



## **"LANDSLIDE OCCURRENCES IN SOUTHERN LEYTE, PHILIPPINES: CONTRIBUTING FACTORS AND IMPLICATIONS TO LOCAL GOVERNANCE"**

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### **Objectives**

- To characterize and produce maps of the landscape attributes of the landslide areas in St. Bernard, Southern Leyte
- To assess the major factors influencing landslide occurrences
- To predict landslide occurrences using the Stability Index Mapping (SINMAP) model

## ➤ The Landslide process

- define
- occurrences

## ➤ Impacts of landslides

- on the community
- on the economy
- on the environment









Photo courtesy of PHIVOLCS

Landslide block detached from the uppermost slope  
which traveled about 2 kilometers down slope





The landslide block detached from the uppermost slope which traveled about 2 kilometers down slope 2 years after the landslide event

## ***Factors Affecting Landslides***

- Causal factors
  - ❖ Geologic formation
  - ❖ slope characteristics
  - ❖ seismicity (earthquake occurrences)
  - ❖ Vegetation / land cover
  - ❖ soil properties
- Triggering factors
  - ❖ rainfall
  - ❖ ground water / hydrology
  - ❖ deconsolidation

# Methods

# Characteristics of Southern Leyte Landscape

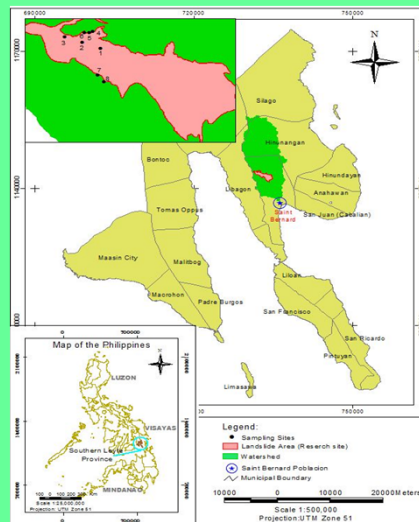


Fig. 1. Geographical location of Southern Leyte and the research site.



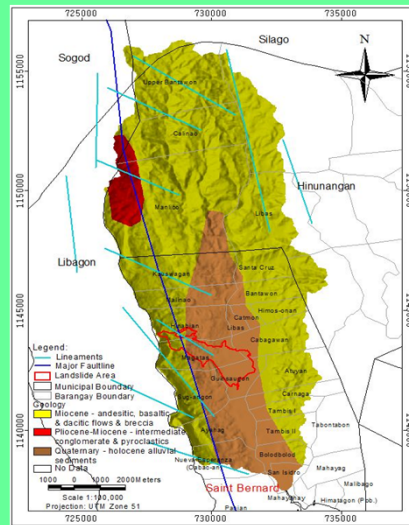


Fig. 2. Geologic map showing the major rock formations in the research site.  
(Source: VSU, GIS unit, 2009)

Table 1. Geology of the research site

GEOLOGY	AREA (ha)	PERCENT
<b>Watershed area:</b>		
Miocene - andesitic, basaltic & dacitic flows & breccia	7496	72.62
Pliocene-Miocene - intermediate conglomerate & pyroclastics	361	3.50
Quaternary - holocene alluvial sediments	2466	23.89
	10323	100.00
<b>Landslide area:</b>		
Miocene - andesitic, basaltic & dacitic flows & breccia	46	14.93
Quaternary - holocene alluvial sediments	263	84.60
Quaternary - Holocene alluvial sediments	1	0.47
	310	100.00



Photo courtesy of PHIVOLCS

Shallow groundwater table as exemplified by the occurrences of springs found abundant on the upper mid-slope of the landslide area



Springs and stream channels found abundant on the lower mid-slope of the landslide area.

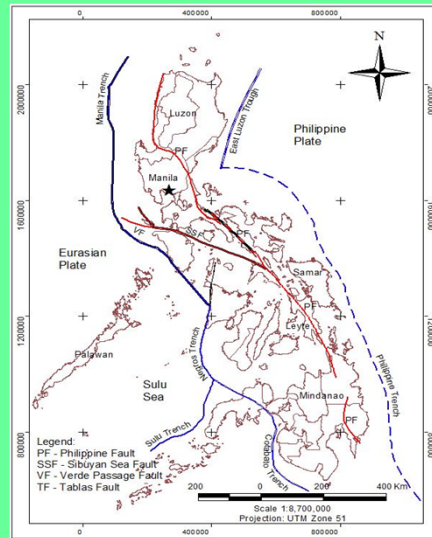


Fig. 3. Map showing plate tectonic setting and location of Philippine fault line (redrawn and modified from Barrier, et. al, 1991).

Table 2. Approximate length (km) of the Philippine fault and fault segments

DESCRIPTION	LENGTH (km)
Philippine fault (North)	628
Philippine fault (Bicol)	223
Philippine fault (Visayas)	523
Total Length of Philippine fault (km)	1,373
Fault segments	
Sibuyan sea fault	480
Philippine fault (Mindanao)	180
Length of Overlap fault (between Bicol and Bondoc Peninsula)	76
Verte Passage fault	136

GIS -based estimate from the modified tectonic map of Barrier et al., 1991



Fig. 4. Map showing the distribution of fault lines in Leyte and Southern Leyte (source: Daag and Buena, 2006).

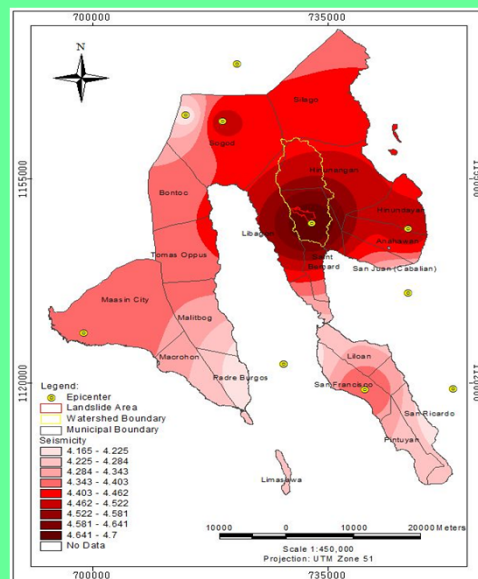


Fig. 5. Seismicity map of Southern Leyte.



Table 3. Seismic occurrences in Southern Leyte island from 2000-2010

YEAR	NO. OF OCCURRENCES	MAGNITUDE SCALE (Ms)
2000	21	4.0 - 5.4
2001	12	4.0 - 4.8
2002	5	4.1 - 4.9
2003	15	4.0 - 5.7
2004	22	4.0 - 5.1
2005	15	4.2 - 5.2
2006	5	2.4 - 4.2
2007	10	2.1 - 3.7
2008	6	3.1 - 4.4
2009	11	2.8 - 5.1
2010	6	2.6 - 4.5
Total	128	

1994 6.4- St. Bernard, SL  
1998 5.9 - SL

Source : Year 2000-2005 data: PHIVOLCS Central Office  
Year 2006- March 2010 <http://earthquake.phivolcs.dost.gov.ph>

Table 4. Seismic occurrences in Southern Leyte on February 17, 2006\*

TIME	MAGNITUDE	LOCATION (EPICENTER)
		10.335°N, 125.051°S with a depth of 5 km
6:27 a.m.	3.3	6 km W of Guinsaugon, St. Bernard, SL ; SE of Sogod, SL PHILVOLCS National Seismic Network
10:36 a.m.	2.6	10.328°N, 125.059°E with a depth of 3 km 5 km W of Guinsaugon, St. Bernard, SL & 11 km SE of Sogod, Southern Leyte
	4.3	National Earthquake Information Center (NEIC) recalculated (Ms) based on additional ground data location at 10.37°N , 125.08°E with a depth of 35 km

\* Source: Daag and Buena, 2006

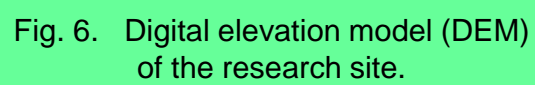


Table 5. Elevation of the watershed and the landslide areas

ELEVATION RANGE	AREA (HA)	PERCENT	AREA (HA)	PERCENT
Watershed area			Landslide area	
1-50	1696	16.43	198	63.70
51-100	783	7.58	36	11.54
101-150	753	7.29	17	5.40
151-200	657	6.37	17	5.32
201-250	592	5.74	13	4.09
251-300	571	5.54	6	1.89
301-350	562	5.45	8	2.55
351-400	551	5.34	7	2.28
401-450	523	5.07	4	1.37
451-500	518	5.02	1	0.48
501-550	452	4.37	1	0.38
551-600	481	4.66	2	0.49
601-650	407	3.95	1	0.35
651-700	395	3.83	1	0.17
701-750	417	4.04	Total 312	100.00
751-800	378	3.66		
801-850	322	3.11		
851-900	207	2.00		
901-950	56	0.54		
951-960	1	0.01		

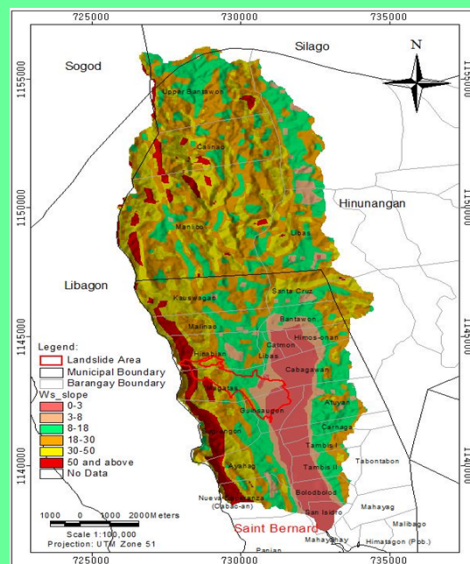


Fig. 7. Slope map of research site.

Table 6. Distribution of slope classes of the watershed and the landslide areas

SLOPE (°)	DESCRIPTION	AREA (ha)	PERCENT
Watershed area:			
0-3	Level to nearly level	921	8.92
3-8	Gently sloping to undulating	576	5.58
8-18	Undulating to rolling	2626	25.44
18-30	Rolling to moderately steep	3481	33.72
30-50	Steep	2135	20.69
50 and above	Very Steep	584	5.66
		10323	100.00
landslide area:			
0-3	Level to nearly level	71	22.96
3-8	Gently sloping to undulating	62	19.90
8-18	Undulating to rolling	64	20.58
18-30	Rolling to moderately steep	53	16.94
30-50	Steep	44	14.17
50 and above	Very Steep	17	5.45
		311	100.00

Table 7. Slope aspect of the watershed and the landslide areas

ASPECT (degrees)	DESCRIPTION	AREA (ha)	PERCENT	AREA (ha)	PERCENT
		watershed area		landslide area	
-1	Flat	0.16	0.00	0.164	0.05
0-22.5,337.5-360	North	712.57	6.90	14.578	4.70
22.5-67.5	Northeast	1591.67	15.42	59.576	19.19
67.5-112.5	East	1990.15	19.28	58.755	18.93
112.5-157.5	Southeast	1424.86	13.81	36.013	11.60
157.5-202.5	South	1202.72	11.65	50.751	16.35
202.5-247.5	Southwest	1440.83	13.96	73.197	23.58
247.5-292.5	West	1222.44	11.84	11.797	3.80
292.5-337.5	Northwest	734.88	7.12	5.601	1.80
		10320.28	100.00	310.432	100.00



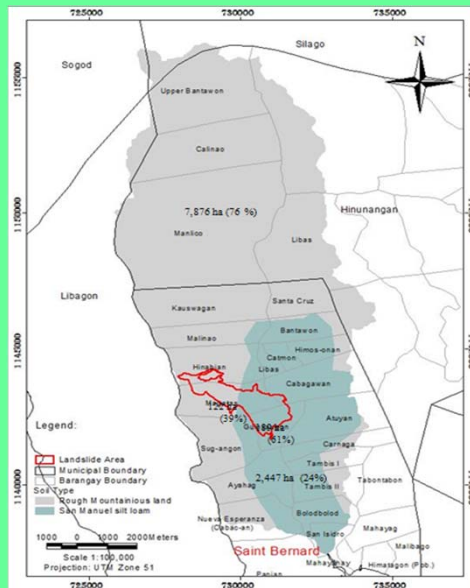


Fig. 8. Soil series distribution of the research site.  
(Source: VSU GIS unit, 2009)



Photo 5. Guinsaun, Saint Bernard, Southern Leyte landslide areas showing very loose soil and rock materials.

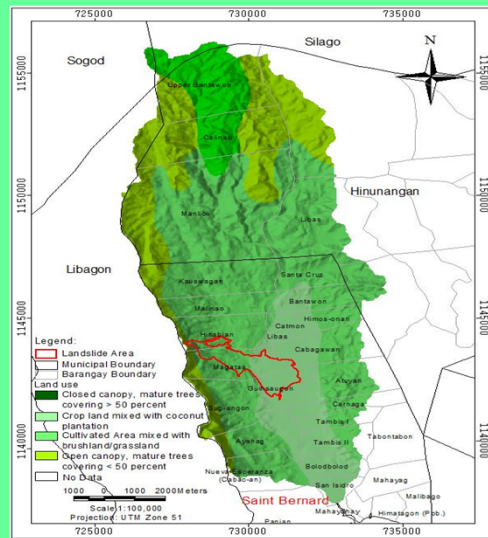


Fig. 9. Vegetation map of the research site (Source: VSU GIS unit, 2009) map of the research site

Table 5. Types of vegetation in the watershed and the landslide

Description	Area (ha)	Percent
<b>watershed area</b>		
Closed canopy, mature trees covering > 50 percent	909	8.81
Open canopy, mature trees covering < 50 percent	2286	22.15
Crop land mixed with coconut plantation	1549	15.00
Cultivated Area mixed with brushland/grassland	5579	54.04
<b>Total</b>	<b>10323</b>	<b>100.00</b>
<b>landslide area</b>		
Open canopy, mature trees covering < 50 percent	1	0.19
Crop land mixed with coconut plantation	183	58.87
Cultivated Area mixed with brushland/grassland	127	40.93
<b>Total</b>	<b>311</b>	<b>100.00</b>

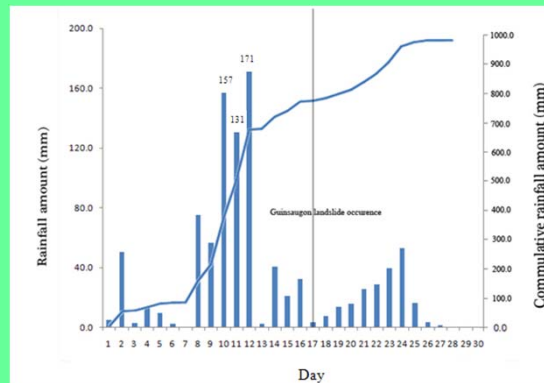
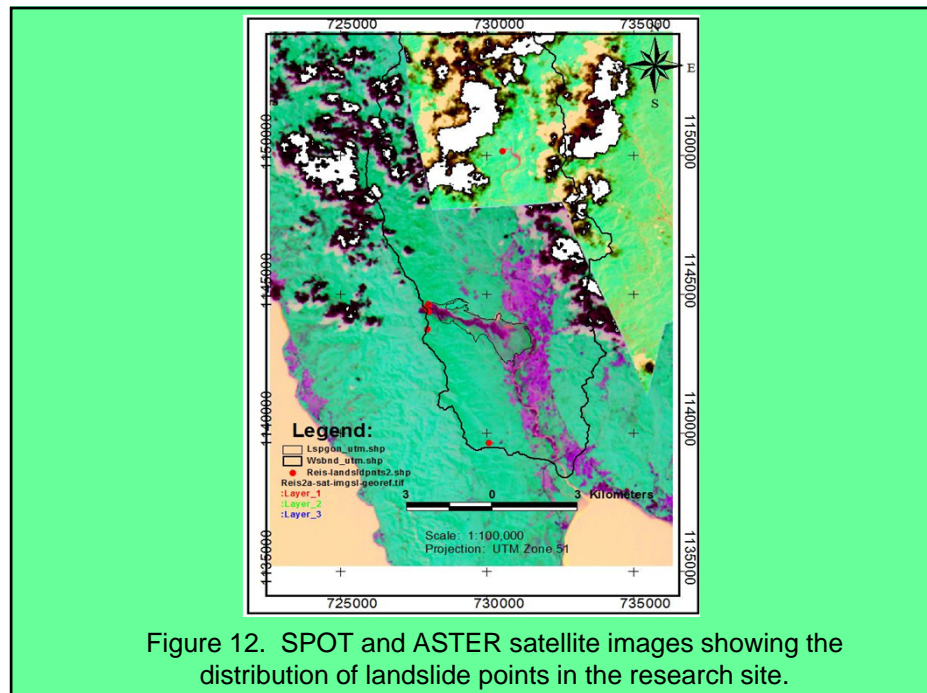


Figure 10. Daily and cumulative rainfall (mm) for the month of February, 2006 at Otikon, Libagon, Southern Leyte (10°9'37" N latitude, 125°2'13" E longitude) rain

## SINMAP MODELING



# SINMAP outputs



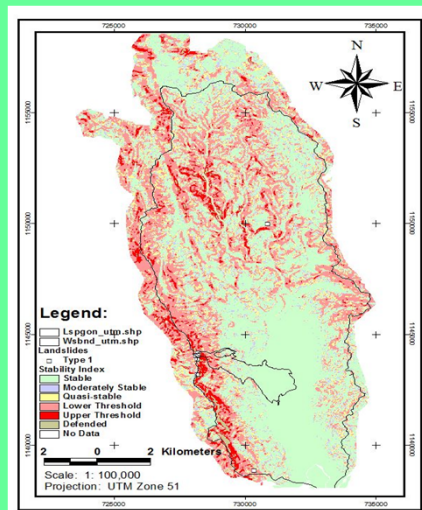


Fig. 13. Map output of SINMAP model showing the stability index of the research site

Table 3. Default stability index classifications of the SINMAP model

CLASSIFICATION	STABILITY INDEX VALUES (SI)
Stable	$SI > 1.5$
Moderately Stable	$1.25 < SI \leq 1.5$
Quasi-stable	$1.0 < SI \leq 1.25$
Lower Threshold	$0.5 < SI \leq 1.0$
Upper Threshold	$0.0 < SI \leq 0.5$
Defended	$SI = 0.0$

Table 4. SINMAP statistical summary showing stability index classification of the study site

	STABLE	MODERATELY STABLE	QUASI- STABLE	LOWER THRESHOLD	UPPER THRESHOLD	DEFEND	TOTAL
<b>Region 1</b>							
Area (km <sup>2</sup> )	59.5	13.5	20.5	39.0	5.7	0.5	138.7
% of region	42.9	9.7	14.8	28.1	4.1	0.4	100.0
#of Landslide	0	0	0	2	1	4	7
% of landslide	0.0	0.0	0.0	28.6	14.3	57.1	100.0
LS Density (#/km <sup>2</sup> )	0.0	0.0	0.0	0.1	0.2	7.9	0.1



## Areas for research

- More research on the hydro-geologic characteristics of watershed areas to monitor changes in underground water level and movement;
- Conduct studies on slope stability analysis
- Landslide inventory mapping and continuous monitoring and assessment of landslide indicators (presence of tension cracks, occurrence of shallow landslides , etc.) in susceptible areas;
- Thorough characterization of areas along the Leyte segment of the Philippine fault to be able to establish danger zones (ex. In Guinsaugon, a 700 m asl elevation had run out distance of > 4 km );
- Intensify research effort on the modeling aspect of landslide studies;
- Establishment of database on Leyte, Philippine landslides;
- Research on the use of devices for early warning system in the event of a landslide occurrence;

## Recommendations

- The watershed should be planted with trees to enhance stability;
- Human settlement is strongly discouraged in the unstable zone and its immediate surrounding vicinity approximately greater than 4 km. run-out distance;
- Set -up additional rain gauging stations for continuous monitoring of rainfall amount , rainfall intensities and duration at strategic places in the island;

