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Landslide Susceptibility Zonation in case of deforestation in Northern Negros Natural Park (NNNP) - Philippines

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Summary

The Philippines is one of the most severely deforested countries in Southeast Asia with around 7 percent remaining forest in 2005. Moreover, due to its geographic circumstances, it is one of the most natural hazard prone countries in the world with frequent occurrence of earthquakes, volcanic eruptions and typhoons, resulting notably in an increasing occurrence of landslides and flash floods.

This work focuses on the North Negros Island and especially the recently proclaimed Northern Negros Natural Park (NNNP) that is considered the largest remaining evergreen forest in Negros Island and one of the largest in the Central Philippines.

Deforestation continues to be a threat for this forest. The fact that this forest is located in mountainous area and that, due to a very high land pressure, people always creep higher to cultivate the steep slopes of these mountains, increase the landslide susceptibility associated with this deforestation.

As an answer to that situation, this research aimed two main objectives.

In a first time a land cover map was produced through digital classification of a 2003 SPOT 5 satellite image focusing on attempt for forest types differentiation in NNNP. Given that conventional method using spectral characteristics of the image revealed to be unsuccessful for this differentiation, this was finally achieved with the use of elevation and the distance to river as classifiers. The land cover map produced has an overall accuracy of 89,2 %.

In a second time, a Landslide Susceptibility Zonation (LSZ) model was designed and implemented in a Geographical Information System (GIS) environment. The nine selected landslide-controlling factors were built from raw data and then combined through Weighted Linear Combination (WLC).Two scenarios corresponding to a “stable forest scenario” and a “deforestation scenario” were modeled. The integration of the land cover map previously produced served successfully as the key factor that enabled to model the Landslide Susceptibility (LS) change due to potential deforestation in NNNP. A sensitivity analysis of the factors used for this modeling was realized by comparison with a “LSZ in case of deforestation” map based on the four main factors only (land cover, land cover change, slope and proximity to river). It appeared that, the LSZ model was not sensitive to the use of other factors than these four main ones. Finally, in order to give an idea of the reliability of the results, the LSZ maps were compared with a landslide inventory realized during the field survey in North Negros. Some limitations in the landslide inventory did not allow drawing pertinent conclusion from this comparison.

In parallel and in order to evaluate the feasibility of integrating the land cover knowledge of local environmentalist into a GIS data base through field survey and 3D-GIS activity in a remote laboratory, a participatory 3D-GIS experience was attempted in Negros. Consistence of results between field and 3D-GIS laboratory experience validate this way of extracting land cover information, which could revealed useful for land cover identification of hardly accessible areas.

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Introduction

A few hundred years ago, due to its moist tropical climate, at least 95 percent of the Philippines was covered by rain forest, harbouring one of the highest densities of unique species anywhere on the earth. In 1900, forests covered had decreased to 70 percent. A century later, the nation is one of the most severely deforested countries in Southeast Asia with around 7 percent remaining forest in 2005.

Deforestation, added to the fact that the Philippines, by virtue of its geographic circumstances, is one of the most natural hazard prone country in the world with frequent occurrence of earthquakes, volcanic eruptions and typhoons, result notably in an increasing occurrence of landslides and flash floods, among other environmental degradation (degraded watersheds, massive soil erosion, depletion of soils and nutrients, silted waterways, coral reef siltation, groundwater depletion,…).

The few remaining forest locates in the mountainous areas which were save until now thanks to reduced accessibility. However, due to steep relief, this ecosystem is much more sensitive to perturbation than vanished lowland forest. If structural problem such as important population growth and lack of appropriate land tenure persist, pressure on the remaining forest will increase more and more. Added to global climate change, this could result in dramatic environmental and socio-economic consequences at mid-term.

This master' thesis is involved within the framework of a project of the "Commission Universitaire pour le Developpement" (CUD) called "Building Local Capabilities in Participative Water Resources Management in the Philippines" which try to give an answer to the environmental and socio-economic problematic previously mentioned. Some of the objectives of the project are to build a comprehensive Geographical Information System (GIS) database for North Negros and Agusan Marsh in Mindanao, in order to support analysis of land use patterns and the social dynamics affecting them, to develop co-management strategies, to find cause and effect relationships between biophysical processes and community issues and concerns and to identify priority areas that need immediate management action such as protection, rehabilitation, and disaster susceptibility establishment.

This work in particular focuses on the North Negros Island and especially the Northern Negros Natural Park (NNNP) and can be summarized in two steps. The first step is the production of a land cover map through classification of a SPOT 5 satellite image. The second step will consist in the realization of a Landslide Susceptibility Zonation (LSZ) GIS model by construction and combination of landslide-controlling factors. The integration of the land cover map previously produced will serve as the key factor that enables to model the Landslide Susceptibility (LS) change due to potential deforestation in NNNP.

In the first chapter, bibliographic searching about landslide process, factors and modeling will be presented. The second chapter will present the study site in North Negros Island and especially NNNP. The third chapter will briefly present the objectives of this work. The material and the methodology used to achieve this work will be got into in the chapter four. Chapter five will present the SPOT 5 satellite image processing and the resulting land cover map. The building of the LSZ model and the LSZ maps produced will be presented in chapter six. Finally a short discussion will end this work in chapter seven.

Chapter I: Bibliographic searching

I.1. Landslides – Significance and impact

Mass movement, among which landslides, in mountainous terrain are a **natural degradation** phenomenon and one of the most important landscape building processes. Most of the terrain in mountainous areas has been subjected to slope failure at least once, under the influence of a variety of causal factors and triggered by events such as earthquakes and extreme rainfall (Van Westen, 1994).

Though occurring naturally, this process has been accelerated by **anthropogenic influences** such as road construction, mining operations, deforestation… (Piyoosh Rautela et al. 2000).

Landslides become **hazardous** when they interfere with human activities. (Hansen, 1984, Chung, 1995).

While landslides have a significant impact, their importance is often **under-estimated** as the landslide damage is considered simply as a result of the triggering processes and thus is included in reports of other phenomena such as earthquakes, flood etc (Schuster 1996).

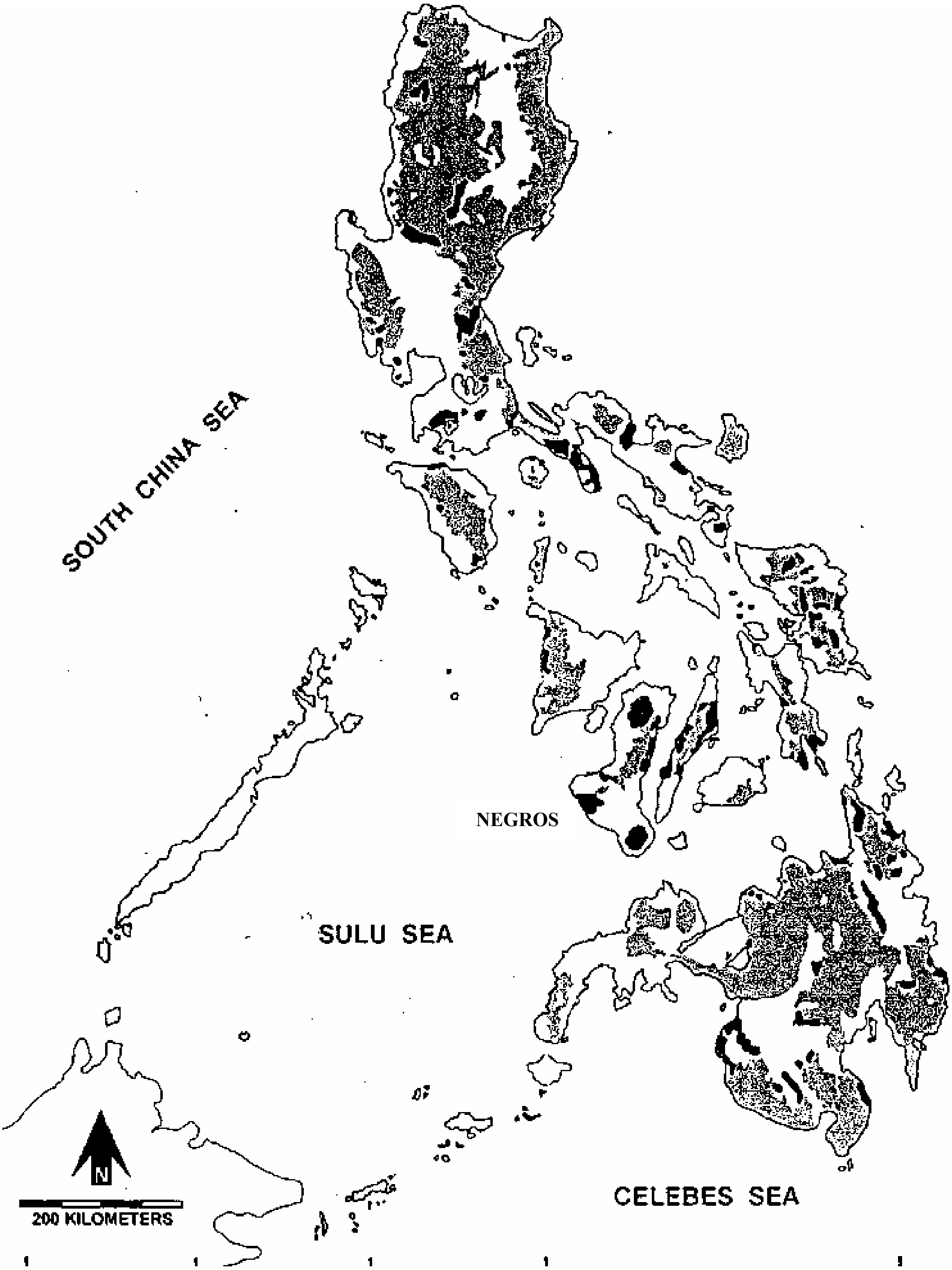
The study of landslides has drawn **global attention** mainly due to increasing awareness of its socio-economic impacts and also increasing pressure of urbanization on the mountain environment (Aleotti et al., 1999).

Worldwide and during the years 1990 to 2005, landslides have represented 4.89% of the natural disasters (www.em-dat.net). They are amongst the most **damaging** natural hazards in the hilly regions (Aleotti et al., 1999).

Landslide impacts are especially serious in **developing countries** where environmental protection and management are harder to sustain (Hansen, 1984, Chung, 1995). Indeed, over 95% of all disasters and fatalities related to landslide in particular, and mass movement in general occur in these countries (Hansen, 1984, Chung, 1995). As regards to the economic damage in many developing countries, natural catastrophes account for 1–2% of the gross national product (Hutchinson 1995). In many cases these effects contribute to economic stagnation and lack of development.

According to Schuster (1996) and Ercanoglu and Gokceoglu (2004), the current trend of landslide occurrence is expected to continue in **future** due to increased unplanned urbanization and development, continued deforestation and increased regional precipitation in landslide prone areas due to changing climatic patterns (Piyoosh Rautela et al. 2000).

Hence, the identification of landslide-prone areas is essential for safer strategic planning of future developmental activities. **Landslide Susceptibility Zonation** (LSZ) of an area becomes a tool for prevention and the base to take actions decreasing the impact of potential landslide or their occurrence. As an example, see the "Earthquake induced landslide hazard map– Philippines" in Map 1.



Map 1: Earthquake induced landslide hazard map – Philippines (WB).

- No present risk
- Low danger zone : these are mountainous areas with steep slopes (>18%) but have a low potential to earthquake-induced landslides
- High danger zone : these areas are susceptible to shallow landsliding in case of an earthquake with Ms=7.5 or with an intensity of PEIS- VII occurs

I.2 Landslide description

I.2.1 Definition, description and classification of landslides

The term **“landslide”** describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing.

Landslide is often confused with **erosion** process. However the conceptual difference between them is clear. Surface erosion is a water-driven process, whereas landslides are gravity driven. Nevertheless, surface erosion is influenced by gravity (i.e., slope gradient affects runoff velocity and thus surface erosion potential) and landslides are affected by water (i.e., pore water pressure reduces soil shear strength). (Roy C. Sidle et al.2006)

Description and classification of landslides was mainly based on the system of Cruden and Varnes (1978), which takes into consideration the types of movements, the materials involved and the states or activities of failed slopes. An abbreviated version of Varnes’ classification of slope movements is shown in Table 1. An illustration of major types of landslides movement is shown in Figure 1.

<table>
<tr><th colspan="2" rowspan="3">TYPE OF MOVEMENT</th><th colspan="3">TYPE OF MATERIAL</th></tr>
<tr><th rowspan="2">BEDROCK</th><th colspan="2">ENGINEERING SOILS</th></tr>
<tr><th>Predominantly coarse</th><th>Predominantly fine</th></tr>
<tr><td colspan="2">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">TOPPLES</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">Rock slide</td><td rowspan="2">Debris slide</td><td rowspan="2">Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td></tr>
<tr><td colspan="2">LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="2">FLOWS</td><td>Rock flow (deep creep)</td><td>Debris flows (soil creep)</td><td>Earth flow (soil creep)</td></tr>
<tr><td colspan="2">COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

Table 1 : Abbreviated version of classification of landslides based on the system of Cruden and Varnes (1978)

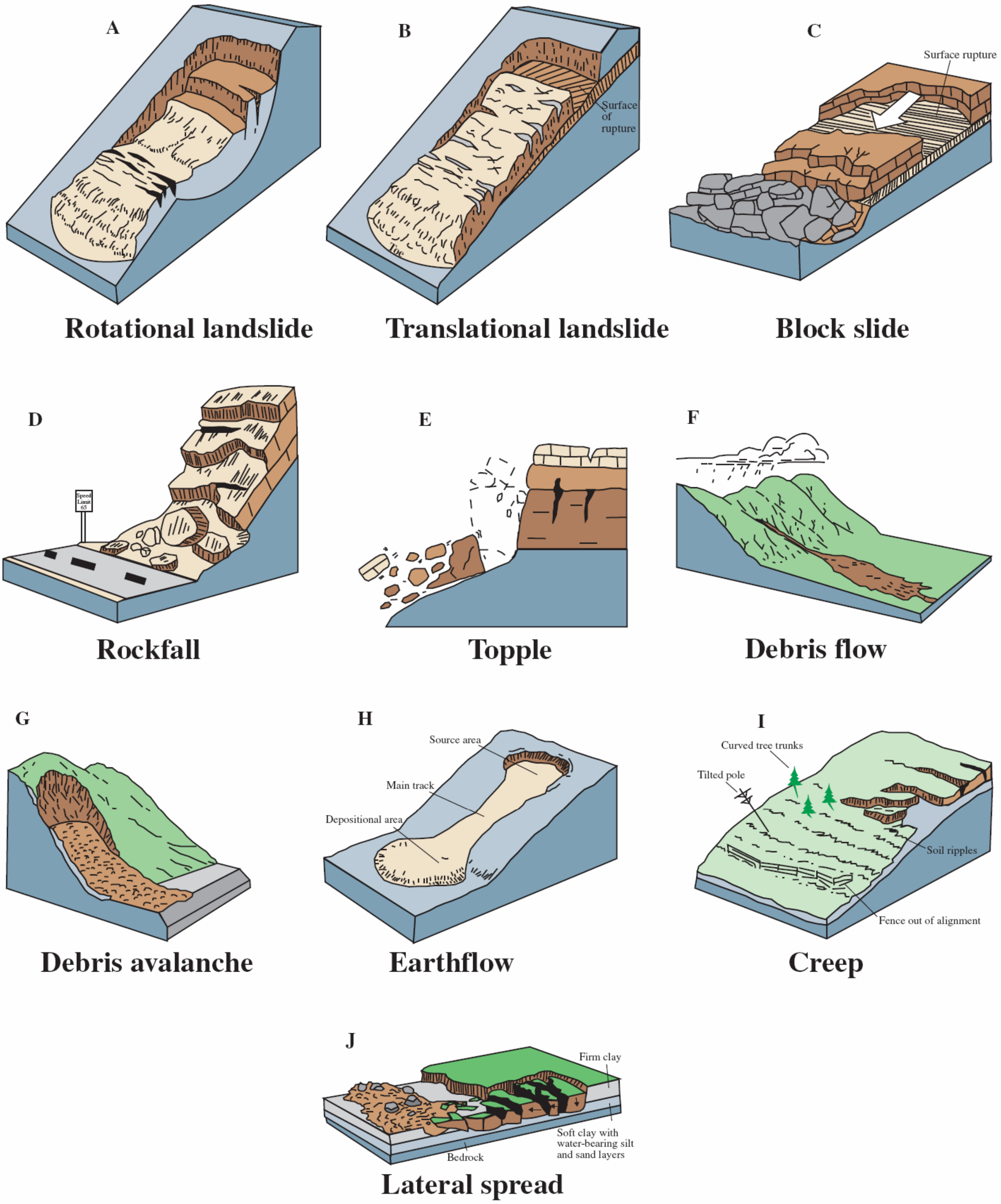


Figure 1: Major types of landslides movement

I.2.2 Landslide process

Broadly speaking, two types of landslide process can be distinguished: shallow and deep-seated landslides.

Shallow subsurface flow, particularly during rainstorms, accumulates in various hill slope positions due to topography (surface and subsurface) and continuity of soil hydrologic pathways. If combined with steep slopes and soils that overlie relatively impermeable substrate, high pore water pressures can develop and trigger a landslide. Such shallow, rapid landslides naturally occur in mountainous forest terrain, particularly in geomorphic hollows (also called zero-order basins) (Tsukamoto and Ohta, 1988 and Sidle and Wu, 1999). Little can be done to prevent such landslides and they are major contributors of 'natural' episodic sediment to streams. A common hydrologic sequence for shallow landslide initiation involves wet antecedent conditions followed by a prolonged period of rainfall with a burst of high intensity (e.g., Sidle and Swanston, 1982; Roy C. Sidle et al.2006).

Deep-seated landslides, such as slumps and earthflows, generally initiate and accelerate in response to a gradual build-up of pore water pressure over weeks or even an entire rainy season (e.g., Wasson and Hall, 1982 and Iverson and Major, 1987). Water recharge into deeper soils is controlled not only by 'small-scale' hydraulic properties (i.e., hydraulic conductivity changes with depth), but also by 'larger scale' phenomena, such as surface tension cracks and fractures in bedrock (Sidle et al., 1985, Montgomery et al., 1997 and Sidle and Chigira, 2004). (Roy C. Sidle et al.2006).

For both shallow and deep-seated landslides, disruption of subsurface flow and flow characteristics in the regolith influence pore water pressure response, and thus, the potential for landslide initiation. (Roy C. Sidle et al.2006).

The major risk to humans occurs with shallow, rapid landslides and the occasional deep, rapid landslides that impact areas where humans settle; conversely, slower, deep-seated landslides rarely cause loss of life, but can inflict extensive property and environmental damage (Roy C. Sidle et al.2006).

Landslides in Negros

Photo 1: Old deep-seated landslide in NNNP

Photo 2: Shallow landslide associated with clearing

Photo 3: Large deep-seated landslide close to a river

Photo 4: Charcoal making or Kaingin (foreground)
Shallow landslide due to clearing (background)

I.2.3 Main landslide-controlling factors

The different landslide controlling factors can be separated in two groups: the pre-disposing factors and the triggering factors.

I.2.3.1 Pre-disposing factors

I.2.3.1.1 Land cover

It is commonly accepted in the literature that the incidence of landslide is inversely related to the vegetation density. More vegetation there is, lower is the landslide susceptibility.

The following sequence expresses the decreasing effect of vegetation on LS.

Bare soil ≤ crop production ≤ grass < grass fallow < shrub fallow ≤ bushes << forest

This sequence is explained by both hydrological and mechanical effects of vegetation on landslide susceptibility. They can be summarized as follow:

- Root system contributes to reinforce the unstable shallow soil mass and hold it in place by binding it to stable sub-soils (Sidle et al. (1985)). Deeper and more strength is the root system, lower is the landslide susceptibility. Woody vegetation especially contributes to ground stability. Note that the root system is much more significant in protecting against shallow landslides than deep-seated landslides (Swanston and Swanson, 1976). Moreover tree roots (both alive and dead) facilitate preferential drainage in contributing to macropore formation in tropical soils (e.g., Noguchi et al., 1997a and Sidle et al., 2001). Such drainage paths could be very important when soils approach saturation to dissipate the formation of zones of positive pore water pressure that could potentially trigger landslides. (Roy C. Sidle et al.2006)

- High year-round evaporation rates of tropical forests (Greenway, 1987 and Bruijnzeel, 2004) act to stabilize hill slopes by preventing pore water pressure from exceeding critical thresholds that will trigger landslides.

- The foliage of vegetation contributes to decrease the rain power on erosion

However, some conflicting evidences concerning the effects of vegetation on slope stability can be found in the literature. This is for example:

- Trees could contribute to induce landslide during storms. Indeed, strong wind in the aerial tree part transmits vibration in the root system which in turns decreases ground stability.

- K.M. Neaupane et al. (2006) proposed that surcharge from weight of trees may (or may not) increase LS.

- Franks (1999) found that sparsely vegetated slopes are most susceptible to failure than non vegetated ones and Dai et al. (2001) found that density of landslide is higher on grassland than on bare lands.

I.2.3.1.2 Deforestation

Logging activities (Douglas et al., 1999), clearance and replacement with agriculture (Larsen and Torres-Sánchez, 1998) in forested steep lands are well known for increasing LS (H.L. Perotto-Baldiviezo et al. 2003).

This may be due to an alteration of the **hydrological cycle** (Chan, 1998; Zhou et al., 2002), decreasing the water storage capacity and finally provoking a faster saturation of the topsoil (Gerrard and Gardner, 2002). For example, in Leyte, Philippines, Chandler and Bisogni (1999) shows that alterations of subsurface flow pathways due to conversion of tropical forests to pasture and tilled agricultural fields disrupt preferential flow paths thereby creating possible (but unproven) scenarios for pore water pressure accretion and landslide initiation. (Roy C. Sidle et al.2006)

Another reason is the alteration of the **rooting system**. Two scenarios can be distinguished: (Roy C. Sidle et al.2006) :

- conversion of mountain forests to cropland or plantations permanently reduces rooting strength
- timber harvesting with subsequent regeneration of secondary forests reduces rooting strength for up to two decades after initial cutting.

A **time lag** of several years is observed between the forest logging and the increase of landslides. Many field investigations in steep forested terrain worldwide have noted up to a 10-fold increase in landslide in the period roughly 3–15 yr after timber harvesting (Bishop and Stevens, 1964, Endo and Tsuruta, 1969, O'Loughlin and Pearce, 1976, Megahan et al., 1978, Wu and Sidle, 1995, Jakob, 2000 and Sakals and Sidle, 2004). This increase in landslide frequency and volume is largely related to the period of minimum rooting strength, caused by root strength deterioration after clear-cut harvesting coupled with the slower recovery of root strength following replanting or natural regeneration (Roy C. Sidle et al.2006)

Moreover, **logging roads** and **log landings** induce severe compaction and heavy disturbance of soil resulting in the creation of rills and gullies which in turns can induce landslides (M.A. Clarke et al. 2006). Logging roads also contribute to increase LS by cutting across the middle of slopes. Higher landslide frequency was also observed where old logging roads and trails change natural drainage paths (Freeman R et al., 1998).

However, as **natural geomorphologic processes**, landslides may be common events in many undisturbed rainforest regions, particularly where there is a susceptibility to earthquake shocks which provide the trigger mechanisms (e.g., Pain and Bowler, 1973) and even in other, seismically stable regions (e.g., Day and de; see also comments by Douglas, 1999). Moreover, according to Dykes (2002) shallow landslides play a key role in the maintenance of characteristic slope forms (Dykes and Thornes, 1996) and contribute to the ecological dynamics of the tropical rainforest system.

I.2.3.1.3Geology

It is widely recognized that geology greatly influences the occurrence of landslides, because lithological and structural variations often lead to a difference in strength and permeability of rocks and soils (Lulseged Ayalew et al. 2005).

Regarding the **soil texture**, fine texture soil and especially clayey soil are responsible for slope instability. Indeed clayey soils are characterized by low permeability and are prone to lose their resistance properties through liquefaction process.

More than a geological formation itself, the **interface between geological formations** characterized by different permeability or resistance is a determinant factor influencing LS. For example, in Bohol – Philippines, field survey on a landslide site shows that the mechanism inducing the landslide was due to the presence of impermeable plastic clay layers, which retained the seeping water above the main body of the landslide, inducing an important pressure. It is believed that the ground did not resist because of the unstable volcanic rock of this site.

It is also widely recognized that landslide susceptibility is higher along **llineaments** which are the structural features that describe the plans of weakness, fractures, faults, tectonic structures and geomorphologic signatures such as topographic breaks,. It has generally been observed that the probability of landslide occurrence increases at sites close to lineaments, which not only affect the surface material structures but also make contribution to terrain permeability causing slope instability. (D.P. Kanungo et al., 2006) (Lulseged Ayalew et al., 2005).

I.2.3.1.4 Topography factors

Surface topography affects the susceptibility of a slope to landslide in several ways which correspond to the individual factors derived from topography: slope gradient, curvatures of slope and aspect are the main ones.

Slope gradient

Slope gradient is recognized as one of the most influent factor on slope stability. LS due to slope gradually increases until 45° (100%) that corresponds to a plateau after which LS decrease rapidly. This can be explained by the interesting observations of Dykes and Thornes (1996) on rainfall-triggered landslides in undisturbed tropical rainforests in relation with slope gradient. The findings of their survey suggest that any slope of 40° and steeper should fail several times every year in response to storm events, but that in reality most of the slopes have failed previously and have not yet regained a critical depth of residual soil or are "slopes with no soil layer with bedrock exposed" (Roy C. Sidle et al.2006). Some approximate values for rates of weathering and slope development suggest that any given slope will not fail at intervals of less than 10,000 years. Therefore, the occurrence of shallow failures will be infrequent but nevertheless significant in terms of regional denudation and ecological diversity.

However, some **nuances** have to be made. While steeper slopes provide greater potential energy to induce failure, they are also indicative of higher strength of materials. This trade-off between increased driving force and increased soil strength appears to reduce the importance of slope steepness (Roth, 1983). Varnes (1978) noticed that steep slopes in competent rocks were more stable than the gentle slope in weaker formation for example.

Curvature

The slope curvature affects principally flow direction and soil moisture concentration. Different curvatures can be distinguished corresponding to profile and plan curvature (straight, concave or convex). The plane curvature determines divergence or convergence of flows while profile curvature determines… According to Pierson (1980) concentration of subsurface drainage within a concave slope, resulting in higher pore water pressures in the axial areas than on flanks, is one possible mechanism responsible for triggering landslides.

Aspect

The aspect which is defined as the direction of maximum slope of the terrain surface of a slope, can influence landslide initiation. **Moisture** retention and **vegetation** is reflected by slope aspect, which in turn may affect soil strength and susceptibility to landslides (F. C. Dai, 2001). The processes that may be operating include exposure to sunlight, prevailing winds and rainfall (Dai et al., 2001a).

If rainfall has a pronounced directional component by influence of a **prevailing wind**, the amount of rainfall falling on a slope may vary depending on its aspect (Wieczorek et al., 1997). For example, Matthew C. Larsen et al., (1998) found a higher frequency of landslides on hill slopes that face prevailing winds. In general, the frequency of landslides was 2.3 times greater on hill slopes facing the prevailing winds than the frequency on hillslopes not facing the prevailing winds.

Moreover, most of the **landslide-triggering storms** are tropical disturbances (Calvesbert, 1970; Larsen and Simon, 1993) which approach the island from the east in the case of Negros. As a consequence slopes facing east are more susceptible to landslide. This could be noticed in the case of Hurricane Mitch which came from the east impacting east facing slopes more strongly (H.L. Perotto-Baldiviezo, 2003)

Finally, a significant part of **annual moisture** input in tropical mountain cloud forests is delivered by condensation and direct contact of cloud droplets (Bruijnzeel and Proctor, 1993). This input of water, known as cloud drip, or horizontal precipitation, is conveyed by clouds moving with the trade winds. (Matthew C. Larsen et al., 1998)

Note that given the low latitude of the **tropics**, the north or south aspect of hill slopes does not cause the large differences in soil temperature that occur in temperate regions (Van Wambeke, 1992). As a consequence, the observation made by Zachar (1982) which concludes that slopes with higher insulation, and associated higher temperatures, have increased landslide, seem not to be pertinent for tropical regions.

I.2.3.1.5 Proximity to drainage

Numerous studies shows that landslide frequency increases when going closer to river networks (Cruden and Varnes, 1996; Wieczorek, 1996;…).

This is explained by the erosion activity, corresponding sometimes to slope undercutting, associated with drainage which is reinforced for intermittent flow regime of streams and gullies. (Dai et al., 2001).

It was also observed in many case that, for a given watershed, majority of landslide occurred in the first orders drainages only (1^{st}, 2^{nd}…) (D.P. Kanungo et al., 2006). Indeed landslides occur rather along small onrush water in uplands than along the large rivers flowing in flat plain.

Moreover, direct environment of the rivers is often characterized by the quite steep slopes of the depression resulting from the ground digging of the river itself through ages and erosion process and in which the riverbed lies. This steep relief increases thus LS (Denis, 2006).

However, few studies found another trend showing that landslide frequency is maximum in low drainage density. This could be explained by the fact that in terrain with low drainage, the water infiltrates in the ground, causing instability (S. Sarkar et al.).

I.2.3.1.6 Road

Roads play a major role in determining landslide occurrence and distribution (Lulseged Ayalewa et al., 2005). In the mountains, depending on their location, it usually serves as a source of landslides. Some slope failures start above roads but are often intercepted by them (Larsen and Parks, 1997 and Shaban et al., 2001).

This can be explained by the fact that roads, presenting important compaction of soil, reduce strongly the permeability of soil and thus infiltration. Exceeding water resulting from storm runoff preferentially flows along roads acting as a barrier or guide for water flow. This is at the origin of the creation of gullies along them. Gullies will enlarge with successive storms and finally be the starting point of landslide. Narrow mountain trails can also behave the same way as gullies.

I.2.3.2 Triggering factors

The triggering factors of landslide could be understood as external factors which set off the landslide movement by shifting the slope from a marginally stable to an actively unstable state. They mainly correspond to rainfall and earthquakes.

Earthquakes' ground vibrations reduce slope stability and often trigger landslides.

Regarding **rainfall**, it is widely recognized that rainfall of important duration and/or intensity are the source of the so-called "rainfall-induced landslides". They are caused by the increased pore pressures and seepage forces in their source areas during periods of intense rainfall (Campbell, 1975; Ellen, 1988; Fleming et al., 1989). The traditional explanation assumes that the rainfall infiltrates vertically into the soil horizon and that the pore pressure rises in response to increasing saturation above the colluviums–bedrock contact (e.g. Campbell, 1975).

Rainfall may lead only to shallow landslides and there may be a predominance of debris flows in some of these areas. Deep seated landslides often correlate with cumulative rainfall for significant antecedent periods (e.g. 15 days, one month, two months or more) rather than to rainfall intensity over short periods (e.g. several hours).

I.3 Landslide Susceptibility Zonation (LSZ)

Generally, the purpose of Landslide Susceptibility Zonation is to highlight the regional distribution of potentially unstable slopes based on a detailed study of the factors responsible for landsliding (Lulseged Ayalewa et al., 2005).

I.3.1 LSZ concepts

I.3.1.1 Difference between Susceptibility and Hazard Zonation

Landslide hazard or landslide susceptibility maps are profoundly affected by conceptual differences.

The term **hazard** is defined by Varnes (1984) as the probability of occurrence of a potentially damaging phenomenon within a specified period of time and area. This definition includes temporal and spatial aspects, causative and triggering factors, and thresholds (Dikau et al., 1996). In this view, the occurrence of landslides is a random process in time, and many landslides are essentially unpredictable.

The focus should, therefore, be on the recognition of landslide prone areas, meaning a differentiation of the spatial probability of occurrence of landslides. This can be achieved by mapping **susceptibility**.

Hazard is not deemed to be synonymous with susceptibility (Brabb, 1984, Soeters and van Westen, 1996, Abolmasov and Obradovic, 1997 and Parise, 2001). Susceptibility can, however, be an important determinant of hazard. Hazard maps are a step or several steps ahead of susceptibility maps. Unlike a susceptibility map, a typical landslide hazard map is expected to portray the scale of hazard, the slope failures that cause or contribute to a disaster (Lulseged Ayalewa et al., 2005) and how far the landslide will travel (Mantovani et al., 1995)

The term **zonation** refers to the division of the land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility (Varnes and IAEG, 1984). For example, the area may thus be categorized as very high susceptibility (VHS), high susceptibility (HS), medium susceptibility (MS), low susceptibility (LS) and very low susceptibility (VLS) zones to produce an LSZ map (D.P. Kanungo et al., 2006)

I.3.1.2 Basic assumptions for LSZ modelling

As a basis for LSZ researchers generally make four fundamental assumptions (Varnes and IAEG 1984; Hutchinson 1995):

- landslides will always occur in the same geological, geomorphological, hydrogeological and climatic conditions as in the past
- the main conditions that cause landsliding are controlled by identifiable physical factors
- the degree of susceptibility can be evaluated
- All types of landslide can be identified and classified

I.3.2 GIS-based LSZ modelling

Due to the availability of a wide range of remote sensing data together with data from other sources in digital form and their analysis using GIS, it has now become possible to prepare different thematic layers corresponding to the causative factors that are responsible for the occurrence of landslides in a region (Gupta and Joshi, 1990, van Westen, 1994, Nagarajan et al., 1998 and Gupta, 2003). The integration of these thematic layers with weights assigned according to their relative importance in a GIS environment leads to the generation of an LSZ map (Gupta et al., 1999, Saha et al., 2002, Sarkar and Kanungo, 2004 and Saha et al., 2005).

Various GIS landslide models exist. They differ in the number, combination and weighting of parameters used, according to the data available, the methodology used and the characteristics of the study site itself. Broadly speaking LSZ method can be divided in qualitative and quantitative method (Aleotti P et al., 1999).

In general **qualitative approaches** are based entirely on the judgement of the person or persons carrying out the susceptibility assessment. The input data are usually derived from assessment during field visits, possibly supported by aerial photo interpretation. One of these methodologies, also defined as Expert Evaluation Approaches (Leroi 1996), consists in the combination or overlaying of index maps with or without weighting (Aleotti P. et al., 1999).

I.3.2.1 Combination of thematic factor maps with weights

On the basis of his expert knowledge on the casual factors of slope instability, the landslide expert combines landslide-controlling factors maps through a **weighted linear combination (WLC)**. A weight which represents their relative importance on LS is given to each factor and each class of factors. Combination of these maps result into a LSZ map (Anbalagan; Pachauri and Sarkar).

Limitation of this method mainly consist on the fact that the exact weighting of the various factor maps is based on subjective decision rules and that no sufficient field knowledge of the important factors can be gathered, which will lead to unacceptable generalisation (Mantovani et al., 1995).

For **minimizing the subjectivity** and bias in the weight assignment process, quantitative methods were developed.

The most common **quantitative** methods simply use a landside inventory map which is statistically correlated (map crossing) with the landslide-controlling factors maps. The correlation helps to determinate the combinations of landslide-controlling factors that have led to past landslides. This combination is supposed to be the best that will predict future landslides. Estimations are then made for areas currently free of landslides, but where similar conditions exist. This results in LSZ maps.

The main **limitation o**f these methods is that they are based on a landslide inventory which is really time consuming if no available data already exist and thus realized in the field.

However, **remote sensing** techniques allows to realize landslide inventory by analyze of images they produce such as aerial photographs or satellite images at the condition that they are of appropriate resolution. Important features that enable recognition of landslides are: their size, their contrast (the difference in spectral characteristics between the landsides and the surrounding areas) and their morphological expression. Rengers et al. (1992) identify minimum sizes of objects to be recognized for various conditions of contrast with their background with SPOT image. This is presented in table 2. Values given in this table should be used only as an indication of the order of magnitude.

Conditions of contrast with respect to their background	SPOT XS (20 m resolution)	SPOT PAN (10 m resolution)
High contrast	200 m	100 m
Low contrast	800 m	400 m

Table 2: Minimum sizes of objects to be recognized for various conditions of

It can be concluded from table 2, that the SPOT images presented in this table are not suitable for identifying mass movement phenomena, unless they are very large. Remote landslide inventory made with non accurate enough resolution should always be followed by an extensive field check.

Another difficulty was brought to light by Francesco Brardinoni et al. (2003) who checked the feasibility of making an inventory of landslides by means of aerial photo interpretation (API) in **old growth tropical forest**. Remotely sensed inventory was followed by a thorough field survey. He showed that the proportion of “non visible” landslides hidden by the forest canopy raised up to 85% of the total number of failures but account for 30% of the volume of debris mobilised only.

I.3.2.2 Weighting procedure for LSZ

LSZ results from the weighting of landslide-controlling factors and their classes. One of the ways to weight them comes from Analytical Hierarchy Process (AHP) which is explained below after a brief introduction to multi-criteria evaluations and multi-criteria decision making in GIS.

Multi-Criteria Evaluations (MCE), also called modelling, is defined as the procedure by witch several criteria need to be evaluated to meet a specific objective, (Voogd, 1983; Carver, 1991).

MCE is most commonly achieved by combination of the two following procedures:

- o Boolean overlay, whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR)..
- o Weighted linear combination (WLC), wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average.

WLC results in a continuous mapping of suitability that may then be masked by one or more Boolean constraints to accommodate qualitative criteria, and finally thresholded to yield a final decision.

Multi-Criteria Decision Making in GIS

In MCE, both WLC and Boolean constraints enable to combine the information from several criteria to form a single index of evaluation, LS for example.

With a weighted linear combination, factors are combined by applying a weight to each, followed by a summation of the results to yield a suitability map:

$S = \Sigma w_i x_i$ where S = suitability
w_i = weight of factor i
x_i = criterion score of factor i

The procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints,

$S = \Sigma w_i x_i * \Pi c_j$ where c_j = criterion score of constraint j
Π = product

All GIS software systems provide the basic tools for evaluating such a model. In addition, in IDRISI software, which has been used for this work, a special module named MCE has been developed to facilitate this process.

Factor and factor classes weighting

Factor classes weight.

Because of the different scales upon which factors are measured, it is necessary that factors be standardized before combination, and that they be transformed, if necessary, such that all factors maps are positively correlated with suitability.

For example, in the case of LSZ, slope factor ranging from 0 to 90° will be standardized in a LS value ranging from 0 to 10. Other landslide-controlling factors will also be standardized the same way.

Factor Weights

A wide variety of techniques exist for the development of weights. In very simple cases, assigning criteria weights may be accomplished by dividing 1.0 among the criteria. However, when the number of criteria is more than a few, and the considerations are many, it becomes quite difficult to make weight evaluations on the set as a whole. Breaking the information down into simple pairwise comparisons in which only two criteria need to be considered at a time can greatly facilitate the weighting process, and will likely produce a more robust set of criteria weights.

The technique described here and implemented in IDRISI is that of pairwise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP).

In the procedure for Multi-Criteria Evaluation using a weighted linear combination outlined above, it is necessary that the weights sum to one. In Saaty's technique, weights of this nature can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved in determining suitability for the stated objective. Ratings are provided on a 9-point continuous scale (Table 3).

Scales	Degree of preferences	Explanation
1	Equally	Two activities contribute equally to the objective.
3	Moderately	Experience and judgment slightly to moderately favour one activity over another.
5	Strongly	Experience and judgment strongly or essentially favour one activity over another.
7	V. strongly	An activity is strongly favoured over another and its dominance is showed in practice.
9	Extremely	The evidence of favouring one activity over another is of the highest degree possible of an affirmation.
2, 4, 6, 8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9.
Reciprocals	Opposites	Used for inverse comparison.

Table 3 : Scale of preference between two parameters in AHP (Saaty, 2000)

In developing the weights, an individual or group compares every possible pairing and enters the ratings into a pairwise comparison matrix (as in Table 22). The procedure then requires that the principal eigenvector of the pairwise comparison matrix be computed to produce a best fit set of weights. A special module named WEIGHT has been developed in IDRISI to calculate the principal eigenvector directly. Note that these weights will sum to one, as is required by the weighted linear combination procedure.

Consistency Ratio (CR)

Since the complete pairwise comparison matrix contains multiple paths by which the relative importance of criteria can be assessed, it is also possible to determine the degree of consistency that has been used in developing the ratings. Saaty (1977) indicates the procedure by which an index of consistency, known as a *consistency ratio*, can be produced. The consistency ratio (CR) indicates the probability that the matrix ratings were randomly generated. Saaty indicates that matrices with CR ratings greater than 0.10 should be re-evaluated. The weighted linear combination (WLC) aggregation method multiplies each standardized factor classes value (i.e., each raster cell within each map) by its factor weight and then sums the results. Since the set of factor weights for an evaluation must sum to one, the resulting suitability map will have the same range of values as the standardized factor classes maps that were used. This result is then multiplied by each of the constraints in turn to “mask out” unsuitable areas.

I.3.2.3 Establishing LSZ classes

Once the landslide probabilities have been calculated for the whole study area, their representation on a map still requests the simplification of the stretched LS values into LS classes and this in order to be more easily readable and thus understandable and useful.

The more common method is to divide the histogram of the probability map into different categories based on **expert opinions** (Guzzetti et al., 1999, Lee and Min, 2001, Dai and Lee, 2002 and Ohlmacher and Davis, 2003). This type of changing continuous data into two or more categories does not take into account the relative position of a case within the probability map and is neither fully automated nor statistically tested.

Several **other methods** are well known:

- **Quantile-based**: each class contains an equal number of features. It is well suited to linearly distributed data and has a disadvantage in that it places widely different values into the same class which can be of non sense especially for susceptibility map.
- **Natural breaks**: classes are based on natural groupings inherent in the data. The group’s boundaries are set where there are relatively big jumps in the data values.
- **Equal intervals** divide the range of data values into equal-sized sub-range. This can largely emphasizes one class relatively to others.
- **Standard deviation**: class breaks are created using mean values and the standard deviations from the mean. It shows how much a data value varies from the mean.

I.3.2.4 Scale of analysis and selection of input data

The requirements for input data for a landslide susceptibility analysis are scale dependent. According to Aleotti et al., (1996) the scale of analysis to be adopted has to be chosen on the basis of the purpose of the assessment and its usefulness, the extent of the studied area and the data availability. For example, large areas susceptibility assessment may be based on the analysis and interpretation of available data, while for smaller areas the assessment of stability could be facilitated by specific geotechnical investigations.

Generally three scales of analysis are distinguished: a regional scale (<1:100 000), a medium scale (1:50,000 to 1:25,000) and a large scale (> 1: 10,000) (Van Westen, 1993). Mantovani et al. (1996) summarize the feasibility and usefulness of applying remote techniques for landslide hazard zonation in three working scales as shown in Table 4.

Type of landslide hazard analysis	Main characteristics	Regional scale	Medium scale	Large scale
Distribution analysis (landslide inventory approach)	Direct mapping of mass movement features resulting in a map that gives information only for those sites where landslides have occurred in the past.	2–3	3–3	3–3
Qualitative analysis (heuristic approach)	Direct or semi-direct methods in which the geomorphologic map is re-classed to a hazard map, or in which several maps are combined into one using subjective decision rules based expert-knowledge.	3–3	3–2	3–1
Statistical approach (stochastic approach)	Indirect methods in which statistical analysis are used to obtain predictions of mass movement from a number of parameter maps.	1–1	3–3	3–2
Deterministic approach (process-based)	Indirect methods in which parameter are combined in slope stability calculations.	1–1	1–2	2–3
Landslide frequency analysis	Indirect methods in which earthquakes and/or rainfall records or hydrological models are used for correlation with known landslide dates to obtain threshold values with a certain frequency.	2–2	3–3	3–2

Table 4 : Summary of the feasibility and usefulness of applying remote techniques for landslide hazard zonation in three working scales (Mantovani et al., 1996)

The first number indicates the **feasibility** of obtaining the information using remote sensing techniques (1=low: it would take too much time and money to gather sufficient information in relation to the expected output; 2=moderate: a considerable investment would be needed, which only moderately justifies the output; 3=good: the necessary input data can be gathered with a reasonable investment related to the expected output).

The second number indicates the **usefulness** (1=of no use: the method doe not result in very useful maps at the particular scale; 2=of limited use: other techniques would be better; 3=useful).

I.3.2.5 Limitations

Whatsoever the LSZ method used sources of error and uncertainty are numerous. It's good to keep them in mind in order to know the limitations of the modelling and thus not to expect more than what the LSZ map produced could actually give. These errors or uncertainties could come from multiple sources (Lulsegedet al., 2005; Aleotti P. et al., 1999):

- The **complexity of the landslide processes** due to the interaction of numerous factors makes difficult the analysis of the cause and effect relationships. Moreover, the triggering of landslides is usually determined by factors such as rainfall, earthquake… which are difficult to forecast in intensity, duration, time and space.
- The limitations and assumptions inherent to the method used, the degree of **subjectivity** depending upon the experience and personal judgement of the researcher for factors weighting or photo-interpretation for example, and the adequacy of the data and method regarding the scale of the analyze and the type of landslides modelled.
- The **data** availability and gathering possibilities, quality and relevance
- **Errors** that could occur in the numerous steps of modeling (data entry, digitization, manipulation within GIS…)

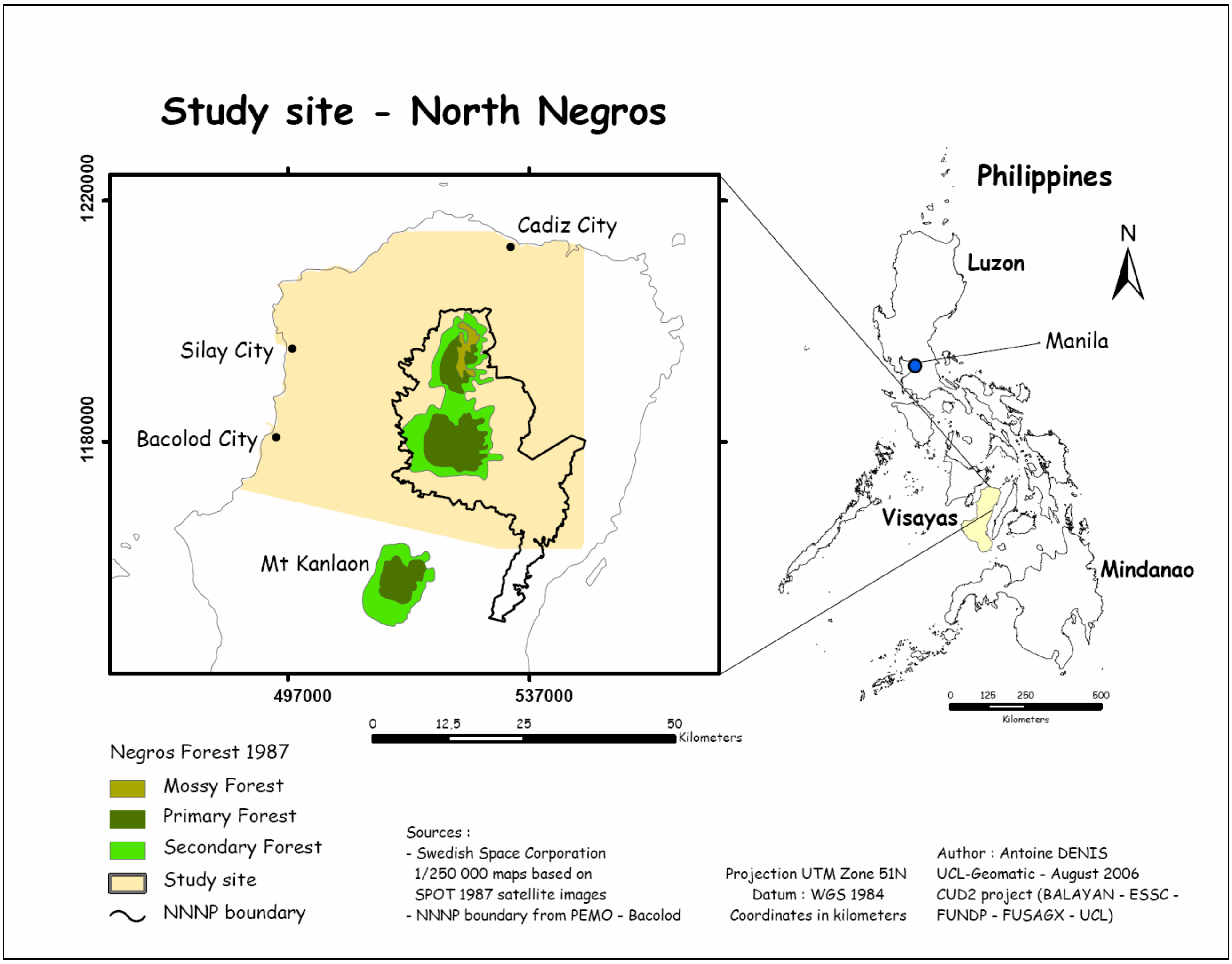
Chapter II: Study site

II.1 Location

The study site is located in North Negros (Map 2). It is totally included in Negros Occidental Province, one of the six provinces that compose the "Western Visayas" (Region VI), lying in the central part of the Philippine Archipelago. Negros occidental has a total land area of 792 607 hectares bounded by the Visayan Sea on the north, by the Guimaras Strait and Panay Gulf on the west, Tanon Strait and Negros Oriental province on the east and Sulu Sea on the south.

The Northern Negros Natural Park (NNNP) is located in the central mountainous part of the study site.

Bacolod City, a highly urbanized independent city, is the provincial capital lying on the west coast.



Map 2: Location of the study site: North Negros

II.2 Climate in Negros Occidental

North Negros' has no pronounced seasonality but is relatively dry from November to April and wet during the rest of the year (climate of Type III).

Mean temperature for the province ranges approximately from a minimum of 22 °C in January and February to a maximum of 37 °C in April with an average of 27 °C (Figure 2). However temperature is nearly constant throughout the year and main differences are due to elevation.

The mean annual rainfall lies around 2000 mm in low land while the mountainous forest receives up to 4500 mm rain. The northeast monsoon prevails during the dry season, while the southeast monsoon dominates during the rainy season.

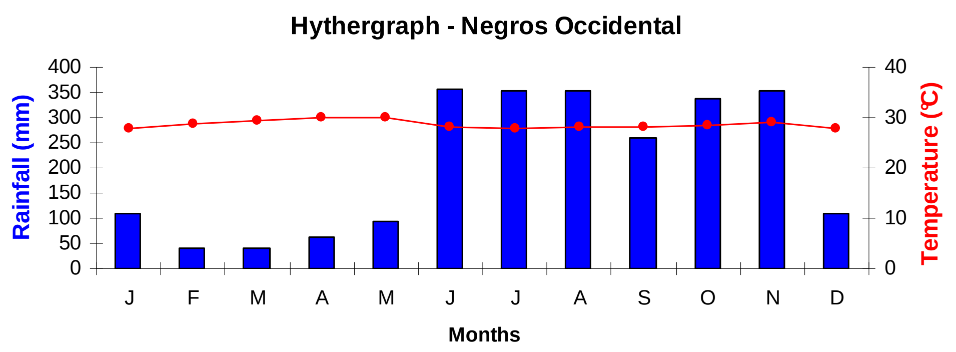


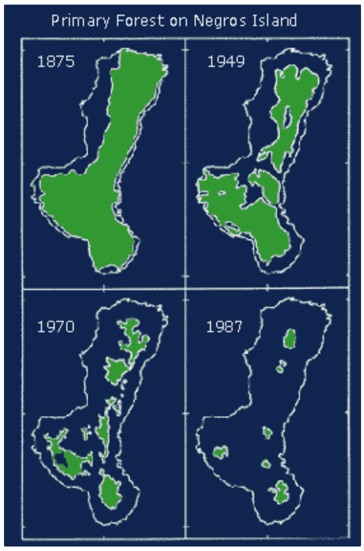
Figure 2: Hythergraph of Negros Occidental.

An average of 20 typhoons, among which 30% are destructive, hit the Philippines each year. Typhoons are born in the North-western Pacific Ocean and move in the north western direction. Their paths coincide quite often with the Visayas, including Negros, where the frequency of typhoon ranges between 0.5 to more than 2 times/year (World Bank, 2005).

The heavy rainfall from typhoons, depression or local storm, associated with earthquakes, trigger landslides from mountain and hill slopes weakened by human activity.

II.3 Diminishing forest of Negros Island

(Adapted from Heaney, L. R. et al.,1998)



Map 3: Diminishing forest of Negros Island from 1875 to 1987 (Redrawn from Heaney 1986, 1998 in)

Prior the arrival of the Spaniard in the 16th Century, 95 percent of Negros Island was covered with rain forest, harbouring one of the highest densities of unique species anywhere on the earth. In 1700 the old growth cover was still of 90 percent. Arrival of large-scale export-based plantation agriculture, especially sugar cane with the boom in sugar prices in the 1850s, made it declined to about 73 percent in 1900.

The 20th Century saw the Negros forest diminishing dramatically to less than 4 percent today.

Short time after its installation in 1898, the American colonial government granted concessions to logging companies, encouraging them to cut new roads into the interior forests of Negros, opening the land to logging and then to a steady stream of workers leaving the plantations to find farmland of their own. Plantation agriculture was further expanded and intensified as the colonial government sought ways to generate foreign currency from exported raw materials and unprocessed foodstuffs. Lumber companies operating on Negros cut the remaining prime lowland forest. At the end of World War II, 60 percent of the forest still remains.

After World War II, when the Philippines became independent, logging increased at a greater rate under combined foreign and Filipino ownership. Taxes on logging that might have paid for reforestation among other things were kept very low, so that few benefits flowed to the local inhabitants. During the 20-year administration of Ferdinand Marcos, logging concessions were given to his supporters and allies; 25-year concessions for up to 100,000 hectares often were sold for a fee of one peso per hectare (about ten cents per acre). Ultimately, under this arrangement, the poor and the middle class subsidized the rich by bearing the costs of floods, droughts, erosion, siltation. Corruption came to be a large factor in logging; many logging companies were owned by politicians who sought to maximize their own profits by keeping taxes unreasonably low (and actual payments lower still), while ignoring the needs of the people in the regions they represented.

Map 4 : Negros Forest in 1992 (Redrawn from a figure by Clara Simpson)

Moreover, during the 1950s and 1960s, the American subsidies to the sugar industry made possible the expansion of sugar-cane fields onto hillsides. Forest cover reached 8 percent when the last remnants of the old-growth rain forest below 850 meters (3,000 feet) were cleared by the mid-1970s. An ever-increasing numbers of workers left the plantations in search of land to farm on the slopes of the mountains.

In 1983, the desperate state of the forest was officially recognized with the imposition of the logging ban. Unfortunately degradation continues until now.

Today, this forest exists as tiny patches of mountain and mossy rain forest near the tops of the mountains; old-growth lowland forest exists only as a few thin ribbons between the mountain forest and the cleared lowlands.

II.4 Land use

(Adapted from Heaney, L. R. et al., 1998)

Coastal area of Negros is heavily populated either by the main cities or the numerous small fisherfolk communities. In the nineties, the building of ponds, bound to raise prawns for exportation to Japan, destroyed majority of the last mangrove swamps. Today, fishponds and mangrove (photo 5) contribute to 2% of the surface of Negros occidental.

Inland from the coast, lie the fertile lowlands of weathered volcanic soil that are mainly occupied with large sugar cane fields (photo 7) in the middle of which the sugar cane factories produce 47 percent of the total sugar production of the country.

Part of the 67 percent of Negros Occidental agricultural land which is not sugar cane is composed of rice fields (photo 9), coconut plantations and other diverse crops of which majority can be planted at any time of the year. Fighting coq farm is also one of the major land uses affecting the landscape (photo 6).

Although the traditional method of farming is shifting cultivation, increased land use pressure due to increasing population density, has caused farmers to shorten or eliminate fallow practices as well as to increase the percentage of steep lands under cultivation (photo 12 and 13).

On the slopes of the mountains that have soil too poor for sugar cane or too isolated for coconut plantations, population often live on the cultivation of small fields of diverse crops and Integrated Social Forestry (fruit trees).

In higher elevation, the second-growth forest left by logging operations in the 1970s and 1980s is endangered by slash-and-burn clearings (photo 10), associated with kaingin (charcoal making) (photo 4).

Land cover and land use

Photo 5: Mangrove forest

Photo 6: Fighting cock farm in elevation (Patag)

Photo 7:
Sugarcane fields at different vegetative phases (foreground)
Hilly grassland (background)

Photo 8: Mango tree plantation
(Aerial photo – ESSC)

Photo 9: Irrigated rice fields
(Aerial photo – ESSC)

Agricultural practices and landscape

Photo 10: Slash and burn agriculture

Photo 11: Heterogeneous agricultural landscape (Aerial photo – ESSC)

Photo 12: Agriculture in hilly areas

Photo 13: Tiger grass cultivation on steep slope

Photo 14: Burning sugarcane field (Aerial photo – ESSC)

II.5. Northern Negros Natural Park (NNNP) (Adapted from IPAP-NNNP)

The Northern Negros Natural Park (NNNP), previously called Northern Negros Forest Reserve (NNFR) is considered the largest remaining evergreen forest in Negros Island and one of the largest in the Central Philippines (photo 15). The NNNP has an aggregate area of 80 454,50 hectares. It is also the largest watershed of Negros Occidental being the main source of water for 13 municipalities and cities. Moreover, NNNP is a wildlife sanctuary where rare, endemic and endangered species of flora and fauna exist.

II.5.1 General topography and physiography

The NNFR is part of the north-trending volcanic belt along with Mount Silay, Mount Mandalagan, Mount Kanlaon and Mount Talinis in the southern part of Negros Island. As part of a stratovolcanic chain, it is underlain by typical volcanic materials.

The topography of NNFR is generally sloping and ranges from moderately rolling to very steep. Slope gradient is from 8% to 50% and more, with most area being 18% slope and above. Two mountain peaks are present within this forest reserve. Mount Silay on the north with a highest point at 1510 meters Above Sea Level (ASL) and Mt. Mandalagan on the south with various peaks of up to 1885 meters ASL. The valley between these two peaks declines to about 400 meters but is characterized by rough often steep terrain.

Four Major river Systems emanate from the NNFR which supports the household and agricultural needs of the northern part of Negros Occidental. These are the Malogo river, Imbang river, Himuga-an river and Bago river.

II.5.2 Vegetative Cover

NNNP was originally covered with thick tropical rainforest. Forest cover is now limited on the two volcanic mountains ranges and is composed mainly of Dipterocarp forest, which ranges from residual to old growth of both non-commercial and commercial values. Patches of undisturbed mossy forest are still present on higher elevation (photo 19). Brush land, cultivated and open areas dominate the landscape along the forest boundary (photo 17). Land cover types in NNNP with corresponding surface (ha) and percentage are shown in Table 5.

Land cover	Area in NNNP (hectares)	Area in NNNP (%)
Old growth forest	3376,5	4,2
Mossy forest	5706,5	7,1
Residual forest	18090	22,5
Reproduction brush (also a secondary growth)	23564	29,3
Open/cultivated areas	29717,5	36,9
Total	80454,5	100

Tableau 5: Land cover types in NNNP with corresponding surface (ha) and percentage (Sources: IPAP-NNNP).

Forest in Negros

Photo 15: View on NNNP Mountain Range from low lands

Photo 16: Old growth forest (Kuyong forest)

Photo 17: Open cultivated forest (foreground)
Residual primary forest (background)

Photo 18: Mountain forest

Photo 19: Mossy forest on steep ridge in high elevation

All the remaining old growth forest (photo 16) of NNFR are now limited to the upper elevation between 1100 and 1880 meters of Mt. Silay and Mt. Mandalagan. The largest portion of these forests was located on Mt. Mandalagan. Patches of second growth, clearings and cogonal (high grass) areas are located on the steep sides of the valley. Communities located on Patag separate the forest into two major fragments. Most of the lowland areas are secondary growth and agricultural areas. Generally, there is no more lowland primary forest existing in NNFR (RBI).

Several dipterocarp species are present within the NNNP, such as Mahogani, Apitong, Red and White Laua-an (Parashorea melaanoan and other Shorea), Tangile (Shorea polysperma), Almon (Shorea almon), and Bagtikan. Hamann (1998), identified the five most important trees families in a transition zone between lowland and lower mountain forest, as being Dipterocarpaceae, Lauraceae, Sapotaceae, Burseraceae and Melastomaceae.
.

II.5.3 Land Use

About 48% of the entire NNNP is occupied among which 0.6 % is residential while 47.4 % is agricultural area. Majority of the 8,814 households are composed of the farmers/ farm-workers (Census of NNFR Occupants, 2003)

II.5.4 Threats

There are numerous threats to the ecological integrity and biodiversity of NNFR. The presence of large settlements and the rural development which attract immigration inside the reserve exerts pressures on the resources of NNFR. Unsustainable and destructive livelihood activities have endangered several endemic fauna and flora and had caused the extinction of others. Large tracts of forestlands have been converted into agricultural use that adopts inappropriate technologies that are dependent on pesticides and chemicals.

Other threats and issues that have impact on the reserve are

- The lack of ancestral domain and tenure rights of Indigenous Peoples and tenured migrants, titled lands, and peace and order problems.
- Lack of Environmental Awareness among stakeholders
- Continuous illegal activities within the reserve such as logging activities, hunting, poaching and gathering of other forest products

The recent proclamation of old NNFR as NNNP should contribute to resolve some of these problems. Indeed, the mission of NNNP as a Natural Park will be to "promote sustainable development through empowerment of communities in the establishment of effective measures in the protection and conservation of natural resources in NNNP (among which a zoning with strict protection zone for 21 000 ha of Old growth, secondary growth and mossy forest) and the provision of other productive endeavour towards the enhancement of their socio-economic well being."

This will be helped by the strong support of the Provincial Government, the willingness of LGUs to participate in the program and the strong support of NGOs and NGAs.

However, a major constraint is the lack of financial support.

Chapter III: Objectives

From the two first chapters it appears that deforestation continues to be a threat on the last remaining forest of North Negros. The fact that these forests are located in mountainous part and that, due to a very high land pressure, people always creep higher to cultivate the always steeper slope of these mountains, increase the landslide susceptibility associated with this deforestation.

As an answer to that situation, this research aims **two main objectives** (Figure 3).

The first objective is to produce a **land cover map** for the North Negros, focusing on the NNNP. Forest type differentiation will be attempt, resulting in an estimation of the remaining forest cover for the study site. Extraction of the land cover information from the SPOT 5 satellite image is realized with both the use of conventional spectral characteristic of the image and the use of the elevation and the distance to river as classifiers.

In parallel and in order to evaluate the feasibility of integrating the environmental knowledge of local environmentalist into a GIS data base through field survey and 3D-GIS in remote laboratory, 3D-GIS participatory experience was attempt in Negros.

Moreover, as this land cover is one of the most crucial input data for the LSZ, its classes have to be relevant for its further integration in the landslide model. This is especially true for the forest since the modelling of the deforestation will be realized on the base of the forest classes.

The second objective is thus to produce a **LSZ model** which enables to express the change of landslide susceptibility due to deforestation.

The different steps followed to achieve this purpose are:

- To find relevant data relative to landslide-controlling factor
- To transform them to be compatible with GIS environment which will serve for the LSZ modelling
- To express and integrate them in a pertinent way for LSZ

In order to visualize the spatial change of LS due to deforestation, two scenarios corresponding to stable state and deforestation, will be model.

Moreover, in order to check the sensitivity of the LSZ model, comparison of the resulting LSZ maps realized with the use of, on one hand the whole nine selected landslide-controlling factors and on the other hand the four main ones, will be realized for the deforestation scenario.

Finally, in order to give an idea of the reliability of the results, the LSZ maps will be compared with a landslide inventory realized during the field survey will be made.

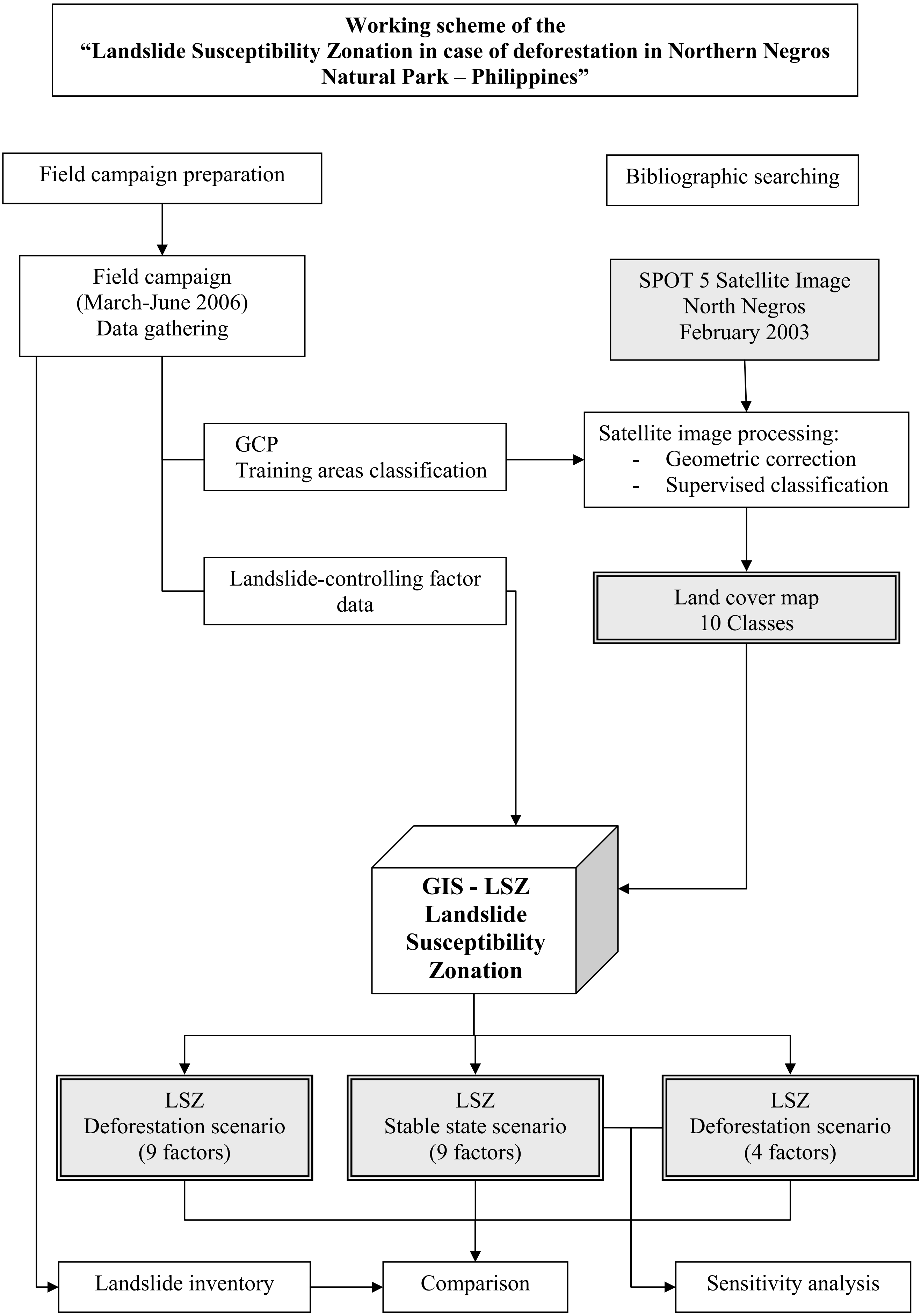


Figure 3: Working scheme of the "Landslide Susceptibility Zonation in case of deforestation in Northern Negros Natural Park – Philippines".

Chapter IV : Data description

IV.0 Introduction

The data description is split in two parts.

The first part presents what could be called the **raw data** available and corresponds mainly to satellite image, thematic maps and auxiliary data.

The second part will focus on the data produced during the **field survey**. The methodology used to get them and the potential difficulties met during their acquisition are gotten into.

Some of these data and their main characteristics are summarized in table 7.

Software's used for this work are finally briefly gotten into.

Data processing will be get into in further chapters relative to their utilization.

Numerous data coming from a wide variety of sources have been used for the realization of this work. Standardization was necessary. All the data used or produced are set in the following coordinate system:

Projected Coordinate System: WGS 1984 UTM Zone 51N
Datum: D_WGS_1984

This choice was made because some original data and GPS points were taken in this coordinate system. Data that were in Datum Luzon 1911 were transformed into WGS 1984 UTM Zone 51N, by Luzon_1911_To_WGS_1984_1 datum transformation.

IV.1 Raw data

IV.1.1 Satellite images

A SPOT 5 satellite image is used as the base for the land cover map production. SPOT satellite will be shortly described before to get into the satellite image itself.

The SPOT satellite Earth Observation System was designed by the CNES (Centre National d'Etude Spatial), the French Space Agency, and developed with the participation of Sweden and Belgium.The system has been operational since 1986 when SPOT 1 was launched. SPOT 5 was launched in May 2002.

SPOT 5 satellite images

A SPOT satellite image is a view of the Earth seen through one of the satellite's high-resolution imaging instruments. The technical characteristics of each instrument determine the spatial resolution and spectral mode of the image.

SPOT images differ by pixel size (5 m, 10 m) and spectral acquisition mode: panchromatic (black and white) and multi spectral (colour and infra red). They have an imaging swatch of 60km * 60 km to 80 km according to the viewing angle.

The two images available for this work are SPOT 5 images. Their main characteristics are summarized in the Table 6.

<table>
<tr><th>Image characteristics</th><th colspan="3">Spot 5 Multispectral (XS)</th><th colspan="3">Spot 5 Panchromatic</th></tr>
<tr><td>**Date – Time**</td><td colspan="3">2003-02-27 – 02:38:27.0</td><td colspan="3">2003-02-27 – 02:38:24.0</td></tr>
<tr><td>**Pre-processing level**</td><td colspan="3">2A</td><td colspan="3">2A</td></tr>
<tr><td>**Incidence angle (°)**</td><td colspan="3">L25.025256</td><td colspan="3">L25.030890</td></tr>
<tr><td>**Orientation angle (°)**</td><td colspan="3">13.053148</td><td colspan="3">13.501571</td></tr>
<tr><td>**Sun angles (°)**</td><td colspan="3">Azimut: 133.007121
Elevation: 61.749059</td><td colspan="3">Azimut: 132.824966
Elevation: 61.803621</td></tr>
<tr><td>**Scene center location**</td><td colspan="3">Latitude N10° 48' 29 »
Longitude E123° 8' 44 »</td><td colspan="3">Latitude N10° 42' 5 »
Longitude E123° 7' 10 »</td></tr>
<tr><td>**Image size (km)**</td><td colspan="3">60 * 60</td><td colspan="3">*</td></tr>
<tr><td>**Ground pixel size (m)**</td><td colspan="3">10 (20 for SWIR then resampled)</td><td colspan="3">5</td></tr>
<tr><td>**Number of spectral bands**</td><td colspan="3">4</td><td colspan="3">1</td></tr>
<tr><td rowspan="5">**Spectral band indicator, wavelengths and spectral name**</td><td>Indicator</td><td>Wavelenght (µm)</td><td>Name</td><td>Indicator</td><td>Wavelenght (µm)</td><td>Name</td></tr>
<tr><td>B1</td><td>0.50 – 0.59</td><td>Green</td><td>PAN</td><td>0.48 – 0.71</td><td>B&W</td></tr>
<tr><td>B2</td><td>0.61 – 0.68</td><td>Red</td><td colspan="3" rowspan="3"></td></tr>
<tr><td>B3</td><td>0.78 – 0.89</td><td>NIR</td></tr>
<tr><td>B4</td><td>1.58 – 1.75</td><td>SWIR</td></tr>
</table>

Table 6: SPOT 5 satellite image and sensors characteristics

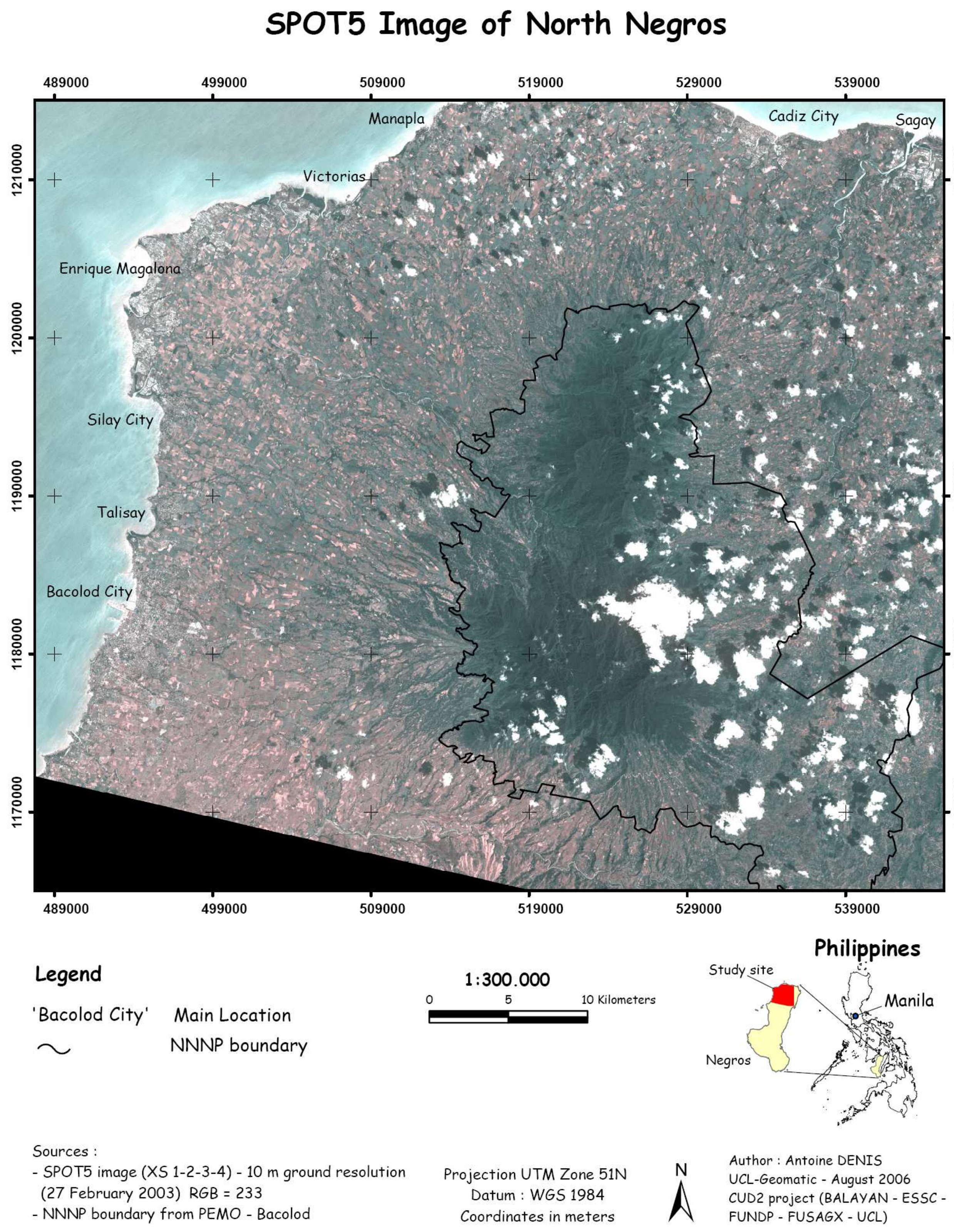


Figure 4 : SPOT 5 image of North Negros

Date and time

The two images are quite old since they were taken in 2003 and as a consequence, some land cover changes may occurred in this time interval. However they were taken in February which corresponds to the beginning month of the field survey. The land cover is thus in the same vegetation state. Nevertheless, this has only very little importance since the vegetation look is really similar the whole year long at this latitude (N 10 °).

The two images were taken with a time-lag of 3 seconds and thus with different but similar orientation angles. Indeed even if angles are not the same due to the very high speed of SPOT satellite turning around the earth, the very long distance earth-satellite makes this time interval negligible. The two images can thus be viewed as having the same angle which allows to merge (pansharp) them without having to correct them before since they match each other (See also Preprocessing level 2A).

Pre-processing level 2A

Level 2A scenes are geometrically rectified, without using Ground Control Points (GCP). For SPOT 5, a global DEM with a post spacing of one kilometre is used. This geometric correction is not really accurate since one mean elevation value per square kilometre only is used. The re-sampling model compensates for systematic distortions effects due to photography condition and performs transformations needed to project the image in a standard map projection (UTM WGS 84). This model is based on known viewing parameters (satellite ephemeris data and altitude, etc.) and does not use external measurements.

Level 2A include also **radiometric correction** of distortions due to differences in sensitivity of the elementary detectors of the viewing instrument.

The location accuracy for 2A level, for a scene with a constant elevation and on flat terrain, is better than 30 m (1σ) for both Spot 5 (PAN and XS). Location accuracy calculations are not valid for parallax errors due to relief.

Captor angles

Incidence angle is the angle formed by the normal (perpendicular line) to the earth at the point of incidence and the captor wave on the earth. This angle is of 25° for both scenes. The orientation angle is the angle between the satellite trajectory and the captor wave to the earth. This angle is of 13°. These two angles correspond to a quite strong oblique viewing of the earth for a satellite image.

Sun angles

The azimuth angle corresponds to the cardinal direction. 133 ° is the equivalent of South East. The sun elevation angle for a terrestrial point is the angles between the skyline in the direction of the sun and the sun's rays in the point. It is of 61 ° in this case.

This image displays prominently the rivers. This is due to the fact that the captor incidence angle (25 °) is nearly equal to the sun incidence angle (90° - 61° = 29 °). The incident sun's rays arrive on the rivers with an angle of 29°, are reflected on these rivers with more or less the same angle which corresponds to the 25 ° of the captor incidence angle. As a consequence, the captors receive a lot of reflected sun rays which explains why the rivers appear so clearly on the SPOT image.

However, both captor and sun incidence angles ads up to the locally very steep topography in mountainous part of the scene, affects strongly the image quality and this in two ways. On one hand the important oblique angle of captor contributes to hide or decrease in size all the slopes and particularly the steep ones that do not face the captor. On the other hand the sun incidence angle creates overexposed and overshadowed areas according to the aspect of mountain slopes. This is translated in very heterogeneous vegetation reflectance, especially for the forested mountains and will be at the origin of further difficulties for spectral land cover differentiation and identification.

Image resolution

Regarding the **spatial resolution**, the image pixel size is 10 m and 5 m for the XS and the Pan image respectively. In term of visual interpretation this enables the distinction of the major part of the land cover features. However, it doesn't enable a detailed interpretation such as the forest type differentiation for example. Note that the original SWIR band spatial resolution is 20 m which is then re-sampled in 10 m.

Regarding the **spectral resolution**, the XS has 4 bands and the PAN1 band. The XS Red, Near Infra Red (NIR) and Short Wave Infra Red (SWIR) band and their combination are well known as the best ones for vegetation identification, whereas the green one is less useful. The PAN band corresponds approximately to green and red XS bands.

The **radiometric correction** or imaging dynamic is on 8 bit.

Brief description of XS scene

The scenes corresponds to North Negros Island, more or less from Bago (South – not visible) to Cadiz (North) and from West coast to East coast. However, part of the extreme North coast and East coast are missing. The image covers partly NNNP only. The southern part, which has been completely deforested, is not visible.

A fast **landscape** analyse identifies three parts. The sea at West and North, the forested mountains in the central par where the NNNP is located t and the low agricultural lands in between.

Some **clouds** and their shadow are presents in East part of the image mostly. This decreases the image quality and corresponds to No data area. However there is only little in comparison with other satellite image of tropical places which often present more important cloud cover.

Presentation of the PAN image is less interesting since no additional features could be described. Moreover, the study site is limited to the extent of the XS image. Anyway the PAN image will not be used.

IV.1.2 Topographic data

The topographic maps available for this work come from the Pilipino National Mapping and Resource Information Authority (NAMRIA), the central mapping agency of the government of the Philippines. Theses maps which were made in collaboration with the American army dates from the fifties. They were produced at scale 1/ 50 000 and the topographic curves represent a difference in altitude of 20 m at least. Projection is transverse mercator projection and the *horizontal* datum is Luzon Datum.

These maps are thus old and several changes might have occurred. For example, new roads have appeared, villages and cities spread and riverbeds could have slightly moved.

River network was digitized by ESSC from these maps and will be used for both land cover map and LSZ model production.

IV.1.3 Elevation data

Particularity of this work is coming from the fact that 2 different sources of elevation data have been used: **SRTM** 1 and a **Digital Elevation Model** (DEM) derived from the NAMRIA topographic map digitized 20 m contours. Elevation data are used for both land cover map and landslide model production.

Description of the 2 sources of elevation data

SRTM

SRTM is coming from the Shuttle Radar Topography Mission (SRTM) that collected interferometric radar data (2000 NASA/NGA) which has been used by the Jet Propulsion Laboratory (JPL) to generate a near-global topography (elevation) data product for latitudes smaller than 60°.

The SRTM has a resolution of 3 arcs second which is equal to a 90 m by 90 m cell size raster resolution. It was originally produced in World Geographic System 1984 (GCS WGS 1984) with datum WGS 1984. Given that the SRTM data comes from interferometric radar the elevation measured is the one of the top of the land cover, which corresponds to the canopy in the case of a dense enough forest for example.

The SRTM used for this study is the SRTM 1, SRTM 2 which is an improved version presenting still some inaccuracies at the time it was necessary for this work. SRTM1 was not originally processed to eliminate data voids and errors with flat water surfaces and coastlines.

These “voids” or “sinks” have to be eliminated or “filled up with data”. A **filtering** of the SRTM has thus been made to remove this surface noise. The method employed uses Delaunay triangulation to fill the bad pixels with triangles calculated from the surrounding good elevation values. The output of this process has values ranging from -33 m to 2423 m Above Sea Level (ASL). This result is considered as satisfactory, given that the negatives elevations cells are only met in the sea where both negatives and positives values are found with an average around 0 m, and that the highest SRTM value (2423 m) corresponds to the highest point of Negros: the top of Mount Kanlaon Volcano culminating at 2435 m elevation. The 12 m elevation difference between the SRTM and the top of the volcano is acceptable since the SRTM is 90 m cell size resolution and consequently smooth the elevation, giving one mean elevation value per 8100 square meters surface.

DEM derived from digitization of NAMRIA topographic map 20 m contours

Contours with 20 m difference in altitude have been manually digitized from above mentioned NAMRIA topographic maps by the Provincial Environment Management Office (PEMO) of Negros Occidental. These contours were only available for the NNNP perimeter.

IV.1.4 Thematic maps of Negros Occidental

The following data are all related to factors influencing landslide. They have been digitized from maps found in Negros Occidental. These maps are mostly old (1953 – Seventies) and no information was available about their accuracy or the way their were produced. Moreover, legend is not documented at all, and sometimes some interesting legend information is not transferred on the drawing itself. However basic information needed for the landslide model could be extracted.

Geology map

- The Geology map date from 1994 and is at 1/250 000 scale.
- Legend presents 13 classes that can be group in igneous (intrusive/extrusive) and sedimentary rocks, most of NNFR being covered with Quaternary volcanic rocks.
- The Negros Island on the geology map was quiet strongly deformed. The island on this map seemed to be elongated.

Soil map

- Soil map date from 1974 and is at scale 1/200 000.
- Legend presents 34 soil classes that can be summarize in different combinations of loam (gravelly, fine or silt), sand and clay, and hydrosol.

Erosion map

- Erosion map date is unknown (later than 1975) and scale is 1/250 000.
- Legend presents 4 erosion classes split up into no-, slight-, moderate- or severe-erosion and are characterized with the importance of sheet or rill erosion, and presence of gullies.

Others maps seemed to present some interesting information related to landslide but several limitations were found such as inconsistence between legend symbol and limits of area they refer to, banning their utilization. Moreover, some were not really understandable by themselves.

IV.1.5 Auxiliary data

Auxiliary data are data that were not directly used but that brought some complementary information for the elaboration of this work.

- **Land cover map of Negros Occidentale** at scale 1/300 000 probably from 2003 or later coming from DENR
- **Forest cover of NNNP,** shapefile presenting 5 forests cover for NNNP only, from DENR
- **Forest cover** from SPOT survey realized by the Swedish Space Corporation in 1987.
- Other **satellites images** of higher spatial resolution were used as a help for visual interpretation of the SPOT 5 image. These are:
  - Ikonos image covering the Silay area, in high resolution jpeg format. This image covers a range of different landscape from sea to forest up lands.
  - DigitalGlobe image of Talisay area, in high resolution jpeg format. This image covers the town of Talisay and its agricultural surroundings only.

Data	Scale / Resolution	Date	Source and remark	Purpose*
SPOT 5 XS image	10 m	Feb 2003	SPOT Image	LC / LSZ
SPOT 5 PAN image	5 m	Feb 2003	SPOT Image	LC / LSZ
Ikonos image	<5 m	recent	Silay City Hall, jpeg format	LC
Digital Globe image	< 5 m	recent	Talisay City Hall, jpeg format	LC
Aerial photography's	Varying	2006	ESSC	LC
Topographic maps	1/50 000	1950'	NAMRIA	LC / LSZ
River network	1/50 000	1950'	NAMRIA topographic maps (from ESSC)	LC / LSZ
Elevation SRTM	90 m	2000	SRTM 1	LC / LSZ
Digitized topographic curves of NNNP	1/50 000 20 m elevation	1950'	PEMO (from NAMRIA topographic maps)	LSZ
Geology map	1/250 000	1994	Mines and Geosciences Dev't Service DENR VI – Iloilo City	LSZ
Soil map	1/200 000	1974	Department of Agriculture-Bureau of Soils-Soil Survey Division-Region VI	LSZ
Erosion map	1/250 000	Later than 1975	Ministry of Agriculture – Bureau of Soils – Manila	LSZ
Land cover map of Negros Occ.	1/300 000	Later than 2003	DENR – Forest Management Bureau – Quezon City	LC
Forest cover for NNNP	?	recent	DENR (shapefile)	LC
Forest cover of Negros	1/250 000	1987	Swedish Space Corporation (shapefile)	LC
Landslide inventory in North Negros	/	2006	Field survey	LSZ

Table 7: List of available data for the LSZ in North Negros
*LC = Land Cover; LSZ = Landslide Susceptibility Zonation

IV.2 Field Data

The field survey that occurred between February and May 2006 had the purpose to collect a maximum of pertinent information that could help in the realization of both the Land cover map and the landslide model.

IV.2.1 Field survey preparation

As a preparation for the field survey and in the purpose to optimize limited time spent in Negros several operations were undertaken before departure.

IV.2.1.1 Visual analysis of the image and selection of area of interest

A thorough analyze of the image was made in the multi-purposes to

- locate areas of interest for the classification,
- get familiarized with the land cover of the study site
- locate potential GCP location
- make a visually interpreted landslide inventory

Moreover, the wide extent of the study site (60 km * 60 km) required to make a selection of the potential area of study. Potential itinerary was even realized in collaboration with local partners.

Attempts for SPOT5 non-supervised classification were made to get an idea of the classification possibilities. However since the software used before departure was ERDAS Imagine 8.3.1. and that the one used for the final classification was the far better eCognition Professional 4.0. This operation has been useless.

The SPOT5 image was printed in numerous 1 / 25 000 scale maps and this in order to:

- easily locate the above mentioned area of interest selected before departure
- make "live matching" of the satellite image and the field reality during field surveys,
- be able to locate oneself in the study site,

The selected SPOT bands that were printed are a fusion of the panchromatic band and XS bands. The PAN band brings a better spatial resolution quality whereas the XS ones bring better spectral resolution. A deep analyze of the different possible bands combination came to the conclusion that the one that best fit the field survey goals is: RGB=321.

IV.2.1.2 Realization of field sheets

In order to catch easily and exhaustively selected pertinent information during the field survey, preparation of field sheets seemed to be a real need before departure. Three types of field sheet were realized:

- **Land cover sheet**, which is split in three parts : area references (coordinates,…), area description (land cover and site) and finally general comments and scheme

- **Landslide sheet,** which is split in: area references, area description (land cover and site), historical context of landslide, landslide description and finally landslide schemes.
- **GCP sheet**, which mainly consist of a zoom on the SPOT image that makes appears the pre identified potential GCP-pixel of interest in order to be able to match it accurately with field environment during field survey

All these sheets are available in Annex.

IV.2.1.3. Pre classification legend

A pre classification legend is realized on the basis of literature information. This classification is hierarchical using several levels of vegetation description, going from rough definition (level 1) for example “tree land”, to more detailed one (last level) for example “Mossy forest”. This enables to adjust the level of land cover description during the field observation. Moreover if the final field classification level is too detailed for the classification process itself, detailed classes can be grouped in the higher level. This pre classification legend is presented in Annex.

IV.2.1.4 Other operations

In order to take into account field constrains, other operations were undertaken. These are for example, understanding the local context in order to be aware of transportation possibilities, material availability, and safety of places to explore due to activity of armed rebels groups…

IV.2.2. Field Survey – Data gathering

IV.2.2. 1 Purpose and georeferenciation

The purpose of the field survey was to collect data that would enable the previously presented objectives of this work. They mainly consist in:

- Location of **training area for classification** of the SPOT 5 image. This is the identification of previously selected or not area that will be used as samples for the definition of the features used for the classification.

- **Landslide inventory**. Being related with other GIS data, it will serve either for calibration of factors influencing landslide or for validation of the landslide model.

- **GCP** collection that request in essence the best location accuracy. These GCP will be used for the geometric correction of the SPOT 5 image (georeferenciation and potential orthorectification)

The **georeferenciation** of data gathered was made possible by using the Global Positioning System (GPS). Two GPS with different accuracy were used:

- **Trimble GeoXM**, which allowed accuracy around 2 m in XYZ. This GPS being very costly and less handiness and due to potential risk to smash it up or it to be stolen, it was only used in very strict conditions which limited its utilization to highway mainly. As a result 25 Trimble GCP were collected on the nearly whole perimeter of the image but not at a variety of elevation since the highest Trimble point locates around 200 meters only. However this seems not to be a problem since very few places such as large crossroads that allows accurate location and thus request that kind of GPS could be found at higher elevation.

- **Garmin eTrex Summit,** of which accuracy in best conditions during the field survey didn't get below 7 m in XY. Z values seemed to be inconsistent and were thus not used. Points collected with the garmin reached mainly two purposes. Some were taken for georeferenciation of area which were not possible to cover with the Trimble. Forest mountain crest and summit for example. Others were taken to locate area of interest for classification. Moreover, several tracks corresponding to visible roads on the satellite image were collected in order to potentially help the georeferenciation of the image.

No differential correction, which could have enhanced the accuracy of the collected GPS data has been made since no base station was available.

IV.2.2.2 Participatory 3D GIS

Given that on one hand, exploration of the forest mountains are made really difficult by the absence of tracks and the tropical steep mountainous forest conditions and that on the other hand some areas are judged not safe due to the presence of armed rebel groups, an experience to evaluate the feasibility to extract land cover information from remote 3D GIS laboratory was carried out with the participation of people knowing very well the environment to study. A "participatory 3D GIS experience" was thus tried out in Negros. This experience sets in two steps, one in the field, and the other in the GIS laboratory. Both steps are realized thanks the active participation of a Bantay Bukid (mountain guide) who knows really well the environment to study and who is already familiarized with the notion of forest classification. More than testing the feasibility to extract land cover information from remote 3D GIS laboratory, the purpose of this activity was also to integrate the knowledge of the Bantay Bukid about forest into a GIS environment and thus to produce information that will serve the land cover map production. The two steps of this experience are explained below.

In a first step landscapes analyse of the selected area is realized. This is done in the field. Two types of areas are analyzed.

First type are areas which were not directly reachable but which were visible in the landscape from already reached points in the mountains and that were close enough to visually interpret the forest type they were covered with. The mountain guide described the land cover. As he is already familiarized with classification system and vocabulary, the equivalence between the local dialect terms and the ones used in the pre classification legend presented above is easy to do. However very few local dialect terms were used since the mountain guide translates nearly automatically words in English. The location of the areas described in this way was made in taking GPS points of the place where from the description was made and taking the direction of the described site with the GPS compass. If possible direction was taken from two distant points in order to find the described area corresponding to the crossing of these two directions. An estimation of the distance of this site is made to help to find the described site in the further laboratory work. Paper drawing is also really helpful and can be easily and rapidly done. Another way to proceed was to use the 2D and 3D printed satellite image and to live match the landscape with the images. Using 3D image was particularly interesting since the second step of this experience consisted in 3D analyse but on computer this time. Landscape pictures were also taken for documentation.

Second type of areas are areas which were either visible but too far to be visually described with enough accuracy, or areas which were not visible but which could be described by the Bantay Bukid with good certitude thanks to his knowledge of the area. This was for example the hidden side of a mountain. These areas were thus just described and located at best. As no personal judgement could be done for these "invisible" areas the equivalence between the "raw description" of the Bantay Bukid and the classification legend established for the first type of area is transposed for this second type.

Degree of certitude/incertitude of the Bantai Bukid concerning his description was noted for both types of areas.

Moreover, since the Bantai Bukid is the key man of this experience, it is really important he gets a deep understanding of it. And this to avoid rough or non appropriate information coming from approximation he could do thinking it has non importance at all. Each step of this experience is thus thoroughly explained notably using a drawing which is presented in Annex XX.

3D GIS-laboratory

This second step takes place in the GIS laboratory and can be summarized as a 3D visual interpretation of the SPOT 5 satellite image by the mountain guide.

The 3D visual interpretation was made with the software ArcScene which doesn't enable the storage of the information that was gathered thanks to this activity. In order to solve this problem, an editing session in ArcMap on the same image but in 2D this time was previously prepared. A point shapefile was created with a field "Class" for the land cover and another field "Accuracy" to state the degree of certitude (or incertitude) of the Bantay Bukid for the analyzed point. Numerous points corresponding to areas identified in the field were created in order to easily locate the area of interest on the satellite image. Theses points were also displayed in ArcScene on the 3D image to easily establish the correspondence between 2D and 3D. The elevation model that gives birth to the third dimension of the SPOT 5 image must translate in a very good way the landscape features in order for the Bantay Bukid to be able to easily recognize them. The SRTM seemed to be not good enough. That's why the DEM finally used for this activity was coming from the digitized topographic curves of NAMRIA maps (20 m difference in altitude) which give a better visual appearance to the 3D. This way, mountains were easily identifiable and could be named individually as it was previously done in the field.

The data collected during the field survey (drawings, pictures, description…) were also used during the activity and this in the purpose to match the field survey (step one) and the 3D GIS laboratory activity (step two).

During the 3D activity itself the Bantay Bukid was asked to recognize on the 3D image the areas identified during the field activity. He was then asked to describe the land cover again for both areas that could be visually interpreted (type 1) and area that could not (type 2). For each 3D point interpreted degree of certitude/incertitude of the Bantay Bukid was noted. The information he produced this way was finally incorporated into the table of attribute of the previously created point shapefile. The 3D visual interpretation and the 2D editing session were thus undertaken simultaneously.

This 3D activity did not really produce new information in comparison to the ones produced in the field since the same areas are analyzed. The only difference is the way they are produced, one in live nature, the other in the remote GIS laboratory. However, a comparison can be made between the results obtained with these two methods. The field activity serves as the reference since the description of the Bantay Bukid could not be better than the one made in the middle of the landscape to analyze, and thus can be used as validation of the 3D GIS laboratory one. In other words, comparing results of two methodologies to produce the same data, one being the reference (field) enables to validate the other or the method to test (laboratory).

Comparison of the results was thus realized. It appears that the information given by the Bantay Bukid in both situations (field and laboratory) were mostly consistent. It seemed thus that the remote laboratory 3D analyse was a reliable way to produce information. On the base of this conclusion, further attempts were made to try to get information about areas that were not taken into account at all during the field survey. This means that an analyze of new areas was made, using 3D image only (pure 3D). The results of this activity were not successful at all. Indeed either high incertitude or no sufficient knowledge concerning the new areas banned the utilization of pure 3D methodology to analyze these new areas.

Conclusion

The purpose of this activity was thus, farther than creating new information for land cover classification, to evaluate the feasibility to extract land cover information from remote 3D GIS laboratory with the participation of a Bantay Bukid who knows really well the site to study. This seemed to be possible since the results obtained by both method (field and laboratory) were consistent. However, attempts to generalize this pure 3D to other areas revealed to be unsuccessful since these new areas were not well known as no field investigation was realized for them particularly.

Only few points were produced this way.

Further improvement

Here is some improvement that could enhance the quality of the results of a 3D GIS activity:

- Working with several people rather than one in order to confront their land cover analyses and to build greater certitude about the final land cover described.
- Using a laptop directly in the field

IV.2.2. 3 Pictures

Pictures that were taken in Negros constitute full-fledged data since they are an important help for the classification and that are used for documentation. Two types of pictures were taken: aerial photography and "Ground" pictures.

Aerial photography

A plane photography campaign has been undertaken by ESSC. I had the chance to be involved for the flight. The purpose of this flight was to generate as much as possible aerial pictures of the study site to help the classification of the SPOT 5 satellite image. The plane used allowed 4 persons on board only, composed of the pilot and three scientists. High resolution digital cameras were used. One vertically through a hole in the floor of the plane (front seat) and the two others (back seats) for oblique shots through lateral windows. A GPS being connected to a laptop with GIS programs was on board and enables to give indications to the pilot to follow the previously realized itinerary. Moreover, camera's clocks were synced with the on board GPS which recorded the tracks of the plane. This was made in the purpose to further make hyperlinks between pictures taken during the flight and GPS points in a GIS environment.

Due to atmospheric conditions the flight over the mountainous part of the study site was strongly limited. Only flight in the perimeter of the mountains was made.

"Ground" pictures

Ground pictures were taken during the whole field survey. Hyperlinks were realized in GIS environment for some of these pictures in the same purpose than aerial photography.

IV.2.2. 4 Field constrains

Several field constrains were encountered and thus limited the data gathering. These are:

- Absence of forest tracks and tropical steep mountainous forest conditions make tough their exploration
- The political context of Negros requests that several operations have to be undertaken before to be allowed to go and study a specific site (courtesy letter, courtesy visit,… for different political level)
- Some areas were judged not safe due to the presence of armed rebel groups and thus their exploration was banned or request additional negotiations
- …

IV.3. Software

Four software's were mainly used:

- OrthoEngine 9.1., Geomatica, PCI Geomatics
- eCognition Professional 4.0, Definiens imaging
- ArcGIS 9.1. ESRI
- IDRISI32 I32.21 Release two

OrthoEngine was used for the geometric correction of the SPOT 5 satellite images

eCognition was used for the classification of the SPOT 5 XS image for the production of the land cover map

Diverse extensions of **ArcGIS** were used, mainly for the realization of the landslide model but also in several other purposes:

- **ArcMap** was used for several operation such as data visualization, general data handling, map digitization, manual georeferenciation, and maps layout,
- **ArcInfo** enabled some data conversion
- **Spatial Analyst** was mainly used to combine raster (raster calculator), reclassify and convert them.
- **3D Analyst** was used to handle transformation on elevation data (TIN, interpolation of elevation…)
- **ArcScene** was mainly used for 3D visualization, especially during the "participatory 3D GIS activity".

Chapter V: Land cover map production

V.1 Preprocessing of the SPOT 5 Image: geometric correction

As it was presented previously in the chapter describing data, the SPOT 5 images have already been preprocessing into level SPOT-2A.

V.1.1 Necessity of Geometric correction

Despite the preprocessing of the image, some quite important inaccuracies were brought to light thanks to a thorough analyze of the images in comparison with others data such as GPS points collected during the field survey and digitized river network. A spatial interval between the image and the other data is identified for mid and high elevation. This interval is due to the image itself since GPS points and SRTM fit perfectly together and fit with the image for low elevation but not for high elevation.

GPS points coming either from Garmin GPS for uplands (inside of mountains included) or Garmin and Trimble one's for lowlands were thus used to try to establish the location accuracy of the raw image SPOT5 2A preprocessing level. This has been evaluated for four different elevations with the help of selected representative GPS points. The points used in low lands correspond to road tracks and crossroads while the ones used in up lands correspond to narrow crests of mountain, summit or other easy localizable natural or human features. These results are presented in the first column of the Table 8. The other columns correspond to results of further explained transformations of the image. Measures are rounded up since the purpose here is just to illustrate the image spatial location inaccuracy.

Elevation	SPOT 2A preprocessing level	Rational Math Model 17 GCP Trimble	Rational Math Model 17 GCP Trimble and 13 Garmin	Manual Geometric correction
10 m	20 m	5 m	5 m	5 m
200 m	40 m	12 m	10 m	8 m
850 m	90 m	65 m	40 m	10 m
1150 m	215 m	180 m	90 m	70 m

Table 8: Location accuracy related with different elevations of SPOT 5 XS image for 2A processing level and others geometric corrections

It is clearly visible in the results that the location accuracy strongly depends on the elevation. Higher is the elevation, bigger are the inaccuracies. The points located in low land, near sea level, present a nearly accurate location with 5 to 20 meter inaccuracy whereas the points of high elevation, in the mountain part, present location inaccuracy up to 200 meters and more.

This observation fully justifies the real need for improvement of the location accuracy. (Moreover a perfect fitting of image with other georeferenced data is essential for further operation such as correction of topographic effect on light and shadow). That's what will be tried in the next subsection with geometric correction.

V.1.2 Attempts for orthorectification

The first geometric correction tried is an orthorectification which is the process of using a rigorous math model and a Digital Elevation Model (DEM) to correct distortions in raw images. Orthorectified images are geometrically corrected and georeferenced imagery. A math model is a mathematical relationship used to correlate the pixels of an image to correct locations on the ground accounting for known distortions (PCI Geomatica).

Different math models exist according to the kind of input imagery to work with.

The Satellite Orbital Model, suitable for SPOT image for example, has not been used for this orthorectification because we were using only a portion of the original image (half a scene) and that the image had already been geometrically processed (preprocessing level 2A of the SPOT 5 Images). Anyway OrtoEngine supports level 1A SPOT 5 Dimap format only and not 2A.

After several attempts it seems that orthorectification of a 2A image is impossible with Ortho Engine. Another software (ENVI) requested RPC files that were not available either. Moreover the SPOT image having already been roughly orthorectified, orthorectifying it again is not theoretically correct.

V.1.3 Georeferenciation

As orthorectification was not possible, a simpler geometric correction is realized. It consists in a georeferenciation which is the process of using Ground Control Points (GCP) to calculate a simple math model that will warp the raw image to fit the ground coordinates.

The math model used for this georeferenciation is the Rational Functions Math Model.
The Rational Functions Math Model is a simple math model that builds a correlation between the pixels and their ground locations. This model is indeed indicated when we are missing the information for a rigorous math model (orthorectification), when the image has been geometrically processed (level 2A), when we don't have the whole image (part of scene), […]
This math model can be accurate since it considers elevation. However, it can require many GCP. This math model uses four polynomials functions of three ground coordinates: latitude, longitude, elevation. Three coefficients have been used for the math model, which corresponds to the minimum coefficient number. More than three coefficients gave very big distortions of the image, especially in mountain. The resampling method used is the Nearest Neighbor Interpolation which identifies the gray level of the pixel closest to the specified input coordinates and assigns that value to the output coordinates.

V.1.4 Ground Control Points (GCP)

A GCP is a feature that can be clearly identified in the raw image and for which the ground coordinate is known.

Concerning the number of GCP requested for georeferenciation, collecting over 20 GCPs per image does not significantly improve the accuracy for math models. Accuracy is improved when collecting GCP evenly throughout the image at a variety of elevations. The quality of the GCP impacts the number needed to ensure accuracy. In the case of Rational Functions, the minimum GCP requested is 5 per image but 19 is recommended (PCI Geomatica).

GCP collected during the field survey, as detailed in…., were used for this georeferenciation. 25 Trimble GCP with 2 m accuracy (X-Y) were available but only 17 or 16 points were used depending on the image to be processed. Indeed some points being really too close from each other are judged useless. The GCP used are mainly located at low elevation on the main coastal road ranging from 10 to 60 meters only. 3 GCP only are higher up to 200 meters elevation.

Elevation was extracted from the SRTM. Difference of elevation between GPS field elevation measures and SRTM is set as incertitude.

Number of points and Root Mean Square (RMS) error corresponding to the first attempt of georeferenciation using the Rational Functions Math Model are presented in the Table 9.

SPOT 5 image	**RMS**		Number of GCP
	meter	pixel	
XS	6.29	0.63	17 Trimble
PAN	4.93	0.99	16 Trimble
Pansharp	3.92	0.78	16 Trimble

Table 9: RMS error for the first attempt of the georeferenciation of the SPOT 5 images using Rational Functions Math Model

The **RMS,** are the difference between the coordinates entered for the GCP and where those points are according to the computed math model. RMS do not necessarily reflect errors in the GCP, but rather the overall quality of the math model. They may indicate bad points, but, generally, they simply indicate how well the computed math model fits the ground control system. In most projects, the RMS would be one pixel or less. The accuracy of GCP, the image resolution… will affect the RMS (PCI Geomatica).

Regarding these results the image georefenrencing (X, Y) seems to be really good (RMS smaller than pixel size and, good number and accuracy of GCP). However, this is only valuable for the perimeter of the image, in low elevation where the GCP have been used. Indeed, having a look in Table 8 shows that the image location accuracy remains really bad for mountain part.

V.1.5 Other georeferenciation

As no satisfying results were obtained in up lands with these 17 Trimble GCP, attempts were made using **Garmin** points located in the mountain. These points were really less accurate since Garmin accuracy is about 8 m in best condition and that natural features such as mountain crest can be less accurately identified than a crossroad for example. However, since the spatial interval between the image and the real mountain location is very important these points seem to be useful to reduce this interval. Up to 13 supplementary Garmin points are thus used at mid and high elevation. Results of this attempt were presented above in the table. No satisfying result was made since, even if the spatial interval is a bit reduced, the RMS error increase to 36 meters when mountain points were used.

Finally, a **manual georeferenciation** using the georeferenced image with 17 GCP Trimble is realized. The image is corrected (X Y displacement) with the help of GPS points and tracks but also with elevation models (SRTM and topographic curves based DEM) since it is easy to match mountain crest, or riverbed of the image with the elevation model where these features appears clearly. This requested a fastidious work since numerous points were needed. This methodology works with a lot of local distortions corresponding to the numerous points used, rather than a global one calculated on the base of few points only as it was the case previously. As a consequence the remaining spatial inaccuracies are not all oriented the same way. The results are a bit better in term of spatial interval but not in term of RMS.

V.1.6 Image Pan sharpening

As described previously the two XS and PAN SPOT image fit each other perfectly. However in the purpose of having both images in a same file and to be able to display different bands combinations more easily, a layer stack was realized.

V.1.7 Conclusion

- No orthorectification seems to be possible for the image used.
- The georeferenciation is half successful only since spatial interval remains between “truth nature” and the image for the mountain part.
- It would have been better to work with a raw SPOT image with no preprocessing to be able to use a Satellite Orbital Model for orthorectification.
- Improvement could be tried with the use of GCP scattered evenly throughout the image at a variety of elevations but it seems that the major problem is coming from the SPOT 5 image preprocessing level 2 A itself which is not suitable for further geometric correction and that revealed to be really not accurate enough for mountain part.

The image that will further be used for the land cover map production is the one which was manually georeferenced. This one is chosen because it is the one that best fit the real mountain location.

V.2 Visual interpretation of the land cover of 2 selected sites of the SPOT 5 image

As an introduction to the land cover classification and the Land cover map realization, a visual interpretation of the land cover of 2 selected sites of the SPOT 5 image (Figure 5) is proposed. In the same time the reader will acquaint himself with the land cover classes further used.

The two sites were selected for their representativeness of the 10 final classes that appear in the Land cover map, covering both low lands and up lands. These 10 classes are both the results of limitations due to technical constrains encountered in the classification process itself for the distinction of the different land cover types and in the same time, the results of the selection of the elements that seems to be the most characteristic (typical) of the landscape in the study site and thus the most interesting to represent on a land cover map. Moreover, this selection is a need in the sense that it is not possible to represent too many different land cover types on the map without taking the risk to make it less or un-readable because of information overload. The further needs in terms of land cover for the landslide model were not a constraint at all since the simple distinction between forest and non forest is sufficient for the model.

The first selected site corresponds to a detail of the North Negros Coast located at the West side of the town of Victorias.

One of the few remaining **Mangrove** of the study site is clearly visible in dark green along the coast. **Fishponds**, appearing in white blue and characterized by rectangular shape constitute another major characteristics of this image and are encompassed between the **Sea** in dark blue in the Northern part of the image and the **Agricultural land,** mainly sugar cane, appearing in green and brown rectangles in the southern part. One of the major **river** of North Negros in the middle of the image flows into the sea. The town of Victorias located on the East side constitutes the main **Built up** area of this image.

This image sample, as many others could do, also illustrates the intensive land use of the lowlands, especially for sugar cane agriculture and fish culture. Moreover a land under development, looking like a white skeleton in the mid-south part of the image, is also one of the typical built up feature of the study site and translates the non-stop conversion of land for housing.

The second selected site corresponds to an entry in NNNP near Campuestohan village at the mountain feet. Barangay Patag is also visible at the extreme North East part of the image.

The transition between Agricultural land and forest is clearly visible in the middle of the image and corresponds more or less to the boundary of NNNP. However some penetrations of cultivated fields inside the NNNP occur in the mid-North part of the image. The cultivated fields seem to be stopped by the relief of the beginning mountain rather than by the NNNP boundary. Several **Riverain forest** embedded in local depressions of the rivers that once gave them birth structures the landscape by alternation with strips of agricultural fields located on the flat areas as soon as the relief permits it in the North-western part of the image. These two examples perfectly illustrate the strong land pressure and the risk for the forest associated with it presented previously. Some **Cultivated tree lands** appears in the South-west part corresponding to Eucalyptus plantation. The south-western part is characterized by the domination of **Open areas** appearing in smooth green-brown mainly corresponding to "fighting coq farm" or grasslands where fighting cocks are raised. Small white squares in the middles of these areas correspond to small bamboo house with or without corrugated roof. Some others open areas are also visible at the feet of the mountains in the center of the image.

The two types of forest of elevation are represented. **Forest from 600 m to 1100 m** is encompassed between the lower agricultural land and the higher **Mountain forest**. No visual distinction can be made between these two types. However the topographic effect on light can be detected. Indeed, the East facing slope appears lighter and smoother than the west facing slopes appearing darker and textured. Finally, some rare small **clouds** are present in the south-east part of the image.

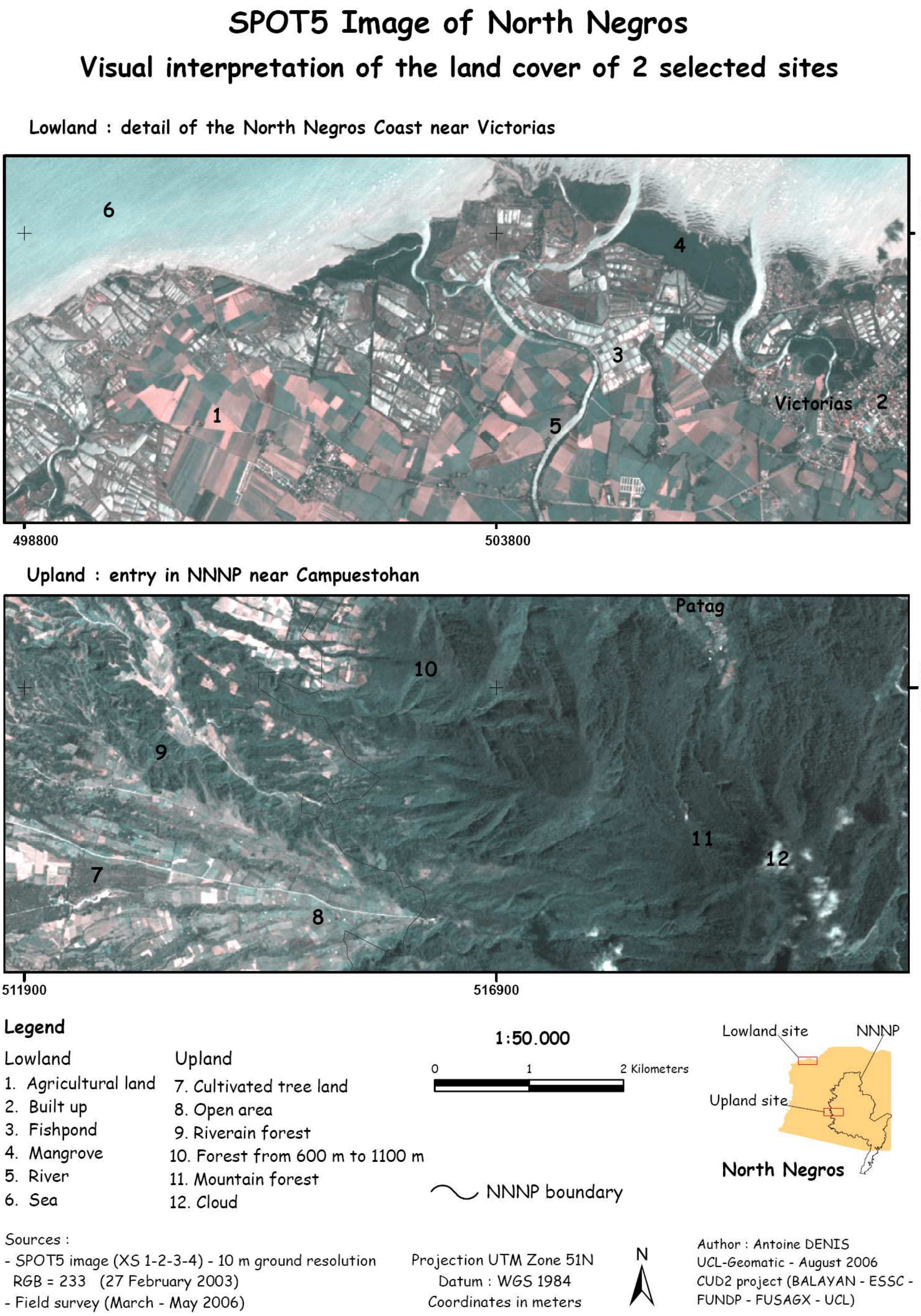


Figure 5 : Visual interpretation of the land cover of 2 selected sites in the SPOT 5 image

Working scheme of the production of the Land cover map

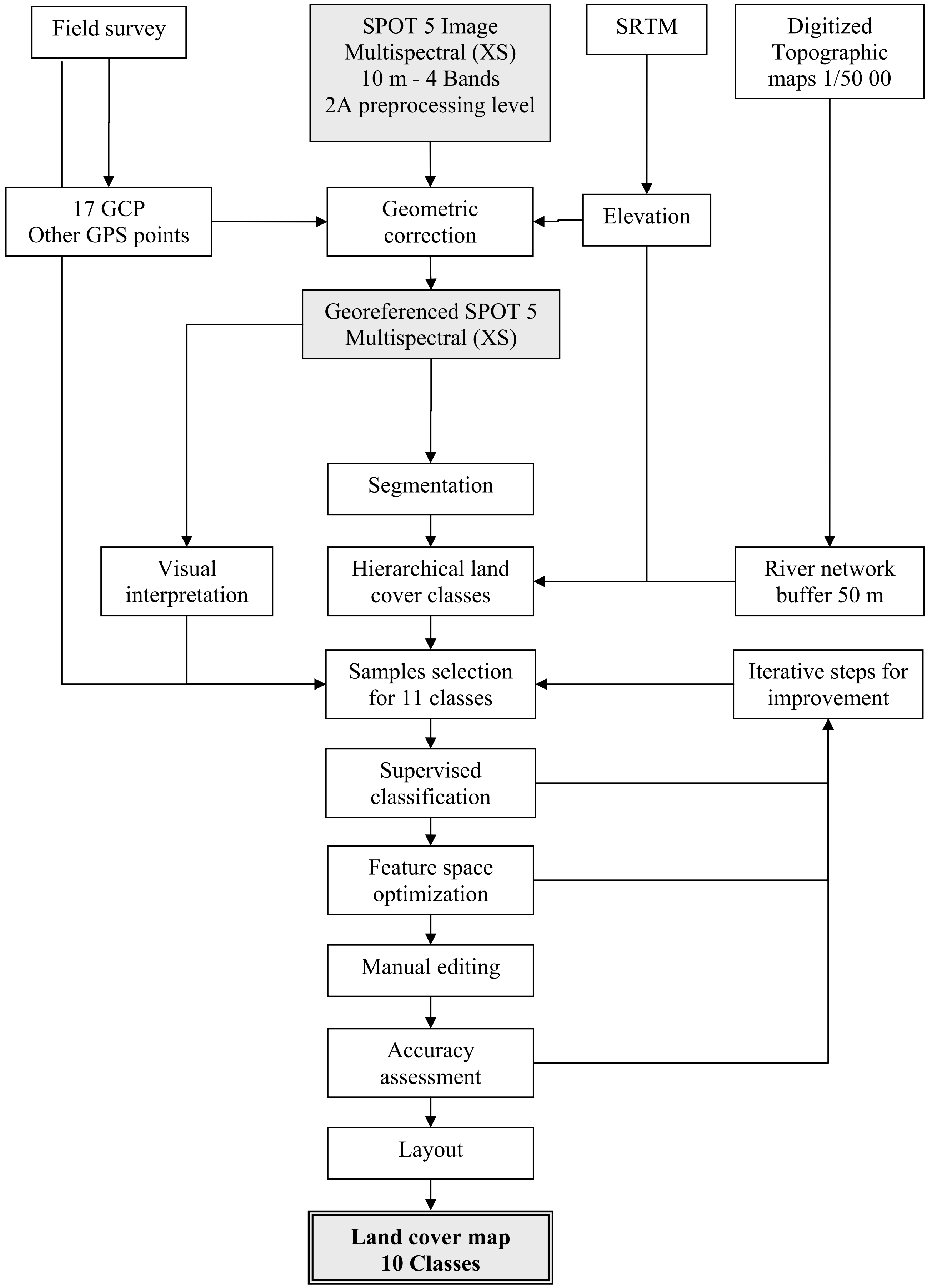


Figure 6: Working scheme of the production of the Land cover map from SPOT 5 image

V.3 Processes of the classification of the SPOT 5 image for Land cover map production.

The method used for the realization of the Land cover map is a **supervised digital classification** using the SPOT 5 satellite image as main input. In this case, optimized characteristics of selected and well known land cover samples will be use as reference for the definition of the land cover classes. Then an extrapolation based on these samples will be realized to the rest of the image through the classification process itself. Finally, the validation of the results is achieved with the help of a confusion matrix giving the proportion of the pixels that are well classified.

The workflow followed is explained below and summarized in a working scheme in Figure 6.

As previously presented, the **software** used for the classification is eCognition Professional 4.0. This software presents the particularity to work with an object oriented approach. Indeed, eCognition does not classify single pixel but rather image objects which are extracted in a previous image object-segmentation step. Moreover eCognition enables to use a hierarchical class's organization and the possibility to work with a large set of features derived from the image)

The eCognition workflow used for this classification is based on an iterative process. However, to be clearer, all the processing steps used for the classification are described here in a single flow without iteration.

V.3.1 Input of the classification

Three inputs are used for the classification.

- SPOT 5 Image multispectral (XS 1-2-3-4)
- SRTM 1 (elevation)
- River buffer

The PAN image has not been used for the reason that, after analyze of its different features, it seemed that it would not bring helpful information regarding the classification.

V.3.2 Segmentation

The segmentation is the creation of the object that will be used for the classification. It is based on the SPOT5 image only.

Some important characteristics of the segmentation are explained below.

- **Scale parameter** determines the heterogeneity and thus the size of the object to be created. After several attempts, it seems that a size of 15 is the more appropriate, being not too big not too small and corresponding to the size of object that best fit the classification purpose.
- **Homogeneity criterion** allows choosing the relative importance to give to Color (spectral heterogeneity) and Shape (spatial heterogeneity) (their sum being 1) in the creation of the object to be used for the classification. A weight of 0.9 is given to color because color is the most important for the differentiation of the Land cover and especially vegetation while shape is not of great help for this purpose since natural features, especially the forest for example, don't present

strong shape characteristics. However value of 0.1 is given to Shape because a certain degree of shape homogeneity often improves the quality of object extraction and that the land cover, even if mainly natural, presents some geometric features (roads, rivers, cultivated fiels,…).

- **Weight of layers**: All the layers were given the same weight of 1.
- One **image object level** is created only. That means that object resulting from a single segmentation scale will be used corresponding to one object size only.

V.3.3 Hierarchical classes

A hierarchical class's organization is used for the classification (figure). Hierarchical means that the classes that will appear in the final classification are child classes of their parents classes from whom they inherit the features description – the object's characteristics used for the classification.

Further explanation is given in the point relating to Elevation (below).

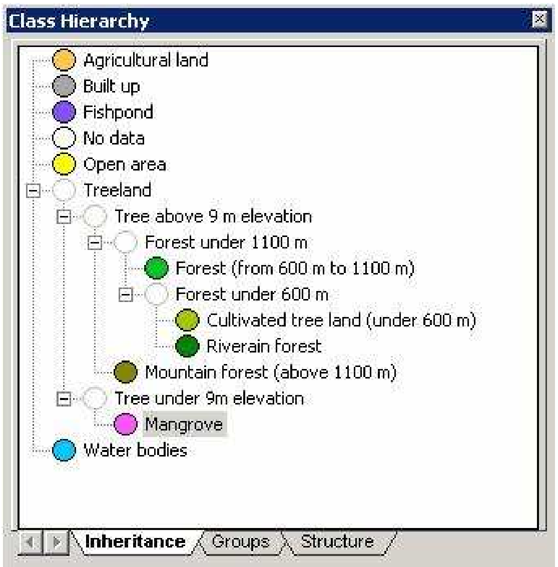


Figure 7: Hierarchical structure of the classes used for the final classification

V.3.4 The Nearest Neighbor Method (NNM)

The main characteristic of the Nearest Neighbor is that it generates automatically multidimensional membership functions (defining the membership of object to a class) based on samples objects rather than one dimensional one. This facilitates class description and classification.

Moreover NNM better suits the following situations this classification has to cope with:

- few samples were available for the forest types differentiation
- it seems that class's could not be separated from each other with only one or a few features

Since the distribution of a class does not need to be continuous when using a nearest neighbor classifier, all the different heterogeneous appearances of agriculture land for example (bare, burned, vegetated,…) were summarize in one class only ("Agricultural land"). This remains valid for others class's.

V.3.5 Samples selection

A few typical "object-samples" corresponding to all the classes to extract were then chosen. These samples were chosen on the base of field data collected during the field survey (see p.) and visual interpretation of the image for easily interpretable areas.

V.3.6 First attempts of forest type's differentiation

A first attempt for forest type's differentiation on the base of their spectral reflectance characteristics only has been tried. The related forest classes were: Mossy – Pine forest, Old growth forest, Regenerating forest, Brush and shrub and Cultivated tree land. This was made for forest that are located in the mountain, at high or low elevation and thus without necessarily being what we will call later "Mountain forest". Each of these classes was split in a "sun-exposed" and a "shadow-exposed" class to try to decrease the important topographic light effect (see data description…). This duplicated the number of samples used.

As no visual interpretation of the SPOT 5 enables identification of different forest types for the forest involved here, samples selection for forest is based on field data collected during the field survey only and this to ensure their reliability.

An additional encountered difficulty for forest classification is that most of the time, no clear limit exists between two types of forest that would suit the classification system. There is rather a gradual transition between two types with a "Transition regenerating forest" between "Regenerating forest" and "Old growth forest" for example. The samples used for this first attempts were thus chosen only for very identifiable forest type and not transition ones.

Attempts giving really no result, this differentiation was abandoned.

Moreover the number of samples necessary for further attempts would be too important (training and test areas for both "sun-exposed" and "shadow-exposed" forest) and were not available.

No topographic correction was tried for the reason that the SPOT image doesn't fit perfectly with the elevation model. This correction being based on the elevation model, this operation would have given wrong results and created noise rather than to facilitate classification. Method base on Normalized Difference Vegetation Index to suppress shadow effect was not tried either.

V.3.7 Use of elevation

As previous attempts for forest types differentiation based on diverse spectral characteristics of vegetation were not successful, this differentiation is made with the help of elevation data.

Checking of the above mentioned spatial interval between DEM and rectified image seems to be small enough to allow this operation and this especially because the DEM is used in this case to define general altitude limits and not aspect of mountain slopes that strongly depends on the location of each individual mountain crest even inside the mountain massif while the general elevation limit is defined for the perimeter of this massif only and thus do not requests such an accuracy. However, this spatial interval is unmistakably source of inaccuracy for the classification.

Once the forests have been identified on the base on spectral characteristics, the elevation is imported in eCognition and then used as input for the definition of the classes in their hierarchical feature space (hierarchical characteristics used for the establishment of the hierarchical legend).

Classes of elevation and forest type it gives birth to are the following:

- **Higher than 1100 m**
  This range corresponds to the class "Mountain forest". The limit of 1100 m is based on both information coming from literature and field observation where Mossy forest begins around 1000 – 1200 m and 1200 m respectively
- **Between 600 m and 1100 m**
  This elevation class corresponds to a variety of forest type. However the limit of 600 m was chosen because it seems to correspond to a real limit between natural forest and cultivated ones (orchards ...).
- **Between 9 m and 600 m**
  This range of elevation corresponds to two types of forest: "Riverain forest" and "Cultivated tree land under 600 m". Visual interpretation of the SPOT5 image in relation with the study of elevation and field knowledge shows that most of the Riverain forest (see also next subsection on River buffer) doesn't climb higher than this limit. Higher, there is no more reason to differentiate potentially Riverain forests (close to river) from the two classes explained above. Field survey allows saying that tree lands under 600 m elevation that are not Riverain forest are always cultivated tree lands.
- **Below 9 m**
  This elevation limit defined the class "Mangrove forest".
  Mangrove being easily identifiable on the satellite image, their visual interpretation accompanied with a check of the elevation it corresponds to gives this limit. The other forests are clearly of higher elevation, even if "Riverain forest" or forest near the coast.
  At first blush it could be thought that this limit should be of 0 m (sea level) but it is not because the elevation source is coming from SRTM and thus express the elevation of the top of the land cover (Mangrove in this case) and logically do not corresponds to 0 m but 0 m + the height of Mangrove trees.

More information on these classes will be presented in subsection "V.4. Legend of the classification"

V.3.8 Use of river buffer

The Riverain forest being one of the main characteristic of the landscape on the study site, it seemed to be very interesting to extract it through the classification process. This being not possible on the base of spectral characteristics only, the use of the river network revealed to be really helpful in the building of this class.

A river buffer of 50 m both sides of the river (100 m total) was created in ArcGIS, using the river network presented previously (see point….) and then imported in eCognition. Concretely, object previously identified as forest object ranging from 9 m to 600 m elevation and partially or totally included in this buffer were assigned to the Riverain forest class.

V.3.9 Iteration

The results of the first classification involving elevation and river buffer present still a large number of objects that have been classified incorrectly, especially for the low- and mid- lands. This is corrected in iterative steps by assigning typically wrongly classified image objects as sample to right class.

V.3.10 Definition of an optimal feature space

In the purpose to find a well suited feature combination to separate the classes in conjunction with the nearest neighbor classifier, the eCognition feature space optimization is used.

On the bases of all Mean, Ratio, Standard deviation (StdD), Minimum (Min) and Maximum (Max) pixel value for the 4 XS SPOT bands and the Mean value for elevation and River buffer, the final optimal feature space is composed of 10 features: XS1 (StdD, Ratio, Min and Max), XS2 (StdD, Max pixel), XS3 (/), XS4 (ratio and StdD), SRTM and River network. The SPOT band XS-1 (NIR) seemed to be the one that contains the more useful information for the general classification since 4 on the5 features proposed were selected. Elevation and River buffer were of course selected since they are the based for forest differentiation and are the second and fourth most important features respectively, the first one being ratio of XS-1, whereas XS-3 (Green) seems to be useless.

The feature space newly defined is now applied to the standard nearest neighbor classifier.

V.3.11 Iteration

As classification results can still be improved after classification with the optimized features space, several iteration are made with the same procedure than the previous ones.

V.3.12 Manual editing

Manual editing was finally used to correct the results of the classification and to bring it into a final form. This method was especially used for the classes “Built up” and “Fishponds”. Indeed, the classification process identified small “green areas” such as urban parks or trees included in City as “Forest” or “Agricultural land” for example. These objects were erased from the main class they were included into in the purpose to present a clearer final Land cover map

V.3.13 Accuracy Assessment

The process of declaring new samples and classifying was stopped when the accuracy assessment of the classification gave significant results. This assessment is realized among other with the help of a confusion matrix.

Analyze of this confusion matrix is realized further in subsection V.6.

V.3.14 Layout

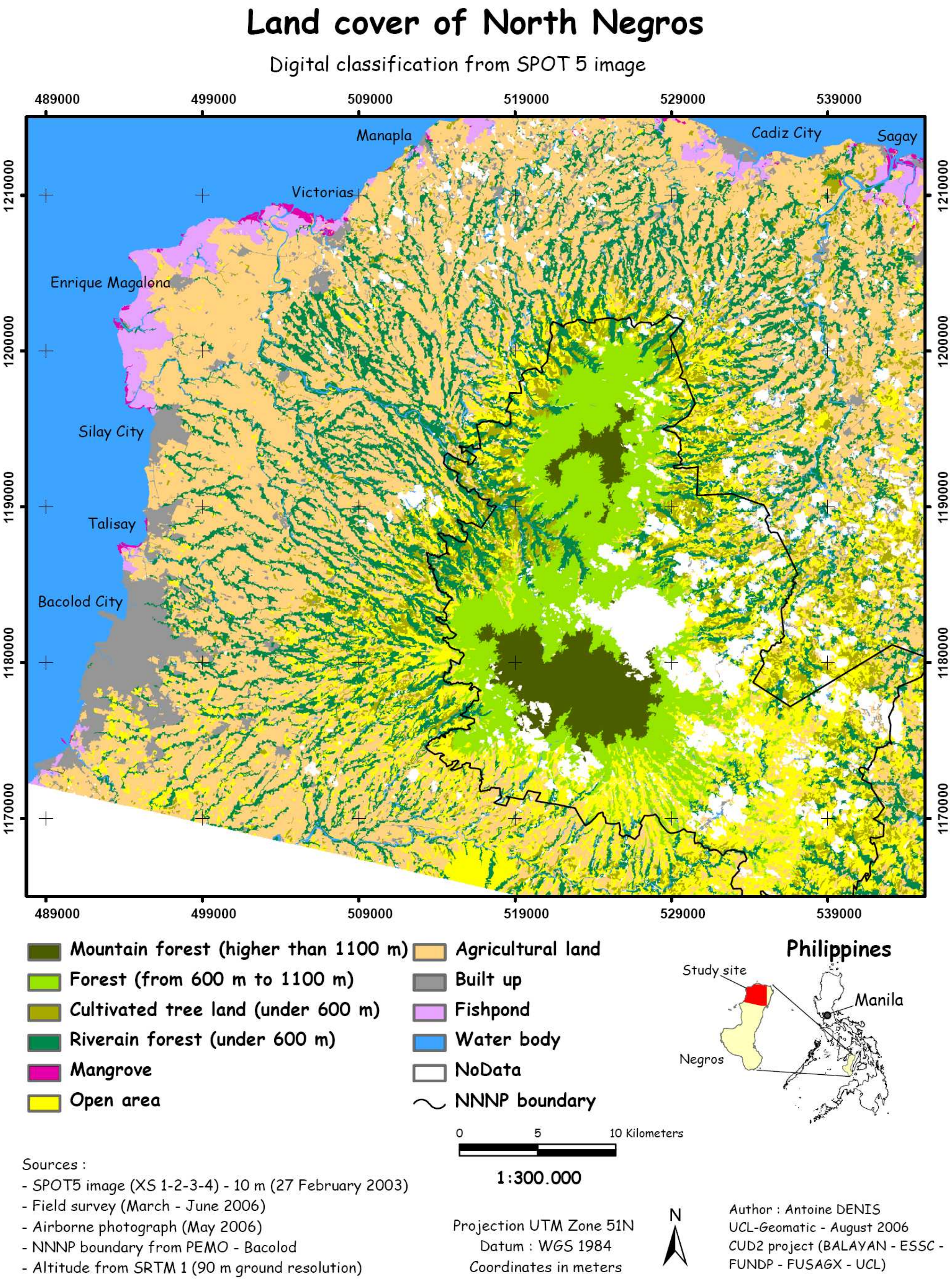
The classification realized can be now imported in ArcGIS software that enables the layout of the Land cover image produced in a Land cover map.

In addition to the land cover itself, some other information complete the land cover map in the purpose to better understand its spatial organization/location(???) and thus to facilitate its reading. These elements are:

- The NNNP boundary
- The location of the main Cities and municipalities

River network was not added because it would overload the map and make it less readable. Road network was not available.

The resulting land cover map is shown in Map 5.



Map 5 : Land cover map of North Negros realized through digital classification of SPOT5 image

V.4 Legend of the classification

The definitions of the elements of the legend that you will find below are described in two points and are organized as the following

- Simplified technical definition used for the classification process
- Land cover types this definition corresponds to

Mountain forest

- All land cover spectrally identified as forest and located higher than 1100 m elevation
- This includes several types of forest
    - **Mountain, Mossy and Pine forests**: forest stand found principally on high elevations and very rough mountainous regions characterized by steep ridges. Low temperature and high rainfall all the year long. The trees are mostly dwarfed, with stems and branches usually covered by epiphytes and mosses. Height comprised between 15 to 20 meters, with a maximum of 25 meters. Trees rarely have buttresses. Rich organic soil. Dominated by Podocarpaceae, Mytaceae and Fagaceae.
    - **Old growth Dipterocarp forest of high elevation**: where relief is less steep and no deforestation occurred. Diameter of two to three meters. Height of 30 to 40 meters. Dipterocarp species.

  However, some patches of regenerating forest mixed with residual primary forest could occur even at this elevation since deforestation or forest fire occurred in a recent past.

Forest (from 600 to 1100m)

- All land cover spectrally identified as forest and ranging from 600 m to 1100m elevation
- This includes
    - **Regenerating forest and regenerating transition forest**. Resulting from previous deforestation or fire. Principally, young secondary forest with a very high density of thin stem (1 to 15 cm approximately). Low closed canopy with height comprised between 7 and 12 meters. Natural fast growth pioneer species or planted exotic or natural species.
    - **Brush and shrub** corresponding to heterogeneous land composed of shrub, brush, giant ferns, cogoon, banana, and rare small trees. Height is approximately comprised between 1 and 6 m.
    - **Old growth forest**: very rare remaining patches of old growth dipterocarpacee forest.

At this elevation, soil on the forest floor is often very thin and rocky. High temperatures and wet conditions all the year.

Riverain forest

- All land cover spectrally identified as forest, lower than 600 m elevation, and partially or totally included in a 50 m buffer distance from rivers (50 m both sides)
- Forested land situated in the close proximity of watercourses, mostly on the riverbank or on small islands in river beds, in the low and flat land or in mid elevation land. The main species are a mix of bamboo, bananas, coconut and other fruit trees according to the proximity of human presence. Width of the Riverain

forest is ranging from a few meters in lowland to 100 meters at higher elevation where river bed widens considerably.

Cultivated tree land

- All land cover spectrally identified as forest, lower than 600 m elevation, and that are not Riverain forest.
- This corresponds mainly to land presenting a very heterogeneous, mixed tree vegetation, mainly human planted tree composition, with fruit trees such as banana, coconut, mango, Lanka, etc, including some orchards and ISF area. Some plantations of Eucalyptus or other tree species is also included. Some rural settlements corresponding to very heterogeneous land presenting a mix of fruit trees and small houses which are partly hidden by the tree canopy were sometimes identify as Cultivated tree land in the case of high relative density of tree / houses.

Mangrove

- All land cover spectrally identified as forest, and located lower than 9 m elevation
- Type of forest occurring on tidal flats along the sea cost extending along the streams where the water is brackish and composed mainly of Bakauan, Potolan, Langarai, Api-api, Nipa palm and the like.

Open area

- All land cover spectrally identified as Open area
- Mostly land predominantly covered by very short grass of 5 to 10 cm height such as pasture, fighting coq field with short grass or golf course, but also other grasslands with some patches of short vegetation approximately up to 80 cm such as short shrubs like ferns, bramble, flowers and higher grass. Agricultural land presenting grass-like vegetation at the time the image was taken is also included as well as grassland damaged presenting earth patches and burned grassland.

Agricultural land

- All land cover spectrally identified as Agricultural land
- Land presenting cultivated crops such as sugar cane (the great majority), rice, vegetables, sweet potato, etc.

Built up

- All land cover spectrally identified as Built up, completed with manual editing
- Land presenting an intensive human use where much of the land is covered by structures. It includes cities, towns, villages, strip development along highways, isolated sugar cane factory,… Some rural settlements corresponding to very heterogeneous land presenting a mix of fruit trees and small houses which are partly hidden by the tree canopy were sometimes identify as built up in the case of low relative density of tree in comparison to houses. Quarries are also included.

Fishpond

- All land cover spectrally identified as Fishpond, completed with manual editing
- A body of water (artificial or natural) where fish and other aquatic products are cultures raised or cultivated under controlled conditions.

Water body

- All land cover spectrally identified as water body but not fishponds

- All water element including Sea and Rivers but not fishponds

No data

- Object that do not correspond to land cover or that it was impossible to classify in any other classes due to really bad spectral characteristics
- Clouds and their ground shadow and some very relief-shaded forested (or else) area

V.5 Analyses of the Land cover map produced

V.5.1 Land cover map as translator of the landscape

This analyze starts from the mountains in the center of the image, then is going down along its slopes and feet to arrive in the high and low elevation agricultural lands striated of Riverain forest and finally ends with the main built up locations, fishponds and Mangroves before to flows into the sea.

The first element that appears is the central forest massif composed of both the **Mountain forest** (dark green) and **Forest from 600 to 1100 m** (light green). Mount Mandalagan in the South and Mount Silay in the North are clearly distinguishable and connected with a strip of Forest from 600 m to 1100 m. Both of them present Mountain forest and this more abundantly for Mount Mandalagan since it presents more land corresponding to this range of elevation. The characteristic crescent shaped Mountain forest of Mount Silay corresponds to the higher elevation perimeter of this old volcano crater. This two distinct mountain forest are surrounded with Forest from 600 m to 1100 m. A very wide cloud hides partly these forest classes in the center-east. However a posteriori elevation check shows that if the land cover hidden by this cloud is forest, it is Forest from 600 m to 1100 m. The “Patag penetration” can be noticed in North-western part of Mount Mandalagan as a mix of open and agricultural land.

Open areas (in yellow) works as a transition between forest land and agricultural ones, mainly corresponding to a range of elevation which not suit the wide sugar cane plantations anymore but that are still flat enough to be cultivated before the relief imposes the land cover to be forested. Lots of open areas can be seen in the South-western part of the map. The wide homogeneous yellow patch in the extreme South corresponds to a burned area on the image which have been identified as a grass land during the field survey.

Cultivated tree land seems to be mixed with Riverain forest in their higher limits (near 600 m). This class is also scattered in small patches on the whole image and is not really well represented. Indeed, the proportion of cultivated tree lands is small on the study site in comparison with the huge sugar cane areas.

The second best element that appears on the land cover map is probably the **Riverain forest** network starting near sea level and ending at an elevation of 600 m according to its definition. These Riverain forests look like what could be called the blood system of this land cover.

Agricultural land (orange), being mainly composed of wide sugar cane fields, occupied the low lands. This is the land cover class that covers the bigger surface of the study site. Agricultural lands are mainly located in the low plain comprised between the sea and the mountain range. However this class climbs until a quite high elevation up to 800 meters in the case of Barangay (village) Patag. In several places agricultural lands are noticed very far inlands in the beginning of the mountain or even further.

Built up (gray) area is of course composed of the main Cities and Municipalities such as Bacolod (Capital City of Negros Occidental) that is by far the biggest one, followed by Silay City and then Talisay and Cadiz City. All the main cities lie on the coast. Another category of built up that appears in this map is composed of the big sugar cane factories. They locate more inlands in the middle of the sugar cane fields and are sometimes surrounded with houses of the factory's workman. A good example is located just in the south of Victorias. Others Baranguay are visible, such as Murcia for example. Road network is very partially visible only. This can be explained regarding the size of the majority of the roads probably too narrow to appear clearly in the classification of a 10 m pixel resolution image. However roads between Talisay and Silay or between Enrique Magalona and Victorias are clearly visible.

Fishponds (lilac) constitute another typical feature of North Negros. They are all located along the coast and seem to complete the building of the coast between the built up areas except for rare places. Most of them are located between Silay and Victorias.

The remaining **Mangrove** (pink) can be seen along the coast, mainly in the surroundings of Talisay, Silay, Victorias and Sagay. Most of them are located in the major rivers mouths and surrounded with fishponds.

Finally, **Water body** is composed of the major rivers of which 3 are clearly visible on the map, and of course of the Sea in East and North.

Clouds occur mainly on the East part of the study site which was also less or not investigated during the field survey. This area is for sure the less well represented of this land cover map.

V.5.2 Land cover in relation with NNNP boundary

It is obvious on the land cover map that the forested surface is much smaller than the NNNP surface in which it is inscribed. Only Mount Mandalagan and Silay are still covered with forest. A large area in the eastern part of NNNP is empty of any forest instead of which open areas and agricultural lands take place.

V.5.3 The elevation limit

Looking at the land cover map, it seems that the elevation limit of 600 meters was correctly chosen. Indeed, the natural apparition of open areas at this elevation limit ("Natural" is used here in the sense that no elevation constrain was used for its identification during the classification process) is well marked on almost whole contour of the Mountains and corresponds to the limit between: on one hand Riverain forest and Cultivated tree land (under 600m) and on the other hand forest above 600 m. The idea behind the limit of 600 m was indeed to separate forest belonging to the forest massif from the ones surrounded with open areas which allows an easy access to theses lower forests. They were thus defined as "cultivated forest" starting from this limit. However, looking in the South-eastern part of the map, it can be seen that long strips of forest classified as

"Forest from 600 m to 1100 m" are mixed with open areas and are completely disconnected with the rest of the mountain forest massif. Moreover they are the continuation of lower Riverain forest. This means that theses tree lands are more probably Riverain forests of high elevation rather than a forest belonging to the massif. A similar remark can be done for the Riverain forest located in between the two Mount Mandalagan and Silay. Indeed some of these are completely surrounded with the class "Forest from 600 m to 1100 m" and should therefore be part of this last class rather than Riverain forest. These are two examples of the limitation of the use of elevation limit as a strict classifier.

V.6 Accuracy assessment of the SPOT5 image classification

The quality of the classification is evaluated with a confusion matrix.

V.6.1 Confusion matrix based on Training and Test Area (TTA) mask

This method uses test areas as a reference for classification quality.

Test areas, consisting of object resulting from the segmentation, were randomly chosen on the segmented image and visually interpreted according to the 10 land cover classes produced. A total of 361 test areas were used with at least 30 samples per classes except for the 2 classes "Open area" (25) and "Cultivated tree land" (12) because very few objects corresponding to those classes were available on the image. Number of samples used per class is given in the last column of the confusion matrix. These samples are different than the one used for the classification. They were then converted into eCognition TTA mask and imported in the classification project to compare the classification with them.

The statistical output is presented as a **confusion matrix** with several accuracy measures.

Notes that for some randomly selected samples, the assignment of a pixel to a class based on visual interpretation was not possible, and as a consequence, these samples were not used.

V.6.2 Analyses of the Confusion matrix

The confusion matrix is presented in Table 10. Measures used to evaluate the accuracy of the classification are defined below that table.

As a rule of thumb, it can be said that the closer the accuracy values are to 1, the better the classification (i.e., the higher the accuracy) of this class (eCognition user guide3)

The **Overall accuracy** is 89.2 % and the KIA is 87.9 %. This translates a quite good classification since only a bit more than 10 % of the whole image is badly classified. This quality of results is coming for sure from the methodology used for the classification. Indeed, using elevation or river buffer as exclusive / inclusive classifiers in addition to previously used spectral one ensure a non ambiguous classification.

The worst results is obtained for the class **“Cultivated tree land”** with 53.3 % producer’s accuracy only and is the only one to be contaminated with 4 other classes. Two reasons can explain this bad result. The first one is that really few samples were used for both training and test areas of this class because small representation of this class in the study area. The fact that this class is contaminated with agricultural land Riverain forest and open are gives us the second reason of this low result. The contamination by Riverain forest should not occurs since ambiguity is impossible for these two classes regarding the classifiers used. This mistake is probably coming from the choice of wrong samples during the validation. Tree land objects quite far from rivers but still partially (even slightly) included in the river buffer could have been interpreted as Cultivated during validation process while they were not. Confusion with agricultural land in full vegetation is understandable. However, the main contamination is coming from the class Open areas that should not be confused with cultivated tree land. This inaccuracy could come from the fact that the feature space to identify it is not really appropriate in addition to the above mentioned lack of samples.

The best result is obtained for the class **“Fishpond**” with 100 % producer’s accuracy. This result is not surprising given the fact that this class was manually edited and that fishponds are easily visually interpreted and demarcated.

The class **water body** presents only 79.2 % producer’s accuracy with contamination by Riverain forest and forest from 600 m to 1100 m. In this case, object visually interpreted as river were classified as “riverain forest” or ”Forest (600 m to 1100 m)”, both of these classes presenting objects close to the rivers. This can be explained by the fact that some object, resulting from the segmentation process of the image, were in some rare cases covering either Riverain forest and a small part of rivers or the inverse. This is especially true for the upper rivers where vegetation begins partially hide parts of the river and no clear distinction can be made.

The class **Built up** seems to be well identified with a producer’s accuracy of 91.5 %. This good result can be explained by the fact that built up is most of the time easily identifiable and that manually editing was realized to bring it to an end. The small contamination by Agricultural land can be explained by the fact that some small groups of isolated dispersed houses in the countryside or presenting a lot of vegetation around them could have been visually identified as built up but classified as agricultural land.

The class **Open area** presents a producer’s accuracy of 85.4 % and is slightly contaminated with 3 other classes among which Riverain forest. A posteriori check shows a more important contamination by Riverain forest that what appears in this validation. This means that more samples should be used for validation in order to better translate the classification accuracy.

Riverain forest presents a producer’s accuracy of 92.7 % which validates the methodology used to identify it. However the contamination with Cultivated tree lands is non-logic and is probably due to the choice of wrong samples during validation. Indeed, object samples that seem to be far enough from rivers (not included in the river buffer) during validation would have been in fact slightly included in the buffer by one of their extremity. Another reason could be that the digitized river network doesn’t always fit perfectly with the image.

Non-logic values are found for both **Mountain forest** and **Forest from 600 m to 1100 m** since they contaminate each other. This is not possible according to the fact that misinterpretation is impossible on the base of the elevation since there is no hesitation to attribute a forest object to a class or an other. An object is either lower on one hand or higher or equal (≥) to 1100 m on the other hand and do not lies on both sides of elevation limit since the feature used for the classification is the mean elevation of the object. A posteriori check shows that this is due to the choice of wrong samples during the validation.

Mangrove presents 93.2 % producer's accuracy and is contaminated by agricultural field only. This good result validates the methodology used to identify it.

Agricultural land with a producer's accuracy of 91.1 is contaminated with open area and cultivated tree.

User's accuracy of 100 % is obtained for the classes "Water body", "Built up", "Mangrove", and "Fishpond" while the most contaminating classes are agricultural land and forest from 600 m to 1100 m that contaminates 4 others classes each.

V.6.3 Conclusion

As **a conclusion** of the analyses of the confusion matrix, it can be said that despite the fact that the overall accuracy is fully satisfying, notably regarding the further needs for the landslide model, some inaccuracies or even mistakes seems to occurred in the general classification process making room for easy further improvements that were not attempted this time because lapse of time.

Confusion matrix based on visual interpretation of randomly selected object of the SPOT 5 image.

User \ Reference Class	Water bodies	Built up	Agricultural land	Mangrove	Open area	Riverain forest	Mountain forest	Forest (600 m to 1100 m)	Cultivated tree land	Fish pond	Sum	samples
Water bodies	7056	0	0	0	0	0	0	0	0	0	7056	30
Built up	0	10024	0	0	0	0	0	0	0	0	10522	57
Agricultural land	0	934	11190	762	584	0	0	0	648	0	14118	40
Mangrove	0	0	0	10451	0	0	0	0	0	0	10451	35
Open area	0	0	372	0	9854	0	0	0	1102	0	11440	25
Riverain forest	379	0	0	0	361	14191	0	0	692	0	15623	59
Mountain forest	0	0	0	0	0	0	18856	3089	0	0	21945	36
Forest (600 m to 1100 m)	357	0	0	0	736	0	787	11692	103	0	13675	32
Cultivated tree land	0	0	715	0	0	1120	0	0	2902	0	4737	12
Fish pond	0	0	0	0	0	0	0	0	0	7227	7227	35
Unclassified	0	0	0	0	0	0	0	0	0	0	0	0
Sum	8904	10958	12277	11213	11535	15311	19643	14781	5447	7227		361
Producer's accuracy (%)	79,2	91,5	91,1	93,2	85,4	92,7	96,0	79,1	53,3	100,0		
User's accuracy (%)	100,0	100	79,3	100,0	86,1	90,8	85,9	85,5	61,3	100,0		
Overall Accuracy (%)	89,2											
KIA (%)	87,9											

Table 10: Confusion matrix based on visual interpretation of randomly selected object of the SPOT 5 image

Elements of the confusion matrix

- **User's classes** (first column) shows the classes to assess (resulting from the classification)
- **Reference classes** (others columns) show the numbers of pixels covered by the TTA mask (*the samples used*) for each class.
- **Producer's accuracy,** estimates the proportion of pixels which are correctly classify per class.
- **User's accuracy,** gives the probability that a pixel classified in a class is actually of this class.
- **Overall accuracy** estimates the proportion of pixels which are correctly classified for all classes.
- **KIA**, Kappa Index of Agreement, measures how well classification and reference classification agree assuming that both of them are independent class assignment of equal reliability
- **Samples** (last column) gives the number of samples per class used for the validation

V.7 Others comments

V.7.1 Utilization of elevation

The **use of elevation** levels as a separator for the forest types is a good alternative when spectral reflectance revealed to be useless or when not enough samples are available and that no visual interpretation is possible for forest type differentiation, on the condition that a reliable bound can be established between the elevation limits and the real vegetation limits.

However, as it was previously partially explained, the concepts of limits that the notion of classification subtends (underlie?) does not always perfectly match with the real vegetation in the sense that transition vegetation often occurs in border zones of two classes rather than a clear limit.

Concerning this classification, despite the fact that elevation classes definition is the fruit of a mature reflexion in relation to the field survey and the literature, elevation could be seen as a more or less “blind limit” source of imprecision since the real elevation limits of vegetation are of course not constant on the whole study area. For example, some rare Riverain forests are still observed at an elevation of 900 meters while the limit given with this classification is 600 meters, under which the wide majority of the Riverain forest lies/locates (?).

From this example it is easy to understand that one elevation range can include several types of forest. That’s the reason why no typical forest type had been attributed to a range of elevation. The names of the forest class take the name of the range of elevation, or a synonym such “Mountain forest” for forest higher than 1100m for example, and then the composition of this class is explained in its definition and not the inverse.

As a conclusion it can be said that the elevation can be a good and particularly easy parameter to use to contribute to the land cover differentiation on the condition to be really conscious of its limitations.

Combination of slope with elevation was not tried because no information could be found on slope limits to give to vegetation limit. Moreover according to the field survey and the previous SPOT87 classification it seems that slope alone or even in conjunction with the altitude would not be of any help for further differentiation of forest type since for example Old Growth forest can be found at the same elevation or higher than mossy ones and that some Old Growth were observed on steeper slope than some mossy forest during the field survey.

V.7.2 Utilization of river buffer

The 50 meters river buffer that was built from the river network reveals to be really helpful and successful for the identification and delimitation of the Riverain forest. This class appears clearly in the Land cover map produced and translates very well this typical feature of the study area. However, the feature function used for its identification (inclusive in the class even if a small part of the object touch the river buffer) seems to be too strong and should be reviewed.

V.7.3 General remark for the use of river buffer

In the case of this classification, the fact that the satellite image was not perfectly georeferenced, especially in the mountain part, introduce a double bias with both the use of the river buffer and the elevation. However this bias seems to be acceptable. Indeed, the river buffer helps to identify Riverain forest under 600 meters where the spatial interval between the image and the georeferenced river network is almost negligible. However in the highest elevation (near 600 m) where the spatial interval is maximum between the river network and the image, a quite important *gap* is noticed. The Riverain forest are still well identified since it depends on the georeferenced river network, but the river itself, depending on the image is misplaced at the border of the Riverain forest rather than to lies in its middle.

V.7.4 Difficulties met

- There is no question that the major difficulty met is the **strong topographic effect** on the light creating very sun-exposed and very shadowed forest area in the mountain which decimate any hope of forest type differentiation on the base of their spectral properties.
- Another difficulty met during this classification is the **wide extent** of the study site. Indeed with the available time and the extent to cope with, it is quite difficult to better translate the landscape diversity. And for example manually editing the whole built up area is a very heavy task. Only the main Cities and municipalities could benefit from this treatment.
- The facts that the image is not correctly georeferenced and that not enough samples for forest classes are available were explained before.

V.7.5 Further improvement

Some improvements, which were not tried by lapse of time, could be done for further classification of this image

- Using different levels of segmentation giving different objects sizes. This would be particularly useful for better extraction of rivers that are better extracted with a bigger scale parameter (bigger size of objects)
- Using the Normalized Difference Vegetation Index (NDVI) to decrease shadow effects in the mountain.
- Trying a new segmentation giving bigger weight to the SPOT band XS-1, since it seems to be the most useful for classification and not using the XS-3, since it seems to be useless.
- ? Using slope as input for the classification for attempt of differentiation of Mountain forest into Mossy and Old Grown Dipterocarpacee forest in the case of a clear slope limit can be established defining Mossy and Old growth forest classes.
- An improvement of the use of elevation, on the condition that at least a few spectral characteristics is usable, would be to use it not as parameter of exclusion / inclusion (0-1) to a class but to make it participate in the building of a class in conjunction with spectral reflectance or other parameters
- Using different elevation limits for the different areas in the purpose to translate the heterogeneity of the real vegetation elevation limit
- Using a less strict feature function for the identification of Riverain forest. A Guaussian curve should suit better than the rectangular function used.

V. 8 Comparison of 3 Land cover realized for NNNP

Three land cover maps of NNNP are available at the end of this study. These are *presented/ visible* on the page and are the following:

- The forest cover resulting from the "1987 SPOT land cover study" carried out by the Swedish Space Corporation (SSC) during the years 1987 and 1988. 3 forest cover types are presented.
- A land cover map coming from the Department of Environment and Natural Resources (DENR) of Negros Occidental. Neither date nor methodology used to achieve it could be found. But it seems it is a quite recent one and that it results from field inventory at least. 4 forest cover types are presented. A fifth one corresponding to mossy forest was presented in the original shapefile. However given that only two extremely small patches of mossy forest which were not visible at the scale 1/500 000 were present in the shapefile, this class was deleted not to confuse the reader.
- The land cover produced during this study with a 2003 SPOT image. 4 forest types and 3 other land covers are presented.

Comparative Analyze of the 3 land covers of NNNP

At first blush it seems that these three land covers are *quite* **different**:
- They do not covers the same area
- The number and types of forest classes are different
- The DENR one seems to be really accurate with the delineation of small forest patches while Sa

However several **similarities** can be noticed.
- The following table proposes equivalence of the classes of the three land cover.

Level	SPOT 1987	DENR	SPOT 2003
1	Primary Mossy	Old Growth (Mossy)	Mountain forest
2	Secondary	Residual	Forest from 600 m to 1100 m
3	/	Reproduction brush	Cultivated – Riverain – Open
4	/	Open cultivated	Open – Agricultural

Tableau 1 : Equivalence of land cover classes for three land covers realized for NNNP

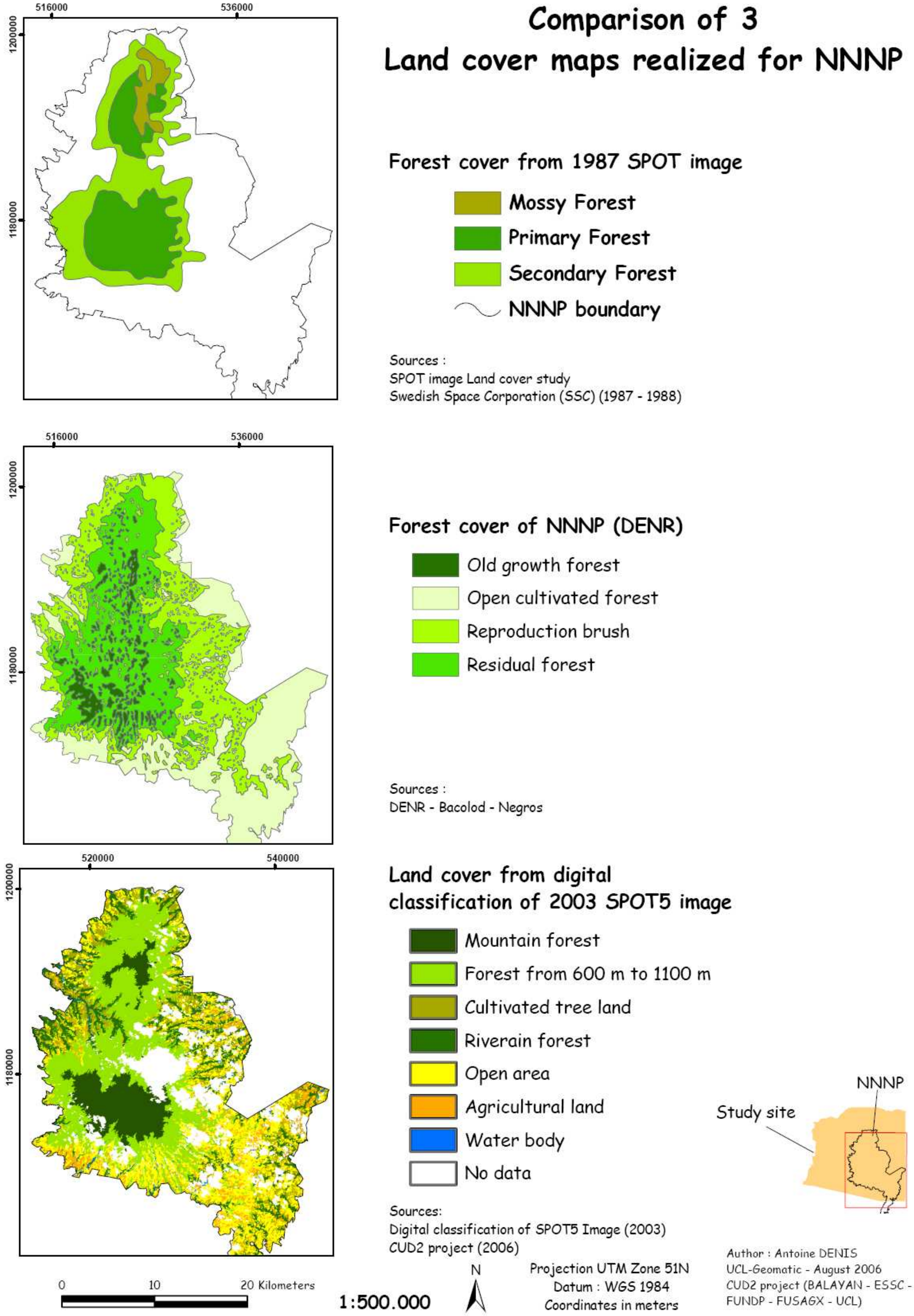
Level 1: SPOT 1987 and SPOT 2003 display prominently level 1 forest as associated with the two Mounts Mandalagan and Silay whereas DENR presents a scattered level 1 forest. High density of "DENR-Old Growth" patches in the Southern part of Mount Mandalagan *catches up* with Level 1 forest at this place for the two SPOTs land cover.

Level 2: The three land covers seem to agree quite perfectly. Boundary shapes as well as surfaces it delineates match each other.

The two next levels are less clear and no data is available for SPOT 1987 – No data corresponding in this case to a non forested land cover.

Level 3 and 4: SPOT 2003 and DENR seems to correspond for the whole perimeter of NNNP. Definition of DENR classes is lacking for further comments.

At the sight of theses three results, it appears clearly that the characteristics of the land cover maps depend strongly of the methodology used to produce them. That's the reason why no temporal evolution analyze is tempt.



Map 6: Comparison of three land cover maps realized for NNNP

V.9 General conclusion and suitability of the land cover map produced for landslide model.

Regarding the **geometric correction**, it can be said that despite the fact that fastidious manually georeferencing could decreased the spatial interval caused by the SPOT 5 image preprocessing level 2A, the resulting corrected image is far from perfection and will remain source of inaccuracy for the further steps of this work. However this inaccuracy seems to be acceptable since the LSZ model doesn't request a better one concerning the land cover factor.

Regarding the **land cover map production**, the use of eCognition as classification software reveals to be of great help for the identification of spectrally non-differentiable forest types, since it enables the use of elevation and river buffer as classifiers. In terms of results, the land cover map produced translates quite well the landscape features of the study site and its accuracy is satisfying even if easy improvement could be brought in further processing.

In addition to the general land cover map itself, the visual interpretation of two representative selected samples of the image, as well as the comparison of the three land cover map for NNNP, enabled the reader to get a better understanding of not only the land cover features but also of the North Negros Occidental contextual situation.

Regarding the **landslide model** needs, the land cover map produced is fully satisfying. The land cover classes that affect differently the susceptibility to landslide are identified. Detailing more deeply theses classes would be useless since this too big accuracy could not be taken into account by the sensitivity of the landslide susceptibility model.

Chapter VI: Landslide Susceptibility Zonation (LSZ) in case of deforestation in NNNP

VI.0 Introduction

The method used to for the LSZ is based on a GIS approach consisting in a Weighted Linear Combination (WLC) of landslide-controlling factors. The general working scheme of the building of the model is presented in Figure 8.

The selection of the LSZ input data is followed by the building of each landslide-controlling factor from these data. The factors can be grouped into three types according to their source:

- **Land cover** (LC) corresponding to the land cover map produced in the preceding chapter. It will be used to derived the Land Cover Change (LCC) being the key factor in the modelling of deforestation
- **Elevation** is built from the SRTM and the elevation contour of NAMRIA topographic maps for better representation of the relief in NNNP
- **Other factors** are built from digitization of thematic maps

The factors and their classes will then be weighted in order to translate their relative Landslide Susceptibility (LS) value. After that, they will be combined in three different LS formulas corresponding to:

- LSZ in stable state scenario, using the whole nine factors previously produced
- LSZ in case of deforestation scenario, using the same nine factors
- LSZ in case of deforestation scenario, using only the four main factors. This will be the base for a sensitivity analysis of the factors.

Finally, the landslide inventory realized during the field survey will be compare with the LSZ maps in order to give an idea of the reliability of the result.

Note that no triggering factors will be used in this modelling and thus that the result is expressed in terms of Susceptibility to landslide and not Hazard which include a temporal dimension as defined by Varnes (1978).

Working scheme for Landslide Susceptibility Zonation (LSZ) in NNNP

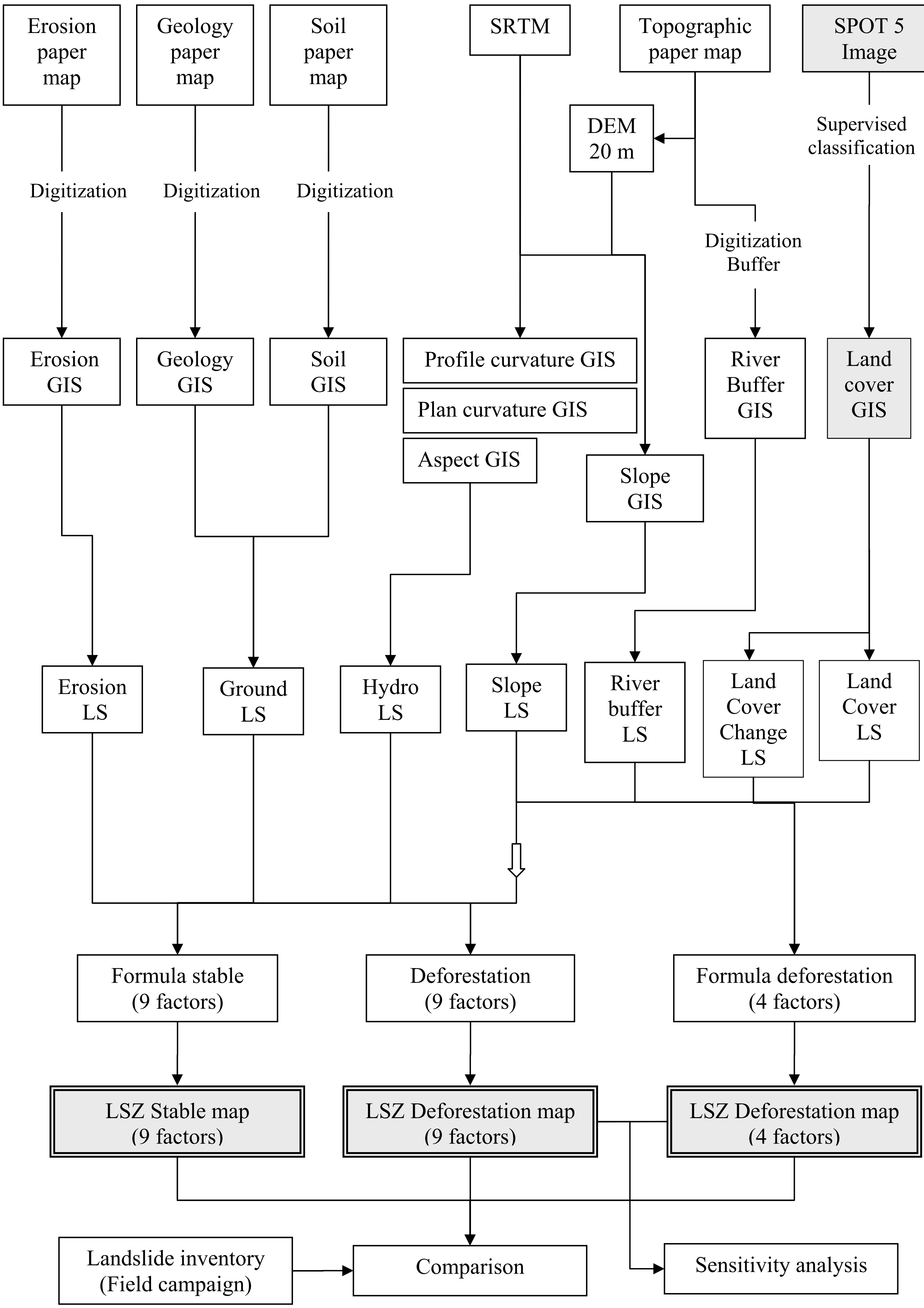


Figure 8: Working scheme for Landslide Susceptibility Zonation (LSZ) in NNNP
(LS = landslide susceptibility value)

VI.1 Choice of input data - Factors

The selection of the factors that will serve as input for the LSZ model is very important since it conditions the LSZ model results. This selection depends on

- The relevance of the factor regarding its power in the prediction of the LS
- The availability and relevance of data concerning the factor
- The possibility to integer the factor in the LSZ model. Indeed, to integer a factor in the LSZ model, information who indicates how to integer this factor must be available. Moreover, for some factors that are very relevant for the LSZ, there is no way to integer them in the model that will be produced. That's the case of the triggering factors for example.

All the potential factors passed thus through this triple filter. The nine resulting selected factors that will finally be used for the building of this LSZ model are:

- Slope
- Land Cover (LC)
- River network
- Erosion
- Geology
- Soil
- Aspect
- Plan curvature
- Profile curvature

However none of these factors express the deforestation itself. The land cover could express the resulting new land cover due to the deforestation but not <u>the change</u> due to deforestation, the perturbation itself corresponding to the abrupt rupture of the pre existing long term established ecosystem equilibrium.

An additional tenth factor was thus created to enable modelling the change corresponding to deforestation in this case. This factor is the

- "Land Cover Change" (LCC)

In order for the different scenarios to be comparable both the LC and the LCC will be considered in the calculation of the LS in the two scenarios. In the stable scenario, the LCC will behave like an "empty" or "ghost" value which is given a value of 0 since there is no change. In the Deforestation scenario, the previously empty LCC will be given a LS value for the land cover classes that change. "The ghost of deforestation will put on weight"!

The relevance of these factors was previously explained in the first chapter.

Ones the selection of the inputs data through the information filter is realized, the factors that will be extracted from these raw data by their modification, aggregation and/or transformation must still to be constructed. The building of the factors is explained in the next subsection.

VI.2 Building of factors

VI.2.1 Elevation and its derivatives

The elevation itself will not be used since it doesn't influence directly the LS. However it is one of the most important data since some relevant factors are derivatives of elevation. These derivatives are Slope, which is the most important, Plan and Profile curvature and finally Aspect. As a consequence, the building of elevation data was a decisive step. This building will be explained in a first time. In a second time the way to get its derivatives will be get into.

VI.2.1.1 Two sources of elevation

As previously mentioned, one of the particularity of this work is the used of two sources of elevation of different spatial resolution. These two elevations data are:

- SRTM 1 with a raster cell resolution of 90 m * 90 m, available for the whole study site.
- DEM coming from the interpolation of digitized topographic contours 20 m difference in altitude, of NAMRIA maps, available for NNNP only.

Given that the study area presents a very heterogeneous relief, varying from flat low land to very steep high mountains, combination of SRTM and contours reveals to be a good manner to represent more accurately the actual varying relief. Both SRTM and contours present advantages and disadvantages according to the kind of relief to represent and as a consequence, the elevation source that suited best the relief have been chosen to represent it.

The general argument that helped to chose between SRTM and the DEM is the following: where more than one topographic contour were included in one SRTM square cell, it is judged that the topographic contours suit best for the relief representation. Elsewhere, the SRTM is used.

In the mountainous part, which is entirely included in NNNP, such abrupt changes are frequents due to the very steep relief. The topographic contours seemed thus to be more appropriate for representing part of NNNP with that kind of relief.

This choice is justified by the following analyze which counted the number of contours included in one SRTM square in NNNP. The table 12 shows the result of this analyze.

Number of 20m topo curves intersecting 1 SRTM cell	Elevation difference	Frequency in NNNP
0 - 1	0 – 20 m (hilly)	Rare
2 - 5	40 – 100 m (sloping)	Usual
6 - 8	120 – 160 m (steep)	Usual
9 – 12	180 – 240 m (very steep)	Rare

Tableau 12: Number of 20 m topographic curves intersecting 1 SRTM cell and corresponding elevation difference and frequency in NNNP

Rare areas of NNNP where SRTM cell are free of contours or intersect 1 only have been represented with SRTM.

Whole rest of the study area (low and middle land) has been represented with the SRTM since several SRTM cells were included between each contours lines.

To summarize, the DEM derived from the topographic map has been used for the NNNP mountainous areas and the SRTM for other area.

VI.2.1.2 Quality assessment of elevation data

A quality assessment for elevation data seemed to be a real need and this particularly for the topographic contours since some errors could be noticed.

Quality assessment of the SRTM was already presented in the data description on p.

Since the LSZ model strongly depends on elevation derivatives such as slope and curvature, the quality assessment of the digitized topographic contours realised here, needed more than elevation measures, but also graphical techniques that offers means of confirmatory data analysis without the use of accurate reference data (Gallant and Hutchinson 2000). The techniques used for the identification of errors, consist in visual analyze of the contours and several derivatives of the DEM derived from them. These techniques and the errors they enabled to discover are summarized below:

- Visual analyze of 3D relief, shaded relief, and slope enables to identify contours with wrong elevation value presenting generally a jump of 100 m (instead of 20 m) between two successive ones. This was translated in nearly vertical abrupt and important elevation change in 3D or sudden and contrasted colour change for hill shade, slope.

- Visual analyze of the 2D contours enables to identify several random and systematic errors, partly due to the practical limits on digitizing accuracy. Random errors consisted the fact that some contours, especially in very steep area, touched or crossed each other and sometimes overlaid for a short distance. Systematic errors were slight irregularities in position of the closely spaced digitized contours with some neighbouring contour lines distinctly closer than adjacent. Moreover contours presented sometimes strong angles rather than to be perfectly curved.

Wrong elevation value and random errors were corrected whereas systematic ones were not.

VI.2.1.3 DEM Interpolation

Once the contours were corrected, the elevation model that has served as the basis to calculate the elevation's derivative could be created. The method used for the interpolation and the cell size of the created elevation raster are of high importance since both of them condition the quality of the DEM to be created. The determination of the appropriate resolution (cell size) of an interpolated DEM is usually a compromise between achieving fidelity to the true surface and respecting practical limits related to the density and accuracy of the source data (20 m contours in this case) (Gallant and Hutchinson 2000).

Several methods such as Spline, Triangulated Irregular Network (TIN) or Inverse Distance Weighted (IDW) were tried with different cell size for each method. For each elevation result, the slope was then computed with different cell size in order to identify the DEM that would give the best slopes.

Numerous attempts drive to the conclusion that the best interpolation method was to convert the contours in points (cell size of 20 m) which were then interpolated with the Natural Neighbour method (cell size of 30 m). A cell size of 20 meter for the conversion in points was the minimum size reachable since smaller one gave files too big for further processing.

Two DEM are finally available: the SRTM (90 m cell size) and the one created by interpolation of the topographic contours (30 m cell size). No fusion of the 2 elevation models was realized. Indeed, their derivatives will be computed separately in different ways since they don't present the same cell size. The fusion will only occur when each derivative will be computed for each.

VI.2.1.4. Elevation's derivatives

Four topographic factors influencing the LS were derived from the elevation model: slope, aspect and plane and profile curvature.

VI.2.1.4.1 Slope

Slope is obtained with the Slope command (Spatial Analyst) and identifies the maximum rate of change between each cell and its neighbors, for example, the steepest downhill descent for the cell. The best slope was obtained with an output cell size of 45 m for the NNNP-DEM while 90 m seemed to be the best for the SRTM.
The Slope map is presented on in Map 7.

VI.2.1.4.1Curvature

Curvature corresponds to the second derivative of the surface (for example, the slope of the slope) and was computed with the Curvature command in ArcMap from elevation raster. The curvature of the surface is calculated on a cell-by-cell basis on a 3 x 3 cells window.
Two types of curvature were computed:

- The **profile curvature** which affects the acceleration and deceleration of flow
- The **plan curvature** which influences convergence and divergence of flow.

Different curvature accuracy will be obtained according to elevation raster used as input and especially its cell resolution. The approach used to determine the best curvature is a visual analyze of the curvature raster produced from the topographic curves in relation with these topographic curves. If the cell size chosen for calculating the curvature is to small, linear features closely associated with the systematic positional error of the contour will appear in the resulting curvature raster. Otherwise they will be absent.

VI.2.1.4.1 Aspect

Aspect corresponds to the direction that a slope faces. It is simply calculated on the base of elevation raster with the Aspect command (Spatial analyst) which gives an aspect value comprised between 0° (North) and 359° to each cell. Flat cells are given a value of -1. The elevation raster used is the same than for slope computing. The cell size has less importance in this case since aspect results are less dependent on it.
The Aspect represented as the further explained LS due to aspect is presented on in Map 8.

VI.2.1.5. Fusion of the elevation's derivatives

These four data were thus produced separately for the SRTM and the DEM corresponding to NNNP. After a re-sampling to a 45 m cell size for each raster they were merged in order to have one raster per data only.

VI.2.2 Other thematic Factors

The other factors that will be used in the LSZ model are derived from thematic maps and corresponds to Geology, Soil, erosion, river network and land cover. Some operations were made on these data to transform them from raw data to ready-prepared data for the LSZ in GIS environment.

VI.2.2.1 Erosion

The Erosion map presented previously (data description) was also available as a paper map, and thus the same operations than the ones undertaken for the soil map were realized.
The final erosion map is presented in Map 9.

VI.2.2.2 River network

The river network presented previously (data description) was already digitized and georeferenced. However, the river network alone is not relevant for the LSZ. Three buffers distance corresponding to three different susceptibility to landslide due to river proximity were constructed from this river network.
The final river network map and the further explained LS due to river network is presented on in Map 10.

VI.2.2.3 Geology

The geology map presented previously (data description) being available as a paper map, several operations were undertaken:

- Scan: the paper map was scanned in a digital file
- Georeferenciation: the scanned map was then georeferenced on the base of the georeferenced SPOT 5 image.
- Geometric correction: the paper map being deformed, a geometric correction was applied in order for this map to fit the real island shape. However, some inaccuracies remain, especially on the east coast, where it was impossible to adjust the map without deforming its other part. However, this map has been used, given that the parts of the map that were included in the study area were not disturbed by that anomaly after geometric correction.
- Digitization: the geometrically corrected map was then digitized
- Edition: the element of the legend were then edited for each polygon created

The final geology map is presented in Map 11.

VI.2.2.4 Soil

The Soil map presented previously (data description) was also available as a paper map, and thus the same operations than the ones undertaken for the geology map were realized, except the geometric correction since this map presents no deformation.

The final soil map is presented on page in Map 12.

VI.2.2.5 Land Cover (LC)

The land cover used for the LSZ is the land cover map produced in the previous chapter (Map 5). The factor corresponding to the land cover change is directly derived from this land cover.

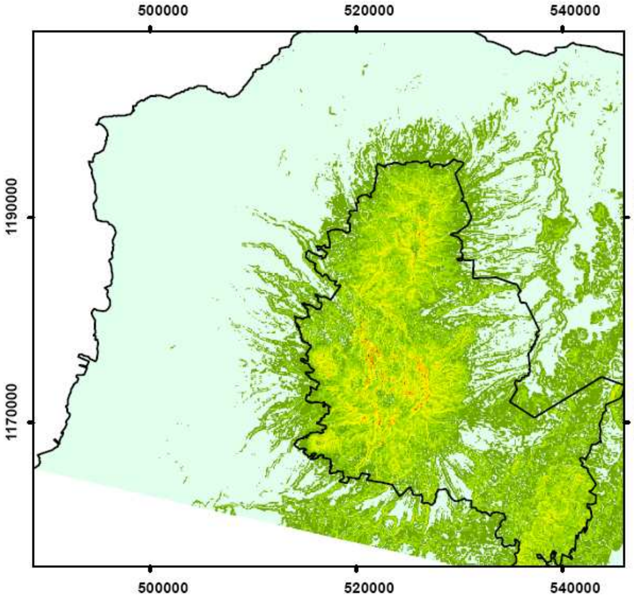
VI.2.2.6 Land Cover Change (LCC)

The LCC will be based on the land cover map (MAP 5).

Conclusion data building

Finally, the results of the data building are nine raster of 45 meters cell size, corresponding to each landslide-controlling factors selected.

Data derived from Digital Elevation Model used for the Landslide Susceptibility Zonation



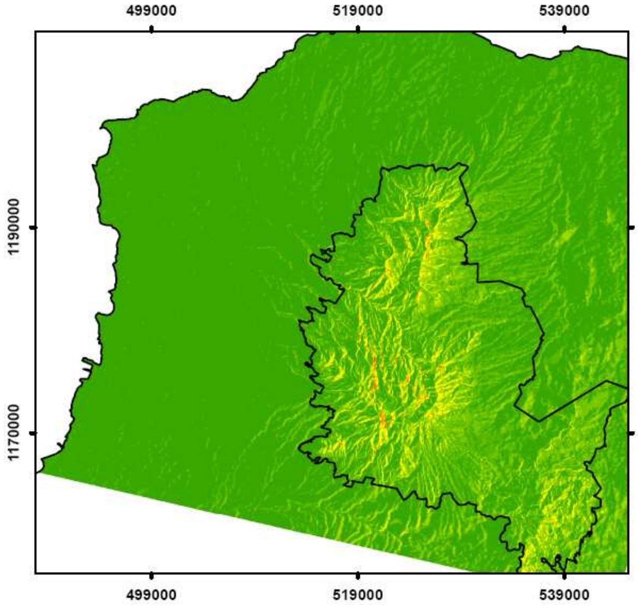
Slope map of North Negros

Slope angle in degree

- 0° - 5°
- 5° - 15°
- 15° - 30°
- 30° - 45°
- 45° - 50°
- 50° - 60°
- 60° - 90°
- No data

NNNP boundary

Sources :
- SRTM 1 - 90 m ground resolution (2000) (SRTM - NASA/NGA) for lowlands
- DEM derived from NAMRIA topographic maps (20 m topo curves) (1956) (PEMO - Bacolod) for uplands



Susceptibility to landslide due to Aspect

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- No data

NNNP boundary

1 = Low susceptibility
10 = High susceptibility

Sources :
- SRTM 1 - 90 m ground resolution (2000) (SRTM - NASA/NGA) for lowlands
- DEM derived from NAMRIA topographic maps (20 m topo curves) (1956) (PEMO - Bacolod) for uplands

0 10 20 Kilometers

1:600.000

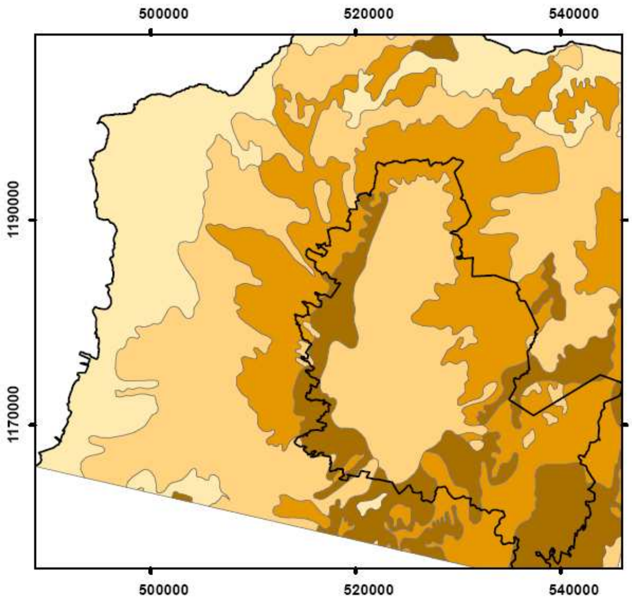
Author : Antoine DENIS
UCL-Geomatic - August 2006
CUD2 project (BALAYAN - ESSC - FUNDP - FUSAGX - UCL)

Projection UTM Zone 51N
Datum : WGS 1984
Coordinates in meters

N

Map 7 : Slope map of North Negros
Map 8 : Susceptibility to landslide due to aspect

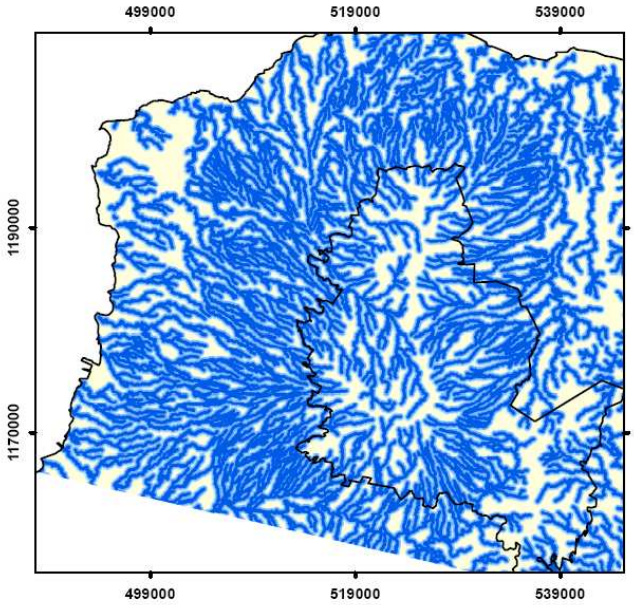
Erosion classes and River network buffer used for the Landslide Susceptibility Zonation



Erosion map of North Negros

- No apparent erosion
- Slight erosion
  - more than 50 % of the area is affected by sheet erosion
  - less than 10 % of the area is affected by rill erosion
- Moderate erosion
  - more than 50 % of the area is affected by sheet erosion
  - 10 to 50 % of the area is affected by rill erosion
  - presence of some gullies
- Severe erosion
  - more than 50 % of the area is affected by sheet and rill erosion
  - conspicuous development of gullies
- No data

Sources :
- Erosion from Erosion map - 1/250 000 (later than 1975) (Ministry of Agriculture - Bureau of Soils - Manila)



Susceptibility to landslide due to River network

Susceptibility	Buffer distance from river
0	> 400 m
3	300 m - 400 m
6	150 m - 300 m
10	0 m - 150 m
No data	
NNNP boundary	

0 = No susceptibility
10 = High susceptibility

Sources :
- NAMRIA topographic maps - 1/50 000 (1956) (digitized by ESSC)

0 10 20 Kilometers

1:600.000

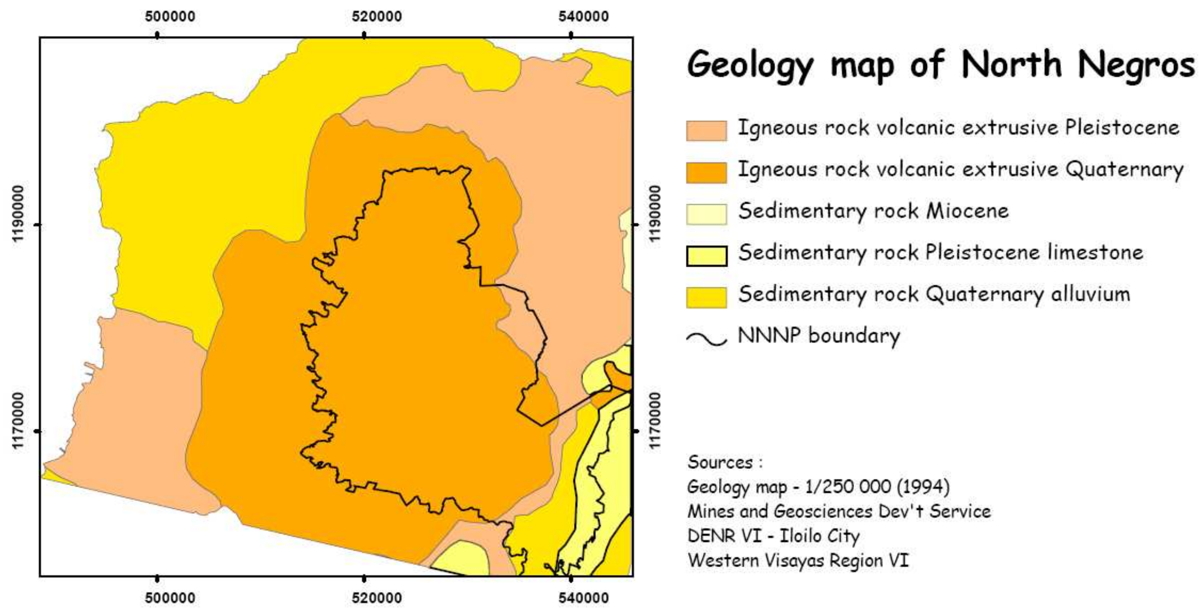
Author : Antoine DENIS
UCL-Geomatic - August 2006
CUD2 project (BALAYAN - ESSC - FUNDP - FUSAGX - UCL)

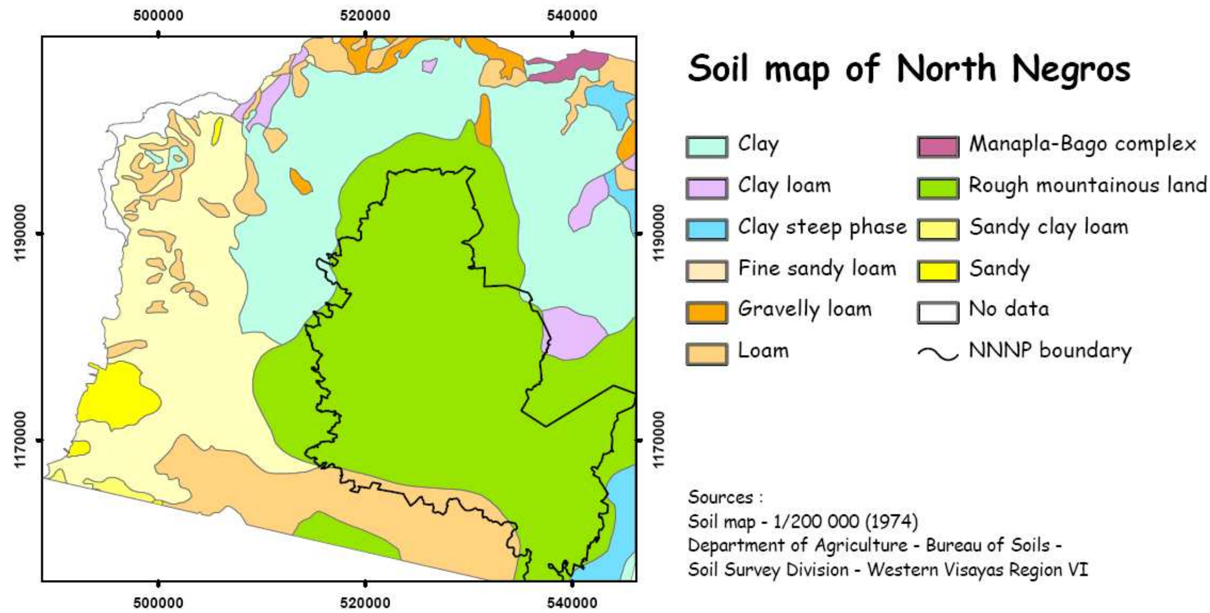
Projection UTM Zone 51N
Datum : WGS 1984
Coordinates in meters

N

Map 9: Erosion map of North Negros
Map 10: Susceptibility to landslide due to river network

Ground data used for the Landslide Susceptibility Zonation





0 10 20 Kilometers

1:600.000

Author : Antoine DENIS
UCL-Geomatic - August 2006
CUD2 project (BALAYAN - ESSC - FUNDP - FUSAGX - UCL)

Projection UTM Zone 51N
Datum : WGS 1984
Coordinates in meters

N

Map 11: Geology map of North Negros
Map 12: Soil map of North Negros

VI.3 Weighting of factors and LSZ formula

Once the factors are identified and built, the way they will be computed in the LSZ model has still to be defined. This is achieved through their weighting that will give them their relative importance in the LSZ mapping. This can be divided in two parts:

- The relative importance to give to each factor (slope, land cover…) called ‘Weight’
- The relative importance to give to each class inside a factor (different classes of slopes….) called ‘Score’

Weighting the factors and their class is similar to give them the value of susceptibility to landslide they represent. A high value attributed to a factor or a class will thus translate a high susceptibility to landslide coming from this factor or class while a low value will translate a low susceptibility to landslide.

The methods to weight the factors and their classes were different and are thus explained separately in the followings subsections.

Finally the combination of the weighted factors with their weighted classes will result in the formula that will state the LS.

For either weighting or formula the three scenarios are presented in the same time.

VI.3.1Weighting of classes of factors

The weighting of the classes, expressing the graduation of LS inside the factor, is based on the literature. No ready-made weighting method or value exist since each LSZ is different in terms of number and type of factors considered, classes represented, spatial context,… As a consequence, a wide variety of classes’ weight is found in literature corresponding to the wide variety of situations encountered. However reading of numerous similar LSZ were used as an indication of what weight to give to the classes.

The class weighting has been realized accordingly to the literature (Chapter one). If other comments are necessary, they will be presented for each factor in the following subsections. Note that weight of factor’s classes will be called “Scores”.

Slope

The slope LS weights are presented in the table 13.

SLOPE (°)	Score S
0 - 5	0
5 – 15	5
15 – 30	8
30 - 45	10
45 - 50	7
50 - 60	3
> 60	1

Table 13: LS weight for slope classes

Aspect

Aspect value translates here the LS due to the exposition to Typhoon. All the typhoons comes from East – South east with really small variants. The wind strength ranges between 95 and 240 kph for the 10 worst typhoons of the Philippines which gives an idea of the lateral effect of rain transported by wind. Consequently, the highest LS value is given to East – South east. The LS values decrease gradually to finally reach 0 for opposite aspect which are considered as protected. Flat areas have an intermediate value since they are less exposed than very exposed ones but more exposed than the protected ones. These values are presented in the following Table 14.

Influence of solar radiance due to aspect on the weathering of the ground was not considered since it seems not to have importance for this tropical forest site and that not enough literature could be found about that.

ASPECT	Score A	Exposition
Flat	5	Intermediate
North	4	Intermediate
North-East	8	Intermediate
East	10	Exposed
South-East	10	Exposed
South	8	Intermediate
South-West	4	Intermediate
West	0	Protected
North-West	0	Protected

Table 14: LS weight and exposition to typhoon for aspect classes

S*A/10	Score AS
0 – 1	1
1 – 2	2
2 – 3	3
3 – 4	4
4 – 5	5
5 – 6	6
6 – 7	7
7 – 8	8
8 – 9	9
9 – 10	10

Table 15: LS weight for aspect classes considering slope

However, these aspect values are independent of the local relief except for flat areas. As consequence, two areas having the same aspect will have the same LS value independently of their respective relief (nearly flat or steep for example). In reality, for areas of same aspect, the LS due to aspect will be bigger for steep ones than nearly flat ones. This can be expressed by multiplying the aspect value with the slope ones and then divided by 10 to get values ranging from 1 to 10 (Table 15).

Curvatures

The Profile Curvature (PrC) expresses the water accumulation. High profile concavity corresponds to high water accumulation and thus high LS.

The Plan Curvature (PlC) expresses the convergence / divergence of water. High plan concavity corresponds to high water convergence and thus high water accumulation or high LS.

Table 16 presents the weight for both plan and profile curvature.

Plan and Profile Curvature	Score PlC and PrC
Highly Convex	1
Convex	2
No	5
Concave	8
Highly Concave	10

Table 16: LS weight for plan and profile curvature classes

Erosion

The erosion map seemed to present a relevant legend regarding the LS. Existing erosion is a sign of ground fragilization and makes it more prone to landslide. Rills and gullies could be the starting point of landslides since that can enlarge with repetitive rain events that will dig them deeply and induce failures finally giving birth to landslide. This legend and corresponding LS values are presented in the Table 17.

EROSION	Rates E
No apparent erosion	0
Slight erosion - more than 50 % of the area is affected by sheet erosion - less than 10 % of the area is affected by rill erosion	3
Moderate erosion - more than 50 % of the area is affected by sheet erosion - 10 to 50 % of the area is affected by rill erosion - presence of some gullies	7
Severe erosion - more than 50 % of the area is affected by sheet and rill erosion - conspicuous development of gullies	10

Table 17: LS weight for erosion classes

River

The three river buffers are given gradual LS value since closer an area is to the river higher is the LS value. This is presented in Table 18, Map10.

River buffer (m)	Rates R
0 – 150	10
150 – 300	6
300 – 400	3

Table 18: LS weight for river buffer classes

Geology

The Geology map presented five classes that were grouped into three LS value since no difference in term of LS could be made for some classes. This is presented in table 19. The highest weight is given to the volcanic geology since volcanic is more unstable and presents fractures that could induce landslide. Sedimentary limestone was given an intermediate value of 5. Limestone is often a factor contributing to landslide but not really a causative one. Other sedimentary geology are rarely associated to landslide in literature.

Notes that this factor is really not sensitive for the NNNP area since almost whole NNNP is covered with the single class volcanic extrusive.

GEOLOGY	Rates G
Igneous rock volcanic extrusive Pleistocene	10
Igneous rock volcanic extrusive Quaternary	10
Sedimentary rock Miocene	0
Sedimentary rock Pleistocene limestone	5
Sedimentary rock Quaternary alluvium	0

Tableau 19: LS weight for geology classes

Soil

The Soil map presented ten classes that were grouped into six LS value since no difference in term of LS could be made for some classes. This is presented in Table 20.

Clayey soils were given the highest LS value since under certain conditions they are prone to liquefaction and they present some waterproof quality which contributes to the retention of water and thus its accumulation which in turn contributes to soil instability.

The class "Rough Mountainous land", presented without any other detail or indication on the soil map was given a value of ten. Indeed on the base of field survey it is considered that the mountain soil is highly prone to landslide. Some big and small landslide and rock slides were seen in the mountains.

LS value of 7 was given to the "Sandy clay loam" since the presence of interfaces between discontinuous layers of clay and sand can be at the origin of soil instability.

The class "Manapla Bago complex" could not be connected to a soil type. Moreover a class corresponding to No data was created since a very small coastal area on the soil map presented a non documented symbol and as a consequence, no soil type could be identified. A *neutral* LS value of 5 was given for both classes. This seems to be acceptable since the areas concerned are very small and coastal and will thus not really affect the final result.

The other classes were attributed a decreasing weight going from clay to loam and then sand according to their content in these types of soil.

Notes that, as for the geology, this factor is really not sensitive for the NNNP area since almost whole NNNP is covered with the single class "Rough Mountainous land".

SOIL	Rates S
Clay	10
Clay loam	8
Clay steep phase	10
Fine sandy loam	3
Gravely loam	3
Loam	5
Manapla Bago Complex	5
Sandy clay loam	7
Sandy loam	2
Rough Mountainous land	10
Other	5

Tableau 20: LS weight for soil classes

Land Cover (LC) and Land cover change (LCC)

The Land cover map presented eleven classes among which the class No data (clouds and their shadows) which covers a relatively important surface, especially above the Mt Mandalagan in the southern part of the image. An analyse of the location of the main no data areas has driven to the conclusion that the value of these areas could be replaced by the value of their highest frequency neighbor. This was realized thanks to the command Shrink in ArcMap. The legend is thus reduced to ten land cover classes.

Once again it is important to call the attention to the fact that a clear distinction has to be made between the two factors

- Land cover which represents the LS coming from the land cover only
- Land cover change which represents the LS coming from the change, the perturbation (due to deforestation) itself.

Stable state scenario

In the case of the stable scenario the land cover is the only factor to be considered since there is no land cover change and as a consequence, the factor LCC has a value of 0. The LS values for stable scenario (LCs) are presented in the first column of the Table 21.

Forested lands are given a low LS value because forest contributes to the stabilization of the ground thanks to their more or less deep roots which fix the ground.

Mountain forests are given the lowest value since they probably present more stable and non disturbed forest which corresponds to more important ground stability.

Forest from 600 m to 1100 m were probably already disturbed once (previous deforestation) since they corresponds mainly to secondary forest. Deforestation occurred for certain areas in a recent past. According to Sidle R. et Al. (2006) "timber harvesting with subsequent regeneration of secondary forests reduce rooting strength for up to two decades after initial cutting". Moreover ground disturbance due to logging roads and logging itself contribute to the soil instability. This class is given a LS of 3.

Cultivated tree land under 600 m and Riverain forest are regularly disturbed by human activity which reduce the ground stability. They are given a LS value of 3.

The Agricultural lands were given the highest value of 10 since the ground is regularly disturbed and not covered with crops, for example during ploughing. The ground seems to be very sensitive under those conditions.

The open areas were given a little lower value of 8 since they are not affected with disturbing agricultural practice. Grazing for grass lands seems not to be disturbing. A high value is given because no trees are present to fix the ground.

All the other classes were given LS of 0. Indeed it seems clear that no landslide could occur in fishponds or mangrove. The rivers used in the land cover are the one that were identified through the classification process. Only the large rivers located in low lands were identified. No landslide could occur in the place of these rivers. It could be thought that built up could influence LS. That's really true for roads or built up located on steep slopes for example. However, as previously explain the built up class of the land cover map do not identify theses cases.

Deforestation scenario

In the case of the deforestation scenario, both land cover and land cover change are considered.

Scenario	**Stable**	**Deforestation**	**Deforestation**
Land Cover	Rates LCs	LCd	LCC
Mountain forest (above 1100m)	1	8	9
Forest from 600 m to 1100 m	3	8	5
Cultivated tree land under 600 m	3	8	4
Riverain forest	3	3	0
Open area	8	8	0
Agricultural land	10	10	0
Mangrove	0	0	0
Fishpond	0	0	0
Water body	0	0	0
Built up	0	0	0

Table 21 : LS weight for land cover (LC) and land cover change (LCC) classes for stable and deforestation scenario

Land cover (LC)

The land cover LS values for deforestation scenario (LCd) are presented in the second column of the Table 21. The LS value of open areas (8) is given to all the classes which will be deforested since it is considered that the resulting land cover from deforestation is an open area. As there is no deforestation for the other classes, their LS values remain the same.

Note that the fact that no deforestation is considered for the riverain forest, this will partially decrease the important LS value around river due to the factor river buffer for areas under 600 m.

Land cover change (LCC)

The land cover change LS values for deforestation scenario (LCC) are presented in the third column of the Table 21. LCC LS values are given for the three forested classes that are considered in deforestation scenario only: Mountain forest (above 1100m), Forest from 600 m to 1100 m, Cultivated tree land under 600 m. No deforestation is considered for the Riverain forest because, according to observations realized during the field survey, it seems that people don't deforest forest along river. This explains why the riverain forests are still abundantly present in low lands.

High LS value of 9 is given to Mountain forests because they are judged to be very sensitive to perturbation (change) since they are considered as never disturbed before, or in any case really less disturbed than the other forests.

Forests from 600 m to 1100 m are given a value of 5 because a majority of them were probably already disturbed once (previous deforestation) since they corresponds mainly to secondary forest, and thus are judged less sensitive to new perturbation. The argument behind this is that some of the landslides that could have occurred due to the previous deforestation have probably already occurred that time.

Cultivated tree lands under 600 m are given a value of 4 since it is considered that they are usually disturbed, but not totally deforested. A deforestation will thus cause abrupt change but not so big than for the two other classes.

As there is no deforestation for all the other classes, their LS values are 0.

VI.3.2. Weighting of factors

The method used for the weighting of factors is the one of Expert evaluation. In order to reduce the subjectivity of this method, the expert appreciation is based on the field survey during which the landslide mechanism in the study site could be understood. Even if the landslide inventory was not directly used through a linear regression, the inventoried landslides contributed of course to the building of knowledge about landslide mechanism and thus contributed to the appreciation of the expert. Literature, presented in the bibliographic searching chapter, was also used as guidelines. However a very great heterogeneity of weighting factors, corresponding to a wide variety of method used, did not allow the expert appreciation to be mainly based on literature. Moreover no example of LSZ in case of deforestation was found. The modelling of deforestation is thus entirely based on the expert appreciation.

No linear regression technique on the base of this inventory seemed to be possible since not enough landslides could be identified to allow this regression.

The **AHP** method accompanied the expert appreciation in order to translate it in a more consistent way. The IDRISI value stating the relative importance of factors and the resulting factor's weights obtained this way are presented in the two following tables:

- Table 22 for stable and deforestation scenario with all the selected factors
- Table 23 for the deforestation scenario with the four main factors only

The weight of factors is calculated in a way to suit a formula which is additive only. Indeed no information was available or could be produced to model interaction between parameters.

In order to deal with fewer factors and to be clearer, the ten factors of the formula are aggregated into seven only. This aggregation consists in:

- Ground = 0.5 * Geology + 0.5 * Soil
- Hydro = 0.5 * Aspect + 0.5 * (0.5 * Profile curvature + 0.5 * Plan curvature)

The newly created data Ground will thus represent the additional LS values of both soil and geology for example.

VI.3.2.1 Stable and deforestation scenario with all the ten selected factors

Factors	Hydro	Ground	Erosion	LC	slope	River	LCC	**Factor's weight**
Hydro	1							0.04
Ground	2	1						0.06
Erosion	2	1	1					0.06
LC	5	4	4	1				0.18
Slope	5	4	4	1	1			0.18
River	5	4	4	1	1	1		0.18
LCC	7	5	5	2	2	2	1	0.30

Table 22: pairwise comparisons matrix for seven aggregated factors and resulting factor's weights (LC = Land Cover; LCC = Land Cover Change)

Consistency Ratio = 0.01

Another way to express the relative importance of factors translated by the IDRISI value can be expressed through this formula:

Hydro 2< Ground = Erosion 4< Slope = River =LC 2< LCC

Where "2<" has to be read "two times less important than" and "=", "same importance than"

The argument based on the field survey behind the pairwise comparison values, can be summarized as follow:

Hydro aggregated factors seemed to be the less important because no obvious relation between these factors and LS appeared during the field survey. The aggregated ground factors seemed to be as important as the erosion factor. Erosion was sensed as a mechanism that could be at the origin of slope failure and thus have an influence on LS as strong as the cumulated underlying soil and geology factors that strongly controls hydrologic process and soil stability. Note that these factors result from thematic map that seemed to be important generalization. As a consequence, it seemed that giving them to much importance could contribute to distort the model.

Several landslides were seen in the proximity to river on steep slopes and most of the time associated with not important land cover. These three factors seemed thus to be linked and have a crucial influence on LS. They were thus judged four times more important than the two previous ones. Moreover, it seemed impossible to distinguish the LS coming from each of them and they are thus given equal importance.

Finally, the LCC, because it is sensed as a strong and abrupt perturbation of the fragile ecosystem equilibrium, seems to have more importance than any other factors.

The Consistency Ratio of 0.01 indicates that the relative importance given to the factors is very consistent.

Factor's weights

Three groups of factors can be identified according to their weight:

- The LCC, which will count nearly for a third (30 %) of the whole factors. This value translates the very important susceptibility weight of the perturbation due to deforestation.
- LC, river buffer and slope have each a 0.18 weight (54 % all together)

This two first group's together account for 84 % of the whole LS weight

- Erosion, Ground, Hydro have finally a very small weight and this *all the more so* that their weight is divided among the factors they include.

This third group account for 16 % of the whole LS weight only.

VI.3.2. 2 Deforestation scenario with the four main factors only

Factor	LC	LCC	Slope	River	**Factor weight**
LC	1				0.2
LCC	2	1			0.4
Slope	1	½	1		0.2
River	1	½	1	1	0.2

Table 23 : pairwise comparisons matrix for four main factors and resulting factor's weights

LC = Land Cover; LCC = Land Cover Change
Consistency Ratio = 0

The CR of 0 indicates that the relative importance given to the factors is perfectly consistent.

The general argument behind these values is the same than previously.

Factor's weights

LCC's weight is the most important and account for nearly half (40 %) of the LS value whereas the three other value account for 20 % each (60 % all together).

VI.3.3 The LS formula

Once all the weights of factors and their classes are defined they can be combined in the formula that will express the LS value for each area (raster cell of 45 m).

Basic formula:

LS = A* Slope + B* Stream + C* Land cover + D*Land cover change +E* Erosion + F* Ground + G* Hydro

Where A, B, C, D, E, F, and G are factors' weights determined from IDRISI analysis.

Moreover the following constrain is added to that formula: if the slope is smaller or equal to 5 degrees, then the LS is null. Indeed it seems that no landslide could occur on slope *smaller* than 5 degrees.

If Slope $\leq 5°$ then LS = 0

This formula will be adapted according to the scenario and the factor used.

Stable state scenario

LS = 0.18* Slope + 0.18* Stream +0.18 * Land cover + 0.30*Land cover change **(LCC=0)** +0.06* Erosion + 0.06* Ground + 0.04* Hydro

As there is no deforestation in stable scenario, the LLC is null

Deforestation scenario

LS = 0.18 * Slope + 0.18* Stream + 0.18* Land cover (LCd) +0.30* Land cover change (LCC) +0.06* Erosion + 0.06* Ground + 0.04* Hydro

Deforestation scenario based on Slope, Stream and Land cover change

LS = 0.2* Slope + 0.2* Stream + 0.2* Land cover (LCd) + 0.4*Land cover change (LCC)

VI.3.4 Landslide Susceptibility value

The resulting LS value logically ranges from 0 to 10. These values have still to be converted in classes of susceptibility in order to be more understandable. Six susceptibility classes were created. These classes and the LS values they correspond to are presented in the Table 24.

The repartition of LS value into classes was made according to the following argument. The purpose is to be more sensitive for susceptible areas and thus to express better the different LS for these areas. As a consequence the LS value spreading out is large (3 LS units) for areas with small LS value and become smaller for more susceptible areas (2 or 1 LS units). Indeed it seems not interesting to go in detailed LS for areas with small LS. As no LS reached the value of 10, the last spreading out was extended from 8 to 10. In reality this last class is smaller than that. Moreover in order for the LSZ map to be more readable, to distinct better the different classes, a graphical analyse of this map helps in the choice of the LS value spreading out.

Susceptibility	LS value
No	**0**
Very low	**0 – 3**
Low	**3 – 5**
Medium	**5 – 7**
High	**7 – 8**
Very high	**8 – 10**

Table 24: LS classes related to LS value

An area classified as “High” LS for example doesn’t mean that this area presents a High LS, but it means that, according to this landslide modelling,

- this area present an higher LS than all the areas classified with lower LS class,
- this area presents a smaller LS than the areas classified with higher LS
- this area presents equal LS than the areas classified as “High” LS

As explained in the introduction, these resulting LS value correspond to spatial LS.
It enables the comparison of LS of one area in comparison with another in terms of more susceptible or less susceptible to landslide. The same is true for the different scenarios.

The same spreading out of LS values in classes is applied for the three LSZ maps.

VI.4 Landslide Susceptibility Zonation maps

The final result of all these successive steps is represented as a LSZ map for each scenario or methods. The three resulting LSZ maps are presented in Maps 13 14 and 15.

VI.4.1 LSZ maps analyze in terms of factors

The individual effect of some factors that were given the most important weights can be easily identified in the three LSZ maps. This is true for the slope, the river buffer and the LCC.

Regarding the **slope**, it is obvious on the three LSZ maps that the LS areas strongly correspond to the mountainous part while there are no LS for the lower lands. This reflects the importance of the slope factor and especially the strong importance of the constrain using slope (if Slope ≤ 5° then LS = 0).
The influence of slope on LS is thus clearly visible.

Regarding the **river buffers**, they clearly appear on the three LSZ maps through the linear shapes of the different LS colours. The High and Very High susceptibility areas are found where the river buffers locate only. This means that only the areas located in the river buffer present High and Very High LS.
The important influence of river on LS shows up really well.

Effect of **LC** is distinguishable for the stable scenario only. Indeed the central part of the forest massif which corresponds to low LS value of land cover (forest) appears in Low or Very low LS. This is due to the LC since the slope LS are high for these areas, that the river buffer is equally present independently of the central or surrounding part of the forest massif and that the LS of LCC is null for this scenario.
The stabilizer function of the forest regarding the LS is clearly visible.

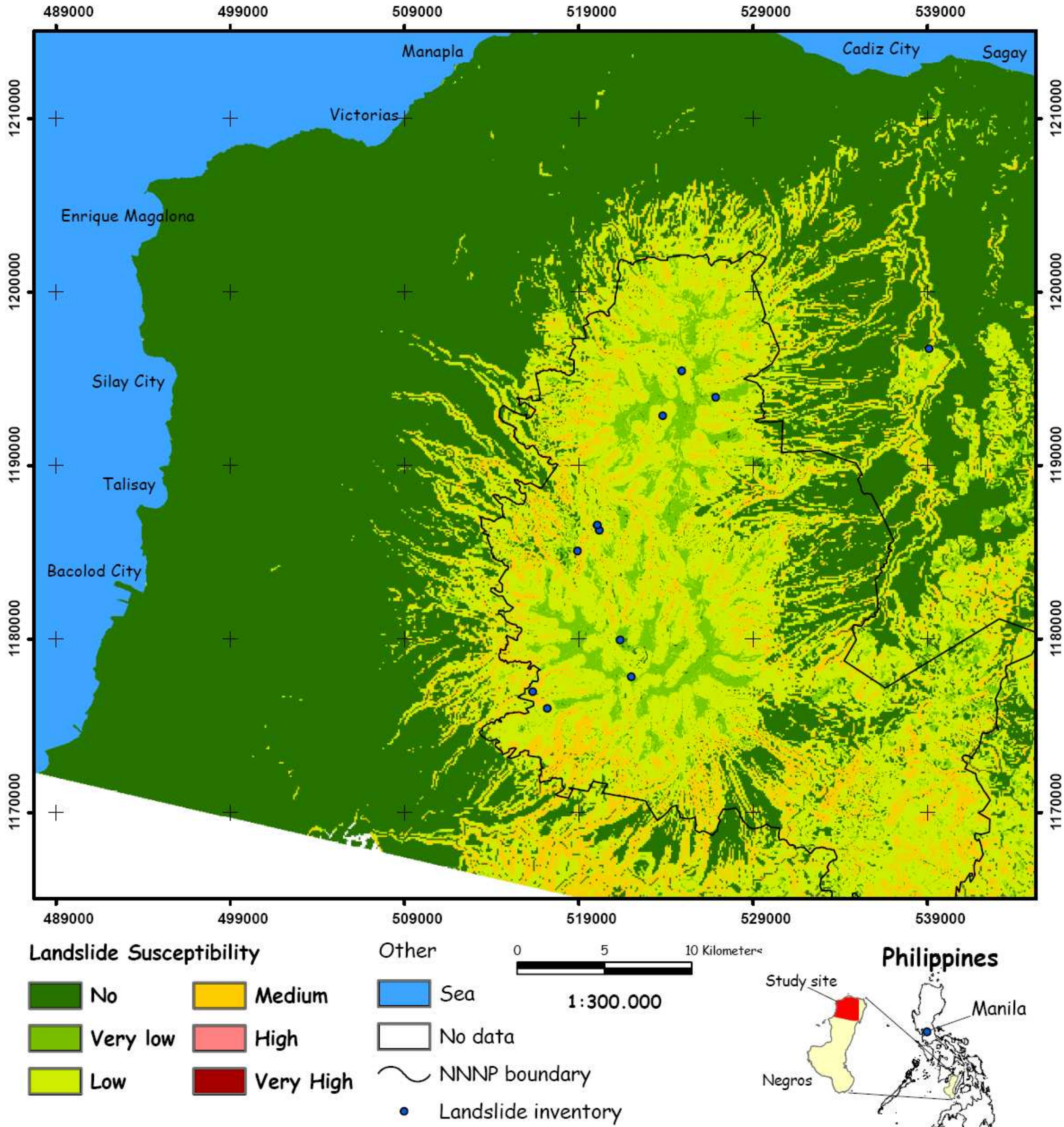
The **LCC** effect**,** which translates the deforestation, is obvious and corresponds to the transformation of the forest part from mainly Low or very low LS in stable scenario into mainly Medium LS with High and Very high LS along the rivers.
Effect of deforestation on the LS is thus clearly visible.

The individual effect of **other factors** is not discernible. This is easily understood regarding the low weight they were given in comparison to the four factors analyzed above.

Moreover the **constraint** is clearly visible in another way than the one mentioned about slope. Indeed the fact that the “Very low class” is nearly not represented is probably due to the fact that the constraint used include nearly all the areas that otherwise could presents that range of LS value (0 – 3) partially due to a really gentle slope . The “Very low Susceptibility” areas are supposed to be replaced by the “No Susceptibility” areas due to the constraint. However, note that in the stable scenario, the class “Very low” is represented in the central part of the massif because here the slopes are too steep to be included in the constraint but that the other factors (forest, no river buffer, no LCC) contribute to “Very low” value for these areas.

Landslide Susceptibility Zonation in North Negros

Stable state scenario



Sources :
- Land cover from digital classification of SPOT5 image (XS 1-2-3-4) - 10 m ground resolution (27 February 2003)
- Rivers network from NAMRIA topographic maps - 1/50 000 (1956) (ESSC)
- Geology from Geology map - 1/250 000 (1994) (MGB- DENR VI, Iloilo City)
- Soil from Soil map - 1/200 000 (1974) (Department of Agriculture - Bureau of Soils - Soils Survey Division - Region VI)
- Erosion from Erosion map - 1/250 000 (later than 1975) (Ministry of Agriculture - Bureau of Soils - Manila)
- Slope, aspect, plane and profile curvature from
  - SRTM 1 - 90 m ground resolution (2000) (SRTM - NASA/NGA) for lowlands
  - DEM from NAMRIA topographic maps (20 m topocurves) (1956) (PEMO) for uplands
- Landslide inventory from field survey (March - June 2006)
- NNNP boundary from PEMO - Bacolod

N

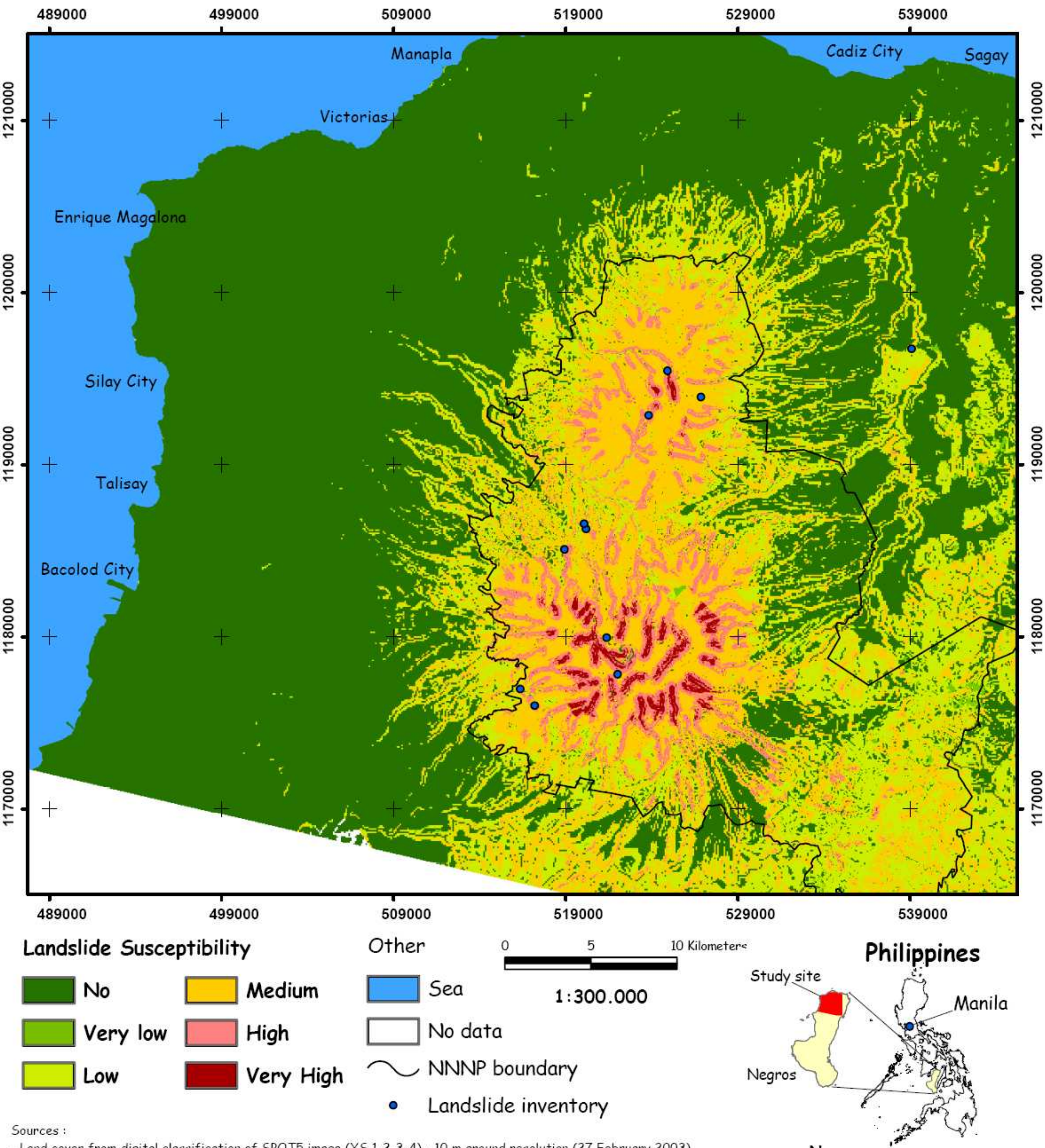
Projection UTM Zone 51N
Datum : WGS 1984
Coordinates in meters

Author : Antoine DENIS
UCL-Geomatic - August 2006
CUD2 project (BALAYAN - ESSC - FUNDP - FUSAGX - UCL)

Map 13 : Landslide Susceptibility Zonation in North Negros - Stable state scenario

Landslide Susceptibility Zonation in North Negros

Deforestation scenario



Sources :

- Land cover from digital classification of SPOT5 image (XS 1-2-3-4) - 10 m ground resolution (27 February 2003)
- Rivers network from NAMRIA topographic maps - 1/50 000 (1956) (ESSC)
- Geology from Geology map - 1/250 000 (1994) (MGB- DENR VI, Iloilo City)
- Soil from Soil map - 1/200 000 (1974) (Department of Agriculture - Bureau of Soils - Soils Survey Division - Region VI)
- Erosion from Erosion map - 1/250 000 (later than 1975) (Ministry of Agriculture - Bureau of Soils - Manila)
- Slope, aspect, plane and profile curvature from
  - SRTM 1 - 90 m ground resolution (2000) (SRTM - NASA/NGA) for lowlands
  - DEM from NAMRIA topographic maps (20 m topocurves) (1956) (PEMO) for uplands
- Landslide inventory from field survey (March - June 2006)
- NNNP boundary from PEMO - Bacolod

Projection UTM Zone 51N
Datum : WGS 1984
Coordinates in meters

Author : Antoine DENIS
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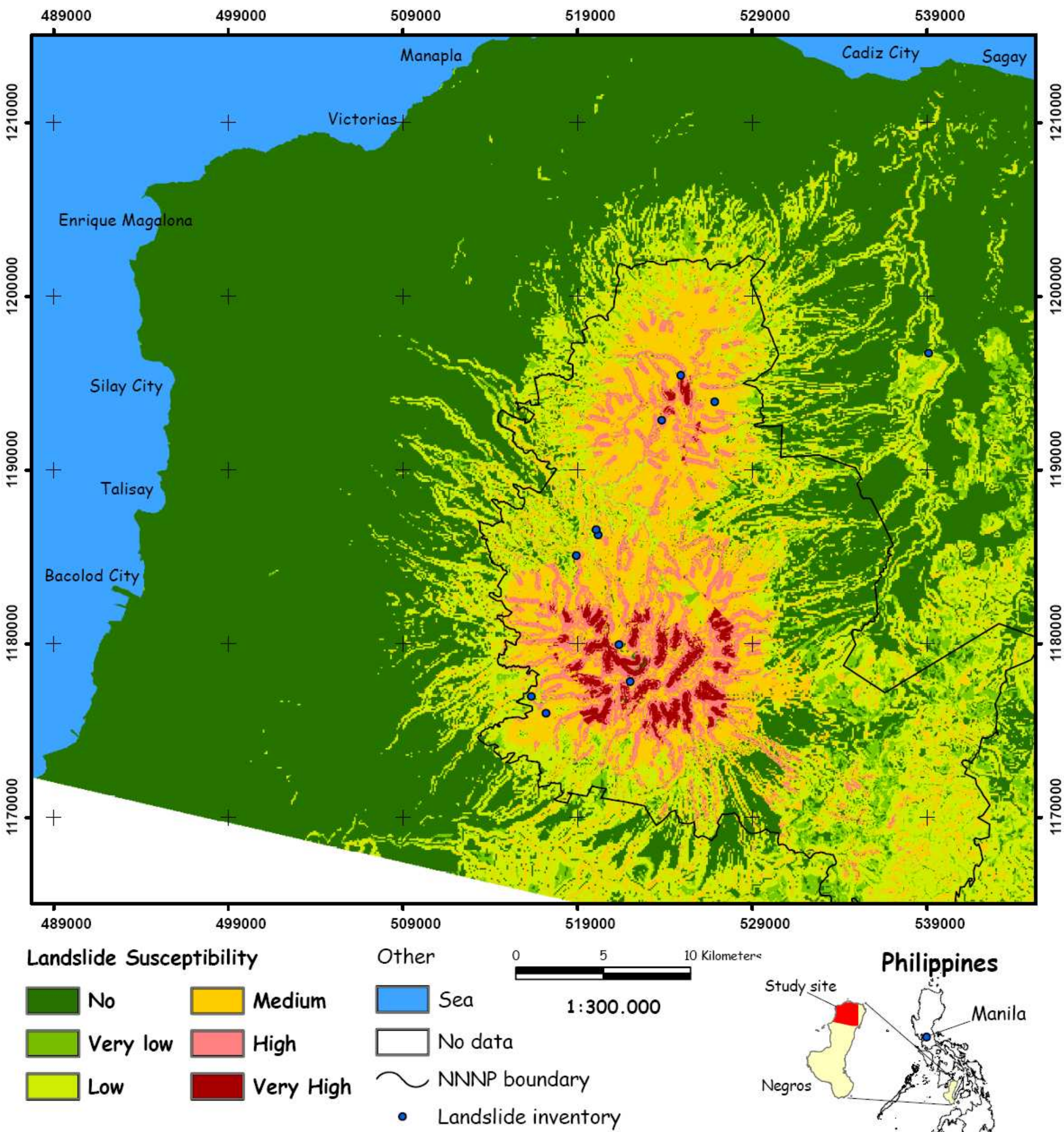
CUD2 project (BALAYAN - ESSC - FUNDP - FUSAGX - UCL)

Map 14: Landslide Susceptibility Zonation in North Negros - Deforestation scenario

Landslide Susceptibility Zonation in North Negros

Deforestation scenario based on Slope, Stream and Land cover change



Sources :
- Land cover from digital classification of SPOT5 image (XS 1-2-3-4) - 10 m ground resolution (27 February 2003)
- Rivers network from NAMRIA topographic maps - 1/50 000 (1956) (ESSC)
- Geology from Geology map - 1/250 000 (1994) (MGB- DENR VI, Iloilo City)
- Soil from Soil map - 1/200 000 (1974) (Department of Agriculture - Bureau of Soils - Soils Survey Division - Region VI)
- Erosion from Erosion map - 1/250 000 (later than 1975) (Ministry of Agriculture - Bureau of Soils - Manila)
- Slope, aspect, plane and profile curvature from
  - SRTM 1 - 90 m ground resolution (2000) (SRTM - NASA/NGA) for lowlands
  - DEM from NAMRIA topographic maps (20 m topocurves) (1956) (PEMO) for uplands
- Landslide inventory from field survey (March - June 2006)
- NNNP boundary from PEMO - Bacolod

Projection UTM Zone 51N
Datum : WGS 1984
Coordinates in meters

Author : Antoine DENIS
UCL-Geomatic - August 2006
CUD2 project (BALAYAN - ESSC - FUNDP - FUSAGX - UCL)

Map 15 : Landslide Susceptibility Zonation in North Negros - Deforestation scenario based on Slope, Stream, and Land cover change

Conclusion

The whole analyze in terms of factors brings to the conclusion that the weighting of factors and classes and the constraint used show up very clearly in the final LSZ maps. This means that the LSZ maps are consistent with the weighting of factors and classes.

VI.4.2 LSZ maps analyze in terms of scenario

For **both scenarios**, the highest LS are found for the mountainous part and other areas are characterized by low LS.

Stable scenario

In the case of the stable scenario, the highest LS values are found for the border of the forest massif and lower, and not for the very steep relief characterizing the interior of the massif. These areas are located where the slopes are quite steep but not very much. They present a land cover corresponding to the classes of agricultural and open areas mainly, which are very sensitive to landslide. The decisive factor is thus in this case the LC.

This shows up that the more susceptible areas to landslide in the case of a stable scenario are the areas at the feet of mountains, characterized with quite important slopes (but not to steep) that still enable their cultivation, and that are thus agricultural or open areas on quite steep slopes. The model thus identifies these areas as the most susceptible to landslide.

The second more susceptible areas for this scenario are the steep forested areas of the interior of the forest massif. Susceptibility, essentially coming from the river buffers and the steep slopes, is however diminished thanks to the land cover corresponding to forest in this area.

Finally the vast majority of lower lands corresponding to agricultural land on very gentle slopes or flat areas present small LS values. This is partially due to the constraint used. Despite the important effect of river buffers on LS, which shows up very well on the maps, the LS stay low since the other factors for these areas do not add enough LS.

Deforestation scenario

In the case of the deforestation scenario, the highest LS values are found for the forest massif where deforestation occurs. All the forest massif is at least covered with “Medium” LS which become “High” or “Very high” LS in the surroundings of the rivers. The vast majority of these areas present the three forest types considered to be deforested and thus received the important LS values related to the LCC factor. Regarding the LSZ map it seems that effect of deforestation shows up very clearly with apparition of at least Medium LS.

It is interesting to note that the “Very high” LS are found in the Mountain forest only (above 1100m). This means that the sensitivity of the model and its simbology (classes spreading out) enable to represent the fact that a deforestation will have more consequences in terms of LS for “untouched” or non perturbed area corresponding to Mountain forest, than for the other forests that were considered as disturbed at least once in the past and as a consequence which were judged less sensitive to a new perturbation.

Comparison of the two scenarios

Comparing the two scenarios, the effect of deforestation is clearly visible. The LS increase due to the deforestation is really well expressed and obvious.
The areas that present the highest LS in the stable scenario keep the same LS but become intermediate LS areas in the deforestation scenario.

All the areas that not correspond to the three forest types considered to be deforested keep the same LS since no change occurs for theses areas in comparison to the stable scenario.

Conclusion

The analyze of the LSZ maps in terms of scenario shows up that they are consistent with the scenarios they illustrate. Indeed the differences of LSZ among the two scenarios are well marked and are consistent with the logic used for the weighting of factors and classes. Moreover this analyze could bring to the light the factors that seemed to be decisive for each scenario.

It also appears that the representation of LS on the LSZ maps is well readable and that lots of information could be extracted from these maps only or in comparison with factors and scenarios.

VI.4.3 Sensitivity analyzes for deforestation scenario

The comparison of the two LSZ maps in case of deforestation produced one with ten factors and the other with the four main ones only enables a general analyze of the sensitivity of the factors used.

The two deforestation scenario maps are quite similar. Only small differences can be noticed among them, corresponding to a few more areas of higher LS for the LSZ using the four main factors.

The fact that there is only few difference between these two scenarios expresses that this model is not very sensitive to the use (or not) of other factors than the four main ones. This was already obvious for the individual factors because they present very small coefficient: factors composing Hydro, Ground and Erosion. Now it is also obvious that all these factors together, which correspond to 16 % of the total LS of the model, are not really sensitive for this modelling. As a consequence and according to the logic that underlies the weighting of factors and classes in this modelling, it seems that further modelling using the same logic could use the four main factors only.

Note that even if the LS is actually sensitive to some of these less important factors, the fact that they are included in 16 % only of the total LS value will hide this sensitivity.

As a conclusion, it can be said that this sensitivity analysis shows that the LSZ results in case of deforestation are not sensitive to the use of other factors than the main four ones.

VI.5.4. LSZ maps analyze in comparison with the landslide inventory

The landslides inventoried during the field survey were reported on the LSZ maps in order to compare them with the LS classes they are included in, and this for each scenario. The table 25 presents the number of landslides inventoried that are included in each LS class on the three LSZ maps.

Analyze of the LSZ results on the base of the landslide inventory presents several strong limitations. These are the followings:

- The small number of landslides inventoried (11) is judged not representative enough to make strong conclusions on their basis only. This inventory is directly dependent on the areas visited during the field survey which are judged not representative enough to extrapolate the information collected to the rest of the study site.
- Some landslides are approximately located on the LSZ map. Indeed not all the landslides could be georeferenced. Some were seen as part of the landscape during the field survey and then located on the base of field description and the satellite image which is not perfectly georeferenced.
- Sometimes landslides inventoried locate near the boarder of two different LS cell. For example only ten meters separates some landslides on the LSZ map from low or high or very high class. In reality these abrupt borders do not exist.

The analyse of this table has thus to be done keeping these limitations in mind. However, despite these limitations it seemed that this comparison could be done in order to give a general appreciation on the LSZ maps produced.

Scenario / Susceptibility	Stable		Deforestation		Deforestation 3	
	landslide	%	landslide	%	landslide	%
No						
Very low	**3**	27				
Low	**7**	64	**2**	18	**2**	18
Medium	**1**	9	**7**	64	**6**	55
High			**2**	18	**3**	27
Very high						
Total	11	100	11	100	11	100

Table 2: Number and percentage of inventoried landslides corresponding to each LS classes for each scenario.

VI.5.4.1 In terms of LS class and scenarios

The first observation is that the landslides inventoried don't correspond to the highest LS classes represented on the LSZ maps for each scenarios ("Medium" for the stable scenario and "High" and "Very High" for the deforestation scenario).

The second observation is that the maximum number of landslides for each scenario is not in the highest LS class represented for the scenario concerned.

These two observations are explained as a non correct fitting between factors and classes weighting of this modelling and the landslides inventoried.

This is explained by the fact that the weighting of factors and classes didn't used directly the landslides inventoried through a linear regression for example but was inspired by both the field survey and literature. As a consequence, there is no real fitting between the landslide inventoried and the LSZ maps.

For both scenarios, no landslide is observed for “No” LS areas. This seems to be normal.

Stable scenario doesn’t present any landslide in “High” and “Very high” LS areas. This is normal since it does not present any “Very high” LS areas.

In the deforestation scenario no landslide is present for the “Very high” LS areas. More than the reason given previously, it could be understood regarding the fact that very few areas are characterized by this LS class.

VI.5.4.2 In terms of Factor

First an analyze for each factor is undertaken. However since the factors are not independent a cross analyze between the main factors is then shortly presented.

River buffers.

As presented in the table 26 the majority of the inventoried landslides (8/11) are included in the two first river buffers (0 – 300 m). Giving a little more important weight to the second river buffer (150 – 300 m) could highly contribute, for the four landslides included in this buffer, to lie in higher LS classes and thus give really better results regarding the landslide inventory. This observation confirms the very important role of the proximity to rivers on the LS. However this has to be related to the fact than an important surface of the study site is actually covered with river buffers.

River buffer	0 m – 150 m	150 m – 300 m	300 m – 400 m	> 400 m
Landslides	4	4	0	3

Table 26: Number of inventoried landslides included into each river buffer

Land cover and land cover change

It is obvious regarding the table 27 that the majority of landslides are included in the general class forest (10 /11) and that most of them are included in area concerned by deforestation (9/11). One landslide corresponds to open areas. The inventory is consistent with the LCC weighting since nine landslides are included in potential deforested areas. However it is not in the case of the stable scenario since Forest class presents low LS value and that most of the landslides (10/11) are included in forest. This could be explained by the fact that some of the landslides inventoried in forest were directly related to previous deforestation (along abandoned logging roads or landslide perpetuating from that time).

LC	Mountain forest	Forest from 600 m to 1100 m	Open area	Riverain forest
LCC	YES		NO	
Landslides	2	7	1	1

Table 27: Number of inventoried landslides included into each land cover

Slope

Most of the landslides (8/11) (Table 28) are included in the two slope weight of 5 (5° to 15°) and 8 (15° to 30°). Only two landslides are included in the judged highest LS slope class weighted with 10 (30° to 45°). This indicates that the slope weighting doesn't correspond to the landslide inventory slope characteristics. In order to adapt the modelling to that inventory the highest LS weight should be given to slopes of 5° to 30°.

Slope weight	3	5	8	10
Landslides	1	4	4	2

Table 28 : Number of inventoried landslides included into each LS slope classes

Cross analyze of different factors

A cross analyze of the main factors on LS was tempt to check if a potential obvious relation between the main factors and the inventoried landslide appeared. Each landslide is related to its characteristics for the three main factors. This is presented in Table 29.

Landslide N°	1	2	3	4	5	6	7	8	9	10	11
Slope weight	10	8	8	8	**5**	**5**	**5**	10	3	5	8
River buffer	0-150	0-150	0-150	< 400	**150-300**	**150-300**	**150-300**	< 400	< 400	0-150	150-300
LC	F6	F6	F6	F6	**F6**	**F6**	**F6**	FM	FM	RF	Open

Table 29: Crossing of inventoried landslides with three factors

The factor combination that is the most represented corresponds to (5, 150-300, F6) for the three landslides number 5, 6 and 7. This is judged not to be an obvious combination since three landslides only are involved. This analyze is stopped here due to this weak result and the limitation cited above.

VI.5.4.3 Conclusion from the comparison with the landslide inventory

A more important landslide inventory and solution to the other limitations cited above should be necessary to draw pertinent conclusions from this analyze. However this analysis was attempted in order to get an idea of how well the landslide inventory and the LSZ maps fit each other. Comparison of the inventory with the LSZ maps shows that they partially fit only. If other new landslides present the same characteristics in term of factor than the ones already inventoried, the weighting of factors and classes should be revised in order for the resulting LSZ maps to fit better this new and more complete landslide inventory.

VI.5 Further improvement

Some proposition or ideas for improvement of this modeling are briefly summarized:

- It seems during the field survey that two factors, that could not be taken into account for this modeling because no data were available, have a strong influence on the LS. These two factors are:
  - The old logging roads resulting from previous deforestation and still present in the forest massif. However their influence will decrease with the time.
  - All the other roads and especially the numerous roads that are under construction or that seem to have to be constructed in a near future even in areas presenting steep relief
- A more important landslide inventory could enable to adjust the factors and classes weighting with the landslides characteristics resulting from this inventory.

VI.6 Other propositions

Two ideas, that were not realized because this modeling seems to be too rough and not validated to enables their realization in a relevant way, are explained here. They could be applied only if the modelling can be improved and validated as fitting to the reality. These two ideas are:

- To distinguish different types of deforestation such as for example “selective logging deforestation” or “slash and burn deforestation” which for sure have different influences on the resulting LS.
- To overlay the Community center with the LSZ maps. Some potential buffer of safety could be thought.

Chapter VII: Discussion

Regarding the objectives presented:

- The quality of the image (important topographic effect, bad georeferenciation) and the difficulty encountered during the field survey in the tropical mountainous forest of North Negros (accessibility, security) are the reasons that not enabled a detailed forest type differentiation. However, this problem was partially solved with the use of an alternative technique of classification (elevation, river buffer). The **land cover map** finally produced fully satisfy the needs for its integration in a LSZ model

- The getting, building, transformation, expression and integration of the input data in a GIS database for the LSZ modelling are satisfying. However uncertainty will remain on the resulting LSZ maps since no thorough validation could be undertaken by lack of sufficient landslide inventory.

It also appears clearly that:

- The methodology used and the results strongly depend of the input data availability and quality, as well as the availability of time to realize the numerous operations undertaken for the achievement of this work.
- Enhancement in both the land cover map and the LSZ modelling should be easy to proceed in potential further operations

Note that the potential use of the "LSZ in case of deforestation maps" as a help in the selection of preferable areas to deforest, in the case of timber harvesting, seems to be not appropriate. Indeed, all the remaining forest is included in the recently proclaimed NNNP where no deforestation is allowed any more. The only deforestation that still occurs is realized through illegal logging on which the LSZ maps are null and void.

However, another type of deforestation is the one caused by the settlement of new people coming from low land and who clear forest to cultivate it on always steeper slope of the mountain. As this trend seems to go on, these maps could be used to prevent people from settling in areas that present a relatively important LS value. However, as the arrival of these people is also most of the time illegal (squatter status), this prevention seem to be difficult to apply too.

What about the future of North Negros?

The present situation in Negros is quite critical. Roundtrip in Negros countryside is sufficient to understand how big the problem is. Illegal logging, kaingin (charcoal making) and slash and burn practice to bring into cultivation new land on steep slope is a commonplace. Settlement of people and building of new roads in steep areas is also a trend that seems not to be going to decrease in the years coming. Some of the reasons for this situation are for sure the important and uncontrolled population growth associated with the lack of appropriate land tenure and the poverty of a large ratio of the population which is obliged to move in always upper lands to find a place where to survive, most of the time, at the expense of the last diminishing mountainous forest. Another remaining problem, maybe the major one, is the lack of money to apply the legislation or to be able to undertake concretely and efficiently the decisive actions that would result in a sufficient protection of one of the last remaining forest of Negros and of the Philippines.

Note that global warming due to the greenhouse effect and especially changes in precipitation, typhoon patterns, occurrence of La Nina and El Nino, and air temperature is an additional element that could strengthen the future landslide activity if nothing is done to prevent the worst to happen.

However, it is clear also that numerous Pilipino people are very conscious of the environmental problematic of Negros in particular and the Philippines in general. Always increasing number of people become aware of that and a strong willingness to protect the environment exist and is currently developing. This can be illustrated by:

- The previous but still in application Northern Negros Forest Reserve Development Program (NNFRDP) that has the following component: protection of forest by organization of Bantay Bukid Brigades, Reforestation Program including Integrated Social Forestry (ISF) and Forest Nursery Establishment, Livelihood project such as rattan and Bamboo growing,…

- The recent establishment of the NNNP, administered by the "NNNP Management Council". It is a policy making body that over see the implementation of all programs relatives to the protection and rehabilitation of NNNP. Some of its strengths are the willingness of LGU to participate in the program, the strong support of NGO, and NGAs (DENR) and the involvement of PEMO, CENROS and PENRO. Moreover it currently develops the "Integrated Protected Area Plan" (IPAP) for NNNP which seems to be promising for an actual enhancement of the environmental and socio-economic situation in NNNP.

Finally, the international community seems to be present through several cooperation projects that can support Pilipino people in their movement for the protection of their extremely rich but threatened environment.

The question is about to know if this environmental awareness will be sufficient to oppose to the current trend where deforestation goes on.

The solution is not one but has to come from a wide variety of sources that are originating in Negros.

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The Philippines' First Website on Tropical Cyclones: Typhoon2000.com

Annexes

Annex 1: Classification field sheet

Annex 2: Field classification legend

Annex 3: GCP field sheet

Annex 4: Landslide field sheet

Annex 5: land cover map of Negros Occidental

ANNEX 1: Classification field sheet

Geographic Coordinate System: GCS_Luzon_1911 Datum: D_Luzon_1911
GPS in use: Trimble GeoXM CUD project
Date:
Hour:
Photo Ref:
Observer: Antoine

Pt N°	GPS file N°	Coordinates
Map N°	Place (name)	X
		Y
		Z

Description of the area

Landcover :

- **PRE:** forest, other wooded land, agro, open land, built up, water b.: +
- **POST**: forest, other wooded land, agro, open land, built up, water b: +

- **Species:** dominance (>75%) mix: dry - irrigated annual - perennial

Strat <=>	Species	Status	Height/matu	%Grnd Cov	Colour	Port/diameter
1			/			
2			/			
3			/			
4			/			
5			/			

(DOminating, dominated, SHrubbery, GRass, bare, EPiphyte, Moss, creeper, roots…)

- **Canopy:** % closing: O <10 10-40 40-75 >75 C Roughness 1 2 3 S Scheme
- **Disturbance**: Gap size Density Timber extraction Human: Fragmentation Regenerating: pioneer plantation

Site Description:

- **Slope (%):** 0-5 5-8 8-12 12-30 30-60 60-100 >100 ; Convexity: Regularity
- **Relief**: Low (valley, plain) Intermediate Up (mountain side, top) Other:
- **Landscape** (type, unity, bond with cover):

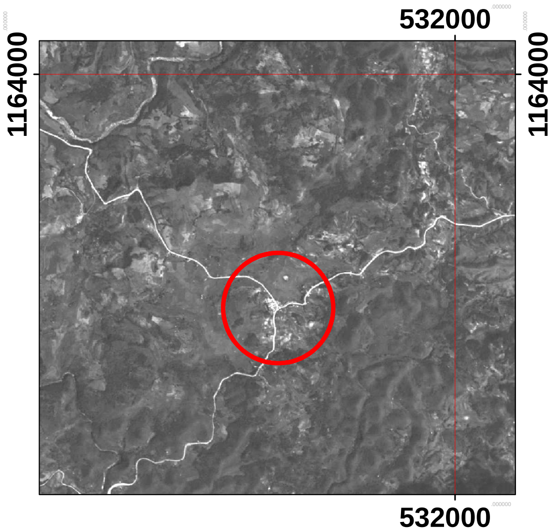
- **Exposition**: clouds
- **Soil** (type, substrate): rocky humus sand roughness other:
- **Water :** river: M m irrigation: water area: Fish pond: Salt extract humidity Other:
- **Surface**: similar area: <0.5 ha >0.5 ha parcel
- Homogeneity: shape:
- **Built up:** density 1 2 3 rural – urban under developpement Roads M m quarries mine

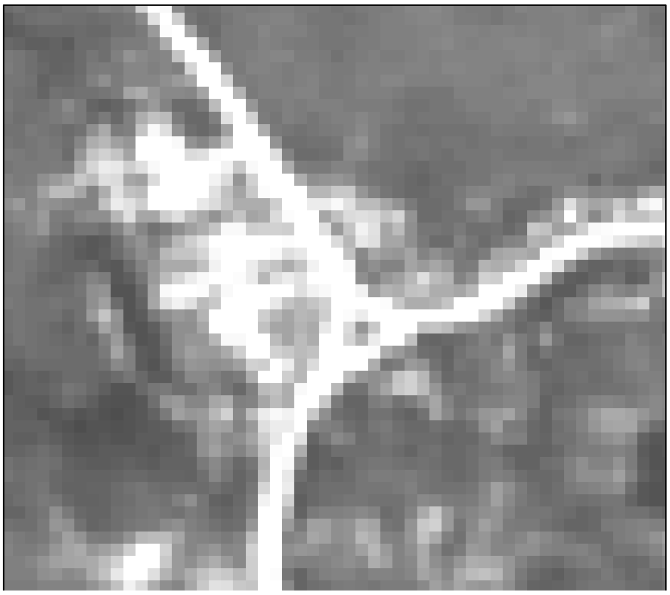
Scheme, General comment:

ANNEX 2: Field classification legend

Field classification legend	
Class	**Type**
Forest	Old dipterocarpacee
	Mossy
	Pines
	Regenerating
	Regenerating transition
	Residual primary
Other land with tree cover	Mangrove
	Orchard
	Eucalyptus plantation
	Brush and shrub
	Riverain forest
Agricultural land	Dry
	Irrigated
Open areas	Pasture
	Grass fallow
	Burned area
	Landslide
	Quarry
Built up	City
	Rural settlement
	Road
Water bodies	Sea
	River
	fishpond

GCP





Date:
Hour:
Photo reference:
GPS ref:

Comment:

Point N° **GPS File N° :**	Coordinate System: Datum:		
ANTE	X :	Y:	Z:
POST Nbr Points Moy :	X :	Y:	Z:

ANNEX 4: Landslide field sheet

Geographic Coordinate System: GCS_Luzon_1911 Datum: D_Luzon_1911	
GPS in use: Trimble GeoXM CUD project	
Observer: Antoine	
Date:	Hour:
Photo Ref:	

Pt N°	GPS file N°	Coordinates
Map N°	Place (name)	X
		Y
		Z

Description of the area

Landcover :

- **Around Species:**
  % Ground Cover Foliage buffer power Roots (depth, distribution, fix power)
- **On LS:** Bare re green pioneer: Plantation more advanced: % cover

General Site Description:

- **Slope (%):** 0-5 5-8 8-12 12-30 30-60 60-100 >100 ; Convexity: Regularity
- **Relief**: Low (valley, plain) Intermediate Up (mountain side, top, Volcano) Other:
- **Exposition**: Macro: Micro:
- **Landscape** (type, unity, bond with cover):
- **Fragmentation**: Gap size Density Homogeneity:
- **Soil** (type, substrate): rocky humus sand lava roughness thickness erosion other:
- **Geology limit:**
- **Lithology:**
- **Geomorphopedo:** fault trace, discontinuity sets, distance: …..
- **Water:** distance…… River: M m Depth river bed
  Irrigation: Water area: Underground-Surface Spring Drainage
  Weathering of superficial bedrock Humidity Clouds Other:
- **Built up:** Roads M m distance….. Habitat: density 1 2 3 rural – urban under-development Distance Quarries Mine
- **Surface**: similar area:

Historical Context:

- **Age**:
- **Disturbance, Activity**:
  Human activity : Timber extraction Big Small Clear cutting Fire Agriculture
  Other:
- **Circumstances**: rain storm intensity duration period
- **Damage**: human natural
- **State of land after LS**:
- **Population perception** (causes effects, reconsideration of impact):

Several schemes (verso): profile, transversal, general shape and particularity

ANNEX 5: Land cover map of Negros Occidental