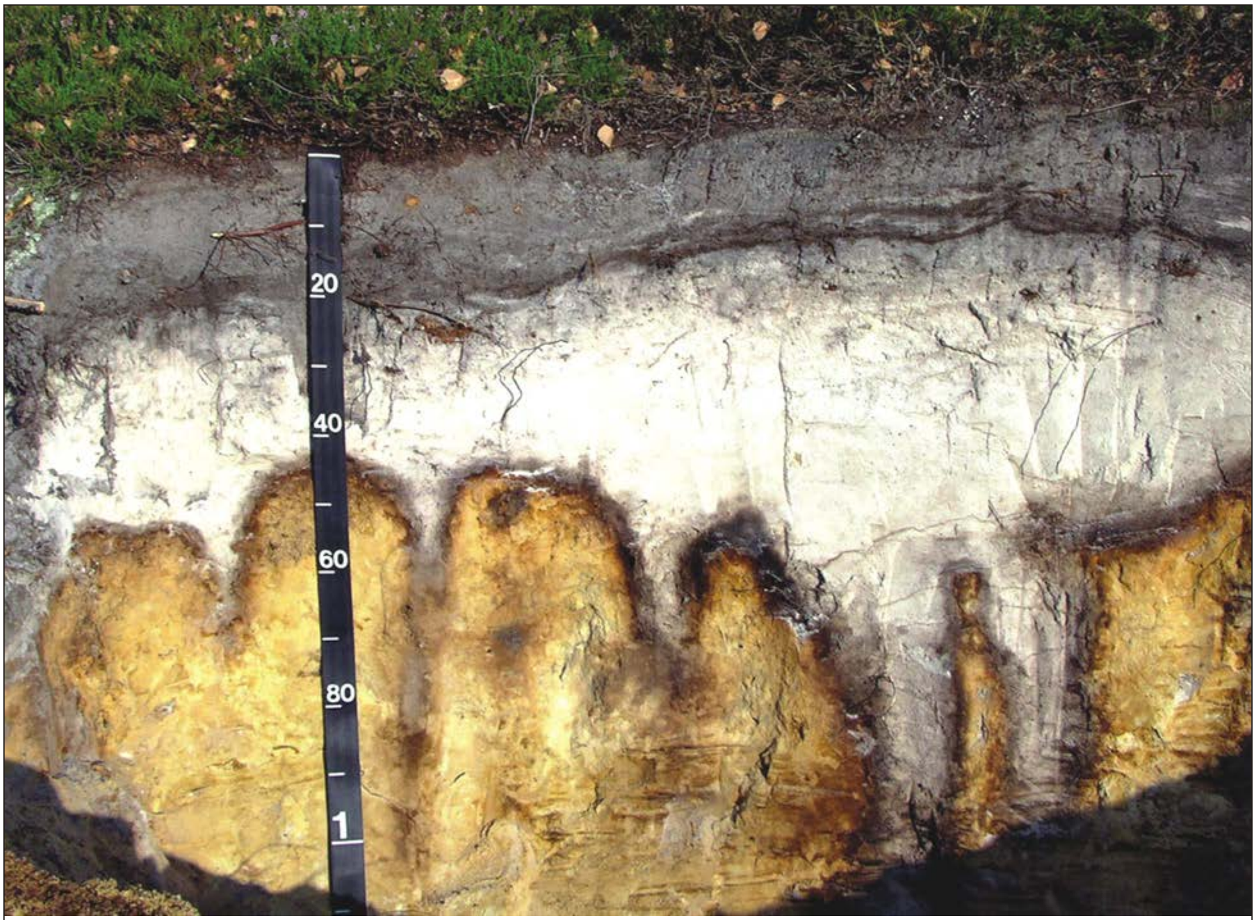

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Research Article
Variability of Soil Development in Hilly Region, Bogowonto Catchment, Java, Indonesia

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Abstract
Background and Objectives: In Java, a transitional landscape zone is widely formed and causes specific soil profile development due to strongly affected by unstable geomorphic condition. The assessment of variability of soil development at transitional landscape zone is less studied. So, the objective of this study was to characterize variability of soil development in a transitional landscape zone of Bogowonto Catchment. **Materials and Methods:** Profile Development Index (PDI) were applied to describe the degree of soil development in nine soil profiles from different part of transitional tertiary and quaternary volcanic-structural landscape. The PDI were used to quantify field properties of soils, like texture, moist consistence, wet consistence, structure, rubification, melanization and pH. Parent material properties were also used as references. The quantified data were analyzed through data normalizing per each horizonto result in profile index and weighted mean profile index. **Results:** The PDI assessment showed that residual soils had the highest index of soil development compared to human-induced soils and landslide-induced soils. Color index (rubification) and textural index are significant to detect residual soils and induced-soils either by geomorphic process or human induces. The same soil types did not always express similar values of PDI because it was depended on geogenic process affected soil parent materials. The study showed that PDI of soils in the transitional landscape zone was not necessarily correlated with parent rock age due to largely disturbed by unstable geomorphic condition. The significant influence of slope inclination was better than slope arrangement in determining the degree of PDI. **Conclusion:** There was no sequential pattern of PDI in a transitional landscape zone as an impact of unsystematic inclination along slopes and various geogenic and geomorphic processes. The disturbed soils either by human or by geomorphic processes were less developed than residual soils.

Key words: Soil variability, soil development, transitional zone, landscape, profile development index

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Variability of soil development has been a current issue over the world. Many studies have discussed about the variability of soil development since the last three decades[1]. They consider the variability of soil development as an effect of systematic variation along catena[2] or deterministic variation related to local geographical factors[3]. Variability of soil development is actually not an impromptu process because many certain factors have influenced on soils and during the soil formation[4].

High degree of soil development variability is commonly found in a hilly region. In such region, the variability of soil development is mainly caused by geomorphic processes where the heterogeneity of relief is dominated[5]. Landslides become a dominant geomorphic process causing the variability of soil development in hilly region[6]. Landslides transport the residual soils to other places and/or mix the residual soils with other deposited soils. Furthermore, this variability can be varied by human activities which generate soil re-distribution[7] in the form of terraces and other land management practices[8].

Development index has been widely used to assess the variability of soil development. In the original study, the development index was purposed for buried soils which have wide ranges of development and their chemical properties have been altered due to burial[9]. Most of previous studies applied various development indices to measure the differences in soil development with age and slope arrangement, for example profile development index (PDI) for Merced river chronosequence[10], Silt-weathering index for colluviums and eolian deposits[11], Buntley-Westin color index for fluvial terraces in Northwestern Italy[12], Hurst color index for estimating soil age in the Western Po Valley, Italy[13].

In Indonesia, the problem of variability of soil development is quite pronounced in Java. Java has a major landscape of hilly and was formed by a complex morpho structure at the past[14]. In most previous studies, the variability of soil development in Indonesia were strongly related to long range of deposition and the variation of weathering process in particular region[15]. The study area, central part of Bogowonto Catchment, is spatially controlled by volcanic deposits and massive geomorphic processes. Therefore, the problem of variability of soil development in the study area is arising.

Research on variability of soil development is important, especially as a basic for soil mapping. The lack of good soil map has brought insufficient soil information, which often leads to false recommendations for crops and soil management. The objective of this study was to characterize soil variability in the transitional zone of tertiary and quaternary volcanic landscape.

MATERIALS AND METHODS

Study site: The study area, central part of Bogowonto Catchment, is included on the South Serayu Mountain Complex laid on 7°17'00"S-8°47'00"S and 109°34'30"E-110°09'00"E. It covers 329.11 km^2 (Fig. 1). It is the transitional landscape zone of sumbing quaternary volcanic-structural systems and menoreh tertiary volcanic-structural systems. The elevation of the area under study ranges from 35-1065 m.s.l.

The topography of the study area is characterized by gently to very steep slopes. The lithological setting of the study area was derived from four geological formations, i.e., Old-Andesitic van Bemmelen Formation (andesitic breccias, lava andesite, tuff, lapili-tuff and agglomerate), Halang Formation (tuff, alternation of marl-sandstone, calcareous tufa) andesitic intrusion and Alluvium. Today, some of these geological formations are covered by quaternary volcanic deposits. Therefore, they formed 3 types of geomorphic units: (1) Volcanic toe-slope, (2) Volcanic-structural hillslope, (3) Fluvio-structural footslope (Fig. 1). The climatic setting of the study area is categorized by tropical monsoon conditions with an abrupt distinction between rainy and dry season. The average annual rainfall varies between 2500 and 4000 mm with a maximum in December and January.

Field design: Purposive sampling was applied in this study based on variation of upper-most soil materials within several geomorphic units. The upper-most soil materials were classified as: (1) Residual soil materials (volcanic ash deposit, weathered and altered andesitic breccias, weathered marls), (2) Landslide-induced soil materials and (3) Human-induced soil materials. The geomorphic units presented in the study area were volcanic toe-slope, structural hillslope, volcanic-structural hillslope with variety of soil materials and slopes (Table 1). Nine soil profiles were selected to represent the variation of upper-most soil materials in the study area (Table 2). Of the total 9 soil profiles, there were 2 profiles derived from volcanic ash deposit, 1 profile derived from altered andesitic breccias, 1 profiles derived from weathered andesitic breccias, 1 profiles derived from weathered marl, 2 profile derived from human-induced soil materials and 2 profiles derived from landslide-induced soil materials. Soils were collected in 2014 and the analyses were done throughout the year.

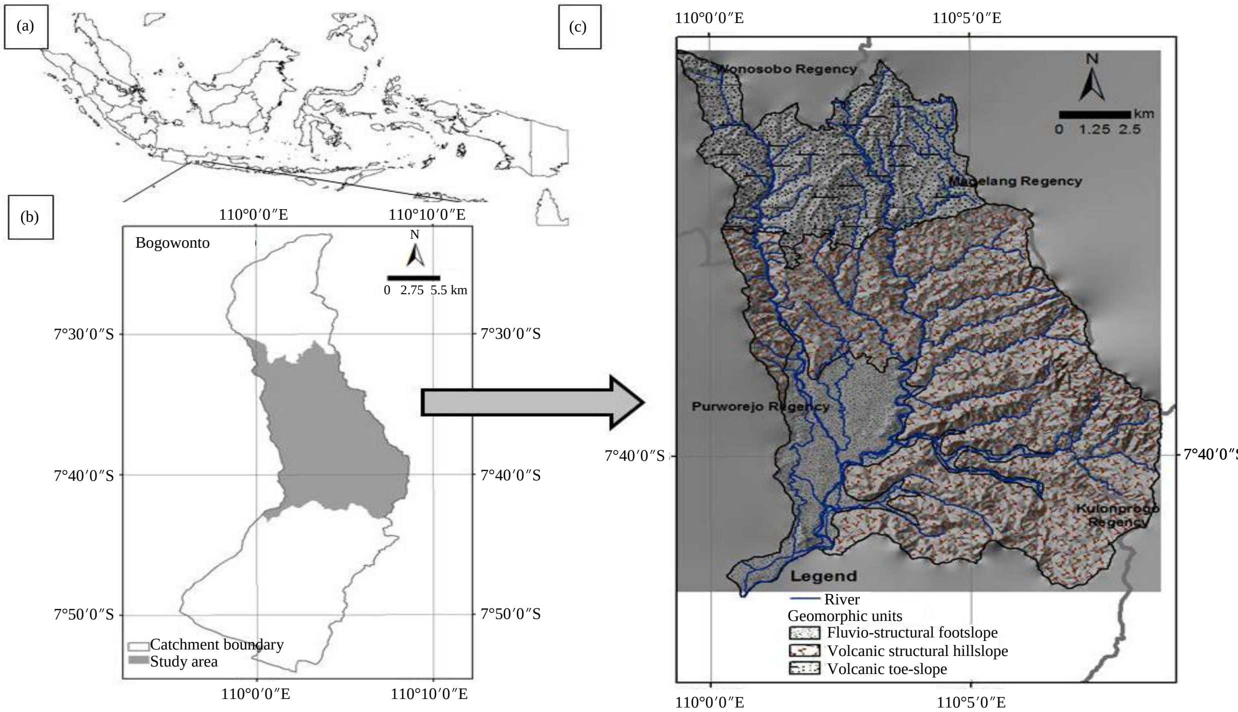

Fig. 1(a-c): Study area: (a) Indonesia, (b) Bogowonto Catchment and (c) Middle Bogowonto

Soil analyses: The 9-soil profiles were analyzed qualitatively and quantitatively. Qualitatively, soil profile development was described by horizon differentiation within the profile. The morphological properties of soils were described using the guideline for soil description[15]. Meanwhile, a quantitative soil profile development was assessed through profile development index or called as soil profile development index (PDI) by Harden[10].

Profile indexing: The PDI expressed the variation of soil development based on seven field morphological properties, i.e., texture (χt), moist consistence (χm), wet consistence (χw), structure (χs), rubification (χr), melanization (χv) and pH (χpH). PDI converted the grade of parameter into a single numerical value in order to result in profile index and weighted mean profile index. These PDI(s) were applied for residual soils, landslide-induced soils and human-induced soils. The quantification of morphological properties among three types of soils in the study area was described on Table 2. In compliment, parent material properties were also used as references in PDI assessment (Table 1).

RESULTS AND DISCUSSION

Soils derived from residual soil materials had the highest profile development index (PDI) compared to other soil materials in the study area (Table 3). Profile development indices of the residual soils varied from 30-126, while, profile development indices of human-induced soils and landslide-induced soils ranged about 20 and <10, respectively. These indices showed that the disturbed soils either by human or by geomorphic processes were less developed.

In the study area, profile development index (PDI) of residual soils was not necessarily correlated with parent rock age (older to younger: Andesitic breccia>marl/sandstone/tuff>altered andesitic breccia>volcanic ash). Table 3 showed that soil developed on andesitic breccias did not have the highest PDI (index = 31.27) although andesitic breccia is the oldest parent rock in the study area which lithology ranged of 17.1-26 million years of age[6]. According to the result, volcanic ash soils had the highest PDI in weathered materials, 42.72. Consequently, variability of soil profile development in the transitional landscape zone was not associated with spatial distribution of parent rocks.

Uncorrelation of residual soils' PDI and parent rock age was because the study area had unstable geomorphic condition. As a transitional landscape zone, this area was surely affected by massive mass movement. Pulungan[16] stated that landslide events in the study area have largely increased since 2007. These landslide events accordingly disrupted the soil profile development in the study area. This finding is in contrast to the study in Spain conducted by Alonso *et al.*[17]

Table 1: Assessment of soil material properties based on geomorphic units

Profiles	Geomorphic unit	Dominant soil materials	Moist color	Texture	Clay films	Structure	Wet-moist consistence*	pH
1	Volcanic toe-slope Vegetation: Shrubs, bushes, natural forests Elevation: 700-1600 m Slope: 8 to >45°	Volcanic ashes	10 YR 8/3 (light yellow orange)	Silt loam	None	Single grain	so, po-lo	6.43
2	Fluvio-structural footslope Vegetation: Shrubs, bushes, agricultural plants Elevation: 400-1000 m Slope: 15-25°	Marl/sandstone/tuff	10 YR 6/1 (brownish gray) 10 YR 8/6 (yellow orange) 10 YR 8/1 (light gray)	Silty clay Sandy loam Silt loam	Yes, thin None None	Massive Massive Massive	s, p-fi so, po-fi so, po-fr	6.91 7.24 7.16
3	Volcanic-structural hillslope Vegetation: Shrubs, bushes, agricultural plants Elevation: 400-1000 m Slope: 15-45°	Altered andesitic breccias	10 YR 7/2 (light gray)/ 5 YR 7/4 (dull orange)	Clay loam/clay	None Yes	Massive	ss, po-fi s, p-fi	6.74 6.52
4	Volcanic-structural hillslope Vegetation: Shrubs, bushes, agricultural plants Elevation: 400-1000 m Slope: 15-45°	Weathered Andesitic breccia	10 YR 6/6 (bright yellowish brown)	Loam	None	Massive	ss, po-fi	6.78

*Consistency: (Wet) so: No-sticky, ss: Slightly sticky, s: Sticky, vs: Very sticky, po: No-plastic, sp: Slightly plastic, p: Plastic, vp: Very plastic, (Moist) vfr: Very friable, fr: Friable, fi: Firm, vfi: Very firm

Table 2: Quantification of soil field properties

			Quantified soil field properties							Normalized data							
Profiles	Soil material (degree of slope)	Horizon (cm)	χt	χs	χw	χm	χr	χv	χpH	χt	χs	χw	χm	χr	χv	χpH	Sum normalized
1	Volcanic ash deposit (13°)	A (0-28)	0	15	0	5	5	20	0.77	0.00	0.43	0.00	0.20	0.17	0.57	1.00	2.37
		BC (28-96)	0	25	10	10	0	10	0.01	0.00	0.71	0.33	0.40	0.00	0.29	0.01	1.74
		C (96-177+)	0	0	0	15	15	10	0.00	0.00	0.00	0.00	0.60	0.50	0.29	0.00	1.39
2	Altered A. breccias (19°)	A (0-27)	20	15	10	0	5	10	0.00	1.00	0.43	1.00	0.00	0.33	0.33	0.00	3.09
		Bt (27-90)	20	25	10	5	5	5	0.41	1.00	0.71	1.00	0.50	0.33	0.17	1.00	4.71
		C (90-216)	20	0	10	5	10	5	0.24	1.00	0.00	1.00	0.50	0.67	0.17	0.59	3.93
3	Weathered A. breccias (16°)	A (0-16)	20	20	10	0	5	10	0.17	1.00	0.57	1.00	0.00	0.33	0.33	0.41	3.64
		C (16-61)	20	0	10	5	10	5	0.09	1.00	0.00	1.00	0.50	0.67	0.17	0.22	3.56
4	Volcanic ash deposit (29°)	A (0-29)	0	15	10	5	10	15	0.36	0.00	0.43	0.33	0.20	0.33	0.43	0.31	2.03
		C (29-148+)	0	0	10	10	10	5	0.24	0.00	0.00	0.33	0.40	0.33	0.14	0.21	1.41
5	Weathered marl (24°)	A (0-21)	0	20	0	0	15	5	0.71	0.00	0.57	0.00	0.00	0.38	0.20	1.00	2.15
		C (21-96)	0	0	0	5	5	5	0.71	0.00	0.00	0.00	0.50	0.13	0.20	1.00	1.83
6	Human-induced soils (21°) (dryland agr)	Ap (0-20)	15	15	10	10	5	15	1.16	0.25	0.43	0.33	0.40	0.08	0.33	0.23	2.05
		Bw (20-44)	35	25	30	15	10	15	0.87	0.58	0.71	1.00	0.60	0.15	0.33	0.17	3.54
		C (44-94+)	0	0	5	15	10	5	0.52	0.00	0.00	0.17	0.60	0.15	0.11	0.10	1.13
7	Human-induced soils (32°) (mixed garden)	Ap (0-36)	5	15	0	5	0	5	0.00	0.08	0.43	0.00	0.20	0.00	0.11	0.00	0.82
		C (36-109+)	5	20	0	10	0	5	0.00	0.08	0.57	0.00	0.40	0.00	0.11	0.00	1.16
8	Landslide-induced mat. (29°)	A (0-17)	30	15	10	0	5	10	0.00	0.50	0.43	0.33	0.00	0.08	0.22	0.00	1.56
		C (17-74+)	0	0	0	0	5	5	0.00	0.00	0.00	0.00	0.00	0.08	0.11	0.00	0.19
9	Landslide-induced mat. (37°)	A (0-13)	15	15	0	0	0	15	0.67	0.25	0.43	0.00	0.00	0.00	0.33	0.13	1.14
		C (13-96+)	0	0	0	0	5	5	0.50	0.00	0.00	0.00	0.00	0.08	0.11	0.10	0.29

χt: Texture, χm: Moist consistence, χw: Wet consistence, χs: Structure, χr: Rubification, χv: Melanization, χpH: pH

Table 3: Index results of quantified soil field properties

Profiles	Soil material (degree of slope)	Horizon (cm)	Index results				
			Sum normalized	Divided by number of properties	Multiplied by horizon thickness	Profile development index	Weighted mean profile(Horizon index)
1	Volcanic ash deposit (13°)	A (0-28)	2.37	0.34	9.52	42.72	0.24
		BC (28-96)	1.74	0.25	17.00		
		C (96-177+)	1.39	0.20	16.20		
2	Altered andesitic breccias (19°)	A (0-27)	3.09	0.44	11.91	124.68	0.58
		Bt (27-90)	4.71	0.67	42.21		
		C (90-216)	3.93	0.56	70.56		
3	Weathered andesitic breccias (16°)	A (0-16)	3.64	0.52	8.32	31.27	0.51
		C (16-61)	3.56	0.51	22.95		
4	Volcanic ash deposit (29°)	A (0-29)	2.03	0.29	8.41	32.21	0.22
		C (29-148+)	1.41	0.20	23.80		
5	Weathered marl (24°)	A (0-21)	2.15	0.31	6.51	26.01	0.27
		C (21-96)	1.83	0.26	19.50		
6	Human-induced soils (21°) (dryland agr)	Ap (0-20)	2.05	0.29	5.87	26.18	0.28
		Bw (20-44)	3.54	0.51	12.20		
		C (44-94+)	1.13	0.16	8.11		
7	Human-induced soils (32°) (mixed garden)	Ap (0-36)	0.82	0.12	4.22	16.63	0.15
		C (36-109+)	1.16	0.17	12.41		
8	Landslide-induced mat. (29°)	A (0-17)	1.56	0.22	3.74	5.45	0.07
		C (17-74+)	0.19	0.03	1.71		
9	Landslide-induced mat. (37°)	A (0-13)	1.14	0.16	2.08	5.40	0.06
		C (13-96+)	0.29	0.04	3.32		

which stated that the profile index increased as the soil age increased. Also, the study of Marsan *et al.*[12] in Italy found that the value of development index increased with the increasing of age.

Among the residual soils, PDI of soil developed on volcanic ash deposit was much higher than that of other soils. Higher index of volcanic ash soils (42.71 and 32.21) indicated that soil profile development in volcanic toe-slope unit was faster than that in structural-volcanic hill slope and structural hill slope units. The detail properties of each unit were as shown in Table 1. Of the seven morphological properties used in index assessment, rubification, structure and moist consistence were the most significant variables to determine soil profile development of residual soils. Melanization, wet consistence, texture and pH were not as significant as previous variables in controlling the soil profile development [Table 2 (profile 1-5)]. Quantification of rubification was an important color index because many different kinds of soils redden with age[18].

The same soil materials did not always express similar values of profile development index (PDI). The PDIs of volcanic ash soils were 42.71 and 32.21 [Table 3 (profile 1 and 4)]. Furthermore, the same parent rock under different geogenic processes (i.e., weathering and alteration) affected the variability of soil development. Profile 2 and 3 (Table 3) showed that soil developed on altered andesitic breccias and on weathered andesitic breccias had large difference of index, 124.68 and 31.27, respectively. A shallower soil depth was formed in soil developed on weathered materials compared to that developed on altered materials (Table 2). It was because geogenic process of both rocks resulted in very different degree of chemical weathering leading to large difference of profile development[19]. The study of Pulungan[16] showed that thick soil on altered materials was due to the result of several B-horizons formation along the profile. This finding was in agreement with the study of Pirajno[20], who showed that a hydrothermal alteration might generate an argillic alteration resulting in layering of argillic horizon under different intensities. Therefore, the results of this study were in line with the study of Zielhofer *et al.*[21] showed that the duration of soil formation drives the degree of soil profile development.

Slope arrangement (upper-, mid-, lower-slope) did not determine the degree of profile development index (PDI) in the transitional landscape zone. Soil developed on weathered marl (profile 5) which was located at lower slope of structural hills had smaller PDI (26.01) than that on altered andesitic breccias (profile 2) at middle slope of structural-volcanic hills (124.68) and on weathered andesitic breccias (profile 3) at upper slope of structural-volcanic hills (31.27). Another condition in Table 3 showed that PDI of volcanic ash soil in the upper slope of the study area was greater than that in the middle slope of the study area. The results of this study were in contrast to the study of Bui *et al.*[22] examined that the development of soil in Vietnam differed at slope arrangement. Also, the study of Badia *et al.*[23] investigated that slope arrangement had positive effect to soil development in semiarid mountainous since the position controlled water retention in soils.

Slope inclination played more important role than slope arrangement in determining variability of soil development in the study area. As a transitional landscape zone, the slope inclination was not sequentially formed based on its slope arrangement. Various intensities of geomorphic processes controlled the natural inclination of slope in particular landscape zone. Under the same soil materials, profile 1 which had lower percentage of slope (13°) resulted in greater PDI than profile 4 (29°), as shown in Table 3. Profile 1 was located in the upper slope, however it did not cause smaller value of PDI. It is because profile 1 had lower slope inclination and thus it had low susceptibility of geomorphic processes either landslides or erosion. Durak and Surucu[24] confirmed that slope characteristics were the major factor in soil development as they associated with an amount of water entering soils to control vertical water movement during soil profile development. Consequently, lower slope inclination of profile 1 had bigger possibility of having more water entering soils than profile 4 and thus resulted in greater PDI of profile 1. Furthermore, Webster[4], Borujeni *et al.*[3] revealed that the soil variability is mostly attributed to dynamical instability or specific local events. Also, the study of Phillips[1] had proved that the irregular variability of soils is closely associated with local geographical variation.

Profile development index (PDI) of soil derived from human-induced soil materials was lower than the index of residual soils. The result showed that PDI of human-induced soils were 16.63 and 26.18. The finding of this study proved that the activities of human, i.e., tillage and terrace practices significantly influenced development of soil profile as they caused disturbances towards soil surfaces and increased the accumulation of clay fraction in sub-surface shown by existence of B-horizon (Table 2 profile 6). The activity of human may not only modified the soil characteristics chemically[25] but also affected the intensity of soil processes[26]. These intensive disturbances made surface soils more prone to soil erosion and hence resulted in less developed soil profile. Consequently, the index of profile development at lower slope which intensively disturbed by human (Table 3 profile 7) was smaller than that at middle slope (Table 3 profile 6).

Structure, moist consistency and pH were significant variables determining soil profile development of human-induced soils. It was indicated by variation in quantified soil field properties among horizons (Table 2). In this soil type, structure was significantly influenced by tillage and other mechanic practices applied on the soil surface and consequently influenced the moist consistency (profile 6 and 7). The study of Alleto and Coquet[27] stated that tillage caused compaction structure of soils as an impact of tillage's mechanical effect. Moreover, Manyiwa and Dikinya[28] examined that especially in clayey soils like the study area, the tillage made the soils becoming more compact due to formation of hard-pan. The pH in human-induced soils was strongly influenced by the fertilization practices used in particular land use types. The results showed that the quantified value of pH in profile 6 was higher than that of pH in profile 7 because profile 6 was applied by dryland agriculture which have more intensive of fertilizer practices. The study of Alfaro *et al.*[29] examined that medium-term of chemical fertilizer application might induce poor soil structures and thus retained soil profile development.

Profile development index (PDI) of soil derived from landslide-induced soil materials was the lowest among all soil types in the study area. It was because landslide-induced soils were derived from landslide deposit which was formed later than residual soils. Therefore, the weathering intensity of landslide-induced soils was still less than that of residual soils. The results showed that profile development index of landslide-induced soils were <10, which were 5.45 and 5.40. Besides, these indices were much lower than the indices of other deposit types like eolian deposit about 20-60[19] or fluvial deposit about 18-47[21].

Texture and structure were significant variables for determining profile development of landslide-induced soils. Finding from this study was also consistent to the study of Jeong *et al.*[30] proved that landslide deposits often had a mix of coarse and fine particle sizes due to soil turning and mixing during gravitational process of the occurrences. According to Table 2, this vertical textural contrast was indicated through drastic changes of texture value quantification within the profile (profile 8 & 9). In other side, various quantification values of structure reflected the changes of soil particles bonding. It was confirmed by Annabi *et al.*[8] that soil aggregation was significantly associated with soil resistance to water erosion or landslides.

Altogether, profile development of residual soils, landslide-induced soils and human-induced soils in hilly region varied spatially. The results showed that the indices of soil profile development were varied from 5.40 to 124.68 (Table 3). Table 3 also presented that horizon indices (HI) of the upper-most horizons were various between one to another soils. It was because development of horizon depth also varied one to another. It proved that local disturbances, i.e., landslides or even human activities play a crucial role to profile development. The distinctness of morphological properties and thickness of horizons were the main indicators for variability of soil profile development in this study (Table 2). However, there was no sequential pattern of profile development index as an impact of unsystematic variation of slope inclination and various geogenic and geomorphic processes in transitional landscape zone.

CONCLUSION

This study concluded that there is no sequential pattern of profile development index in the transitional landscape zone. Spatial variability of soil profile development in the transitional landscape zone is varied based on geomorphic unit and is not associated with the spatial pattern of parent rocks. Quantification of morphological properties can effectively express the differences of development stage of soil profile which result in various profile indices (PDI). Therefore, it has confirmed that soil-scape concept is significant to characterize the spatial variability of soil profile development in the transitional landscape zone rather than soil catena concept.

SIGNIFICANCE STATEMENT

The study evaluated the variability of soil development in hilly region of Indonesia and found that there is no sequential pattern of PDI in a transitional landscape zone and disturbed soils either by human or by geomorphic processes are less developed than residual soils. These findings might be used as a reference for other research of soil development under similar characteristics of area. This will help the researchers to detailed research on the disturbed soil rehabilitation.

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