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Landscape and Soil Characteristics of Landslide-Affected Cadac-an Watershed in Leyte, Philippines

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Abstract

The continuous and increasing degradation problem in Leyte watershed due to landslide occurrences explains the importance of the characterization of these areas. Hence, this study was carried out to characterize the landscape and soil properties in the landslide-prone watershed. Landslide cuts, serving as representative soil profiles in Cadac-an watershed, were used for examination and characterization. Among the landscape characteristics determined were fault line, geomorphology and land use. Profiles were sampled for the analyses of soil properties such pH (Potentiometric method), percent organic matter (OM) (loss of weight on ignition), available phosphorus (P) (Olsen extraction method), cation exchange capacity (CEC) (ammonium acetate method) and exchangeable bases: calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). Cadac-an watershed was observed to be dominated by andesitic materials characterized by the presence of the active Leyte segment of the Philippine Fault. It is rugged and mountainous with brushes and grasses as the dominant vegetation. Generally, soils from the landslide areas in Cadac-an watershed had a very strongly acidic to moderately alkaline pH, high to low OM and P content, very high to low CEC, high to low exchangeable K, Ca and Mg, and low exchangeable Na.

***Keywords**:* degradation, watershed, Philippine fault zone, geomorphology, land use

1. Introduction

Leyte is characterized by rugged and mountainous terrain with a torrential rainfall pattern. These geologic and climatic setting in addition to frequent tectonic movement contributes to its instability and results in numerous disasters including the occurrences of landslides. Landslides are considered as one of the most serious environmental problems in the country, particularly in Leyte. Major landslide events are recorded in Leyte along with Southern Leyte such as in Ormoc City (1991), Panaon Island (2003) and St. Bernard (2006) that claimed 5,000, 200 and 1,000 lives, respectively (Jadina, 2013). Largely, this catastrophic event happened in watershed areas affecting its functions and ecosystem services.

Sustainability of watershed resources is increasingly destroyed and degraded by causal factors such as habitat destruction or removal of vegetation, overexploitation, pollution and rapid population growth and climate change, which influence natural processes including landslides (Thapa, 2005). Moreover, these degradation problems seriously destroy the water and soil resources affecting water security and soil productivity. The degradation of watershed resources at an alarming rate jeopardizes food security besides posing a major threat to biodiversity and the functions of the fragile ecosystem (Walia *et al*., 2010).

With continuous destruction of the watershed, studies are needed to evaluate watershed components most importantly the soil properties. Characterization of soil properties is considered to be the initial process in watershed management since every component of the watershed is dependent on the degree of soil quality and health. The soil serves as the habitat for many organisms and is important in maintaining biodiversity. It also serves as a storage medium for water depending on its properties, namely depth and texture. Moreover, soil properties can influence the kinds and amount of vegetation or the plant community structure, which affects natural processes including runoff leading to erosion and landslide occurrences (Black, 2007). According to Cabelin and Jadina (2019), soil properties such as texture, bulk density, porosity, moisture content, and hydraulic conductivity are significant factors influencing the occurrence of landslides.

Research works on degraded watershed caused by landslides are necessary to gain additional information on the biophysical attributes of the area, which will be useful in planning for mitigation measures. It is important for appropriate land use that will enhance positive impacts and minimize the negative consequences (Cruz, 1999). Through this, resources are protected, conserved and sustained. Hence, it plays a vital role in sustainable watershed management.

Studies on watershed degradation are increasing but less has been done concerning watershed degradation by landslide occurrences particularly in Leyte Island. Degradation caused by landslides is at its peak in the area. Thus, studies on the characterization of its soil and landscape become a pressing need. Therefore, this study adopted the descriptive analysis method and aimed to characterize some of the landscape characteristics and properties of the soils in the landslide areas of Cadac-an watershed.

2. Methodology

2.1 The Study Sites

The study area was the Cadac-an watershed, which covers parts of the municipalities of Abuyog, Mahaplag, and Javier, Leyte, Philippines. Each municipality was represented by either a landslide cut or a tension crack for soil horizon examination and sampling for laboratory analyses.

2.2 Secondary Data Collection

The fault line map was sourced out from the Philippine Institute of Volcanology and Seismology (PHIVOLCS). Biophysical and morphological characteristics of the watershed such as geomorphology and land use were obtained in digital format from the Philippine Department of Agriculture – Bureau of Agricultural Research (DA-BAR) and Visayas State University Geographic Information System (VSU-GIS) Services Unit.

All shapefiles obtained were projected to Universal Transverse Mercator (UTM) projection (Zone 51). Maps were produced using GIS software and then laid out into a presentable format wherein relevant information like coordinates, projection, north arrow, map scale, and legend were displayed.

2.3 Soil Horizon Characterization, Sampling and Preparation of Soil Samples

Standard procedures for soil description (Food and Agriculture Organization of the United Nations, 2006) were used for the determination of soil horizon. The collection of soil samples at field capacity (two days after rainfall occurs) was done once from the lower to the uppermost horizon. A sample of about 3 kg from each horizon was collected and placed in labelled bags. The samples were air-dried, pulverized, and sieved through a 2 mm screen prior to chemical analyses.

2.4 Soil Chemical Properties Determination

Soil pH was determined by a potentiometric method using a soil-water ratio of 1:2.5 (van Reeuwijk, 1995). Soil organic matter (OM) determination in percentage (%) was done by the loss of weight on ignition (Northeast Regional Publication, 1995).

Extractable phosphorus (P) expressed in milligram per kilogram (mg/kg) was determined using the Olsen extraction method (Olsen and Sommers, 1982). Cation exchange capacity (CEC) determination in centimole per kilogram (cmolc/kg) was carried out using the 1 normal (N) ammonium acetate (NH_4OAc) pH 7.0 method (van Reeuwijk, 1995). Exchangeable bases, namely calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) (cmolc/kg) were identified from the extracts from CEC determination with the use of an atomic absorption spectrophotometer (Varian SpectrAA 220 FS) (Varian, Inc., USA).

3. Results and Discussion

3.1 Description of the Study Site

The study site was the Cadac-an watershed located at the central highlands of Leyte, Philippines with a total land area of 65,957.50 hectares (ha). It is bounded by 10° 26’ to 10° 48’ north latitude and 124° 50’ to 125° 7’ east longitude (Figure 1). Located on the north are the municipalities of Javier and MacArthur, on the south are Mahaplag and Sogod, on the east are Baybay and Inopacan, and on the west are Abuyog and Silago. Cadac-an watershed covers most parts of Javier, Abuyog, and Mahaplag municipality. Table 1 shows the geophologic or site characteristics of the landslide areas of Cadac-an watershed.

3.2 Landscape Characteristics of Cadac-an Watershed Affected by Landslides

3.2.1 Geologic Characteristics and the Leyte Segment of the Philippine Fault Zone (PFZ)

Leyte Island is located in the eastern part of the Visayas region in the Philippines. The rock formation is composed of Pliocene-Quaternary volcanic cones mainly andesitic in nature, tertiary sediments and thick successions of tertiary volcanic and volcaniclastic rocks (Aurelio, 1992; Sajona *et al*. as cited by Evans *et al.*, 2007). Moreover, andesitic and dacitic lava flows and pyroclastics dominate as parent materials in central Leyte while coralline limestone shaped the large parts of Leyte's Karst landscapes (Marohn *et al.*, 2005). In the study of Jadina (2013), it was observed that Miocene-andesitic, basaltic, dacitic flows, and breccia geologic formation – dominant in the southern part of Leyte Island – are highly susceptible to landslides. This can be attributed to the presence of the active Leyte segment of the Philippine Fault and other contributing factors.

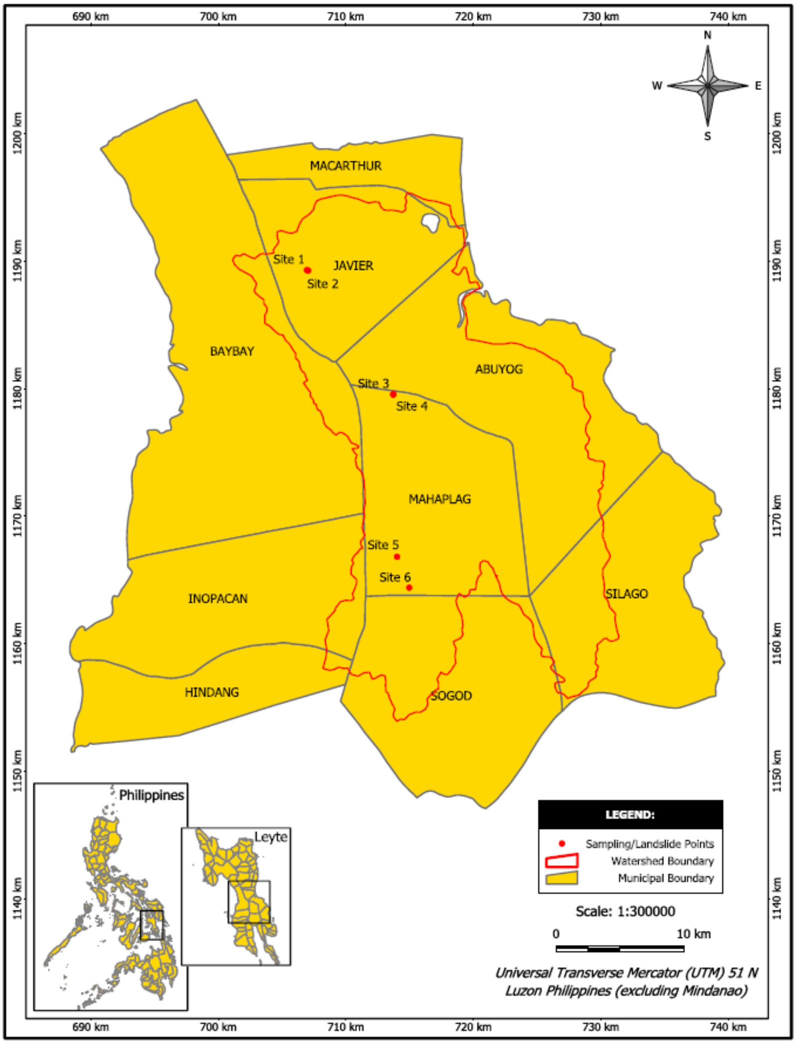

Figure 1. Map showing the extent of the Cadac-an watershed

Table 1. Geophologic or site characteristics of the landslide areas in Cadac-an watershed in Leyte, Philippines (Cabelin and Jadina, 2019)

Profiles	Location	Site Characteristics				
		Coordinates	Physiographic Position	Elevation (meter above sea level)	Slope Gradient	Vegetation
1	Guindapunan, Javier (landslide cut)	10º 45′ 12.5″ N 124º 53′ 31.1″ E	Summit	258.2	Steep	*Cocos nucifera*, *Musa textilis*, *Musa sp.*, shrubs and some species from family Poaceae
2	Guindapunan, Javier (landslide cut)	10º 45′ 10.4″ N 124º 53′ 32.9″ E	Shoulder	261.0	Steep	*Cocos nucifera*, *Musa textilis*, *Musa sp.*, shrubs and some species from family Poaceae
3	Balinsasayao, Abuyog (tension crack)	10º 39′ 53.2″ N 124º 57′ 14.8″ E	Summit	327.9	Sloping	*Cocos nucifera*, *Musa sp.*, shrubs and some species from family Pteridophyta and Poaceae
4	Balinsasayao, Abuyog (landslide/road cut)	10º 39′ 52.6″ N 124º 57′ 14.0″ E	Shoulder	336.2	Sloping	*Cocos nucifera*, *Musa sp.*, *Manihot esculenta*, shrubs and some species from family Pteridophyta and Poaceae
5	Mahayahay, Mahaplag (landslide/road cut)	10º 32′ 57.6″ N 124º 57′ 20.9″ E	Shoulder	85.7	Gently sloping	*Cocos nucifera*, *Musa sp.*, *Arachis pintoi*, shrubs and some species from family Pteridophyta and Poaceae
6	Polahongon, Mahaplag (landslide/road cut)	10º 31′ 38.6″ N 124º 57′ 51.8″ E	Shoulder	92.3	Gently sloping	*Cocos nucifera*, *Musa sp.*, *Leucaena leucocephala*, *Arachis pintoi*, shrubs and some species from family Pteridophyta and Poaceae

The rugged and mountainous surface expression of Leyte Island is brought about the active Leyte segment of the PFZ. The fault is estimated to stretch 1,200 km across the Philippines archipelago from Luzon to Mindanao Island and the left-lateral PFZ has slip rates averaging from 0.55 to 3.5 cm/year (Duquesnoy, 1997; Cole *et al.* as cited by Makino *et al.*, 2007). Thus, regional discontinuities are formed and thick clay-rich gouge zones are developed in the surface prominent in the entire province and other locations along PFZ (Hart *et al*., 2002).

The Philippine Fault passes at the center of Cadac-an watershed in Leyte Island resulting in unstable geographic location and frequent landslide occurrences (Figure 2).

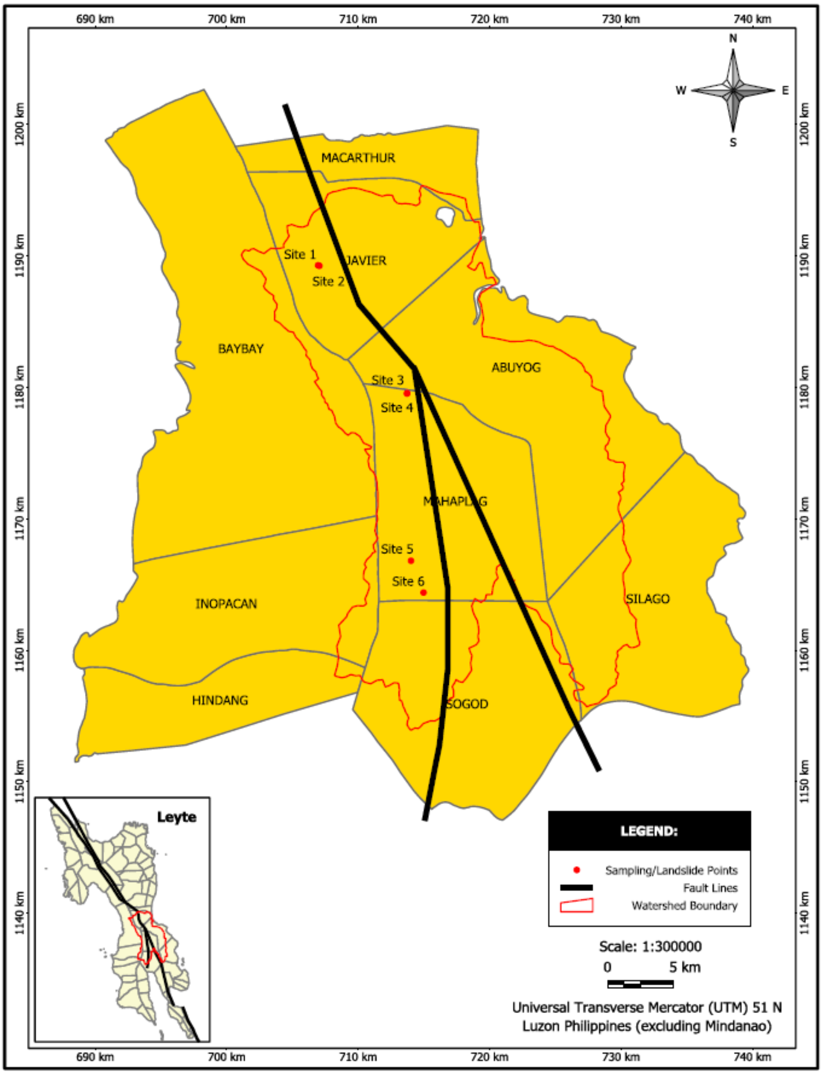

Figure 2. Map showing the fault line in Cadac-an watershed

The Guinsaugon landslide, the largest known mass wasting in the Philippines that happened in the southern part of Leyte Island, occurred on the steep fault scarp of the PFZ (Lagmay *et al*., 2006; Luzon *et al*., 2014). Moreover, in the study of Jadina (2013), landslide occurrences in the southern part of Leyte Island were studied. It was observed that most landslides occur within the 4-km distance from the fault line and as the distance from the fault line increases, the number of landslide occurrences decreases.

3.2.2 Geomorphology of the Watershed

The geomorphology of Leyte Island is rugged and mountainous caused by the uplift and faulting, which result in instability and landslide occurrences (Evans *et al*., 2007). Cadac-an watershed is characterized by rolling to moderately steep slope (29.20 % or 19,185.05 ha). Some parts are flat to nearly level (19.74 % or 12,969.90 ha), steep (17.22 % or 11,316.49 ha), very steep (15.31 % or 10,061.95 ha), undulating to rolling (12.82 % or 8,422.87 ha), and gently sloping to undulating (4.30 % or 2,825.53 ha) (Figure 3 and Table 1).

The probability of landslide occurrence is greater in steep slopes. In the study of Kuwano *et al*. (2009), it was observed that landslides in Panaon Island, Southern Leyte took place at moderately steep slopes at angles between 30° to 40°. The results of the study conducted by Jadina (2013) clearly established a strong relationship between the slope angle and the occurrence of a landslide in the southern part of Leyte Island. It was observed that the highest percentage (54%) of landslides occurred at an angle greater than 50° due to the increase in shear stress in the soil as the slope angle increases. As the slope angle increases, the shear stress in the soil and other unconsolidated materials normally rise creating a higher probability of landslide occurrences (Lee and Evangelista as cited by Indelicato, 2015).

3.2.3 Land Use in the Watershed

Land use plays an important role in soil formation since it directly affects several factors such as water conditions and organic and nutrient inputs. A large area of Cadac-an watershed particularly at higher elevation was dominated with mixed brushland and grassland (48.87% or 32,121.83 ha) while other parts were open canopy (13.73% or 9,017.19 ha), arable land (13.03% or 8,560.88 ha), coconut plantation (11.65% or 7,659.07 ha), crop land mixed with coconut plantation (6.57% or 4,315.83 ha), closed canopy

(6.08% or 3,994.90 ha), mangrove vegetation (0.05% or 30.37 ha), and built-up area (0.04% or 23.95 ha) (Figure 4).

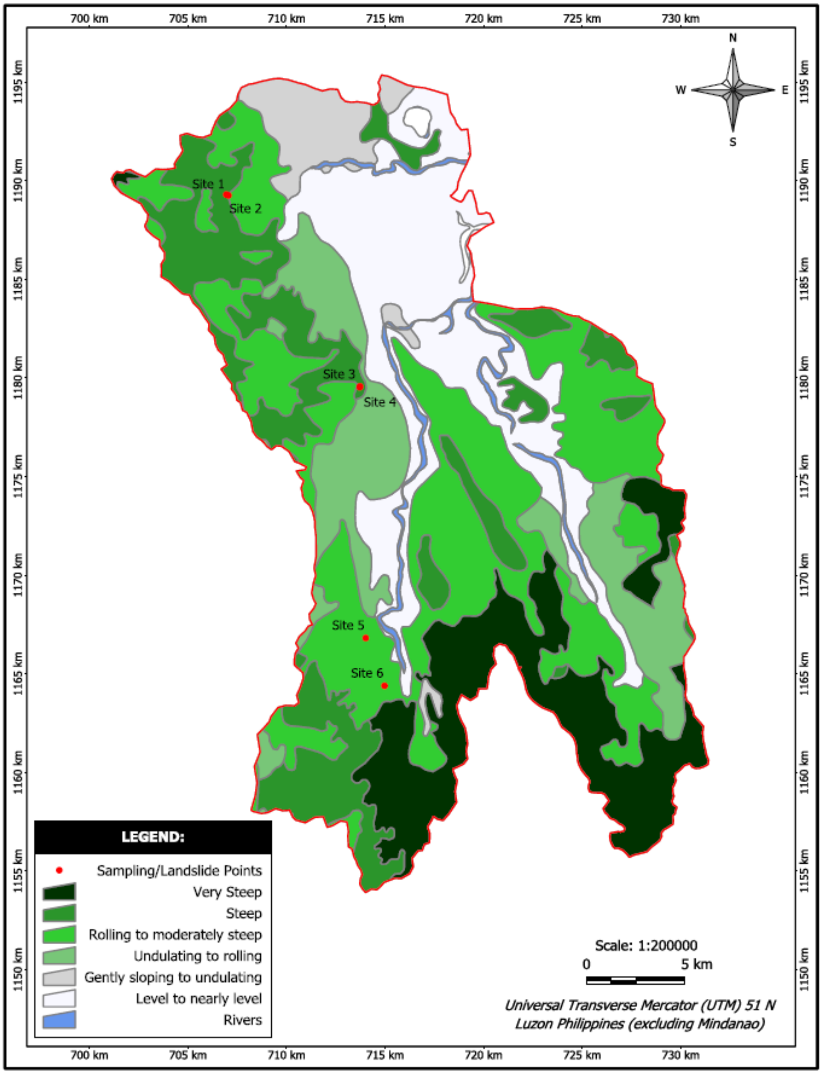

Figure 3. Map showing the slope classes in the Cadac-an watershed

Jadina (2013) observed that frequency of landslide occurrences in the southern part of Leyte was highest in cultivated areas (generally crops with shallow root systems) mixed with brushland and grassland. This is because intensive cultivation loosens the soils and hastens the process of soil erosion and possible landslides in addition to its topographic location which is steep slopes. This result simply indicates the importance of land use and vegetation as a factor influencing the process of a landslide.

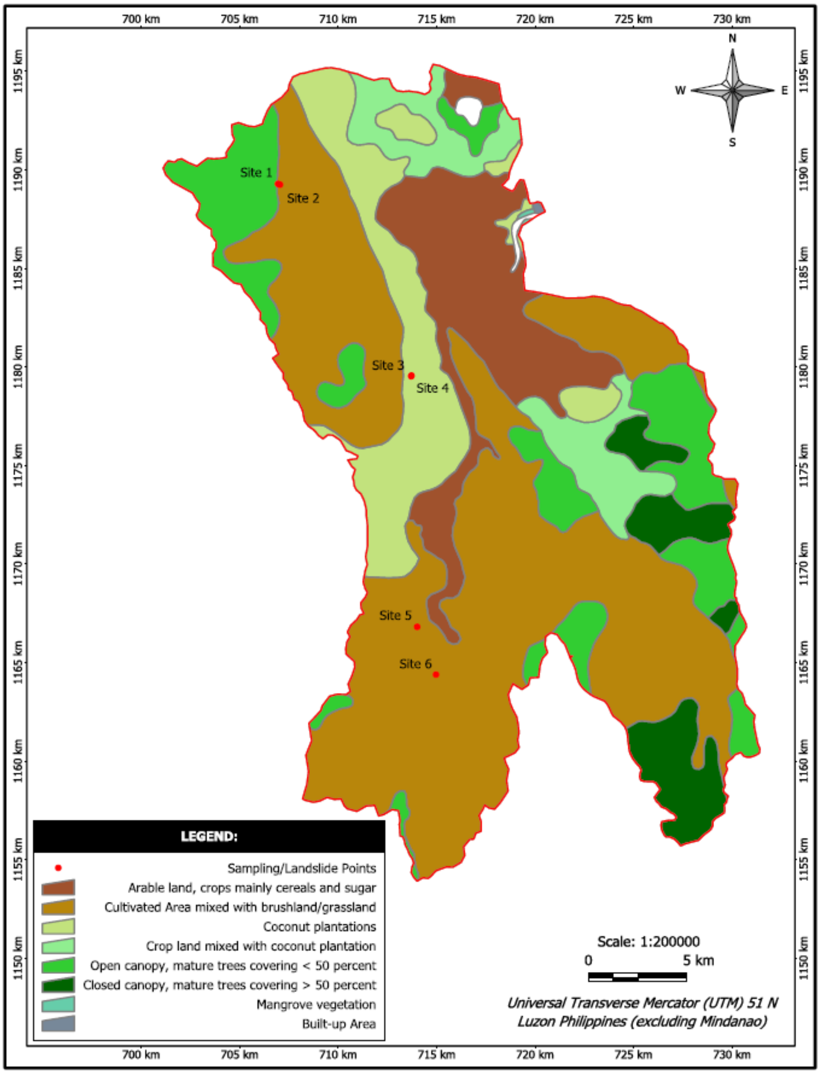

Figure 4. Map showing the land use in the Cadac-an watershed in Leyte, Philippines

3.3 Chemical Characteristics of the Soils from the Landslide Areas of Cadac-an Watershed

3.3.1 Soil pH

Soil pH or soil reaction, which refers to the acidity or alkalinity of the soil, is a measure of the activity of hydrogen ions in the soil solution through pH units (Brady and Weil, 1999). Table 2 shows the pH of soils from Cadac-an watershed. Results revealed that soils from profiles 1, 2, 3, 4 and 5 had a very strongly to moderately acidic soil with pH ranged from 4.50 to 5.85. On the other hand, soils from profile six were slightly to moderately alkaline with 7.83 to 8.22 pH. The pH values of these soils are greatly influenced by its parent material, originating from volcanic materials in which pH varies from acidic to basic (Mizota and van Reeuwijk, 1989).

Moreover, results showed that soil pH level increases with depth having lower pH or more acidic in the surface horizon compared to subsurface horizons. The higher acidity of the surface horizon can be due to the higher amount of OM from leaf litter and other organic materials. The decomposition of these organic materials produced organic and inorganic acids, thereby lowering the pH (Tesema, 2008).

3.3.2 Soil Organic Matter Content

Soil organic matter (SOM) is a complex and varied mixture of organic substances. It includes undecomposed, partly decomposed, and decomposed plant and animal residues.

Results showed that OM content is relatively high in the surface horizon (3.43-6.99%) compared to subsurface horizons (0.07-5.15%) (Table 2). This is expected as organic materials particularly from leaf litter are generally deposited at the surface soils. The continuous accumulation of undecayed and partially decomposed plant and animal residues would increase SOM. The high percentage of OM in the surface horizon promotes darker color and better soil aggregation (Bewket and Stroosnijder, 2003; Genxu *et al.*, 2004).

Table 2. Chemical characteristics of soils from the landslide areas of Cadac-an watershed in Leyte, Philippines

Site Profile/ Soil Horizon	pH(*)	OM(**) (%)	Extractable P(**) (mg/kg)	CEC(**) (cmolc/kg)	Exchangeable bases(**) (cmolc/kg)			
					K	Na	Ca	Mg
Site Profile 1 (Guindapunan, Javier, Leyte) (10º 45′ 12.5″ N – 124º 53′ 31.1″ E)								
A	4.50 (very strongly acid)	3.43 (high)	4.86 (low)	42.21 (very high)	0.88 (high)	0.57 (low)	0.65 (low)	0.36 (low)
AB	4.56 (very strongly acid)	2.21 (high)	3.98 (low)	42.68 (very high)	0.07 (high)	0.81 (low)	0.67 (low)	0.18 (low)
BC	4.58 (very strongly acid)	2.00 (high)	0.88 (low)	34.61 (high)	0.05 (medium)	0.76 (low)	0.64 (low)	0.18 (low)
Site Profile 2 (Guindapunan, Javier, Leyte) (10º 45′ 10.4″ N – 124º 53′ 32.9″ E)								
A	5.09 (very strongly acid)	3.49 (high)	21.67 (high)	21.73 (medium)	0.49 (medium)	0.90 (low)	3.37 (low)	0.70 (medium)
C1	5.51 (strongly acid)	1.43 (high)	11.29 (medium)	18.79 (medium)	0.20 (low)	0.90 (low)	1.17 (low)	0.09 (low)
C2	5.85 (moderately acid)	0.07 (low)	13.27 (medium)	11.11 (low)	0.09 (low)	0.64 (low)	1.20 (low)	Trace
Site Profile 3 (Balinsasayao, Abuyog, Leyte) (10º 39′ 53.2″ N – 124º 57′ 14.8″ E)								
A	4.55 (very strongly acid)	6.99 (high)	10.61 (medium)	34.53 (high)	0.39 (medium)	0.58 (low)	2.19 (low)	3.84 (medium)
BA	4.70 (very strongly acid)	5.15 (high)	2.21 (low)	32.46 (high)	0.11(low)	0.47 (low)	1.48 (low)	1.02 (medium)
BC	4.73 (very strongly acid)	2.81 (high)	0.88 (low)	33.46 (high)	0.13 (low)	0.46 (low)	0.85 (low)	0.56 (medium)
C	4.76(very strongly acid)	2.54 (high)	1.77 (low)	36.27 (high)	Trace	0.47 (low)	0.78 (low)	0.44 (low)
Site Profile 4 (Balinsasayao, Abuyog, Leyte) (10º 39′ 52.6″ N – 124º 57′ 14.0″ E)								
A	5.47 (strongly acid)	6.48 (high)	11.94 (medium)	40.45 (very high)	1.43 (high)	0.48 (low)	2.98 (low)	0.32 (low)
BA	5.56 (strongly acid)	3.98 (high)	2.21 (low)	36.24 (high)	0.87 (high)	0.49 (low)	4.72 (medium)	0.02 (low)
BC	5.62 (moderately acid)	1.63 (high)	2.65 (low)	35.19 (high)	0.49 (medium)	0.51 (low)	5.33 (medium)	Trace
C	5.76 (moderately acid)	1.83 (high)	2.06 (low)	37.41 (high)	0.14 (low)	0.50 (low)	4.96 (medium)	Trace
Site Profile 5 (Mahayahay, Mahaplag, Leyte) (10º 32′ 57.6″ N – 124º 57′ 20.9″ E)								
A	4.98 (very strongly acid)	6.72 (high)	10.61 (medium)	79.94 (very high)	0.35 (medium)	0.52 (low)	19.69 (high)	5.27 (high)
AB	5.04 (very strongly acid)	4.01 (high)	1.33 (low)	73.21 (very high)	0.04 (low)	0.41 (low)	11.50 (high)	4.84 (high)
B1	5.18 (strongly acid)	3.30 (high)	1.30 (low)	79.24 (very high)	0.02 (low)	0.42 (low)	5.50 (medium)	4.32 (high)
B2	5.19 (strongly acid)	3.25 (high)	0.88 (low)	75.07 (very high)	0.03 (low)	0.42 (low)	9.57 (medium)	4.04 (high)
Site Profile 6 (Polahongon, Mahaplag, Leyte) (10º 31′ 38.6″ N – 124º 57′ 51.8″ E)								
A	8.22 (moderately alkaline)	4.12 (high)	24.84 (high)	52.37 (very high)	1.03 (high)	0.48 (low)	6.55 (medium)	1.48 (medium)
C1	8.14 (moderately alkaline)	1.53 (high)	6.63 (medium)	48.32 (very high)	0.26 (medium)	0.47 (low)	5.59 (medium)	1.42 (medium)
C2	7.97 (moderately alkaline)	1.75 (high)	6.19 (medium)	47.89 (very high)	0.18 (low)	0.44 (low)	5.54 (medium)	1.93 (medium)
C3	7.83 (slightly alkaline)	1.72 (high)	7.52 (medium)	47.58 (very high)	0.19 (low)	0.46 (low)	5.56 (medium)	2.69 (medium)

*According to National Soil Survey Center (1998), criteria for describing the level of pH in the soil
**According to Landon (1991), interpretation of soil chemical properties

3.3.3 Extractable Phosphorus

Phosphorus (P) is a primary macronutrient that often limits the productivity and growth of terrestrial plants (Yang *et al*., 2013). Generally, soils in the tropical and sub-tropical regions are phosphorus-deficient, which limits the crop yield (Begum and Islam, 2005).

Results revealed that soils from Cadac-an watershed contain high to low P content (24.84-0.88 mg/kg) (Table 2). This could be attributed to the uptake and removal by the crops, runoff or leaching, and to soils' acidic condition. Acidic soils have a high P-fixing capacity resulting in limited P supply for the crops (Thomas *et al*., 1999). Moreover, it was observed that P content in the profile decreases with depth. The greater P content in the surface soils can be ascribed to the considerable amount of OM present in the surface horizon while low P content in deeper soils can also be the aftereffect of low organic matter. Moreover, P content can also be an inherent characteristic of the parent material influencing the amount of P that is released during weathering and either retained in soils or lost through leaching and erosion (Yang *et al*., 2013).

3.3.4 CEC and Exchangeable Bases

CEC is defined as the total of exchangeable cations such as K, Na, Ca and Mg, present in the soil expressed in cmolc/kg of soil. This is a distinctive property of the soil as it affects reactions and interactions of elements and nutrients present in the soil.

CEC of the soils from each profile varies from very high to low (79.94-11.11 cmolc/kg) (Table 2). This property is directly influenced by the clay content which is higher on those soils composed of a high amount of clay. In addition, it was observed that surface soils have greater CEC compared to the subsurface which can be related to the OM (humus) that influenced the soil's ability to hold exchangeable cations.

The exchangeable bases determined include K, Na, Ca, and Mg. Results showed that soils from Cadac-an watershed contain high (1.43 cmolc/kg) to low (0.02 cmolc/kg) amount of exchangeable K, low (0.41-0.90 cmolc/kg) amount of exchangeable Na, high (19.69 cmolc/kg) to low (0.64 cmolc/kg) amount of exchangeable Ca, and high (5.27 cmolc/kg) to low (0.02 cmolc/kg) amount of exchangeable Mg (Table 2). In profile five where exchangeable Ca (11.50 to 19.69 cmolc/kg) and Mg (4.04-5.27 cmolc/kg) was higher could be possibly attributed to the characteristics of its parent material which is believed to be shale.

4. Conclusion and Recommendation

The continuous and increasing degradation problem in Leyte watershed due to landslide occurrences justifies the importance of the characterization of these areas. Cadac-an watershed was observed to be dominated by andesitic materials characterized by the presence of the active Leyte segment of the Philippine Fault. It is rugged and mountainous with brushes and grasses as the dominant vegetation.

Generally, soils from the landslide areas in Cadac-an watershed had a very strongly acidic to moderately alkaline pH (4.50-8.22), high to low OM (6.99-0.07%) and P content (24.84-0.88 mg/kg), very high to low CEC (79.94-11.11 cmolc/kg), high to low exchangeable K (1.43-0.02 cmolc/kg), Ca (19.69-0.64 cmolc/kg), and Mg (5.27-0.02 cmolc/kg), and low exchangeable Na (0.41-0.90 cmolc/kg).

With increasing frequencies of catastrophic landslide occurrences, a thorough and continuous study is needed to provide an efficient and effective measure to mitigate impacts of the phenomenon in the watershed areas in Leyte, Philippines. It is highly recommended and encouraged to plant more trees, prohibit tree cutting, delineate danger zones, establish more rain gauge stations and provide early warning systems to prepare for the consequences brought by the landslides. Further studies should be conducted to include inventory and establishment of a database of landslide occurrences for Leyte Island and landslide modeling and prediction.

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