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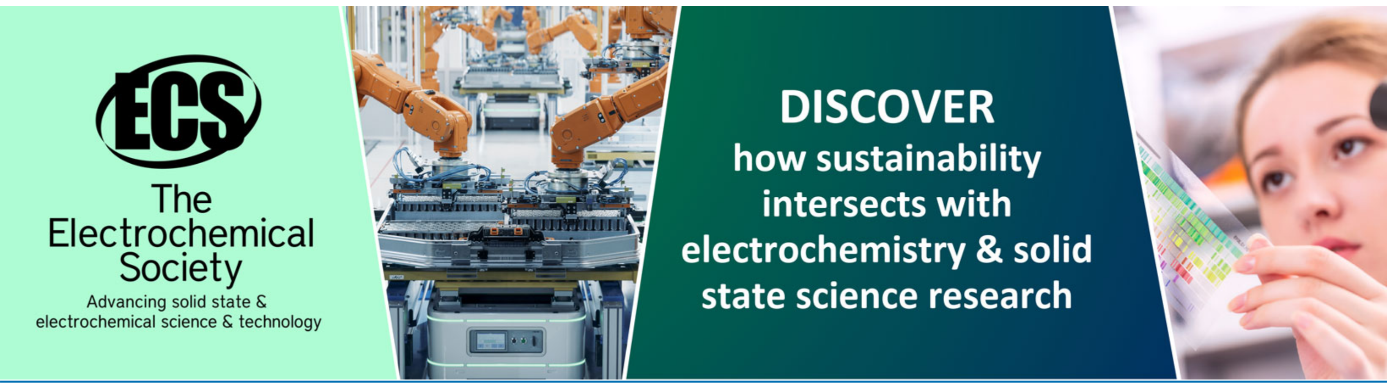

Land degradation index of tropical forest landscape in Batang Toru watershed using spatial analysis

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ABSTRACT
Forest degradation and deforestation have reduced the functions of forest ecosystem in Batang Toru watershed landscape. The degree of land degradation rate can be minimized by restoring the functions of forest ecosystem. Data concerning the degree of land degradation is needed to restore the functions of forest ecosystem. This research aims to obtain spatial distribution characteristics of land as well as land degradation index in Batang Toru watershed landscape. Land degradation was determined by using 3 variables, namely soil chemical and physical properties, as well as erosion type which occur in the site. Each variable was ranked through Likert scale. The total score of all land degradation indicators was converted into land degradation index. The study found that land degradation index in Batang Toru watershed landscape consist of very low (0,00-0,2), low (0.21-0,4), moderate (0.41-0,60), high (0.61-0.80) and very high (0.81-1.00). Most of Batang Toru watershed areas fall into moderate land degradation category.

Keywords: restoration, forest ecosystem, watershed, likert scale, spatial analysis

1. Introduction

One of the consequences of uncontrolled population growth is increased land degradation in some parts of the world, where more than 30% of cultivation areas, 30% of forest areas and 10% of grasslands are undergoing degradation [1]. Land degradation has a negative impact on some 2.6 billion people [2]. Land degradation is increasing in tropical countries due to high temperature and rainfall resulting in increased surface runoff, nutrient leaching, and erosion [3]. The most significant form of land degradation in Asian region is soil erosion, followed by degradation of chemical properties such as decreased soil organic matter content and nutrient leaching. Changes in land use and land management pattern lead to the change in soil organic matter content.

Land degradation will have a negative impact on humans and other living things. Land degradation will lead to a decline in crop productivity in the future, increased migration and food vulnerability, pose a hazard to resources and basic ecosystems, and cause a loss of biodiversity through habitat change due to forest degradation at both species and genetic levels [4, 5]. In addition, land degradation will have an impact on the socio-economic life of the people who depend on the land as their source of livelihood. Deforestation is one of the factors that trigger land degradation. Land degradation in Indonesia occurred in 16% of its total land area or 31,370,634 ha, or lower than that in the Asia Pacific region of 22.26% of total land area [1]. Indonesia's critical land area in 2010 reached 81,664,294.90 ha, or greater than that in 2006 of 77,806,880.78 ha. Critical land in North Sumatra in 2010 reached 2,753,596.70 ha [6]. North Sumatra suffered deforestation of 6,508,525 ha (28%) during 1985-1997 [7]. The resulting impacts include major floods and landslides in 2006, as well as floods in 2007 and 2010 in North Sumatra. Batang Toru watershed as one of the remaining tropical forest ecosystems in Sumatra suffered deforestation at a rate of 1.17% per year during 1994-2009 which reduced its forest area from 162,000 ha to 151,000 ha in 2009. As a result, critical land area in Batang Toru watershed increased from 13,000 ha in 2005 to 17,000 ha in 2009.

Land degradation can serve as a disturbance indicator of the stability of forest ecosystem. A stable forest ecosystem is characterized by a stable watershed condition. A stable watershed is indicated by minor variations in water flow during dry and rainy seasons, as well as low surface runoff. These conditions will prevent flooding and erosion, thus minimizing land degradation. Field indicators that can be observed and measured are erosion and soil characteristics.

The stability of damaged ecosystem can be restored through conservation, rehabilitation, and restoration. The area of damage is large enough so that a method for determining priority sites is needed to ensure successful rehabilitation and restoration. One of the indices that can be used in this respect is land degradation index that defines the degree of severity of land degradation. The degree of land degradation can serve as one of the indicators to determine which ecosystems that need to be prioritized for rehabilitation and restoration. A research on land degradation index has not been conducted yet, whereas the information used in current land rehabilitation planning is the degree of critical land in the watershed area. Thanks to land degradation index, it is possible to know the location and degree of degraded land that need to be prioritized for ecosystem restoration and could potentially lead to successful rehabilitation and restoration. The study aims to determine land degradation index in Batang Toru watershed landscape.

2. Methodology

2.1. Time and Location of Research

The research was conducted in Batang Toru watershed (DAS) which consists of Puli, Sarulla and Toru Hilir (sub-watersheds), in North Sumatera Province. The study area is located between 1°10'36.47" - 1°10'36.60" North Latitude and 98°23'8.22" - 98°49'15" East Longitude (Figure 1). The research site covers an area of 202,783 ha with elevations ranging from 0 to 2000 m above sea level. Based on the topography, the research site consists of flat to ramp areas (0% - 15%) of about 75.66% of the total area and slope to very steep slope areas (> 15%) of about 24.34% of the total area.

Oldeman climate classification divides the research site into 3 climate types, namely type A, and D1. Based on the Decree of the Minister of Forestry (SK) No. 44 of 2005, the research site consists of Conservation Forest (0.06%), Nature Reserve (6.27%), Production Forest (39.10%), Protected Forest (2.93%), Limited Production Forest (12.55%) and other uses (39.08%). Nature reserve, protected forest and conservation forest are managed by the Ministry of Environment and Forestry and are important biodiversity sites in the island of Sumatra.

2.2. Research Materials and Tools

The data used in this research are Landsat satellite imagery in 2013, 1: 250.000 scale land units map, 1: 50.000 scale contour map, vegetation data, soil physical and chemical properties, and erosion types in the field. The land cover map was produced by interpreting Landsat 8 OLI satellite imagery in 2013 as well as through field verification. The interpretation of satellite imagery used ENVI 4.5 software. Data on soil physical and chemical properties were obtained from soil samples taken in the field using purposive sampling method based on a combination of land units, land cover and sub-watersheds. The tools used in this research consist of field survey instruments and data analysis tools. Field survey activity used GPS, haga hypsometer, phi band, land drill, and soil ring. While the tools used to analyze the data is TAL (Texture AutoLookup), and Excel.

2.3. Data Collection and Analysis

A total of 140 sample plots were surveyed to verify land cover type. The quadrangular sample plot with a size 50 m x 50 m was divided into 4 quadrants of 25 m x 25 m. The vegetation data collected from the sample plots are trees, poles, stakes and seedlings. The tree level was measured in all quadrants, the pole was measured in 10 m x 10 m plot in one quadrant, the stake was measured in 5 m x 5 m sub-plot, and the seedling level was measured in a plot of 2 m x 2 m in one quadrant. Soil sampling for measuring bulk density as well as soil physical and chemical properties were done in 54 sample plots. A total of 54 soil sample plots were systematically placed which are adequate to represent 3 watershed areas and 7 land cover types. The soil samples taken were undisturbed soil samples at a depth of 10 - 20 cm, and composite soil at a depth of 10 - 40 cm. To know their physical and chemical properties, soil samples were analyzed in the Soil Laboratory of SEAMEO BIOTROP.

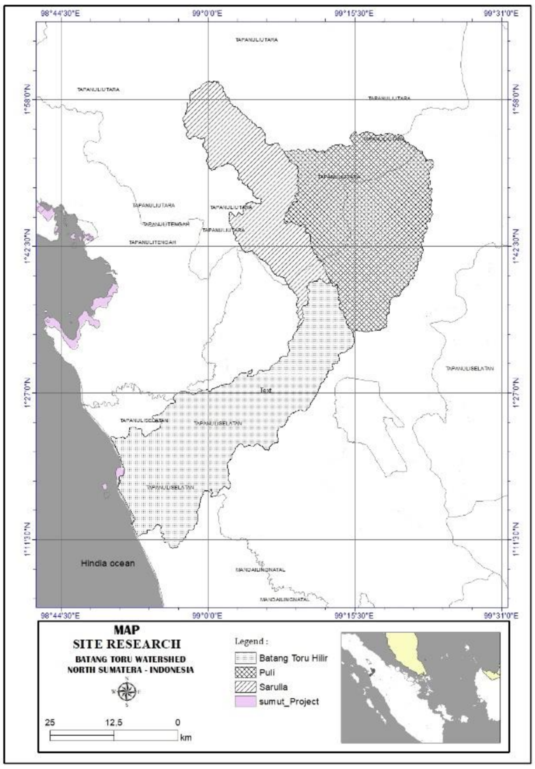


Figure 1. Research site

The collected vegetation data were analyzed to obtain the values of diversity index, individual density and basal area [8]. Meanwhile, the soil samples were analyzed to know their physical and chemical properties. Soil physical properties that were analyzed are bulk density (BD), and 3 (three) soil texture classes, while the soil chemical property that was analyzed was organic C (*Walkey & Black*). The results of soil texture analysis were interpreted using TAL software to obtain soil texture class. Likewise, the physical and chemical properties of soil were each classified into 5 classes [9, 10] and were assessed using the Likert scale.

The physical and chemical properties of soil and the occurrence of erosion in the field served as indicators of land degradation. The score of each land degradation indicator are listed in Table 1.

The score of each indicator was then summed to obtain land degradation score [10] using equation (1). The factors used in equation (1) are land degradation indicators listed in Table 1. The total summed score was converted (rescaled) into land degradation index as formulated in equation (2). Then, based on land units and land cover types, the converted score was spatially analyzed to obtain land degradation distribution map. The spatial analysis was done using Arc GIS 9.3 software .

$$Wdl = \sum_{i=1}^{n} wdl_i x fdl_i \qquad (1).$$

Notes:
Wdl = the total summed score of land degradation
wdl_i = the weight of factor i
fdl_i = the score of factor i

$$\mathrm{Ind_{DL}} = \frac{(\mathrm{score_{input}} - \mathrm{score_{min}})}{\mathrm{score_{tot-maks}} - \mathrm{skor_{tot-min}}} \mathrm{x}(\mathrm{ind\_DL_{maks}} - \mathrm{ind\_DL_{min}}) \qquad (2)$$

Notes:

$\mathrm{Ind_{DL}}$ = the value of degradation index (rescaling)
S_{total}= the total summed score of land degradation as input (Wdl value)
score $_{totmin}$= the minimum score of total land degradation score
$\mathrm{Score_{tot-max}}$= the maximum score of total land degradation score
Ind_DL $_{max}$= the highest index value of rescaling results
Ind_DL $_{min}$= the lowest index value of rescaling results

Land degradation indices were grouped into 5 (five) classes with equal width interval (Table 2). The purpose of land degradation classes is to spatially demonstrate land degradation degree in Batang Toru watershed.

Table 1. Scores and indicators of soil physical and chemical properties in degraded land

Indicator	Class	Score	Land Degradation Degree
1. Soil texture class[a]	Texture class		
	Silty clay	5	Very high
	Silty sand	4	High
	Sandy clay	3	Moderate
	Silty clay	2	Low
	Loam	1	Very low
2. Organic C[b]	Organic C class (gr / 100 gram)		
	<0.1	5	Very high
	1.00 - 2.00	4	High
	2.01 - 3.00	3	Moderate
	3.01 - 5.00	2	Low
	> 5.00	1	Very low
Bulk density[c]	Bulk density class (gr / cm3)		
	> 1.9	5	Very high
	1.6 - 1.9	4	High
	1.3 - 1.6	3	Moderate
	1.0-1.3	2	Low
	<0.1	1	Very low
Erosion type[d]	Erosion class		
	Big gully, landslide	5	Very high
	Gully	4	High
	Rill	3	Moderate
	Sheet	2	Low
	No data	1	Very low

Remarks: [a] [10], [b] [11], [c] [12] [d][10], modified

Table 2. The range of land degradation indices and degrees

Land Degradation Index	Land Degradation Degree
0.00 - 0.20	Very low
0.21 - 0.40	Low
0.41 - 0.60	Moderate
0.61 - 0.80	High
0.81 - 1.00	Very high

3. RESULTS AND DISCUSSION

3.1. Land cover in Batang Toru Watershed

The interpretation of Landsat 8 OLI satellite imagery revealed that land cover types consist of forest, mixed garden, crop estate, bare land, paddy field, settlement, dryland agriculture, and water body (Table 3). The majority of Batang Toru Watershed landscape consists of forest (33.65%), followed by mixed garden (29.54%) and dryland agriculture (13.02%). Based on sub-watershed areas, Sarula sub-watershed (41.68%) has the highest proportion of forest and dryland agriculture areas. Ecologically speaking, Sarula watershed will be better than other sub watersheds because it has larger proportion of forest area. Forest ecosystem is capable of controlling the water system in a watershed with an area of <100 km^2 [13] can prevent erosion [14] and play a role in improving the climate. Dense forest canopy will decelerate the throughfall and accelerate the stemflow thus preventing the water from reaching the forest floor. The littered forest floor provides a living space for microorganisms, increases porosity and reduces surface runoff rate. Extensive dryland agriculture in Sarula can increase land degradation if not managed properly based on soil and water conservation rules. Planting crops on terraces can minimize the occurrence of erosion. In addition, the cultivation of agricultural land will degrade soil quality. The resulting impacts are erosion and the leaching of nutrients, which will degrade the land.

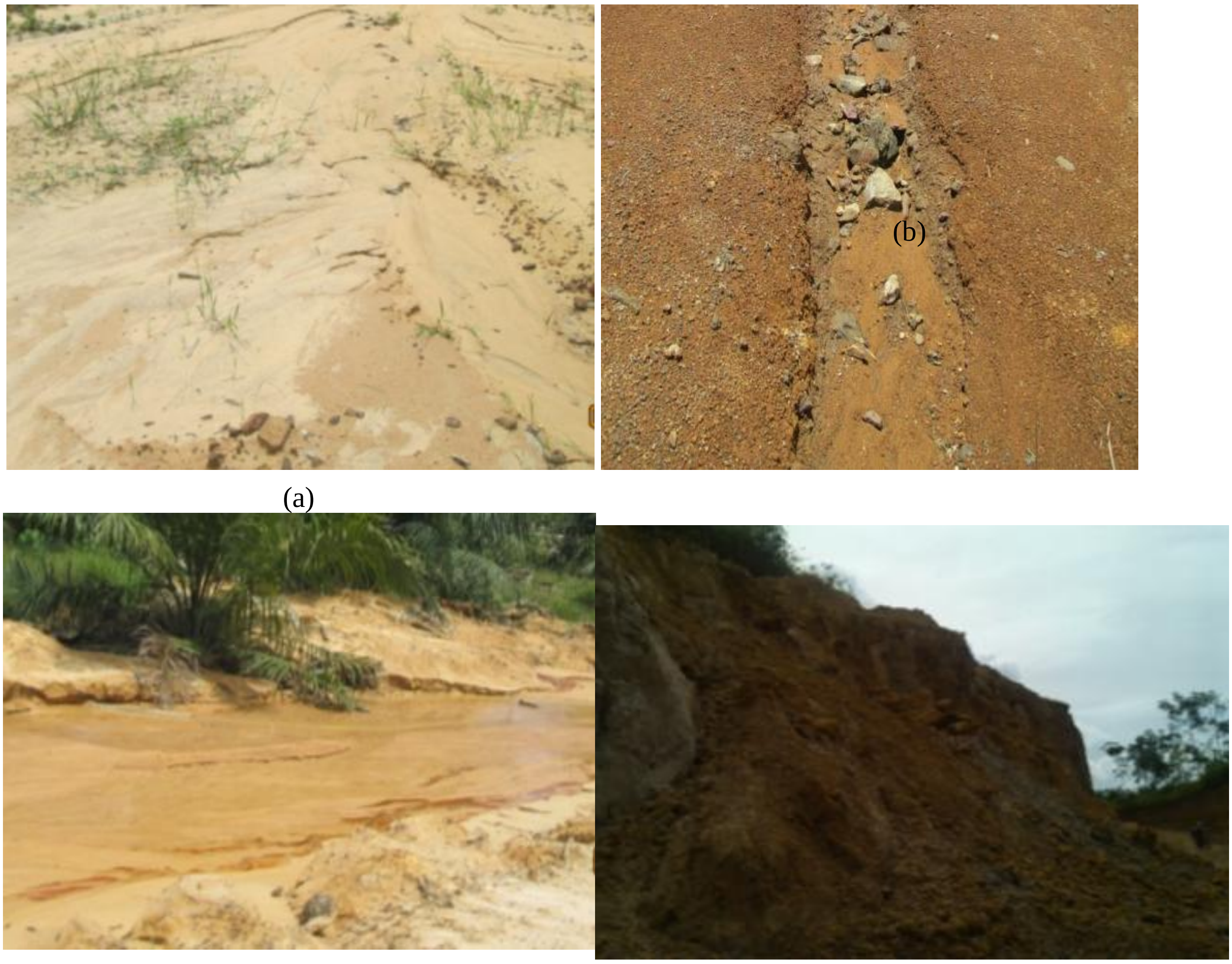
Table 3. Area distribution of land cover type in the research site

	Sub watershed							
Land cover	Batang Toru Hilir	(%)	Puli	(%)	Sarula	(%)	Batang Toru (*Total*)	(%)
Bare land	9,428	11.40	1,716	2.30	237	0.52	11,382	5.61
Water body	1,971	2.38	-	-	-	-	1,971	0.97
Forest	21,750	26.30	27,545	36.91	18,943	41.68	68,239	33.65
Mixed garden	14,751	17.83	27,420	36.74	17,725	39.00	59,895	29.54
Settlement	1,109	1.34	319	0.43	123	27	1,551	0.76
Dryland agriculture	15,807	19.11	5,240	7.02	5,365	11.80	26,412	13.02
Paddy field	3,227	3.90	12,384	16.59	2,926	6.44	18,537	9.14
Crop estate	14,665	17.73	-	-	131	0,29	14,796	7.30
Total	82,709		74,624		45,450		202,783	

Remark: "-" = no class

3.2. Soil erosion

The results of field verification and visual observation revealed that soil erosion consists of rill erosion, sheet erosion and landslide (Figure 2). Rill erosion, gully and landslide were mostly found on steep slopes, both forested and non-forested ones. Forest degradation leading to gully had also been found in Mount Leuser National Park (TNGL) [15]. Rill and sheet erosions were found in sparse forest stands, mixed garden and bare land. The absence of ground cover vegetation has been proven to facilitate the flow of water carrying sediments throughout its course to the lowland areas. Land clearing for gardens and roads leads to erosion. The land which was traditionally opened by the community generally caused sheet erosion. Nevertheless, its resulting damage is limited, and can still be restored naturally (Lund, 2009). Intensive and massive land clearing caused gully and landslide. It's difficult to restore the damage due to massive scouring and shifting of soil.



(c) (d)

Figure 2. Types of erosion occurring in the research site (a) sheet erosion, (b) rill erosion, (c) gully erosion and (d) landslide

3.3. Soil physical and chemical properties in Batang Toru watershed

The lowest and the highest soil bulk density (BD) values in Batang Toru Watershed were 0.75 gr/cm^3 and 1.47 gr/cm^3 respectively (Table 4). The highest BD value was found in bare land, while the lowest BI was found in forest (Table 4) and swamp land unit. Based on the lowest and the highest soil BD values in the research site, the soil condition is still quite good with solid structure [16]

In Batang Toru Watershed landscape, the lowest BD value in natural forest area was 0.90 gr/cm^3, which was suspected to have suffered disturbance (Table 4). But this condition is better compared to forests in Palolo with BD value of 1.24 g/cm^3 [17]. In Batang Toru Watershed, the lowest BD value in agricultural land of 0.80 g/cm^3 and the highest of 1.03 gr/cm^3 (Table 5) were better than the agricultural land in the TNGL area which has BD value of about 1.36 ± 0.14 gr/cm^3 [18]. Land use change from forest to agriculture has damaged soil characteristics [18], and reduced soil fertility [15]. In fact, deforestation became the main indirect cause of the decline in soil nutrients [18, 19]. Table 3 shows that forest has lower BD values compared to other land uses (mixed garden, dryland agriculture, paddy field and crop estate). Forest has the ability to maintain soil structure so that it has high porosity and high organic matter which was indicated by low BD value.

Organic C indicates the level of soil fertility. Data in Table 4 shows that forest and mixed garden have higher organic C than other land cover types. Forest has higher organic C because the volume of litter accumulating on the forest floor protects the soil. Similar condition occurred in mixed garden where its upper layer or site is also the accumulation result of the produced litter. The mixed gardens in the research site is almost similar to natural forest based on their site conditions and vegetation parameters. The basal area of mixed gardens in the research site reached an average of 23.3 m^2/ ha, close to the basal area of the forest which reached an average of 34.3 m^2/Ha. Its relatively fertile soil will attract people to convert forest land into cultivated land. The real threat to the existence of forests occurred in forests located on lands that have a relatively high organic matter.

Low organic C can be found in paddy fields which is suspected due to its eroded top layer. In addition, low organic C is thought to be caused by intensive cultivation of land and paddy fields.

Table 4. Bulk density and organic C values based on land cover type in Batang Toru watershed

Land cover	Organic C (%)		Bulk density (g / cm^3)	
	Maximum	Minimum	Maximum	Minimum
Bare land	0.90	0.04	1.47	1.02
Water body	-	-	-	-
Forest	3.33	1.01	1.01	0.90
Mixed garden	2.45	0.76	1. 04	0.94
Settlement	1.50	0.04	1.13	1.00
Dry land agriculture	1.83	1.00	1.03	0.80

3.4. Batang Toru Hilir Sub-watershed

Toru Hilir sub-watershed is located in the downstream area of Batang Toru watershed. The lowest and the highest soil BD values in Toru Hilir sub-watershed was 0.89 gr/cm^3 and 1.47 gr/cm^3, respectively (Table 5). Based on land cover type, bare land has the highest BD (1.47 gr/cm^3), while the lowest BD was found in forest. Higher BD value in bare land indicates higher disturbance in that area compared to other land cover types or the possibility of soil compaction in that area. The downstream area of Toru Hilir sub-watershed comprises of plantation and agricultural land so that land clearing and cultivation activities tend to be higher. Nevertheless, the BD value in Toru watershed still falls into the low category [11]. Most of the downstream areas are in the lowlands (71.46%) with flat to ramp elevation of 70.88%. Areas in low elevation and slope suffered high disturbance [20, 21]

The lowest and the highest organic C in Toru Hilir watershed are 0.04% and 3.98%, respectively, which is fairly high [22, 16]. In Toru Hilir sub-watershed, forest has the highest organic C among other land cover types, whereas the lowest organic C was found in bare land.

Table 5. Soil bulk density and organic C based on land cover type in Batang Toru Hilir sub-watershed)

Land cover	Bulk density (gr/cm^3)		Organic C (%)	
	Maximum	Minimum	Maximum	Minimum
Bare land	1.47	1.02	0.60	0.04
Water body	0.98	0.89	3.98	1.14
Forest	-	-	3.33	1.28
Mixed garden	0.97	0.97	0.65	0.65
Settlement	-	-	-	-
Dryland agriculture	1.03	0.80	1.83	1.00

Remark): "-" = no soil sample

3.5. Puli Sub-watershed

Puli sub-watershed is located in the midstream of Batang Toru watershed at an altitude of 400-2000 meters above sea level. Puli sub-watershed has a total area of approximately 74,624 ha. The lowest and the highest soil BD value in Puli sub-watershed were 0.84 gr/cm^3 and 1.11 gr/cm^3, respectively (Table 6). Paddy field has the highest BD, whereas the lowest BD was found in forest and mixed gardens. Forest cover in Puli sub-watershed is mostly located at a high altitude (1000-2000 m) so that disturbance to forest is low [20,21]. In undisturbed natural forests, soil conditions tend to be stable and soil degradation is smaller. Forest restoration in Puli sub-watershed, has a very high chance of being successful. It’s because based on its soil BD value, the land in Puli sub-watershed can support plant growth well [16].

The lowest and the highest organic C in Puli Sub-watershed were 0.04% and 3.81%, respectively. The highest organic C value falls into high category [20,16] which supports plant growth. Forest has the highest organic C, whereas the lowest organic C value was found in paddy field. Natural forest cover is more capable of preventing erosion, and if erosion is found in natural forests it is due to geological factors [15]. Paddy field has low organic C value due to absorption by agricultural crops.

Table 6. Soil bulk density and organic C values based on land cover type in Puli sub-watershed

Land cover	Bulk density (gr/cm^3)		Organic C (%)	
	Maximum	Minimum	Maximum	Minimum
Bare land	-	-	-	-
Water body	0.92	0.84	3.81	1. 04
Forest	1.12	0.90	3.22	1.01
Mixed garden	1.02	0.94	2.28	0.74
Settlement	1.11	1.00	1.12	0.04
Dryland agriculture	-	-	-	-

Remark: "-" = no soil sample

3.6. Sarula Sub-Watershed

Sarula sub-watershed is located in the upstream area of Batang Toru watershed at an altitude of 200 - 1800 meters with a total area of about 45,450 ha. Table 7 shows that the lowest BD value in Sarula sub-watershed was 0.75 g/cm^3 while the highest was 1.13 gr/cm^3. Paddy field has the highest BD, whereas the lowest BD was found in forest. Natural forest in Sarulla sub-watershed is mostly located at an altitude of 800-2000 meters above sea level in moderate steep to steep slopes which have

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minimized disturbance intensity. In addition, dense tree has prevented erosion [14] because the resulting litter covers the forest floor [13]. Meanwhile, paddy fields are generally open so that the surface runoff tends to be high. Paddy field has undergone intensive cultivation which leads to soil compaction.

Data from soil sample analysis showed that the lowest organic C value in Sarula sub-watershed was 0.75% while the highest was 3.85%. The soil organic C in Sarulla sub-watershed falls into high category [20,16]. Land cover type with higher organic C is forest whereas that with lower organic C is dryland agricultural land. Trees that cover the land have prevented surface runoff and erosion so that the presence of organic C in soil can be maintained. The soil structure and permeability of forest land is better [17]. However, there is a low organic C in natural forest due to rill erosion occurring in the forest floor. Rill erosion occurs due to the animals that cross and lay the area bare. The high intensity of crossing triggered erosion that forms a rill.

In dryland agricultural land, crop cultivation and planting can reduce nutrients and change soil structure. The opening of ground surface leads to erosion. Erosion will transport a portion of organic C to a relatively low elevation land. Based on a research by [17] the change in forest functions degrade the quality of soil physical properties. Forest with dense vegetation has a closed, dense canopy. Its dense canopy reduces the stemflow so that the rainwater does not fall directly to the ground and becomes runoff. A dense canopy produces a huge volume of litter. The litter covers the forest floor so that it can block the runoff and allow water to infiltrate the soil. Dense vegetation cover can reduce runoff and increase water absorption. The denser the canopy, the higher its ability to prevent land degradation will be [15].

Table 7. Soil bulk density and organic C based on land cover type in Sarula sub-watershed

Land cover	Bulk density (gr/cm^3)		Organic C (%)	
	Maximum	Minimum	Maximum	Minimum
Bare land	-	-	-	-
Water body	1.02	75	3.85	1.06
Forest	-	-	-	-
Mixed garden	1. 04	0.92	2.45	0.90
Settlement	1.13	1.13	1.50	0.75
Dryland agriculture	-	-	-	-

Remark: "-" = no soil sample

3.7. Land degradation index

Land degradation is determined by using soil physical and chemical characteristics, land units type and land cover type. Overlay map of land unit type and land cover type produced land degradation degree in Batang Toru watershed area as illustrated in Figure 3-b. Land degradation index in Batang Toru Watershed consists of 5 (five) classes, namely index range of 0.00 - 0.20 (very low land degradation) 0.21 – 0.40 (low land degradation), 0.41 - 0/60 (moderate land degradation), 0.61 to 0.80 (high land degradation) and 0.81 – 1.00 (very high land degradation). Based on the extent, moderate land degradation index has the largest percentage of total area that is equal to 30.17% (Table 8). This was subsequently followed by low land degradation index (29.21%), very low (21.35%), high (16.49%) and very high (2.78%).

In Toru Hilir sub-watershed, the high land degradation index covers an area of 25,983 ha. The area is larger than high land degradation index areas in Sarulla (3,771 ha) and Puli sub-watersheds (3,693 ha). This indicates that LAND disturbance in Batang Toru sub-watershed is bigger than in the two other sub-watersheds. The relatively lower percentage of forest area and the relatively higher percentage of dryland agriculture and settlement in Batang Toru sub-watershed are among the factors that trigger land degradation. In addition, most of Batang Toru Hilir watershed areas are located in relatively flat areas where human activities are relatively high, so that human disturbance is relatively higher.

Table 8. Area distribution of land degradation degree based on sub-watershed

Land degradation degree	Batang Toru Hilir		Puli		Sarulla		Total	*Total*
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Very low	17,787	21.51	14,499	19.43	11,014	24.23	43,300	21.35
Low	12,514	15.13	26,663	35.73	20,050	44.12	59,227	29.21
M*oderate*	25,045	30.28	27,482	36.83	8.649	19.03	61,177	30.17
High	25,983	31.42	3,693	4.95	3,771	8.30	33,448	16.49
Very high	1,380	1.67	2,287	3.07	1.966	4.33	5,633	2.78
Total	82,709		74,624		45,450		202,783	

Based on land cover type, high land degradation degree was mostly found in dryland agricultural land. Much of its areas have high and very high land degradation indices (Table 9). Similarly, most of crop estate areas have high to moderate land degradation indices. This suggests that long-term and intensive land cultivation and management on dryland agricultural land and crop estate areas caused land degradation. Agricultural lands and crop estates are generally located on a relatively flat area adjacent to roads. Flat, near road areas will suffer high disturbance so that the threat of land degradation is high [23, 24]. Flat areas are suitable for cultivation. In the long run, plant cultivation will trigger land degradation. Traditional crop cultivation tends to destroy forests, but thanks to its limited degradation, forests can restore themselves [25]. Farmers who are unaware of land management technologies cannot manage their land properly, which will further degrade their land. Rehabilitation using crop varieties that are used as the source of livelihoods by farmers is needed to restore the land.

Meanwhile, most of the forests and mixed gardens have very low to low land degradation indices. Mixed garden sites have nearly similar condition with that of forest in that both floors are covered by litters and ground cover. This can prevent runoff and improve water infiltration.

Table 9. Land degradation indices in Puli, Sarulla and Toru Hilir sub-watersheds based on land cover type

Land cover	Area (ha)					
	Very low	Low	Moderate	High	Very high	Total
Bare land	2	468	3,640	7,272	-	11,382
Water body	1,965	6	-	-	-	1,971
Forest	41,320	26,919	-	-	-	68,239
Mixed garden	-	29,307	30,588	-	-	59,895
Settlement	7	-	1,064	479	-	1,551
Dryland agriculture	-	94	2,397	18,288	5.633	26,412
Paddy field	1	16	15,659	2,862	-	18,537
Crop estate	6	2,418	7,826	4,547	-	14,796
Total	43,300	59,227	61,177	33,448	5,633	202,783

Source: Soil and spatial analysis
Remark: "-" = no soil sample

Figure 3-b shows a very high degree of degradation in Sarula sub-watershed, high degradation degree in Toru Hilir sub-watershed and very low degree of degradation in the relatively compact Sarula

watershed. Therefore, efforts to restore the function of forest ecosystem can be started through forest rehabilitation and restoration in Sarula sub-watershed because it has a relatively large compact, very high degraded area. In addition, Sarula sub-watershed is located in the upstream area of Batang Toru watershed. Forest ecosystem restoration in the upstream area can affect the ecosystem in the downstream area along the watershed.

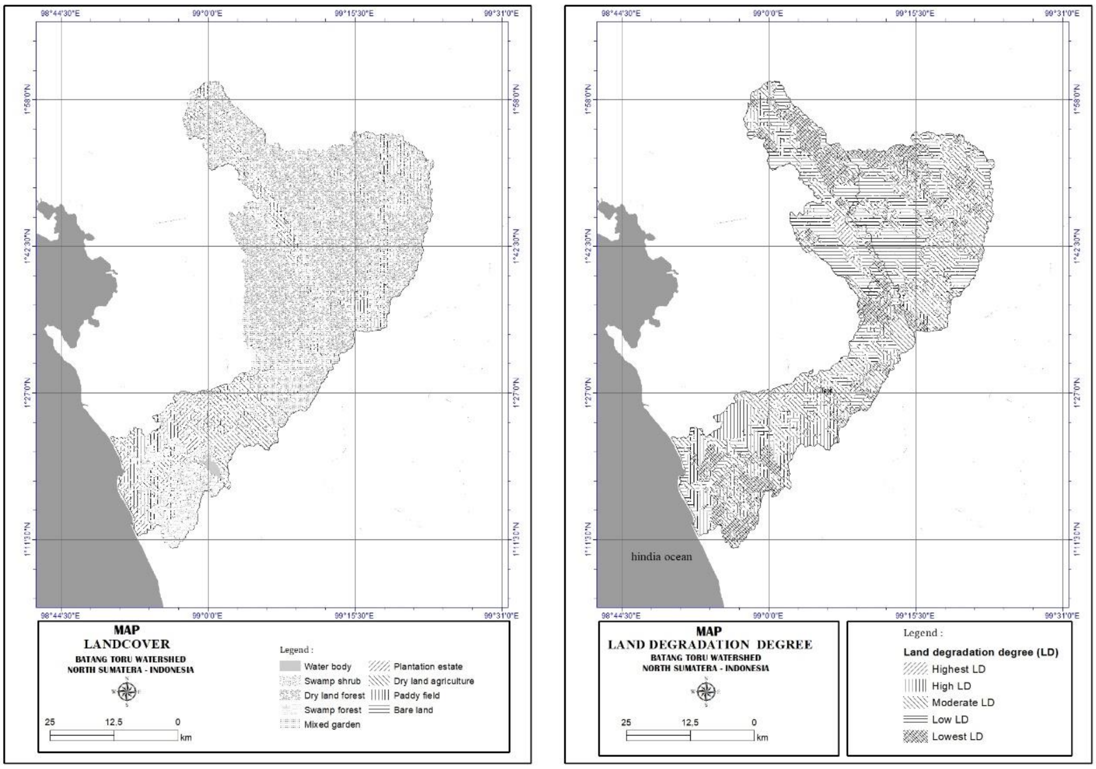

Figure 3. Land cover map of 2013 (a), and land degradation index map (b)

4. Conclusion and suggestions

4.1. Conclusion

Bulk density, texture and organic C of soil physical and chemical properties in Batang Toru Watershed landscape is relatively good and can support plant growth. The area percentage of land degradation index in Batang Toru Watershed landscape consists of very low degree of land degradation (29.21%), low land degradation (21.35%), moderate land degradation (30.17%), high land degradation (16.49%) and very high land degradation (2.78%). Forest and mixed garden have lower land degradation degree. Dryland agriculture and crop estate have high to very high land degradation indices. Most of the areas with high and very high land degradation indices are located Batang Toru Hilir sub-watershed. This land degradation distribution map can be used as a reference data in preparing forest and land rehabilitation as well as forest ecosystem restoration plans

4.2. Suggestions

1. The condition of mixed gardens in the research site is quite good, so that it can be used as one of the rehabilitation and restoration methods of Batang Toru watershed landscape ecosystem. Local tree species that serve as the source of community livelihoods can be used as major plants in addition to pioneer species.
2. More detailed research is needed on each sub-watershed unit and the field samples taken should be adapted to the types of land unit, land cover and various slope classes.

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