Determining the Effect of Social and Ecological Factors on Land Use Land Cover Diversity in Northern Upland Vietnam using Spatial Regression

by

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Geography

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April 2013

ACKNOWLEDGMENTS

First and foremost I would like to thank my supervisor Thi-Thanh-Hiên Pham. I am extremely grateful to have had the opportunity to work with her for the last year. Without her advice on the methodology and assistance in the data collection process this thesis would not have been possible. I would like to further extend my gratitude to my reader Sarah Turner for her on going advice and support. I would like to thank both of them for going beyond the requirements of a supervisor and reader and providing me with inspiration and skilful review throughout all stages of this journey.

I would like to thank Margaret Kalacska for allowing me to use her remote sensing laboratory during the early stages of this project. I would also like to thank my friends and family for providing ongoing love and encouragement. Finally, I would like to acknowledge and thank everyone who provided me with advice and editing assistance throughout the final steps of this project including Paige Garbutt, Jared Simpson, Maryann Watts and Daniel Haberman.

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ABSTRACT

This research explores the relationship between land use land cover (LULC) diversity, socio-economic and ecological factors in five border districts of Lào Cai Province, Vietnam from 1999 to 2009. Within this area, a series of government policies and unique ethnic minority livelihood strategies have influenced local land use decisions. Diversity was regressed against elevation, slope, distance to border, distance to roads and distance to markets using a global regression and geographically weighted regression. The results suggest a drastic increase in forest cover and urban regions as well as a decrease in agricultural fields. This may indicate a shift in livelihood strategies to cardamom production or diversified strategies such as textile sales or tourism initiatives. Overall, the five variables were effective predictors of LULC diversity. Ecological variables are more significant indicators of diversity in 2009 suggesting that land use is inhibited by ecological variables when social variables increase in extent and accessibility.

CHAPTER 1: INTRODUCTION

Global land use change, including deforestation, agricultural expansion and urbanization, are occurring at an unprecedented pace and have major implications for the environment (climate change, land degradation, water depletion) and human well-being (food provision and security, and disease) (Foley et al., 2005; Jakobsen et al., 2007). Since the early 1990s, processes guiding land use and land cover change (LULCC) have drawn significant attention from researchers and funding institutions, including the Global Land Project and the International Geosphere-Biosphere Programme (Entwisle and Stern, 2005; Gutman, 2004). Consequently there is a growing body of research on LULCC being conducted in various geographic regions and socio-political contexts (Chowdhury and Turner, 2006; Gray et al., 2008; López-Carr et al., 2012; Müller and Munroe, 2008), including Southeast Asia and Vietnam (Cassidy et al., 2010; Fox and Vogler, 2005; Walsh et al., 2001). However, there is still a need to understand the causal mechanisms of LULCC, such as the role of exogenous and endogenous forces, be they socio-economic, political or ecological. This research focuses on the role these forces play in predicting LULCC and diversity in a border upland province of Vietnam.

1.1 Market integration, upland livelihoods and government policies in Lào Cai Province, Vietnam

In response to the increasing connectedness of the global economy, many countries have diversified their political agendas to encourage national economic growth and international integration. Vietnam is no exception to this phenomenon. The Greater Mekong Subregion Program is a regional economic cooperation scheme funded by the Asian Development Bank. Its main objectives are to improve economic relations and facilitate trade between Vietnam, the People's Republic of China, Làos, Myanmar, Thailand and Cambodia (Turner, 2013). Within Vietnam, one aspect of the national plan is to connect isolated northern upland communities with rapidly expanding city centers and Yunnan Province, China.

The province of Lào Cai is one of several provinces located in northern upland Vietnam targeted by market integration and trade route development schemes. This research considers five northern districts of Lào Cai, all of which border Yunnan Province, China (Figure 1.1). This area covers approximately 2800km^2 and is mostly mountainous with a mean elevation of 758m and a slope of 19°. The Red River passes through the central part of the province and the Chay River passes through the eastern segment.

Figure 1.1: Study area border districts in northern Lào Cai Province, Vietnam.
Source: (Turner, 2011, 5)

In 2009 the total population of this area was approximately 200,000 (GSO, 2009). A large number of inhabitants live within the Red River Valley where they practice lowland land uses such as paddy rice production (Roche and Michaud, 2000). Sparsely populated ethnic minority groups (predominately from the Yao and Hmong groups) characterize the uplands and are distributed heterogeneously throughout the mountainous terrain. Traditional land uses of upland ethnic groups are rotational swidden plots (Turner, 2011). However, more recent livelihood strategies incorporate a mixture of swidden plots, corn or upland rice fields, the collection of non-timber forest products such as fuel, honey or herbs and small-scale commercial exchanges of cardamom, textiles, alcohol, game or other products (Bonnin and Turner, 2012; Turner, 2011).

Prior to the 1960s, land in the uplands was owned by the state and consisted of relatively homogenous forest or agricultural systems (Castella et al., 2005). Since then, land ownership has been transferred to the household and various government policies have been implemented to control land use, in particular crop choices and deforestation. More recently, policies aim to sedentarize ethnic minority groups through fixed agriculture systems, while integrating them into the regional and national economy. Since ethnic minority relations with the state are at times weak, the interpretation and implementation of these policies has been carried out to varying degrees throughout the uplands (Turner, 2011).

1.2 Objectives and research aims

To analyze the effect that state-led agricultural and forestry policies have had on land use in Vietnam, several studies have examined land use transitions at the national or district level (Castella et al., 2005; Fox and Vogler, 2005; Meyfroidt and Lambin, 2008a). However, the effects of policy reforms are heterogeneous and vary considerably across regions based on local interpretation and implementation (Castella et al., 2005). Within the northern uplands, the influence of local policies has high spatial variability due to the diversity of biological and social conditions (Clement et al., 2009). Land use land cover (LULC) diversity is a good illustrator of how a land use system adapts to change (Cassidy et al., 2010) and is used within this project as an indicator of local variations of the impact of these policies. To date, there have been no land use studies in the provinces and districts along the Sino-Vietnamese border because of security reasons and difficult physical access. This project **aims to understand the effect national economic, agricultural and forestry policies have had on local land use and livelihood strategies within the border districts of Lào Cai Province over a ten year period.** The main objectives are to:

- Determine how LULC and LULC diversity have changed between 1999 and 2009 within the five border districts
- Determine the local influence of physical conditions (elevation, slope) and access to the regional and national economy (distance to roads, distance to markets and distance to the Sino-Vietnamese border) on changes in LULC diversity
- Understand how the observed land use changes are related to ethnic minority livelihood strategies and state-led land use policies

1.3 Theoretical and technical approaches to understand LULC change in the uplands

To develop a methodology and analyze LULC change and diversity, this project works within three main bodies of literature: coupled human and natural systems, land change science and livelihood theory. Coupled human and natural systems (CHANS) are used to understand the reciprocal relationship between humans and the natural systems in which they live. Within the project, the local influence of both natural (ecological) and human (socio-economic) are considered. Land change science literature is used to develop a methodology. Remote sensing techniques are used to obtain and prepare maps depicting LULC and LULC diversity while statistical analyses, specifically regression-based techniques, are preformed to develop predictive relationships between LULC diversity, socio-economic and ecological variables. Livelihoods literature is used to develop a context and interpret results of the classification and statistical methodologies.

1.4 Thesis outline

Following this introductory chapter, in Chapter 2 (Conceptual Framework) I present three main bodies of literature drawn upon throughout this study: coupled human and natural systems, land change science and livelihood theory. Chapter 3 (Context) further expands upon the unique social and political environment in the Vietnamese uplands with a focus on land use policy, ethnic groups and their livelihoods. Chapter 4 (Data and Methodology) explains the data sources and methodology followed for this project. Chapter 5 (Results) presents the results of a land use classification and statistical regression analyses. Finally, in Chapter 6 (Discussion and Conclusions) I examine the main land use transitions, the effectiveness of state-based land use policies and suggest implications for livelihood strategies and future food security in the uplands. I draw upon two case studies, one rural and one urban, to explain spatial variation in the main findings.

CHAPTER 2: CONCEPTUAL FRAMEWORK

In order to develop a methodology and interpret the results, this study draws on three main areas of academic literature: coupled human natural systems, land change science and livelihood theory. From each body of literature, key elements are extracted (see Figure 1.2) which are relevant to this study.

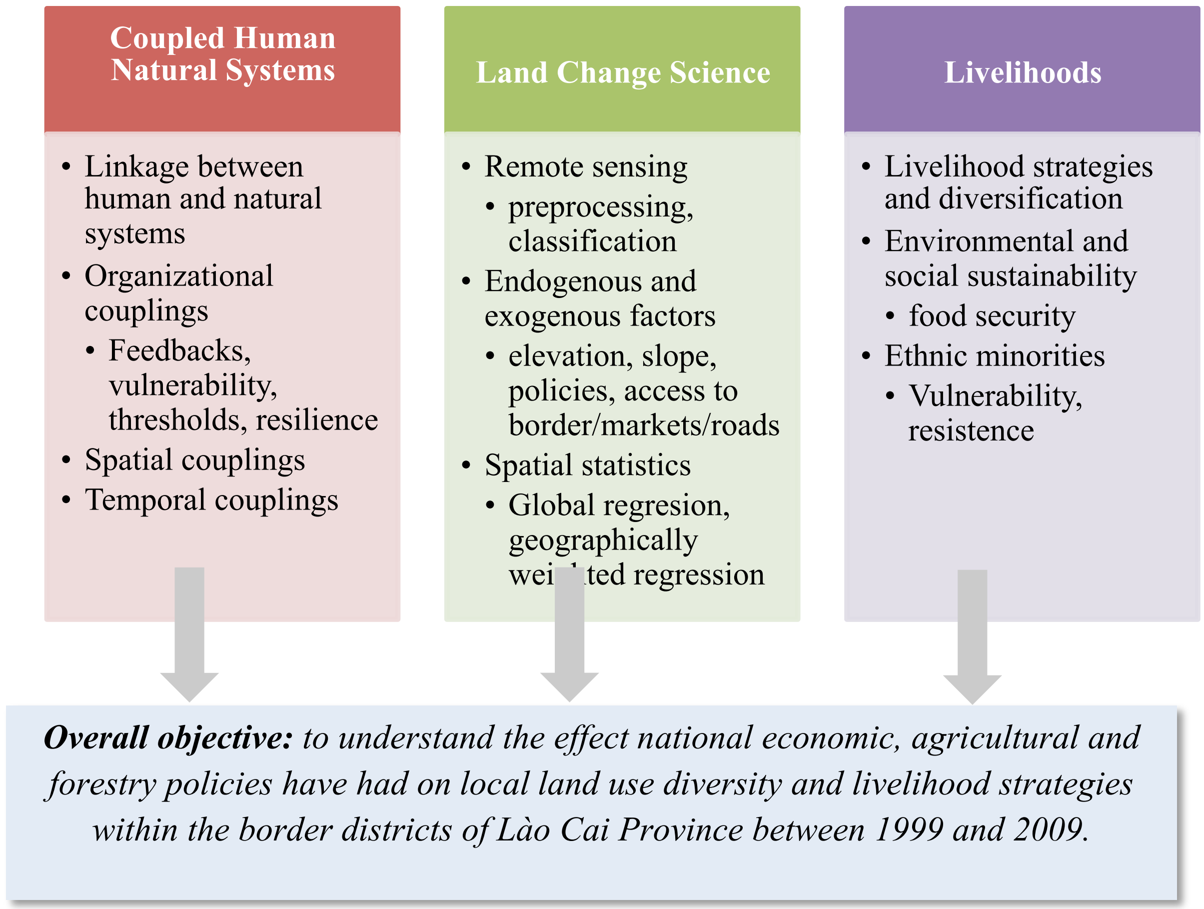


Figure 2.1: Conceptual framework used throughout this thesis.

2.1 Coupled human and natural systems

A coupled human and natural systems (CHANS) approach is the overarching umbrella body of literature that underpins this project. Advocates of this approach argue that interactions between humans and their environment are interrelated and highly dependent on each other (Liu et al., 2007b; Liu et al., 2007a; Manson, 2001; McPeak et al., 2006). CHANS is a highly complex framework that combines both social and natural sciences to understand the reciprocal relationship between humans and the ecological systems in which they live. It emerged as an academic framework to cover a gap that was left when socio-ecologic systems and human-environment interactions were studied separately (Liu et al., 2007a). This emerging multidisciplinary approach is an academic response towards the study of holistic integrated systems in conjunction with disciplinary specializations (McConnell et al., 2011).

Liu (2007b) outlines four key elements that are included within a CHANS framework: the study of social and ecological variables, a cross-disciplinary scientific perspective, a variety of tools and techniques and a multi-temporal viewpoint. The complex interactions and feedbacks that occur between human and natural systems are considered through the study of ecological variables (e.g. landscape, wildlife), social variables (e.g. policy, economy, agents, actors) and variables common to both disciplines. Within CHANS studies, scientists from all disciplines collaborate to gain a detailed interdisciplinary perspective. Tools and techniques from ecological and social sciences are used in conjunction with tools from external disciplines, such as remote sensing and GIS. CHANS studies are context specific to gain a unique understanding of the interactions between various elements over a historical period (Liu et al., 2007b). The CHANS framework introduces a set of variables that must be considered and evaluated when conducting an analysis that spans across human and natural systems. These variables include the temporal scope, the spatial extent, the level of decision-making unit, the links between the systems, the role of stochastic events or critical thresholds in the evolution of the systems and relevant policy that has shaped them (McPeak et al., 2006). This study combines these elements by analyzing how political and historical events in upland Vietnam have influenced land use diversity at the district level over a decade.

CHANS employs a series of couplings, or reciprocal relationships, to examine why and how a system has changed (Liu et al., 2007b; Liu et al., 2007a). The first of these couplings are organizational in nature and may include the dynamics of feedbacks, thresholds and resilience to disturbances. Organizational couplings may also include emergent properties caused by elements external to human and natural systems, such as the indirect effects of technology and vulnerability to natural or human shocks. The second set of couplings is spatial and includes coupling across spatial scales (household, regional, national, international), couplings beyond national boundaries and heterogeneity of systems across space. The third set of couplings concerns time and includes cumulative effects of humans on natural systems, accumulating (or legacy) effects and time lags between change and evidence of change.

Land use land cover change (LULCC) has emerged as a central research initiative of CHANS approaches (López-Carr et al., 2012; Turner et al., 2007). Previous modeling of human-environment interactions used agent-based models that focused primarily on individual decisions and were unable to explain variation across spatial and temporal scales (López-Carr et al., 2012). By introducing statistical models that predict regional change into the CHANS framework, the researcher is able to compare nested models of cumulative effects at large spatial scales and a series of temporal intervals (López-Carr et al., 2012). A nested model allows the researcher to model a response by using hierarchal levels of multiple variables to determine overall significance of each variable within the system. Within this study, land change is seen as coupled and reciprocal to policy change, property regimes and land degradation. Overarching social conditions, such as poverty or national policies, tend to be difficult to connect empirically to land outcomes on a large scale basis because of the complexity and number of linkages involved (Turner et al., 2007). This study therefore considers the localized effect of variables through a geographically weighted regression. Overall, the couplings introduced within the CHANS framework will be used within this study to understand the highly connected and interrelated relationship between natural systems (land use, land diversity) and social mechanisms (policy, livelihoods) in the northern Lào Cai Province.

2.2 Land change science

The second body of academic literature I draw upon for my conceptual framework is land change science. Land change science "seeks to understand the human and environment dynamics that give rise to changed land uses and covers" (Rindfuss et al., 2004, 13976). It works within the CHANS framework to spatially represent land change and interpret results with respect to social phenomena (López-Carr et al., 2012). The two main objectives of land change science are to determine the amount of land use change and the cause of change (Rindfuss et al., 2004). Remote sensing, Geographic Information Systems (GIS) and spatial statistics are the main tools used to monitor and examine LULCC over time (Cassidy et al., 2010; Clement et al., 2009; Fox and Vogler, 2005; Müller and Munroe, 2005; Rogan and Chen, 2004). The term *land cover* is used to refer to the type of feature present on the land surface whereas *land use* refers to the human or economic activity within a parcel of land (Lillesand et al., 2008). One variable evaluated within this context is land use land cover diversity (LULCD), or the number of land uses within a predefined spatial extent. To spatially represent the correlation between social and ecological variables land use can be modeled as a dependent variable with respect to various social and ecological factors using GIS and statistics. Cassidy et al. (2010) define three levels of analysis that LULC diversity can be measured at. The micro-scale is synonymous with the household or farm level and represents an area of one hectare, the meso-scale looks at the community level and represents 100 hectares while the macro-scale is used for district level analyses and represents 10,000 hectares. At the micro-scale, Cassidy et al. (2010) hypothesize that LULC diversity varies in Southeast Asia with respect to distance to roads, distance to markets and elevation with skewed polynomial distributions represented in Figure 2.2. At the meso-scale, used within this thesis, these relationships are expected to exhibit smoother curves with larger intercepts.

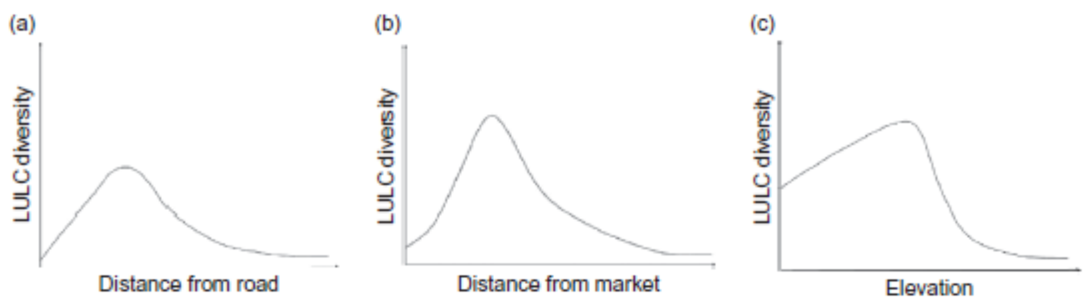


Figure 2.2: Hypothesized relationships between LULC diversity and (a) distance to roads, (b) distance to market and (c) elevation.
Source: (Cassidy et al., 2010)

The second objective of land change sciecne seeks to understand underlying factors that cause LULC transition. Within forested ecosystems, such as the one considered in this study, there are many broad explanatory frameworks to account for forest transition, including theories that incorporate economic development, resource scarcity and globalization (Lambin and Meyfroidt, 2010). To determine the causes of LULC and diversity an understanding of how people make land-use decisions at the local, regional, national and international level is required (Lambin et al., 2003; Lambin and Meyfroidt, 2010). According to Lambin et al. (2003, 225) land use change is generally driven by the following factors:

- Resource scarcity leading to increased pressure on remaining resources
- Changing opportunities created by markets
- Policy intervention
- Loss of adaptive capacity and increased vulnerability
- Change in social organization and access to resources

These forces can be classified into endogenous or exogenous factors (Lambin and Meyfroidt, 2010). Endogenous factors are socio-ecological and can include changes to biophysical variables such as land degradation or ecosystem services. For instance, depleted soil nutrients can inhibit crop growth and cause a parcel of land to transition from crops to shrubs or grass. Exogenous factors are socio-economic, such as economic development, urbanization or globalization, and will change independently of ecological systems. For instance, urban sprawl will eventually convert all other land uses to urban to compensate for increased housing and development. Within Vietnam, the dominant drivers of land use change are predicted to be globalization and government policies regulating forest transition (Meyfroidt and Lambin, 2008a). Within this study, the validity of this statement for meso-scale upland land use is tested. A LULC classification is derived using remote sensing techniques and converted into a diversity index. Diversity is regressed against a variety of ecological and economic variables to determine the significance of various endogenous and exogenous factors on land use transition between 1999 and 2009.

2.3 Livelihoods

A third body of literature on livelihoods will be drawn upon to understand the connection between LULC diversity and ethnic minority livelihood strategies in the northern uplands. Livelihoods literature examines how people make a living in complex circumstances (Chambers and Conway, 1992; De Haan and Zoomers, 2005; Ellis, 1998; Scoones, 2009; Turner, 2011, 2012). The livelihoods approach emerged within academia in the early 1990s and can be summarized by concepts outlined in Figure 2.3. It was introduced by Chambers and Conway and can briefly be defined as “the capabilities, assets (stores, resources, claims and access) and activities required for a means of living” (Chambers and Conway, 1992, 6). Livelihoods are considered environmentally and socially sustainable if they preserve the natural resource base and if they are able to cope with stresses and shocks, while promoting or enhancing assets and capabilities to react and adapt to change (Chambers and Conway, 1992; De Haan and Zoomers, 2005; Scoones, 2009). The livelihoods framework emphasizes five assets: natural capital, physical capital, human capital, financial capital and social capital, which are all mediated by social and institutional processes (Ellis, 2000; Scoones, 2009). Over time, the livelihoods framework has matured and begun to emphasize understandings of power, politics and institutions (Scoones, 2009). Access to resources and social relations (gender, family, kin, caste, class and ethnicity) are also important in facilitating sustainable livelihoods (Ellis, 2000; Turner, 2012).

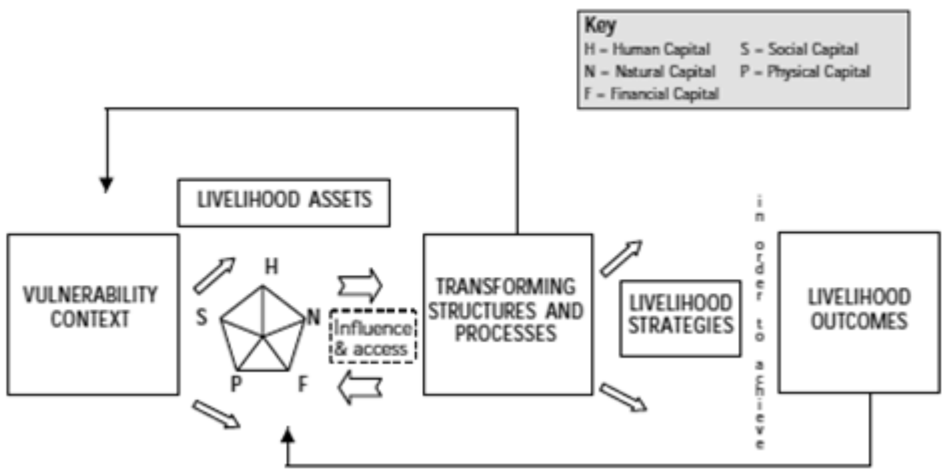


Figure 2.3: Main concepts of the livelihoods framework.
Source: (DFID, 1999)

Households may pursue a livelihood strategy by combining, reproducing or transforming their resource base (Bonnin, 2011; De Haan and Zoomers, 2005). Scoones (1998) identifies three broad clusters of livelihood strategies: livelihood diversification, agricultural intensification/extensification and migration. This thesis will examine both livelihood diversification and agricultural intensification/extensification as strategies to reduce ethnic minority vulnerabilities associated with LULCC. Livelihood diversification is important for developing and maintaining a sustainable livelihood. It can occur through the development of a set of dissimilar income sources (farm, non-farm, remittances) and is determined by seasonality, labour markets, risk, coping, credit and accumulation (Ellis, 1998, 2000; Turner, 2012). In rural farming communities, diversification is expected to reduce the risk of income failure or intra-year income variability by enhancing resilience to seasonal climatic variations and market instability (Ellis, 1998). Agricultural intensification can occur by increasing the productivity of a plot of land through investment in labour and technology while extensification can occur by increasing the amount of land under cultivation, or diversifying to off-farm income sources (Scoones, 2009).

Within the upland regions of northern Vietnam, economic liberalization, transitioning land use policies and numerous state-sponsored development strategies are presenting ethnic minorities with opportunities to diversify their livelihoods (Turner, 2012). Within the timeframe of this study, there has been a marked change in access to natural capital (i.e. land) and economic capital (i.e. technology, markets, credit) (Alther et al., 2002; Glewwe et al., 2004). By spatially analyzing how LULC diversity has changed in these locations, the livelihoods framework can be used to assess if resulting land use changes have increased or decreased ethnic minority vulnerability and assets.

To summarize, this chapter has brought together the core ideas of CHANS, land change science and the livelihoods framework, as shown in Figure 2.1. Main elements and methodologies from each area of research will be used to help answer the central research aim of understanding the effect national policies have had on local land use diversity and livelihood strategies within the border districts of Lào Cai Province over a ten year period.

CHAPTER 3: CONTEXT

The following chapter introduces the study area and the specific social, political and economic conditions that arise within it. Land use policies, historical drivers of land use change and ethnic minority dynamics are discussed.

3.1 Study Area

This study examines LULCC and diversity between 1999 and 2009 in Lào Cai province, located in northern upland Vietnam (Figure 1.1). Lào Cai province borders the provinces of Lai Châu to the west, Hà Giang to the east and Yunnan, China to the north. The study encompasses five border districts of Lào Cai Province: the city of Lào Cai, Mường Khương, Bảo Thắng, Bát Xát, Si Ma Cai and the communes (wards) within them.

Land use within this region is strongly influence by local topography (Roche and Michaud, 2000). Elevation ranges vastly between 27-2990m and slope between 0-83°. There are two main rivers: the Red River (in the center) and the Chay River (in the east) (Figure 3.1). Precipitation varies with respect to windward and leeward mountain dynamics. Temperatures are cooler and there is higher humidity in areas of high elevation, resulting in frequent fog and cloud cover (Roche and Michaud, 2000).

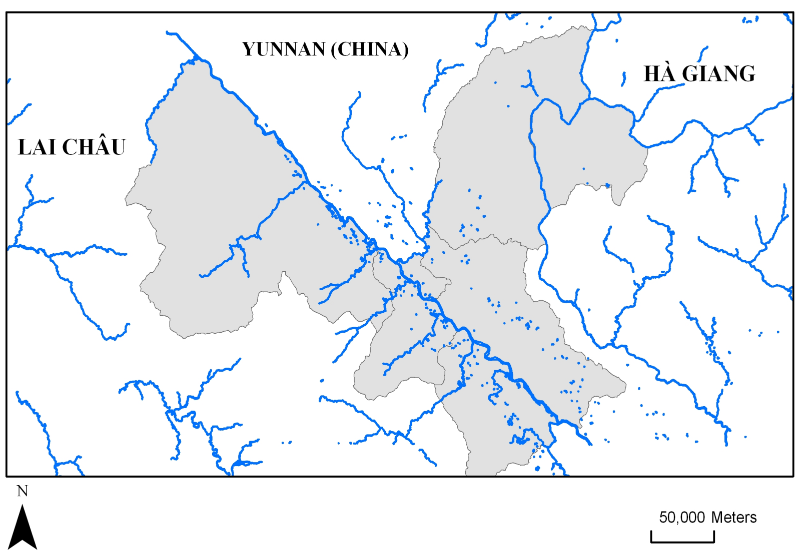


Figure 3.1: Hydrological regions of the study area.
Source: (Ministry of Natural Resources and Environment, 2010)

3.2 Land use policies and land use change in northern upland Vietnam

Although the land cover transformations that occurred within the study area have been poorly understood due to difficult physical access, some generalizations can be made based on previous studies and French archival documents. Since at least the 1880s until the 1960s, the dominant land use within the uplands was swidden with a long fallow system (Leisz, 2009). In the1960s, agricultural collectivization led to the introduction of homogeneous high-impact agriculture systems (Castella et al., 2005). Nevertheless, oral histories from the study area suggest that these collectives were not introduced to the same intensity as elsewhere in the uplands-to-midlands where the state had greater and easier access for control (S. Turner, personal communication, October 2012). Starting in the late 1980s, the national government began a series of economic reforms, known as *Đổi mới*, that aimed to stimulate economic growth and push Vietnam towards a regulated market economy (Glewwe et al., 2004). The result of this has been various policy changes that have directly and indirectly affected land use systems within the uplands (Castella et al., 2005; Fatoux et al., 2002; Jakobsen, 2006; Turner, 2011). A summary of recent political changes is shown in Table 3.1.

In conjunction with the *Đổi mới* reforms, a series of land laws were introduced that allocated land to communities or individual households. These laws removed price controls on agricultural products, allowed for the sale of surplus to markets, encouraged sedentary livelihoods and allowed households to hold tenure rights for crops and forestland (Castella et al., 2006). Concurrently, hybrid rice seeds were introduced to facilitate high intensity yields in order to increase market sales and prevent food insecurity. Households were encouraged to abandon traditional extensive seed varieties in favour of state-sponsored high yield varieties (Bonnin and Turner, 2012).

In response to *Đổi mới* and cooperative dismantlement, massive deforestation occurred to make room for agricultural expansion, population growth and wood exploitation for rural and urban use (Castella et al., 2006; Meyfroidt and Lambin, 2008a). In the late 1980s, forest covered only 17 percent of the northern mountains (WorldBank, 2003). In the 1990s several policies were introduced to protect Vietnam’s rapidly declining forest cover. For instance, Program 327 and the Five Million Hectare Reforestation Program (5MHRP) halted deforestation and encouraged reforestation. These programs had the largest success rates far from urban cores where natural forest regeneration occurred, as well as in regions with steep slopes and low agricultural suitability (Meyfroidt and Lambin, 2008a). Concurrently, opium production was banned and in areas where the state has the greatest access and some land use was redistributed to fruit tree development and animal husbandry. As of 2003, forest cover in Lào Cai Province was estimated to be above 30 percent (WorldBank, 2003).

Table 3.3: Government policies affecting land use in northern Vietnam uplands.

Year	**Vietnam government decrees and interventions**
1960s	• Agricultural collectivization implemented in the northern uplands.
1979	• Border war between China and Vietnam.
1981	• Individual households are assigned agricultural quotas and can retain any extra harvest.
1986	• Communist party begins *Đổi mới* reforms to encourage economic growth and market-oriented planning.
1988	• Resolution 10. Cooperative system dismantled and wet-rice land shares are allocated to households.
1991	• Law on Forest Protection and Development. Defined three types of forest and separate regulations for each: protection forest, special-use forest, production forest.
1992	• Program 327. Aimed at restoration and protection of forests as well as establishment of special use forests. Also banned wood exports and reduced tree felling to 88%.
1993	• Resolution 6. Government bans opium production. • Decree 5: Land law. Inhabitants given land tenure rights (20 year renewable rights for annual crops and 50 year rights for perennial crops and forest land). • Independent international tourism permitted.
1997	• Permanent logging ban in special-use forests and 30-year ban in critical watersheds.
1998	• Five Million Hectare Reforestation Program. • Decree 20. Introduction of commodity subsidies for ethnic minority areas.
1999	• Subsidized rice seed program introduced in Lào Cai province.

Source: (Turner, 2011, 4)

3.3 Ethnic composition, state intervention in the uplands and ethnic minority livelihoods

Vietnam is home to fifty-four different ethnic groups, defined using the criteria of language, material life, culture and ethnic consciousness (WorldBank, 2009). Fifty-three of these groups are considered to be ethnic minorities representing an estimated 12.6 percent of the national population (Glewwe et al., 2004; WorldBank, 2009). The province of Lào Cai represents a large fraction of ethnic minorities. The 2009 national census indicated that within Lào Cai province 36 percent of inhabitants were Kinh (national Vietnamese) and the remaining 64 percent of inhabitants were ethnic minorities belonging to the Tay, Nung, Giay, Hmong and Yao/Dao ethnic groups (GSO, 2009) (Table 3.2). Within the uplands, the concentration of ethnic groups can be represented using a spatial gradient (Roche and Michaud, 2000; WorldBank, 2009). The Kinh population is concentrated within urban environments, such as the Red River Valley. The poorest (by economic indicators) of the ethnic groups live in sparse, mountainous regions where they have limited access to basic resources (Glewwe et al., 2004). Within mountainous regions the Tai-speaking groups (Tay, Thai and Nung) typically live in valleys where wet-rice farming is practiced while the Hmong and Yao (Dao) live on high altitude, steep mountainous slopes (Roche et al., 2004; WorldBank, 2009). However population distribution is not homogenous and there can be as low as two or as many as seven ethnic groups present in each commune (Michaud et al., 2002).

Table 3.4: Population by official ethnic group: Vietnam and Lào Cai.

Ethnic group	**National population**			**Lào Cai Province population**		
	Total	Rural	Urban	Total	Rural	Urban
Kinh	73,594,427	49,708,761	23,885,666	212,528	105,838	106,690
Tay	1,626,392	1,405,454	220,938	94,243	86,159	8,084
Nung	968,800	867,049	101,751	25,591	23,909	1,682
Giay	58,617	51,286	7,331	28,606	25,909	3,078
Hmong	1,068,189	1,042,507	25,682	146,147	142,165	3,982
Yao/Dao	751,067	727,479	23,588	88,379	84,384	3,995

Source: (Bonnin, 2011, 99; GSO, 2009)

Ethnic groups located close to the border often have kin living on the other side. These groups are often not isolated within Vietnam, rather they are trans-national groups with few patriotic ties to the state (WorldBank, 2009). These groups have developed and maintained a highly complex network of cross-border trade of key ethnic minority-oriented commodities that operates independently from state-based structures, and which have been in place for centuries (Bonnin, 2011; Turner, 2011, 2013).

Throughout history, state-upland ethnic minority relationships have been weak and characterized by factors such as lack of trust, cultural differences, different agricultural norms and distance from the political core. Such factors in turn have led to the formation of inequalities and the generalization of ethnic minorities as "backward" people (Turner and Michaud, 2008). These assumptions are based on comparisons with Kinh people and have no recognition of a disadvantaged state-based development history nor different livelihood aims (WorldBank, 2009). State-minority relationships are also often highly dependent on the group being discussed. Those groups who most closely identify with the Vietnamese state and Kinh population, such as the Tày, are often favoured through better resource access, whereas those groups with fewer ties to the state, such as the Hmong, are considered to be in a state of poverty with few physical and social assets (WorldBank, 2009).

3.3.1 Ethnic minorities and land use

Since the mid-1980s and the introduction of the *Đổi mới* reforms, the government has endeavoured to integrate ethnic minority groups into the national economy (Turner and Michaud, 2008). This has been emphasized in land use laws that encourage upland residents to abandon traditional agricultural systems and pursue fixed agriculture based on sedentary livelihoods that operate within a core-periphery economic model (Glewwe et al., 2004; Jakobsen et al., 2007). Local remote marketplaces have been upgraded and improved while road infrastructure development means that market relations have been extended far into the uplands. For some ethnic minorities, market access has resulted in an increased reliance on commodity networks instead of traditional subsistence livelihoods, such as an increased trade in cardamom, livestock, textiles and homemade alcohols (Turner, 2012).

Land use laws were developed at the national level and passed down through various administrative levels to the villages where local leaders and farmers altered them as much as possible to meet local needs (Alther et al., 2002). The main goal of Resolution 10 in 1988 was to transition away from upland self-sufficiency into full national market integration (Castella et al., 2006). Swidden cultivation was banned to protect rapidly declining soil fertility and market access routes were upgraded to encourage economic integration (Castella et al., 2005). The subsequent 1993 Land Law aimed to convert rotational-swidden households to sedantaried livelihood systems in order to increase agricultural production in the uplands (especially through monocropping and plantation systems) and to combat deforestation (Castella et al., 2006).In 1998 Decree 20 called for the subsidization of all hybrid seeds, fertilizers and pesticides for ethnic minorities in order to encourage mono-cropping, fixed agriculture and cash-cropping (Turner, 2012). Although these policies and incentives have resulted in increased crop yields in some cases and provided alternative livelihood strategies, the results have not been uniform and upland residents have met economic expansion and modernization with careful negotiation and at times resistance (Turner and Michaud, 2008).

3.3.2 Ethnic minority livelihood strategies

Traditional ethnic minority livelihood strategies were based on long-fallow swidden cultivation systems. More recently, livelihoods have incorporated sedentary upland fields to produce corn or maize as an annual staple crop (Turner, 2011). In response to some of the policies mentioned above, upland households have intensified agricultural production by supplementing or replacing traditional rice with hybrid varieties and the use of pesticides, both of which require an annual income source to maintain (Turner, 2012). Many households also maintain small rotational plots, although illegal, and supplemental home gardens for food crops such as beans, taro, pumpkins and cucumber. Forests, although managed by a range of different protection laws, are also used by ethnic minorities for the provision of non-traditional forest products (NTFP) such as cardamom, bamboo, herbs and honey (Bonnin and Turner, 2012). Food production is minor when compared to agricultural fields, however NTFPs are used by upland groups to diversify livelihoods, especially during times of land use transformation (Jakobsen, 2006). Although not considered in this study, livestock (especially buffalo) are important forms of livelihood insurance and are used for crop maintenance, religious ceremonies or household consumption (Turner, 2012). Contemporary market activities include small-scale cross border trade, cardamom cultivation, textile and alcohol production as well as tourism activities.

This study aims to explore in greater detail how these socio-cultural, political and economic influences in Lào Cai Province have interplayed with LULC and LULC diversity. This project uses ecological (slope, elevation) and social (distance to roads, border, market) variables as indicators of these forces to determine the localized spatial influence they have had on LULC diversity in 1999 and 2009.

CHAPTER 4: DATA AND METHODOLOGY

The following chapter outlines the data sources and main methods involved in computing the dependent variable of land use diversity and the independent variables of elevation, slope, distance to roads, distance to markets and distance to Sino-Vietnamese border. It also outlines the spatial statistic processes involved in computing a global regression and local regression using the geographically weighted regression method.

4.1 Data

This project used a combination of remote sensing and GIS raster and vector data sets. To cover the time span of the study, datasets from both 1999 and 2009 were used. Landsat images from 1999 (ETM+) and 2009 (TM5) were obtained from the United States Geological Survey (USGS) for Lào Cai Province (see Appendix for full sensor characteristics) (NASA Landsat Program, 1999; NASA Landsat Program 2009). Three additional geospatial datasets were downloaded to complete the analysis. A 30m-resolution digital elevation model (DEM) for Vietnam was obtained from USGS. The 2009 road and market networks were obtained from the LULC map of the Ministry of Natural Resources and Environment (2010) and 1999 datasets were obtained from the GIS Atlas of Vietnam (2000). Field knowledge and interviews by my supervisor were used to verify market networks (S. Turner, personal communication, June 2012; Lê Manh An, Department of Environment and Natural Resources in Lào Cai, personal communication, October 2012).

LULCC can be analyzed at the household, community or district level. According to a study conduced in a Thailand-Cambodia border region, LULC diversity is correlated with underlying biophysical and socioeconomic mechanisms at the community level in Southeast Asia (Cassidy et al., 2010). Thus, this study used a grid of 33 x 33 pixels superimposed on all datasets to represent an area of approximately 100ha.

4.2 Land cover classification

4.21 Pre-processing of Landsat Images

Prior to performing these analyses, the Landsat images were pre-processed using ENVI (version 4.7) to remove distortions caused by sensor errors, atmospheric interference and surface irregularities. Radiometric corrections were undertaken to convert image values to BIL, perform layer stacking and add wavelength characteristics to each band. In regions of rough terrain and steep slopes, the topographic correction process was critical in order to remove reflectance distortions (Riano et al., 2003). Various atmospheric correction methods including the cosine correction, improved cosine correction, SCS algorithm and C-correction were tested (Law and Nichol, 2004; Riano et al., 2003). The outputs of these methods were examined and the improved cosine correction was selected for this study. Cloud and shadow masking was conducted on the 2009 image using methods outlined by Martinuzzi et al. (2007).

4.2.2 Land cover classification

LULC in the study area was classified based on Level I land cover types (Anderson, 1976). Land cover was classified into six land cover types from the Landsat images by eCognition using the main steps of segmentation and rule-based classification (Dorren et al., 2003). Two segmentations and rule-based classifications were undertaken at different scales using the same band composition (bands 1-5, 7), colour/shape ratio (0.2/0.8) and compactness/smoothness ratio (0.3/0.7). The first segmentation was conducted at a scale of 50 and rules were used at this level to identify C*louds and shadow*, W*ater and Bare soil* classes. The second segmentation was conducted at a scale of 10. A second set of rules was used to classify segments created at this level into three vegetation classes of S*hrubs*, M*ixed trees* and *Dense trees*.

4.2.3 Creation of land use types

The land cover classes were separated into nine LULC classes using a 2010 base map provided by the Vietnam ministry of natural resources, fieldwork and the topography of the region (Figure 4.1). The Landsat *Bare soil* class was further divided into four LULC types. Pixels having a high road density are representative of urban areas and were renamed as *Built-up.* Other *Bare soil* pixels were renamed as agriculture, based on the slope and crop calendar of the study area (Table 4.1). Crop information was collected from the official crop calendar of the Department of Agriculture in Lào Cai (2010) and field knowledge from S. Turner (personal communication, October 2012). At the time of acquisition of the images (December 2009 and November 1999), there were only a few patches of vegetables, pineapples and bananas growing. It was extrapolated that road-free bare soil areas on the two images are likely to be agricultural areas. Three agricultural types were created based on the slope of the agricultural fields *Paddy fields* (slope $< 5^{o}$), *Upland fields* (slope from 5^{o} to 25^{o}) and *Steep fields* (slope $> 25^{o}$).

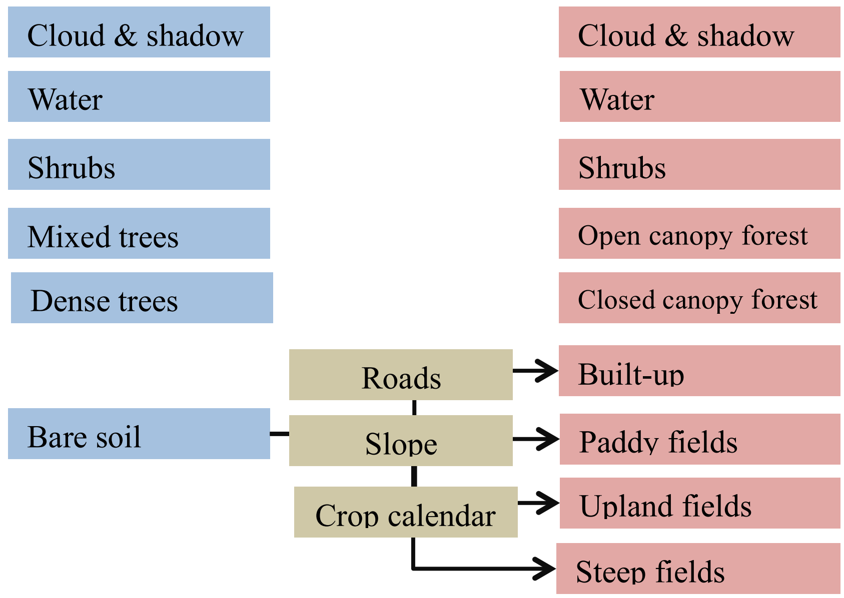
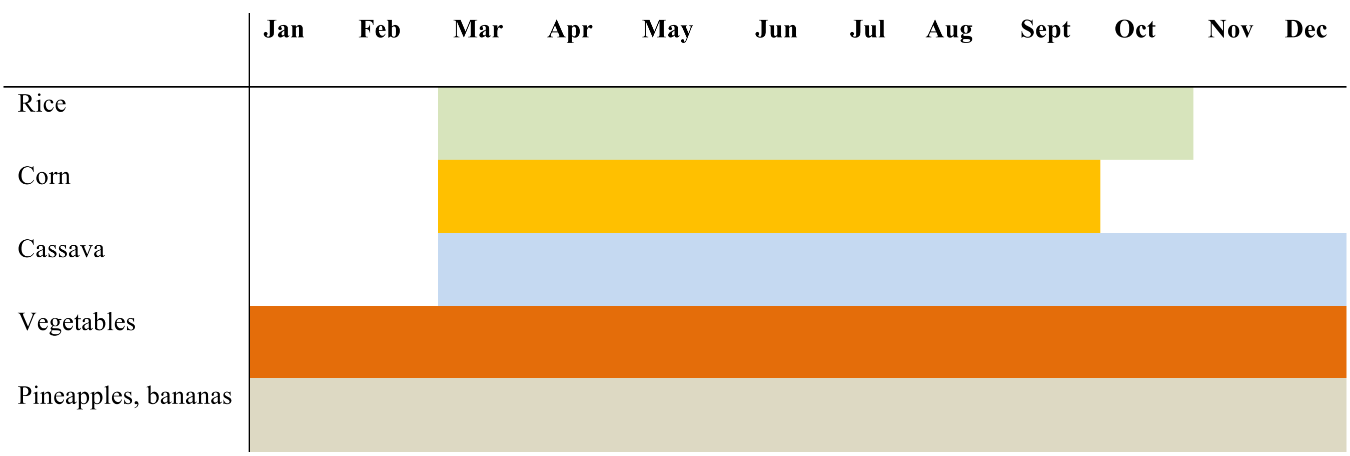


Figure 4.1: Separation of Landsat-based land-cover classes (depicted in blue) into land-use land-cover classes (depicted in red).

Table 4.1: Crop calendar of the study area. Blank cells represent months where there are no crops.



Source: (Department of Agriculture, 2012)

An accuracy assessment was conducted for the 2009 LULC classification using a reference dataset composed of 172 points. Two sources of information were used to identify different classes within the reference dataset:

- Government land cover map: used for *Water* and *Closed canopy forest*. According to interviews with Lê Manh An, Department of Environment and Natural Resources in Lào Cai, (July 2012), these two classes are reliable on the government map.

- Fieldwork conducted with the assistance of the department of Natural Resources in Lào Cai: used for the *Agriculture, Shrubs, Open canopy forest* and *Built-up* classes (Figure 4.2).

A buffer zone of 30m was created around each reference point and a confusion matrix was computed from overlaying the Landsat-based classification and the reference dataset (Table 4.2). Confusion matrices compare the relationship between the reference dataset and the classification results (Lillesand et al., 2008). The overall accuracy for the classification is 78%. Since reference data is unavailable for the 1999 classification, an accuracy assessment was not performed. However, the same criteria were used to classify these images and it can be inferred that their accuracy is similar.

Table 4.2: Confusion matrix for the 2009 LULC classification (units of m^2). The results indicate an overall accuracy of 78%.

		Reference data							
		WATER	CLOSED CAN	OPEN CAN	SHRUB	BUILT UP	AGRI	**Total**	**Acc.**
Classification	WATER	72	0	0	0	0	0	72	100
	CLOSED CAN	0	108	9	0	0	0	117	92
	OPEN CAN	0	9	108	18	0	18	153	71
	SHRUB	9	0	18	144	9	0	180	80
	BUILT UP	0	0	9	0	108	45	162	67
	AGRI	27	0	9	18	9	198	261	76
	Total	108	117	153	180	126	261	945	
	Acc.	67	92	71	80	86	76		**78**

Figure 4.2: Open canopy forest, agriculture and urban areas in the study area.
(Credits: Lê Manh Anh)

4.4 Regression analyses

Both global and local (geographically weighted) regressions were conducted using ArcGIS (ESRI, 2011). Variables used for the regression analyses were selected based on availability and relative social and ecological importance to this study. The dependent variable for this analysis was LULC diversity. Land use heterogeneity, or diversity, within parcels or plots of land is often measured using the Shannon Index (Acharya and Bennett, 2001; Fédoroff et al., 2005; Jiang et al., 2003; Rescia et al., 2010). The Shannon index, calculated using Equation 1, is dependent on the diversity of land use and the evenness of a particular land use type within each parcel (Acharya and Bennett, 2001). Using this index, the greater the number of land use types and the more similar they are in proportion, the higher the diversity value.

$$H = -\sum_{i=1}^{n} (p_i \ln p_i) \qquad [1]$$

The independent variables include elevation, slope, distance to roads, distance to markets and distance to the Sino-Vietnamese border. Elevation and slope were selected as independent geophysical variables. Elevation was obtained directly from the DEM dataset. Slope was calculated from the DEM dataset using the slope function in ENVI. Distance to roads, distance to border and distance to markets were used as independent socioeconomic variables and were calculated using road and market networks as well as a cost raster to account for vertical distance travelled. The cost raster was designed following methods outlined by Cassidy et al. (2010) by assigning roads a value of 1 and all other surfaces a value of 10. All dependent and independent variables were averaged into the meso-scale unit of analysis.

4.4.1 Global regression

A global regression model was conducted in GEODA determine the overall fit of the variables across the study area (Anselin et al., 2006). A global regression uses spatial data to calculate regression coefficients for the entire area being analyzed (Matthews and Yang, 2012). One main assumption of global statistics is that of independent observations. Spatial autocorrelation occurs when the spatial distribution of values is not random and thus not independent (Mennis and Jordan, 2005). If observations of the independent variables are spatially clustered the parameter estimates are biased and too precise (Ackerman, 2010). Under these circumstances, spatial autocorrelation must be calculated and adjusted for in the global model.

The global regression was conducted using two spatial autoregressive models (Anselin, 2005). An OLS model eliminated bias in parameter estimates by calculating residuals (Equation 2). Similarly, the SAR model modified the typical linear regression equation by adding a term that corrected for spatial autocorrelation (Equation 3) (Kissling and Carl, 2008). Before conducting the SAR model, spatial autocorrelation on residuals of the respective OLS model was tested in order to verify non-random distribution. Rook distance weights matrices include adjacent neighbouring cells and were used since the study area cells are regular and have identical size and shape.

$$y = \rho W y + X\beta + \varepsilon \qquad [2]$$

$$y = X\beta + \lambda W(y - X\beta) + \varepsilon \qquad [3]$$

In Equations 2 and 3, y is the dependent variable, X is independent variables, β is the vector of slopes associated with X, ε is a vector of error terms, W is the spatial lag term, ρ is the spatial lag coefficient, and λ is the spatial error coefficient.

4.4.2 Geographically weighted regression

To understand the localized effect of physical and social independent variables on LULC diversity, a multi-variable regression was calculated using ArcGIS. Geographically weighted regression (GWR) allows for the analyst to determine if there are regression relationships between variables within localized geographic space (Wheeler and Páez, 2010). It differs from a global regression because it defines individual relationships between variables from location to location and assumes that observations spatially close to each other influence each other greater than observations further apart (Mennis, 2006). The GWR analysis used the spatial coordinates of data points and an adaptive bandwidth kernel function to calculate inter-point distances and weights that represent localized spatial dependence between observations. A local regression equation was generated using a parameter estimate for each observation using Equation 4:

$$\widehat{y}_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \qquad [4]$$

where $\hat{y}_i$ is the estimated value of the dependent variable for observation i, $ß_0$ is the intercept, (u_i,v_i) is the coordinate location of observation *i*, $ß_k$ is the parameter estimate for variable k, x_{ik} is the value for the *k*th variable for observation *i* and ε_i is the standard error. Outputs of the GWR are a parameter estimate, t-value and goodness of fit for each observation. T-values were mapped to show significance of each independent value on land cover diversity.

CHAPTER 5: RESULTS

This chapter contains the results of the independent and dependent variable pre-processing, LULC classification and regression analyses for both 1999 and 2009.

5.1 LULCC and diversity

The following section displays the results of the LULC classification and LULC diversity calculation used for the dependent variable.

5.2.1 Results of the classification

The results of the LULC classification yielded nine different LULC types (Figure 5.1). The dominant class for both 1999 and 2009 was shrubs. The largest change between the study years was a 413 percent increase in closed-canopy forest class concentrated east of Mường Hum and a 528 percent increase in built-up areas predominately within the Red River valley (Table 5.1). The two classifications were overlaid to determine conversion between classes (See Appendix). The largest transitions include:

- Open forest into closed forest (~357km^2): mostly around Mường Hum, in the east of Bảo Thắng district and southwest of Lào Cai city.
- Shrubs into closed forest (~310km^2): shrubs in transition areas may be bamboo or small planted trees. These conversions occurred along the border in Muong Khuong, in the east of Bảo Thắng district and certain areas of Si Ma Cai.
- Upland fields into shrubs (~239km^2): this could be due to change in crop types or in crop calendar. These changes occurred in the west of the Red river valley and in dispersed areas of Bảo Thắng.
- Shrubs into open forest (~230km^2): this occurred in small areas throughout the region.
- Upland fields into closed forest (~230km^2): this occurred east of Muong Khuong, south of Si Ma Cai and in Mường Hum.

Table 5.1: LULC class area and percent change

Class	1999 Area (km^2)	1999 Percent total	2009 Area (km^2)	2009 Percent total	Percent change
Water	17.3	0.6	20.7	1.2	19.2
Closed canopy forest	204.9	7.4	105.1	5.9	412.7
Open canopy forest	564.5	20.5	486.0	27.2	-13.9
Shrubs	869.8	31.6	552.5	31.0	-36.5
Built-up	12.7	0.5	79.6	4.5	528.4
Paddy fields	135.9	4.9	76.6	4.3	-43.7
Upland fields	756.3	27.5	280.6	15.7	-62.9
Steep fields	38.7	1.4	5.0	0.3	-87.2
Unclassified	153.6	5.6	178.1	10.0	15.9

5.2.2 Shannon diversity index

The Shannon diversity index is used as the dependent variable for the regression analyses. It was calculated at the meso-scale and is shown in Figure 5.2. A value close to 0 indicates no LULC diversity while a value close to 2 indicates a high LULC diversity. Grid cells with only a few LULC types have values closer to zero while cells with up to 8 LULC types have a value close to 2. In 1999 the highest diversity is along the Red River where there is a mixture of urban, rural and water land uses. In 2009 there is a significant increase in diversity throughout the entire study area. The western edge of the Sino-Vietnamese border, northwest of Bát Xát experiences a large increase in diversity while the mountainous region west of Mường Hum has a significant decrease in diversity. Overall there is an increase in the maximum number of LULC types within each community and a slight increase in the mean diversity (Table 5.2). In 2009 there is more variation in the number of LULC types across the study area.

Table 5.2: Shannon diversity simple statistics.

	Minimum	Maximum	Mean	Std Dev
1999	0	1.668	1.017	0.273
2009	0	1.845	1.039	0.423

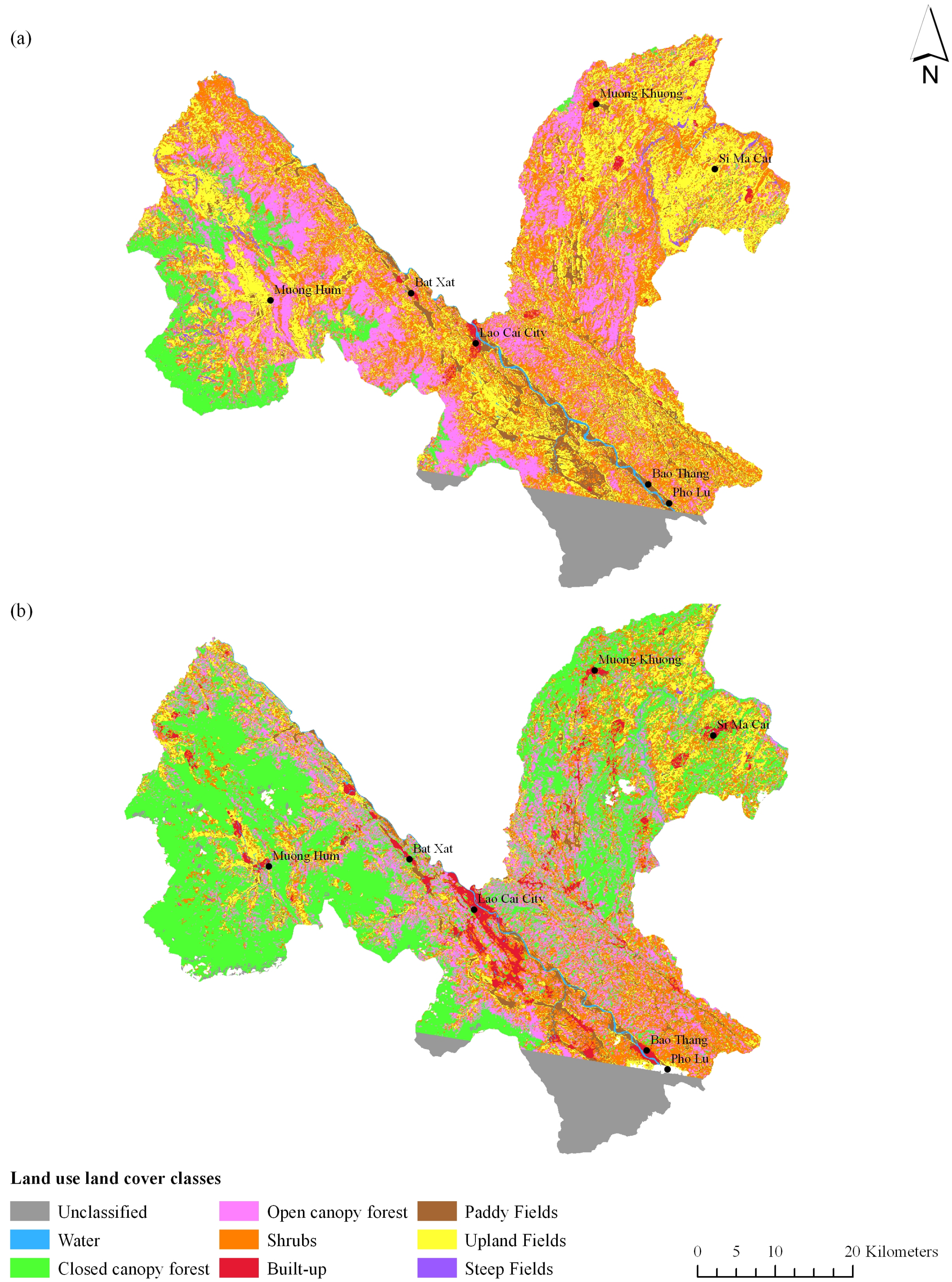


Figure 5.1: Results of the LULC classification for (a) 1999 and (b) 2009. White areas in 2009 indicate cloud cover.

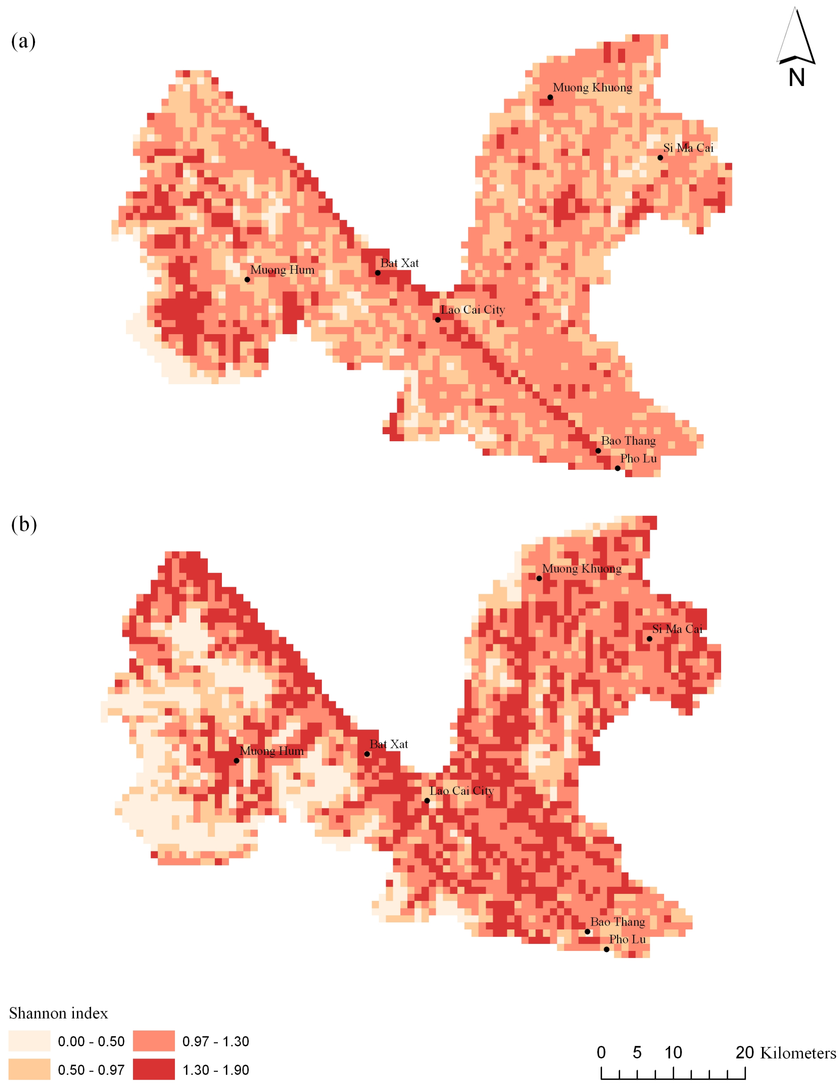


Figure 5.2: Values of the Shannon diversity index for (a) 1999 and (b) 2009 at a meso-scale (33x33) resolution.

In order to examine patterns of LULC diversity, a global spatial autocorrelation index was computed. Moran's I coefficients for autocorrelation are 0.526 for 1999 and 0.680 for 2009 at p=0.01. Local indicators of spatial autocorrelation (LISA) show positive spatial autocorrelation in regions where cells have a similar LULC diversity and a negative autocorrelation in regions where LULC diversity is dispersed (Figure 5.3). Regions of high diversity are along the Red River valley where there is urban expansion and a mixture of transitioning land use types. In 2009, the Red River valley continues to be highly diversified and there are new diversified regions along the border (northwest of Bát Xát) and Bảo Thắng district. In both years, regions of low diversity occur where there is extensive closed-canopy forest cover in the west of Bát Xát district.

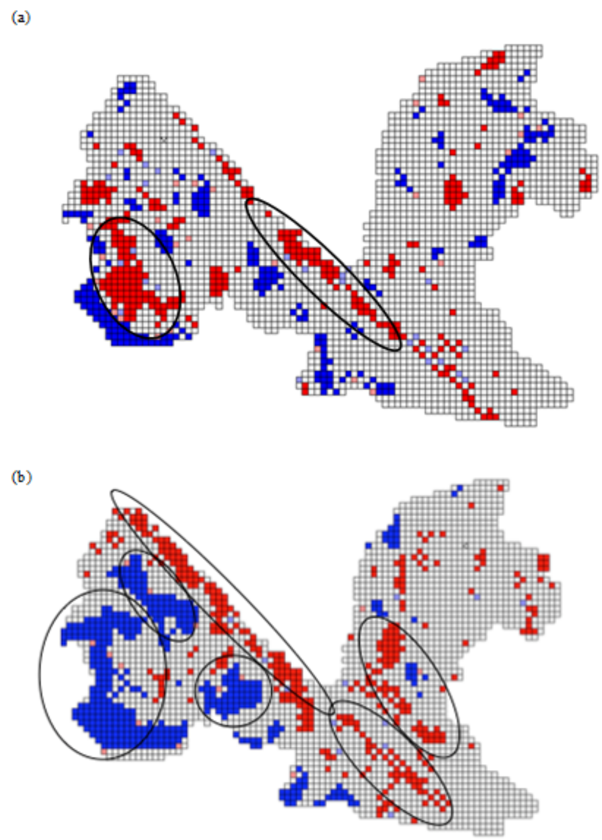


Figure 5.3: Local indicators of positive spatial autocorrelation for (a) 1999 and (b) 2009. Red regions represent areas of high land diversity and blue regions represent areas of low land diversity.

5.2 Independent variables

Figure 5.4 displays the independent ecological variables used as GWR inputs. These variables are constant across the time frame of the study. The elevation ranges from 27-2990m above sea level with the highest elevations east of Mường Hum and to the west and south of Si Ma Cai (Table 5.3). The slope ranges from 0-83 degrees with the lowest slopes along the Red River valley. The mean elevation is 758m while the mean slope is 19°.

Table 5.3: Simple statistics for the socio-economic and ecological factors. Distances are weighted as a function of the elevation and cost raster (see Chapter 4).

Variable	Minimum	Maximum	Mean	Standard deviation
Elevation (m)	27	2990	757.9	614.1
Slope (degrees)	0	83.1	18.9	10.3
Distance to roads (m)				
1999	0	9566.3	897.1	1174.5
2009	0	2464.8	249.6	270.2
Distance to markets (m)				
1999	0	190003.7	58924.2	32422.5
2009	0	176845.8	56510.1	31144.3
Distance to border (m)				
1999	0	375467.2	118735.5	89198.0
2009	0	353770.9	111865.1	82936.2

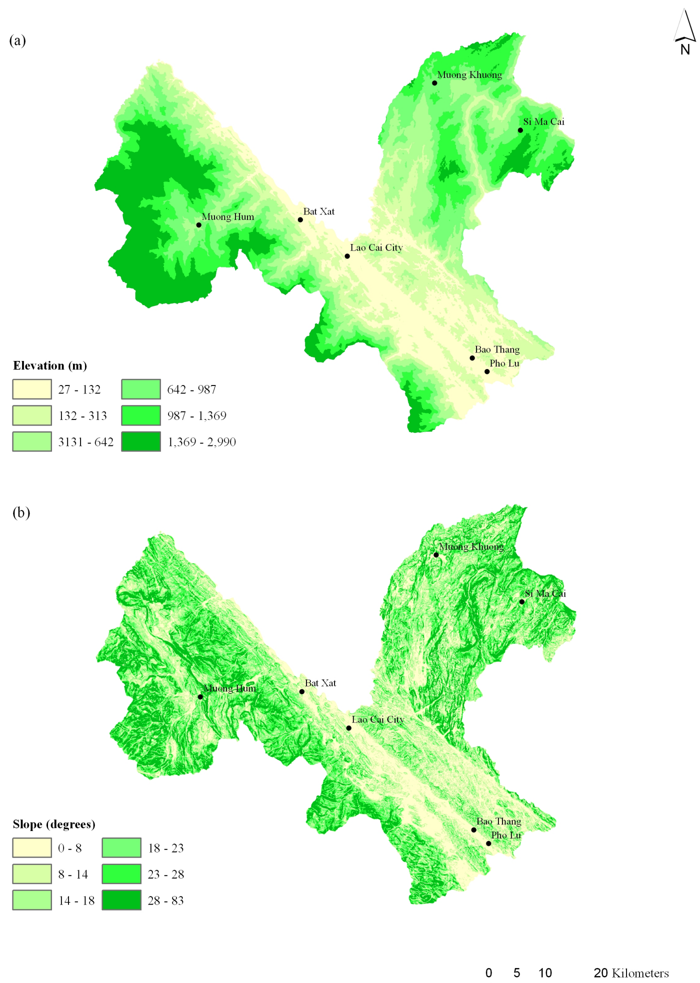


Figure 5.4: Ecological independent variables (a) elevation and (b) slope.

Figure 5.5 displays the socio-economic independent variables used as GWR inputs. The distance to roads variable changes from a mean of 900m to 250m as there is an increase in the extent and distribution of the road network from1999 to 2009 (Table 5.3). Distance to markets remains relatively constant (59km to 57km) since there are no additional markets developed between 1999 and 2009 and traditional markets are located near existing road networks. The distance to border variable is slightly modified in 2009 (119km to 11km) due to an increase in the extent of the road network.

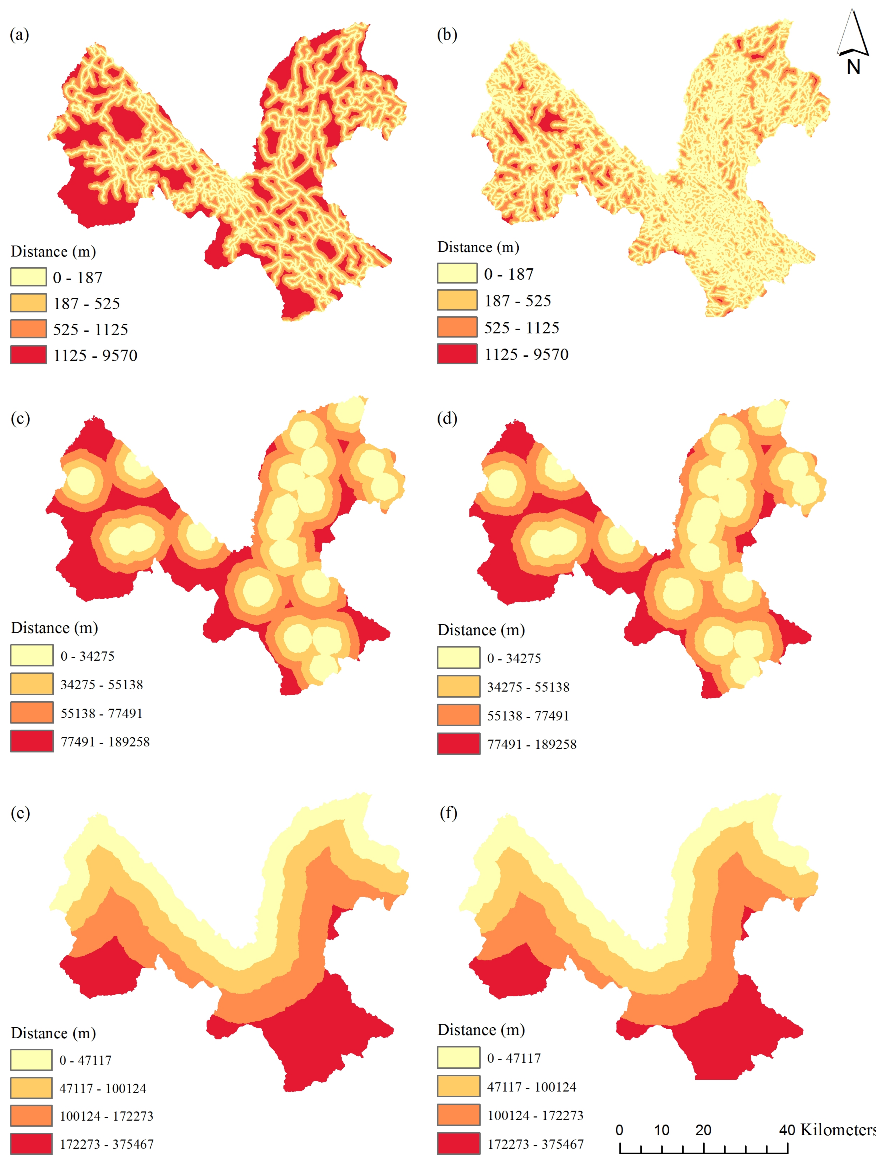


Figure 5.5: Socio-economic independent variables (a) distance to roads in 1999, (b) distance to roads in 2009, (c) distance to markets in 1999, (d) distance to markets in 2009, (e) distance to Sino-Vietnamese border in 1999 and (f) distance to Sino-Vietnamese border 2009.

5.3 Relationship between socio-ecological factors and LULC diversity

The following section presents the results of the geographically weighted regression and global regression.

5.31 Global regression

An overall regression was conducted to test the global effect of the independent variables on LULC diversity using both an OLS and SAR model. The results indicate the SAR model is more robust thus it will be used for interpretation (Table 5.4). Globally, in 1999 distance to roads and distance to markets are significant in predicting LULC diversity. In 2009 all variables are significant at a p=0.05 level of significance. Correlations with distance to roads are both negative but stronger in 1999 indicating that areas further from roads have less diversity in 1999 than in 2009. Correlations with distance to markets are also both negative but strong in 2009, indicating that in 2009 areas further from markets had less diversity than in 1999. Distance to border was only significant in 2009 and showed a negative correlation with diversity. Correlations with ecological variables are not significant in 1999 but are very significant in 2009. Both these variables show negative relationships indicating that areas with high elevation and slope have low diversity.

Table 5.4: Results of the global regression analysis for the OLS and SAR model.

Parameter	**1999**				**2009**			
	OLS		**SAR-error**		**OLS**		**SAR-error**	
Variable	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value
Intercept	1.157	69.830	1.083	35.693	1.606	79.955	1.594	42.868
Elevation	0.000	4.525	0.000	0.009	0.000	-21.163	0.000	-11.756
Slope	-0.005	-6.177	0.001	1.076	-0.007	-6.590	-0.008	-6.229
Distance Roads	-0.000067	-11.944	-0.000068	-6.881	-0.000273	-8.891	-0.000164	-5.068
Distance Markets	-0.000001	-3.397	-0.000001	-2.216	-0.000002	-7.480	-0.000002	-3.140
Distance Border	0.000000	3.020	0.000000	1.640	-0.000001	-6.443	0.000000	-2.305
Spatial autoreg.			0.068	40.426			0.693	42.648
(Adjusted or Pseudo) R2	0.120		0.482		0.421		0.675	
AIC	326		-760		1610		412	
Moran's I	0.460		-0.044		0.486		-0.042	
Lagrange Multiplier (lag)	1139.520				1201.227			
Robust Lagrange Multiplier (lag)	25.479				0.022			
Lagrange Multiplier (error)	1116.251				1247.242			
Robust Lagrange Multiplier (error)	2.211				46.037			

5.3.2 Geographically weighted regression

The following section spatially represents the significance levels of each of the independent variables. Table 5.5 summarizes t-value significance levels. A t-value above +1.96 represents a statistically significant relationship and positive correlation with LULC diversity. A t-value below -1.96 represents a statistically significant relationship and a negative correlation with LULC diversity.

Figure 5.6 displays the resultant t-values of the independent ecological variables of elevation and slope. In 1999 a high elevation is a significant factor increasing LULC diversity around Mường Hum and Si Ma Cai (Figure 5.5a). Near Bảo Thắng and Phố Lu diversity decreases with increasing elevation. In 2009 high elevation plays a significant role in decreasing diversity across the entire study region (Figure 5.5b). In 1999 high slope is a factor in increasing diversity west of Mường Hum and around Si Ma Cai in regions of ethnic minority settlement and low slope increases diversity in low-lying flat regions around the Red River, used predominately for urban and agricultural uses (Figure 5.5c). In 2009 it is no longer a significant factor within the valley region (except in the urban area around Lào Cai) and it is correlated with low diversity in regions of high-moderate slope (Figure 5.5d).

Table 5.5: T-value significance levels for n=infinity degrees of freedom.

Value	α level of significance
± 1.96	0.05
± 2.58	0.01
± 3.29	0.001

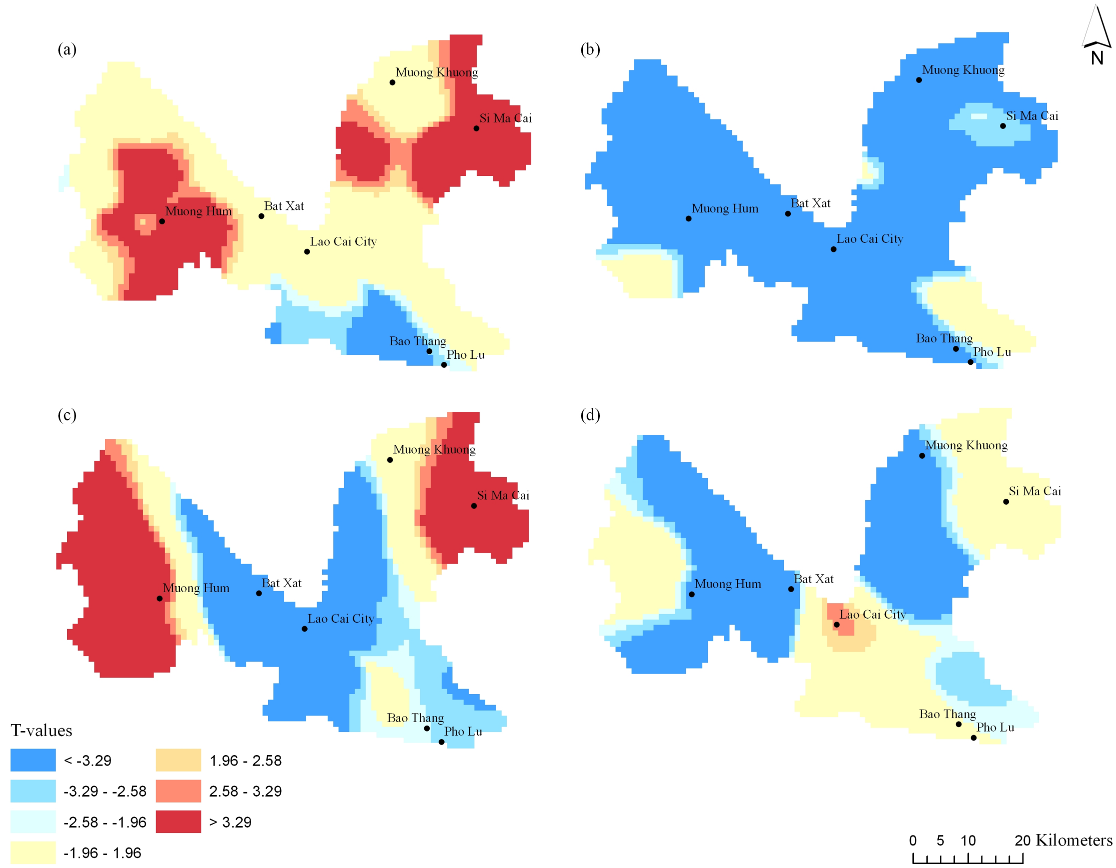


Figure 5.6: T-value results of the geographically weighted regression for independent ecological variables (a) elevation in 1999, (b) elevation in 2009, (c) slope in 1999 and (d) slope in 2009.

Figure 5.7 displays the independent socio-economic variable t-values. In 1999 the distance to roads variable is negatively correlated with diversity surrounding Mường Hum where the road network is sparse (Figure 5.7a). This indicates that as distance to roads increases the level of diversity decreases. There is also negative correlation near Lào Cai City and a positive correlation north of Si Ma Cai. In 2009 the distance to roads variable shows a negative correlation throughout most of the study area (Figure 5.7b). In 1999 the distance to markets variable is negatively correlated with diversity near Muong Khuong and Si Ma Cai and positively correlated with diversity in the southwest region of the study area (Figure 5.7a). In 2009 there is little change in the distance to markets variable, however outside of Si Ma Ca distance no longer becomes a significant factor in predicting diversity (Figure 5.7b). In 1999 distance to border is positively correlated with diversity southwest of Mường Hum and immediately surrounding Si Ma Ca (Figure 5.7a). This correlation means that as distance to the border increases the amount of diversity increases. In 2009 distance to border becomes positively correlated with diversity throughout most of the study region outside of the Red River valley and negatively correlated with diversity in the northwest and southeast portions of the study area (Figure 5.7b).

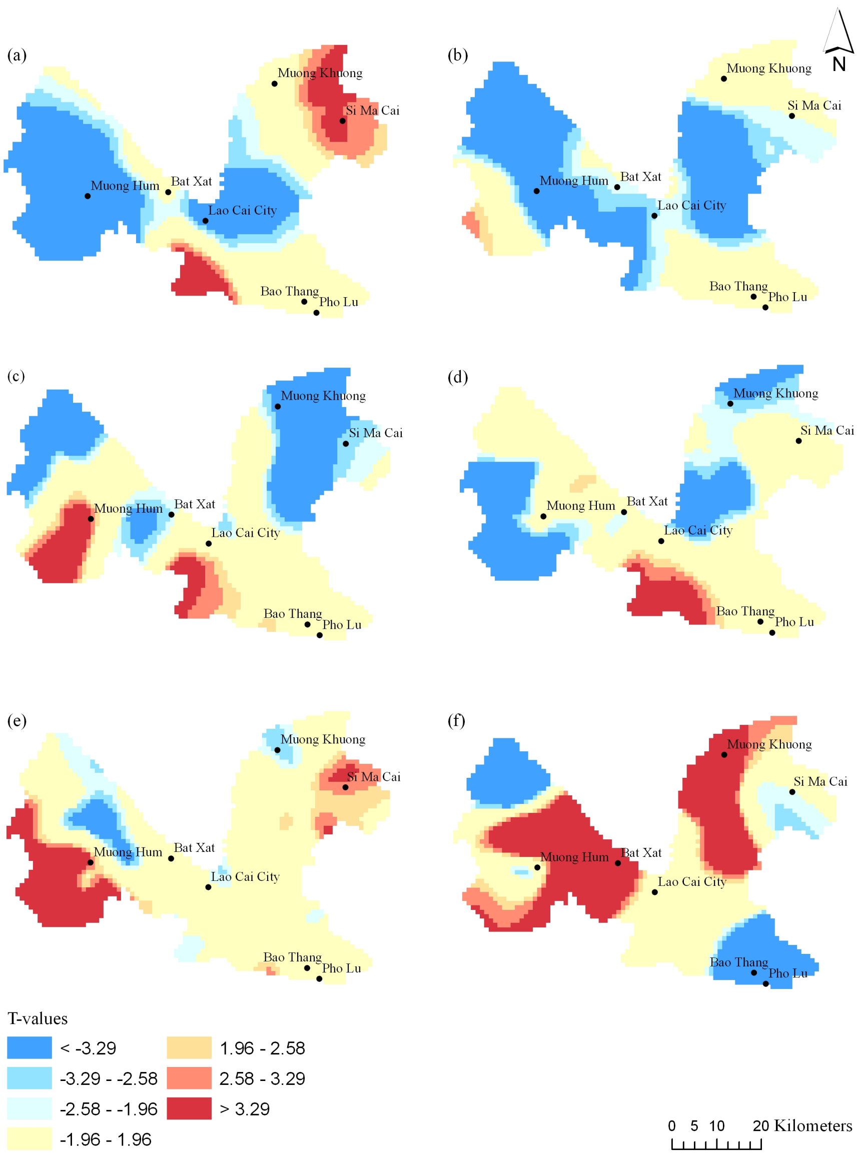


Figure 5.7: T-value results of the geographically weighted regression for independent socio-economic variables (a) distance to roads in 1999, (b) distance to roads in 2009, (c) distance to markets in 1999, (d) distance to markets in 2009, (e) distance to border in 1999 and (f) distance to border in 2009.

Figure 5.8 indicates the most significant factors affecting LULC diversity within the study area. In 1999 roads are the most significant factor where there is a spare road network (low diversity with high distance), slope is the most important factor within the lowlands (low diversity with high slope), distance to markets is the most important factor where there is a large concentration of markets (low diversity with high distance) and elevation is the most important factor in the high elevation area in the east (high diversity with high elevation) (Figure 5.8a). In 2009 elevation is the most significant independent variable throughout most of the study area (low diversity with high elevation), distance to border is significant furthest away from the border (low diversity with high distance) and distance to markets is significant in the southwest where there are few markets (high diversity with high distance) (Figure 5.8b).

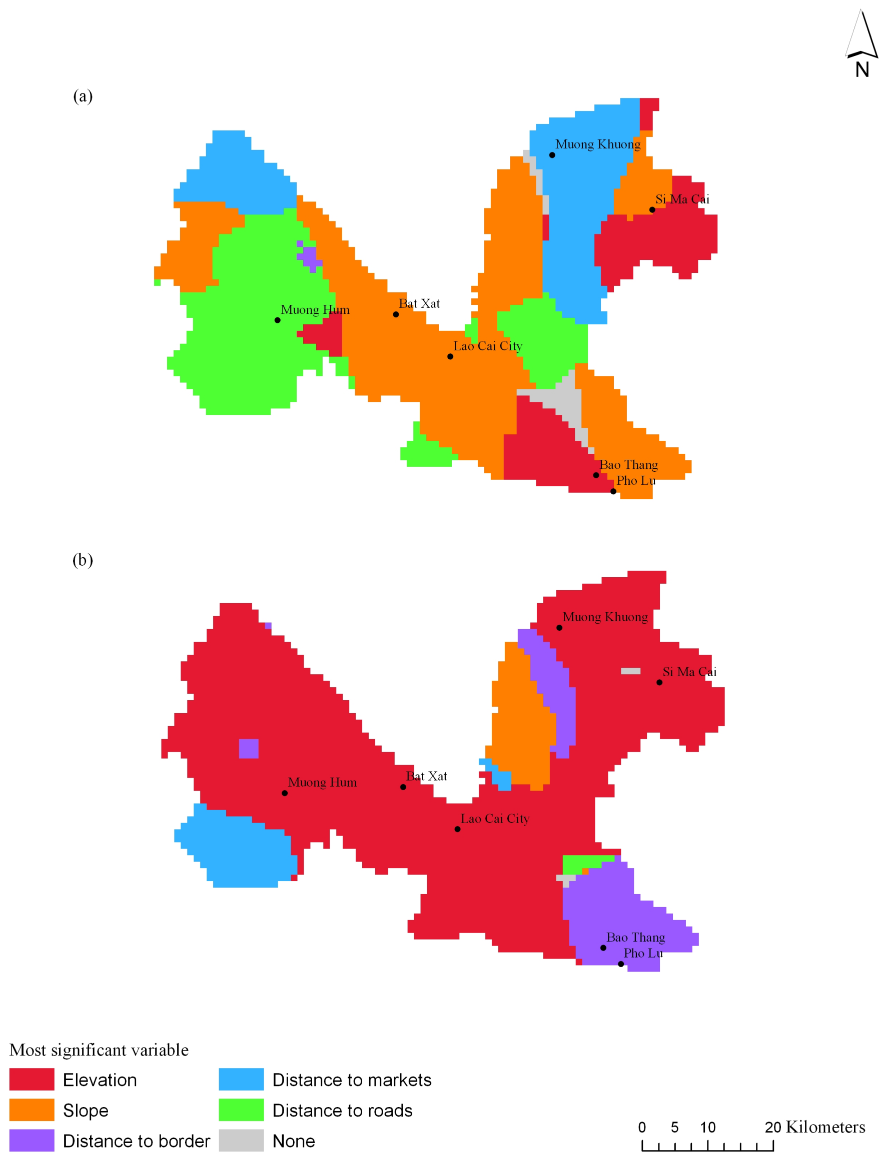


Figure 5.8: Most significant independent variable affecting LULC diversity in (a) 1999 and (b) 2009.

CHAPTER 6: DISCUSSIONS AND CONCLUSIONS

The following chapter discusses the main implications of the results. I outline the importance of human and natural interactions, the degree of success of government policies and main transformations in LULC diversity between 1999 and 2009. I draw main conclusions and focus on the results of the five independent GWR variables in two case studies. Finally, this chapter concludes with remarks on the limitations of this project and plans for future research.

6.1 Interaction between human-natural systems

Throughout the study area for both 1999 and 2009 at the community level there is evidence that a strong relationship exists between social and ecological systems. In both global and local regressions there is a high degree of connectivity between social variables, environmental variables and the number and type of human-induced land uses. There was a large shift between the relative importance of each variable between the two study years, which suggests that humans will alter their land use strategies in order to adapt to social and ecological change. Throughout most of the study area, LULC diversity decreases with increasing distance to roads, distance to markets, elevation and slope while it increases with decreasing distance to border. However, there is large local variation in diversity in response to the unique importance of these five factors. These results are similar to those of Cassidy et al. (2010) however instead of using a polynomial regression to account for non-linear relationships, this study considered local regressions. Results of the GWR regression indicate that throughout the study area, ecological factors are more significant barriers to increasing LULC diversity than socio-economic factors, especially in 2009.

6.2 Response to state land-use policies

The effect of state-led land use policies varies throughout the region. The regional successes or failures of Resolution 10, the 1993 Land Law and reforestation programs will be discussed. The main objective of Resolution 10 in 1988 was to integrate upland ethnic minorities into the national economy through a transition from self-sufficiency to full market integration (Sikor and Truong, 2002). Throughout the study area there is evidence that the infrastructure required for upland integration was significantly improved between 1999 and 2009 as there was an extensive increase in the extent of the road network. In 1999 the maximum distance to a road was 9.5km which declined to 2.5km in 2009. Similarly, an increase in the extent of the road network has facilitated increased market access by decreasing the maximum distance to markets from 190km to 176km. Alther et al. (2002) suggest that increased accessibility in the uplands can significantly increase market integration of ethnic minorities as there are more opportunities to sell agricultural surplus, obtain access to knowledge or resources and secure non-agricultural income.

The main objectives of the 1993 Land Law were to facilitate sedentary livelihoods through fixed agricultural systems, such as intensive paddy field production and plantations, and to protect upland slopes from extensive deforestation caused by dismantlement of the collective system (Castella et al., 2006). The results of the land classification suggest that the first objective was not met in the northern uplands of Lào Cai, as there was a decrease in paddy fields, upland fields and steep fields between 1999 and 2009. However, the diversity of land use decreases significantly in some regions, which can suggest a shift to homogenized land use. This shift may suggest a transition away from traditional swidden based practices, which typically involve rotating land use between fields, forest cover and shrubs. Additionally, sedentary livelihoods would require a smaller area, which may indicate the success of the program. In another upland Vietnam province, Castella (2006, 156) found that most upland households were hesitant to pursue plantations as a livelihood strategy as they are “a highly uncertain source of income because of village remoteness and market uncertainty”. Contrary to these results, there is some evidence for the successful implementation of plantations, particularly pineapple plantations in Muong Khuong (S. Turner, Personal communication, March 2013).

In conjunction with reforestation programs such as the 5MHRP and Program 327 the reforestation objective of the Land Law was fully achieved. Between 1999 and 2009 there was a 413% increase in closed canopy forest. This increase is compatible with a national study that found the extent of the forest network increased during this time period (Meyfroidt and Lambin, 2008b). The increase came predominately from land that was previously classified as shrubs and open canopy forest. This land use change may be from a combination of factors (S. Turner, personal communication, March 2013). Program 327 and the 5MHRP were implemented in Lào Cai province however critiques of Program 327 by forestry officials and local residents suggest that the outcomes were very significant. The 5MHRP, or Decision/Program 661 results are less clear but patches of planted forest (agro-forestry farms) are visible throughout the province.

Alternatively, there has been an increasing interest among ethnic minorities to grow cardamom, which has potentially led to a renewed interest to maintain forests.

6.3 Changes in Diversity

The biggest predictors of LULC diversity are resources that are the most limited (Fatoux et al., 2002; Lambin and Meyfroidt, 2010). Multiple studies in the Vietnamese uplands have suggested a declining ecological resource base as land use systems become more stressed (Alther et al., 2002; Fatoux et al., 2002; Meyfroidt and Lambin, 2008b). The result of this is signs of land degradation including deteriorating soil and forest quality (Castella et al., 2002). Environmental stresses in the uplands are caused by agricultural intensification of existing land use and expanding land use from population growth, urban sprawl and land allocation strategies (Turner, 2012; WorldBank, 2009). Between 1999 and 2009 there is a shift in the relative importance of ecological variables. The local regression suggests that in 1999 socio-economic variables and ecological variables are equally significant in predicting LULC diversity. By 2009 the most significant variable predicting LULC diversity, and thus the most limited resource, is elevation. As the availability of land decreases socio-economic barriers, such as distance to roads, become less important while high elevation significantly limits diversity throughout the study area.

The effects of land degradation are unsustainable and there is evidence that households are moving away from homogenous systems while diversifying land use strategies to generate alternative opportunities. There was an overall increase of LULC diversity between 1999 and 2009. Changes in diversity occur in regions populated by ethnic minorities and regions populated by Vietnamese Kinh. Additionally, there has been an increase in economic activities that are not visible through LULC studies such as textile sales or tourism initiatives (Turner, 2012). Stress on soil and water quality of agricultural systems presents challenges for future land management and hints at the complexity of interactions between human and natural systems.

6.4 Case studies

The following section discusses in detail the local effects of each variable in a rural and urban case study.

6.4.1 Rural change

In the region southwest of Mường Hum there has been a significant transition to low diversity land use dominated by closed canopy forest. High slope and elevation, a sparse road network and fewer markets characterize this region. The dominant ethnic group is the Hmong with some populations of Yao (Roche et al., 2004). In 1999 this region was largely classified as upland fields used to grow dry rice and corn. A decrease in upland fields could suggest a move towards state-sponsored high intensity hybrid rice that requires less land for greater yields. LULC transition in this area may also be a response to government officials having greater road access to this area and prohibiting swidden cultivation. This has implications for local food security, as hybrid rice is only available in government distribution centers, has a short sowing period, must be purchased annually and requires the use of harmful pesticides (Bonnin and Turner, 2012).

As suggested earlier, the increase in forest cover may be a response to reforestation land use policies or a shift towards cardamom cultivation. Cardamom is a low-labour crop, grown within the shade of forests, that is becoming increasingly demanded in the international market (Turner, 2012). Forest networks are also used by the Hmong for the collection of other forest products such as honey, fuel wood, game and herbal medicine (Turner, 2011). Through discussions with my reader Sarah Turner, I have learned that cardamom is being exported by traders who enter the villages and bring it to Lào Cai City. It is possible that markets near Mường Hum are being used as well. After income is obtained from cardamom many households purchase meat, salt, cooking fat, gifts and household items such as oil, blankets, cooking pots, motorcycles, building material, fertilizer and seeds (Turner, 2012). However, the long-term sustainability of cardamom cultivation is an issue as yields are highly variable depending on annual weather conditions and intermediary traders are unreliable and untrustworthy (Turner, 2012). Overall, this suggests an ethnic minority shift away from subsistence living and integration into local and regional markets through cardamom cultivation.

Households undergoing significant land transformations must find ways to increase the productivity of new or existing land uses without degrading ecological resources while simultaneously developing secure market access and buyers (Fatoux et al., 2002). Throughout the rest of the rural regions in the study area, there is a drastic decline in upland and paddy fields, which may suggest a district-wide decline in swidden cultivation. This raises questions about food security since 50-60 percent of Lào Cai is considered to be food insecure (Bonnin and Turner, 2012). However qualitative fieldwork will need to be undertaken to determine if alternative livelihood strategies have developed as fieldwork conducted by Turner (2012) indicates the Hmong have not felt inclined to abandon their semi-subsistence livelihood strategies.

6.4.2 Urban change

Throughout the study area there has been a 528% increase in urban infrastructure. The majority of this growth has occurred within the Red River valley near Lào Cai City. This growth can be linked to national plans to facilitate cross-border trade and the Greater Mekong Subregion North-South Economic corridor. The Vietnamese government is investing extensively in this region to keep up with growth and highway development occurring in Yunnan (Turner, 2013). The *2020 Lào Cai Economic Development Plan* prioritizes investment in construction, renovation and upgrading of facilities at the Lào Cai-Yunnan international border, as well as the construction of new border crossings to facilitate increased trade (People's Committee, 2010).

Although LULC diversity within this corridor increased between 1999 and 2009, I suggest that this is increase is temporary due to transitioning land and with time diversity will decrease as the entire region becomes urbanized. The main LULC shift that occurred in this region was a transition from paddy fields to urban. This may have implications for local food security as more food will have to be imported from surrounding regions. It may also present food production opportunities for nearby villages.

To predict LULC diversity in this region there is little importance on socio-economic variables. I suggest this is because there is the minimal distance to roads and markets, and the shortest distance to border. Ecological variables are significant and demonstrate that low slope is important for high diversity. This may be related to a mixture of agricultural land uses on the rural-urban fringe. Significant urban growth between 1999 and 2009 also occurs near other towns in the study area including Mường Hum, Bát Xát, Bảo Thắng, Muong Khuong and Si Ma Ca.

6.4 Conclusions

To conclude, this study has found that national policies have been effective in encouraging LULC change in the northern districts of Lào Cai Province. There has been an increase in urban infrastructure and rural infrastructure required to access markets. There has also been an increase in forest cover and a decrease in upland swidden cultivation. The diversity of land use has increased suggesting a transition between land uses or the diversification of livelihood strategies. Overall, LULC diversity in this region is predicted best by ecological variables such as slope and elevation.

It is important to note that the patterns that have emerged are at the community or village level. Complex interactions and decisions are made at the household level and require more detailed studies. Changes in LULC and diversity raise questions about the sustainability of developing land use systems from both an ecological perspective (soil and water quality) and access perspective (access to seeds, knowledge, markets). From this quantitative analysis it is unclear the extent of the effect of change in LULC diversity on food security. Qualitative fieldwork will need to be conducted to determine the crops and seed varieties being grown, the presence of small household gardens, local ethnic resistance to government polices and the extent of household diversification strategies through initiatives such as crop diversification, livestock trade and off-farm activities.

One source of error in this project could arise from an inaccurate classification of the Landsat images. The accuracy assessment for the 2009 image was 78%. From a remote sensing point of view this is good, however an accuracy assessment for the 1999 image was not conducted due to the unavailability of reference data. Additionally, local perceptions of different land uses will yield different ground truth classes. Future research will expand to the neighbouring provinces of Lai Chau, Ha Giang and Yunnan, China. Cultural and other economic variables will also be considered to further understand the associations between ethnic minorities and land use change. The long-term aims of the project will be to determine how state policies have been effective across a wide range of local conditions.

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APPENDIX

This thesis used Landsat images to derive a LULC classification. Sensor characteristics for each image are displayed below.

Image	Sensor Characteristics
2009 - 11 - 12 - Landsat TM5	SUN_AZIMUTH = 150.4954143 SUN_ELEVATION = 43.9284807 SCENE_CENTER_SCAN_TIME = 03:19:31.8220630Z SCENE_CENTER_LAT = 23.11700 SCENE_CENTER_LON = 104.29789 (Mean) Ground elevation: 1.131485320
1999 - 12 - 27 - Landsat ETM+	SUN_AZIMUTH = 150.2886551 SUN_ELEVATION = 37.3895716 SCENE_CENTER_SCAN_TIME= 03:21:46.9251773 SCENE_CENTER_LAT = +23.1179586 SCENE_CENTER_LON = +104.2866630 (Mean) Ground elevation: 1.131485320

Source: (NASA Landsat Program, 1999; NASA Landsat Program, 2009