainfall has changed the physicochemical properties of soils, but cultivated in monoculture has at some degree increased soil erodibility.

1. Introduction

Land with sloping topography in the tropic area had many used for an intensively cropping system for needing the community feed. Tropical region always connected with a high rainfall activity [1], where the period of rainy season from the equator to 30°N in May to October while from the equator to 30°S in November to April [2]. Cooperate rainfall and cultivation increased many processes in soil, such as weathering, alteration, eluviation, and illuviation [3], and as an important agent to decrease soil degradation.

Land use with intensively used giving significance for decreasing soil physicochemical properties [4, 5]. Soil degradation usually disturbed soil organic-carbon content [6], texture [7, 8], and fertility of soil [9]. Intensive cropping in the tropical region always becomes one of important driving forces of soil degradation, especially erosion and landslides.

The primary aim of this study is to analyze the states and the dynamics of soil physicochemical properties to evaluate soil degradation in the tropical region a high rainfall in agricultural areas.

2. Materials and Method

2.1. Study site

Soil was taken from a high degree of landslides-prone area and no-landslides area with different land use types in three districts of South Sulawesi, Indonesia 9 (figure 1) based on ESDM data [10]. The coordinates location were; Enrekang District for degraded soil; E1: 119°50'43.69"E and 3°16'52.32"S;
and E3: 119°47'48.34"E and 3°14'37.65"S; while for non-degraded soil were; E2 119°50'44.44"E and 3°16'53.89"S; and E4: 119°47'48.60"E and 3°16'14.36.86"S, North Toraja District for degraded soil; T1: 119°53'13.11"E and 2°52'26.96"S; and T3: 119°53'26.87"E and 2°52’1.96"S, and for non-degraded soil were; T2: 119°53’13.32"E and 2°52’29.51"S; and T4: 119°53’25.09"E and 2°52’5.45"S, and East Luwu District for degraded soil were; L1: 120°48’0.72"E and 2°22’57.06"S; and L3: 120°47’40.19"E and 2°22’23.46"S; and for non-degraded soil were; L2: 120°48’4.33"E and 2°22’59.49"S; and L4: 120°47’36.64"E and 2°22’25.26"S. The area had an elevation of 320-1542 m above sea level (asl) and slope topography range of 40-60%.

Figure 1. Location map of study area

2.2. Soil analysis

The soils analysis were pH with pH meter, texture with hydrometer method, Cation Exchange Capacity (CEC) with 1 M NH₄OAc, cations of Ca, Mg, K and Na done by extracting with ammonium acetate in pH 7 then measured with an Atomic absorption spectrophotometer, base saturation (BS), permeability with permeameter, and C-Organic content with Walkley and Black method. Soil erodibility from [11] modified by [12] was used to evaluate soil degradation degree.

The equation from Wischmeier and Smith (1978) is:

\[ 100K = 1.292 \times [2.1M^{1.14}(10^{-4})(12-a) + 3,25(b-2) + 2.5(c-3)] \]

where:

- \( K \) = Soil erodibility
- \( M \) = percent fines sand + percent silt (0.1-0.02mm) times the quantity 100-percent clay
- \( a \) = percent organic matter,
- \( b \) = the soil-structure code used in soil classification, and
- \( c \) = the profile-permeability class.

The soil temperature in 25 and 50 cm depth were measured with soil temperature tools and soil minerals were analyzed with X-Ray Diffractometer (XRD) Shimadzu XRD-7000.
3. Results

3.1. Rainfall Data
Mean annual precipitation in 1979-2016 ranges from 1853.15 to 2981.30 mm year\(^{-1}\) [13, 14]. The data showed that the distribution of rainfall becoming extreme start from 1991, where Enrekang District has dry season extreme, but in 2000 where North Toraja District and East Luwu had wet season extreme and reached 4500-5200 mm year\(^{-1}\) (figure 2). The extreme climate still continued until now. This was a connection to global warming phenomena [15] and impact of green revolution which caused intensively cropping in all region in Indonesia [16].

![Distribution of Rainfall](image)

**Figure 2.** Distribution of rainfall from 1979 to 2016 from Enrekang District, North Toraja district and East Luwu district

3.2. Physicochemical Properties of Soil
Degraded soils at 25 cm depth have a temperature ranging from 24 to 34 °C, and 23-29 °C at 50 cm depth. The area was used for paddy field in North Toraja, palm oil and cacao in East Luwu, crop and coffee plantation in Enrekang District. The range of soil pH was 4.5-6.4, and it indicated increasing of leaching process. Texture dominated with silt loam-clay loam with difference in the fraction presentation, and C-organic ranged of 0.98-2.91% (table 1). Soils with non-degraded had a temperature at 25 cm depth ranging of 26-31°C and 23-29 °C at 50 cm depth. Land used dominating with mixed plants and shrubs. The range of soil pH was 5.0-6.5, texture was very varied and dominated with silt loam, clay loam, and sandy clay loam, and C-organic ranged of 1.09-2.89%. BS and CEC in degraded soil and non-degraded soil had same variation from first layer and second layer and gave not much contribution to soil degradation.

3.3. Soil Erodibility
The permeability of soil degraded ranged of 0.1-3.5 cm/hour with criterion of very slow-moderate and the index erodibility was 0.3-0.5 with soil clay minerals dominated with montmorillonite, vermiculite, illite, kaolinite, and halloysite. Permeability of soil non-degraded ranged of 0.2-4.9 cm hour\(^{-1}\) with criterion of very slow-moderate and the index erodibility was 0.1-0.3 with soil clay minerals dominated with illite, kaolinite, and halloysite (table 2).
### Table 1. Physicochemical properties of soil

| Soil layer | Soil depth | Sand | Fine sand | Silt | Clay | Texture | pH | C-Organic | Exchangeable Cations | CEC | BS |
|------------|------------|------|-----------|------|------|---------|----|----------|----------------------|-----|-----|
|            | cm         | %    | %         |      |      |         |    | %        | H_2O Ca Mg K Na      |     |     |
| E1.1       | 0-10       | 5    | 12        | 41   | 42   | Clay loam | 4.5| 2.91     | 6.84 1.24 0.22 0.36   | 24.62 | 39  |
| E1.2       | 10-30      | 5    | 12        | 38   | 45   | Clay      | 5.6| 1.86     | 6.14 1.86 0.16 0.25   | 26.25 | 32  |
| E2.1       | 0-10       | 4    | 17        | 42   | 37   | Clay loam | 6.0| 2.41     | 6.92 2.24 0.28 0.36   | 24.62 | 40  |
| E2.1       | 10-20      | 4    | 15        | 31   | 50   | clay      | 6.0| 1.86     | 6.78 2.13 0.23 0.25   | 26.20 | 36  |
| E3.1       | 0-10       | 4    | 19        | 40   | 37   | Clay Loam | 5.7| 2.67     | 6.85 3.25 0.21 0.21   | 25.32 | 42  |
| E3.2       | 10-30      | 2    | 10        | 39   | 49   | Clay      | 5.8| 2.14     | 7.42 3.22 0.19 0.25   | 26.32 | 42  |
| T1.1       | 0-10       | 5    | 11        | 57   | 27   | Silt loam | 5.6| 2.06     | 6.56 2.65 0.19 0.25   | 20.89 | 47  |
| T1.2       | 10-40      | 4    | 8         | 50   | 28   | Silty clay | 5.8| 1.86     | 7.25 3.41 0.36 0.28   | 21.85 | 52  |

### Table 2. Soil erodibility index from different land use types

| Soil layer | Organic Matter | Cramer | Code of Permeability | Code of structure | Soil Mineral | Land Use types |
|------------|----------------|--------|----------------------|------------------|--------------|----------------|
| E1.1       | 5.02           | 0.5    | 5                    | 3                | soil degraded, montmorillonite (28.6%), vermiculite (5.9%) | crop |
| E1.2       | 3.21           | 0.1    | 6                    | 4                | illite (12.5%), kaolinite (6%), halloysite (47) | crop |
| E2.1       | 4.15           | 0.5    | 5                    | 2                | soil non-degraded, montmorillonite (0.8%), illite (5.8%), | shub |
| E2.2       | 3.21           | 0.4    | 6                    | 3                | chlorite (32.7%), halloysite (52.5), kaolinite (8.2%) | coffe |
| E3.1       | 4.60           | 0.4    | 6                    | 3                | chlorite (10.3%), halloysite (38.3%), kaolinite (22%) | paddy fields |
| E3.2       | 3.69           | 0.2    | 6                    | 3                | chlorite (10.3%), halloysite (38.3%), kaolinite (22%) | paddy fields |
| E4.1       | 4.98           | 0.5    | 5                    | 3                | soil degraded, montmorillonite (12.1%), vermiculite (7.4%) | mixed plants |
| E4.2       | 4.34           | 0.3    | 6                    | 3                | soil non-degraded, montmorillonite (16.6%), illite (12.8%) | mixed plants |
| T1.1       | 4.88           | 1.3    | 6                    | 4                | soil-degraded, montmorillonite (28.6%), vermiculite (5.9%) | paddy fields |
| T1.2       | 4.36           | 0.4    | 6                    | 4                | illite (12.1%), kaolinite (23.1%), halloysite (39.4%) | paddy fields |
| T2.1       | 4.40           | 0.5    | 6                    | 3                | soil non-degraded, montmorillonite (0.8%), illite (5.8%), | shub |
| T2.2       | 4.15           | 0.6    | 6                    | 3                | chlorite (32.7%), halloysite (52.5), kaolinite (8.2%) | coffe |
| T3.1       | 4.97           | 1.3    | 5                    | 3                | chlorite (10.3%), halloysite (38.3%), kaolinite (22%) | paddy fields |
| T3.2       | 4.02           | 0.4    | 6                    | 3                | soil degraded, montmorillonite (28.6%), vermiculite (5.9%) | mixed plants |
| T4.1       | 4.80           | 0.8    | 5                    | 6                | soil non-degraded, montmorillonite (16.6%), illite (12.8%) | mixed plants |
| T4.2       | 3.69           | 0.6    | 6                    | 3                | soil non-degraded, montmorillonite (16.6%), illite (12.8%) | mixed plants |
| L1.1       | 3.19           | 3.3    | 4                    | 3                | soil degraded, montmorillonite (28.6%), vermiculite (5.9%) | cocoa |
| L1.2       | 1.69           | 0.3    | 6                    | 3                | kaolinite (94%), halloysite (1.8%), | cocoa |
| L2.1       | 3.38           | 4.9    | 5                    | 2                | soil non-degraded, montmorillonite (0.7%), illite (20.5%) | mixed plants |
| L2.2       | 2.72           | 1.5    | 5                    | 3                | soil non-degraded, montmorillonite (0.7%), illite (20.5%) | mixed plants |
| L3.1       | 3.03           | 1.6    | 5                    | 4                | kaolinite (74.8%), halloysite (4%), | palm oil |
| L3.2       | 2.84           | 1.2    | 5                    | 3                | kaolinite (74.8%), halloysite (4%), | palm oil |
| L4.1       | 1.88           | 0.4    | 6                    | 3                | soil degraded, montmorillonite (28.6%), vermiculite (5.9%) | shub |
| L4.2       | 2.43           | 1.9    | 5                    | 3                | soil degraded, montmorillonite (28.6%), vermiculite (5.9%) | shub |

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**Note:** The tables represent the physicochemical properties and erodibility index of different soil layers and land use types, indicating various soil characteristics such as texture, pH, organic content, and permeability, as well as the erosion risk associated with different land use activities.
4. Discussion
Physicochemical properties of soil on degraded soil and non-degraded soil with different land use types showed the difference in soil texture conditions from the percentage of fine-coarse soil fractions. The difference in the size of the soil fraction affected the cohesiveness of the soil grains and influenced soil erodibility index value [4, 17, 18]. Degraded soils in cultivated soils had larger erodibility index values with greater difference of organic material content between first layer and second layer of soil at same profile, compared with non-degraded soils, the percentage difference between organic matter content in first layer to second layer was very small (table 1). Organic matter had functioned as an aggregate binding of soil fraction, so the soil is difficult to degrade [6].

Differences in the value of the erodibility indexes in the first and second layers of soil profile lead to decrease in soil stability so that the soils were easily eroded (table 2). Differences in the value of the erodibility index generally occur on land used for monoculture plantations, whereas land used for mixed plantations and shrub, the stability of the soil in second layer is higher or equal than layer in first layer so as to prevent soil degradation. According to Dibal et al. [17], mixed plants is one of management to retain soil from degradation, especially in the tropical region with high activity of rainfall, where study area had high mean annuals of rainfall categories [14]. Rainfall contributed to increase weathering in soil and produced secondary clay minerals. These minerals can absorb water in their surface crystal and in interlayer space of crystal [19, 20] and caused the soil permeability slower. Variety of clay minerals in soil have contributed to decreasing soil stability [21, 22, 23] and triggering erosion-landslides.

Soils structure in form of blocky shape in the second layer of profile had a relationship to trigger the erosion/landslides. Blocky structure indicated to present of clay minerals fraction in the soil and inhibits water sub-surface movement downward [24]. This support with permeability data, where the value of permeability became very slow downward (table 2).

5. Conclusions
Land use for cultivated in the high intensity of rainfall has changed the physicochemical properties of soils, but cultivated in monoculture has at some degree increased soil erodibility.

Acknowledgments
Thanks to the Ministry of Research, Technology and Higher Education Indonesia for the bppdn scholarship and dissertation grant.

Thanks to the Post-Graduate Program and LP2M of Hasanuddin University for the opportunity to do this research.

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