Study on the Impacts of Feeder Road Expansion on Livelihood and Spatial Pattern

Case Study in Natong Cluster, Huaphan Province, Lao PDR

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STUDY ON THE IMPACTS OF FEEDER ROAD EXPANSION ON LIVELIHOOD AND SPATIAL PATTERN

CASE STUDY IN NATONG CLUSTER, HUAPHAN PROVINCE, LAO PDR

ABSTRACT

Maize is an important cash crop in commercial agriculture system in northern Laos. Maize production constrains with the lack of production areas and the sparse of road network for transporting products led to feeder road construction to reach maize production areas with hand tractors or small trucks. This has been widely increased in the north part where people rely on growing maize as a cash crop for better livelihood. The study assesses the impact of the feeder roads on livelihood through statistical analysis and quantified spatial pattern based on spatial analysis employing Geographic Information System (GIS) and Remote Sensing Techniques. The data used for livelihood analysis include primary data from field work in the beginning of 2016 and secondary data from Catch-Up project in 2009 (**www.asia-uplands.org/Catch-Up/index.php**), and data used in spatial pattern analysis include Landsat imageries (2003, 2008, 2013, and 2015), SPOT image of 2015, aerial photo of 2014, data from ground survey in 2016, and other related GIS data. The study revealed that:

1) The impacts of the feeder roads expansion on livelihood were both positive and negative. The positive impact was that it eased accessing to production areas, reduced constrains with accessing to the fields and products transportation. It allowed remote communities engage into the market economy through intensive cropping of maize. Villagers could invest in basic livelihood assets such as better house, motorcycles for transportation, send children to schools, etc. and also invest in off-farm activities. However, these maize-driven land use changes also came with negative impacts such as reduction of income from NTFP, soil erosion and land degradation that reduce the yields in the upland fields and force villagers to use more inputs, to contract more debts and engage in more economically risky activities as compared with the previous decade.

2)   Feeder road expansion in order to support maize production led to changes in spatial pattern arrangement. It caused decreasing of natural forest cover in every year. Agricultural land, in particular upland crop system, increased inversely to open forest. The expansion of agricultural land seemed to move towards to forest areas. Land use intensity gradually emerged along the feeder roads and land sparing appeared as at the beginning state.

Different livelihood alternatives are already explored by villagers and may be further supported by development projects in the future such as conservation agriculture or opportunities for income diversification through livestock or off-farm activities.

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Abbreviations

DFID   the UK Department for International Development
FAO   Food and Agriculture Organization
IPCC   Intergovernmental Panel on Climate Change
NTFPs   Non-timber Forest Products
PRF   the Poverty Reduction Fund project
TEV   the Total Economic Value
TOA   Top of Atmosphere
USGS   The United States Geological Survey
GoL   Government of Lao People's Democratic Republic

Chapter 1 Introduction

This chapter introduces the context of the study, that is, the shift from subsistence agriculture to market-oriented agriculture in the northern uplands of Lao PDR, and the role of feeder roads for reaching to remote upland agricultural production areas. Then the chapter presents the objectives of the study, research questions, theoretical framework, literature review, and conceptual framework.

1.1 Background of the Study

Feeder road construction to access to production areas has been widely increased in Lao People's Democratic Republic (Laos), particularly in the north part. The economic development constrains in the northern Laos are the sparse of road networks for transportation and the limited-land for agriculture production because of high slope mountainous topography which covers large area of northern region. Population in this region are mainly farmers, but due to the lack of low-land for agriculture expansion, many farmers cultivate in upland areas. These farmers are classified as rural residents who live with low income (Pimhidzai, Fenton, Souksavath, & Sisoulath, 2013).

In order to improve rural farmers' livelihood, the government of Laos set four targets for agriculture development: (1) ensure food security, (2) commercial production, (3) poverty reduction and shifting cultivation stabilization, and (4) sustainable forest management (NAFRI, 2014). Commercial agriculture leads to the shift from Swidden-based subsistence agriculture to monocropping-based commercial agriculture, which is known as the agrarian transition. It has been addressed that commercial agriculture brought new opportunities for income generation in the form of commercial crops (Shi, 2008; Voungvisouk, 2014). Maize is an important cash crop in commercial agriculture system in northern Laos. It contributed to the agrarian transition as government prioritized growing this crop for exporting to neighboring countries such as China, Vietnam, and Thailand (Ministry of Planning and Investment, 2011). Maize has contributed great amount in gross domestic product (GDP) and its area has increased from 86,000 ha in 2005 to 212,745 ha in 2010 during implementation the 6th National Socio-economic Development Plan (2005 – 2010) (Ministry of Planning and Investment, 2011).

Natong village cluster (group of villages) of Xiengkhor district, Huaphan province, is a case that almost all households generate income from maize. A study by Viau et al, (2009) revealed

that maize was first introduced in these villages in 2005 by few villagers. The great benefit from maize production in that first year attracted other villagers to adopt this cash crop instead of rice and led to maize expansion in the region (Viau, Keophosay, & Castella, 2009). Maize is a major source of income for all households in Natong village cluster. It provided great benefits and improved household economy (Keophosay, Viau, & Castella, 2011). At the beginning of maize production, farmers faced constrain with products transportation that they had to carry maize back to the village. In upland rice based swidden system, they have to carry back 1 or 2 tones harvest per hectare to the village. But with maize, they have to carry much higher weights about 6t/ha (Viau, Keophosay, & Castella, 2009). Therefore, farmers decided to construct feeder roads to their agricultural production areas by themselves or contract the maize company to open the road through a loan that they reimburse by selling their maize production at a lower price to reimburse their debt.

Feeder roads construction were begun in Nanong (a village of Natong village cluster) in 2006, it then expanded very fast to other villages in few years later. The roads played important role in transition from traditional subsistence production systems to market-oriented systems as it eased villagers to access to production areas with hand tractors or small trucks. As a result, villagers can overcome labour constrain in transporting products, and they were able to expand maize field as much as their labour force could support. It is largely recognized that improved physical accessibility of upland areas to market outlets has a positive impact on livelihoods by providing income generation opportunities. However, many researches pointed the negative consequences in terms of concentration of agricultural production along the roads, deforestation, and land degradation which would return unsustainable natural resources (Castella, et al., 2013; Rivera, 2015).

This study analyzed the patterns of maize expansion. The study aimed at raising understanding on the impact of the feeder road construction on livelihood outcomes from maize-based livelihood strategy. Two questions are addressed for this study. (1) How has feeder road contributed to livelihood outcomes since the adoption of maize producing? (2) How feeder road affect spatial pattern in term of spatial arrangement of land use and land cover?

1.2 Research objectives

1) To quantify the livelihood outcomes relate to feeder roads construction through investigation changes in pattern of income generation, assets, agriculture practices, and farmers' perception on environmental change.
2) To quantify spatial pattern changes in the study area applying Geographic Information Systems.

1.3 Study area

Many villages in northern upland of Laos that involved in maize production are characterize by feeder road networks. In this study, we selected a case from Huaphan province which is one of top range provinces that are producing maize. This research concentrated on some of the villages of Natong cluster (Group of villages) of Xiengkhor district, which is classified as the maize district based on the number of villages involved in maize contracts - 49 villages or about 80% of the total 62 villages in the district generated their main income from selling maize under contract farming (Willi, 2011). Natong village cluster is composed of 9 villages, namely, Natong, Nanong, Xiengdaen, Deua, Phouk, Thaensan, Sobpin, and Sobdoung. In this study, 5 villages (Natong, Nanong, Xiengdaen, Deua, Phouk) were selected based on their location and their similarities in term of maize production patterns.

1.4 Methods

This research applied Geographic Information System (GIS) in analysis the impact of feeder roads on spatial pattern and we applied mix-method for analyzing the impacts on livelihood outcome.

In the processes of spatial pattern analysis, we first generated land use and land cover maps by using Remote Sensing techniques. Then we generated feeder roads data from aerial photograph and SPOT satellite image. The feeder road data and land use and land cover maps were then verified by ground-truth checking using GPS. After the data generation processes completed, we conducted data analysis using GIS software (ArcGIS Desktop) and Remote Sensing Software (ERDAS Imagine). The main function used include "matrix union", "combine", and "intersect" for land use and land cover changes, agriculture expansion, and agriculture land use intensity.

The livelihood outcomes were analyzed using mix-method such as contents analysis to

analysis data from interviewing, focus group, as well as official documents from related district authorities. The livelihood outcomes were evaluated through income generation pattern, assets, and some changes in agricultural practices.

1.5 Expected outcome

This study is expected to provide outcome to support understanding the trade-offs between economic benefits and environmental losses, and social consequences through following contexts.

1) Maize expansion and feeder roads construction trajectories.
2) Impacts of feeder road construction on spatial pattern in term of land use and land cover arrangement induced by agricultural land expansion and land use intensity.
3) Changes in livelihood outcomes in relation with investment in feeder road construction through investigating income generation pattern, changes in assets, and agricultural production.

1.6 Definition of the key words

Feeder road: a minor road connects to the major one. All feeder roads in our study area are one-way travelling by small truck, approximately 3 meters-wide. Farmers invested in construction of these roads in order to improve maize production by reducing times spent on accessing to production areas, expanding production areas, facilitating products transportation by truck instead of labors.

Feeder road expansion: refers to increasing amount of feeder road, not the expansion in width of the roads.

Spatial pattern: refers to land use and land cover characteristics and their cover proportion in the study areas.

Land use: the land managed by villagers for settlements, farming, or other activities. Land use in our study area consists of residence areas and agricultural areas.

Land cover: the characteristics over the surface which include natural and human-modification of natural land cover. Land cover in our context include dense forest, open forest, fallow, agriculture area, residence area, and water area.

Land use and land cover change: the changes from one category of land use and land cover in before to other categories in later years.

Livelihood outcome: the results of pursuing livelihood strategies.

Lao PDR: a landlocked country located in the central of mainland Southeast Asia, bordered by China to the north, Vietnam to the east, Cambodia to the south, Thailand to the west and southwest, and Myanmar (Burma) to the northwest. It is divided into 17 provinces include Phongsaly, Luangnamtha, Bokeo, Oudomxay, **Huaphan**, Xiengkhuang, Luangprabang, Sayabouly, Vientiane, Bolikhamxay, Khammouan, Savanakhet, Salavan, Sekong, Attapeu, and Champasak. There is one prefecture, Vientiane capital city of Laos.

1.7 Thesis structure

This research report is divided into 5 chapters.

1) **Chapter 1 introduction**: this chapter introduced background of the study, research questions, objectives of the research, hypothesis of research, study area, over view of method employed, expected outcome, key words definition, and present the structure of the report.

2) **Chapter 2 Literatures review**: presents theories and concepts relate to context of study which include land use intensity, land sharing and land sparing, sustainable livelihood framework, concepts of spatial analysis, digital image processing, policies relate to land use planning, agricultural plan, related studies, and conceptual framework of this study.

3) **Chapter 3 General information of the study area:** present essential background data of the study area including, Geographic feature, population, infrastructure, institutes, and agriculture in the study area.

4) **Chapter 4 Impact of feeder roads on livelihood:** presents the changes in livelihood outcome looking through changes in income generation pattern, assets, and agricultural practices.

5) **Chapter 5 Impact of feeder roads on spatial pattern:** presents expansion trajectory of feeder roads including expansion pattern and construction processes, changes in spatial pattern in aspect of land use and land cover, dynamic of upland agriculture and forest, land use intensity.

6) **Chapter 6 Conclusion, Discussion, and Forward Looking:** presents the conclusion, discussion, implication, limitations, and forward looking.

Chapter 2 Literatures review

This chapter presents theories and concepts relate to context of study which include land use intensity, land sharing and land sparing, sustainable livelihood framework, concepts of spatial analysis, digital image processing, policies relate to land use planning, agricultural plan, related studies, and conceptual framework of this study.

2.1 Concepts relate to context of study

This study aimed at analyzing the impacts of maize expansion driven by feeder roads on spatial pattern and livelihood outcome. To formulate the concept framework of the study, we reviewed related concepts or theories including.

1) Strategy for agricultural development
2) Agricultural land use intensity
3) Land sharing versus land sparing
4) Spatial analysis
5) Sustainable livelihood framework

2.1.1 Lao PDR's strategy for agriculture development 2011-2020

Agriculture development strategy (ADS) is a long term framework for developing agriculture sector. It serves as a reference for decision making for agriculture development. The vision of the government of Laos for the development of agriculture, forestry, natural resources and rural areas is based on a concept of long-term and sustainable development, including social and ecological dimensions (Ministry of Agriculture and Forestry, 2010). The long-term development goals for agriculture sector are (1) gradual introduction and increased application of modernized lowland market-oriented agricultural production, adapted to climate change and focused on the smallholder farmers, and (2) conservation of upland ecosystems, ensuring food security and improving the livelihoods of rural communities. The strategic direction strategy given to the Ministry of Agriculture and Forestry for the agriculture, natural resources, and rural is to ensure a successful gradual transition from subsistence into commercial smallholder production. This can be achieved by applying innovative technologies for high quality production for valued-added agro-processing and domestic, regional, and world markets. Smallholder farming systems and the economies of rural communities will become more diversified and be upgraded to increase production for food security and to improve rural living by farmers groups and contract farming to local traders, agro-

processors, and agribusiness enterprises. The aim is to contribute to reducing rural poverty by creating rural employment opportunities, transferring modern technologies to increase productivity, channeling agricultural production inputs and finance, and facilitating linkages to regional and global value chains.

Additional investments in irrigation, rural market access roads, and other high-cost rural infrastructure will be linked to smart agriculture, which will be developed into an operational concept for Laos. The concept is about successfully linking the interesting in investments of the private sector to a set of social and ecological conditionality to ensure that not only the investors themselves, but also Lao society and rural smallholders benefit from such investments. The major themes of agriculture, natural resources, and rural sector strategy include a strong focus on modernizing agricultural production and creating value-added food and agricultural products aimed at reducing rural poverty, maintaining food security, and applying results-based management to the natural resources that provide the foundation for sustainable agricultural and rural development (Ministry of Agriculture and Forestry, 2010).

2.1.2 Sustainable livelihoods framework

According to Robert Chamber and Gordon R. Conway (1991), "a livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living; a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term". In 1999, the UK Department for International Development (DFID) refined Chambers and Conway definition of livelihood. DFID defined that "a livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from shocks and stresses and maintain and enhance its capabilities and assets both now and in the future, whilst not undermining the natural resource base" (Satgé, 2002).

The livelihoods framework is a way of understanding how households derive their livelihoods by drawing on capabilities and assets to develop livelihood strategies composed of a range of activities (Satgé, 2002), it demonstrates the factors that constrain or enhance livelihood opportunities and shows how they relate to one another (Serrat, 2008). One of the most widely

used frameworks is the one used by the UK Department for International Development (Satgé, 2002) as shown in the (Figure 2-1).
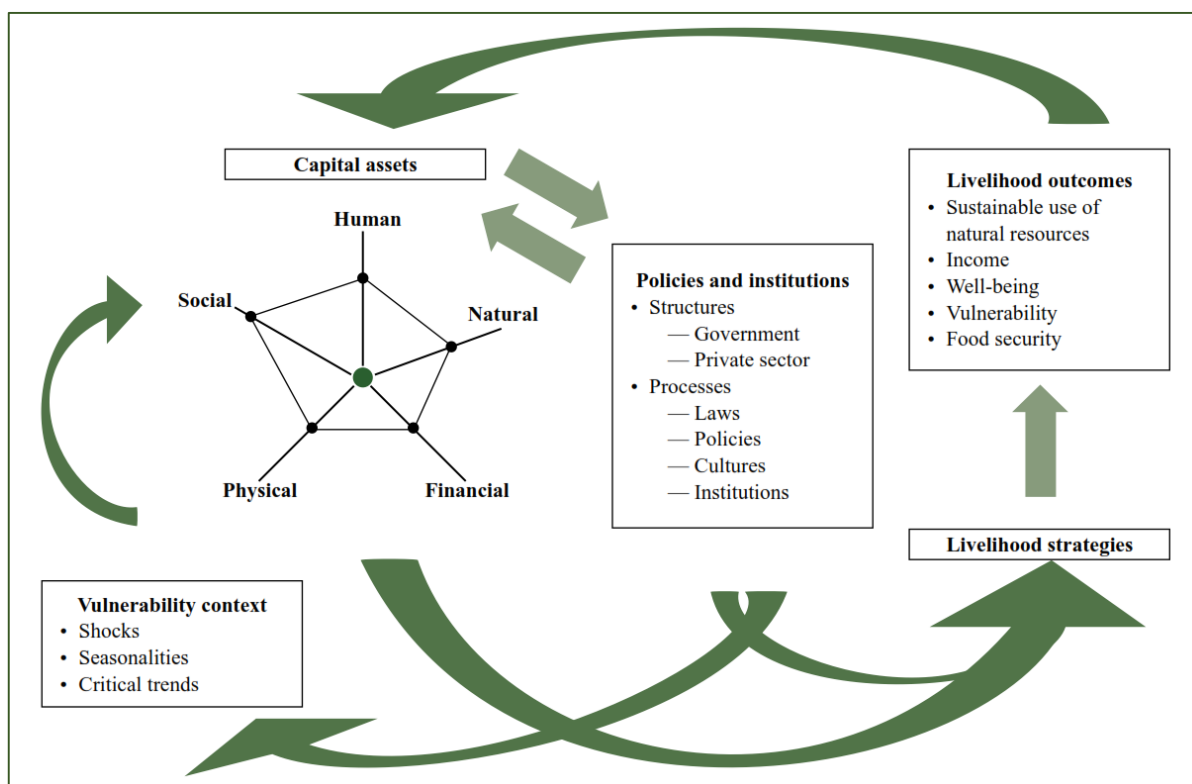
Figure 2-1 Sustainable livelihoods framework

Source: Olivier Serrat (ADB) adapted from Department for International Development of the United Kingdom

2.1.2.1 Livelihood assets

The livelihoods assets comprise of (Serrat, 2008):

1) Human capital, e.g., health, nutrition, education, knowledge and skills, capacity to work, capacity to adapt.

2) Social capital, e.g., networks and connections (patronage, neighborhoods, kinship), relation of trust and mutual understanding and support, formal and informal groups, share values and behaviors, common rules and sanctions, collective representation, mechanisms for participation in decision-making, leadership.

3) Natural capital, e.g., land and produce, water and aquatic resources, trees and forest products, wildlife, wild foods and fibers, biodiversity, environmental services.

4) Physical capital, e.g., infrastructure (transport, roads, vehicles, secure shelter and buildings, water supply and sanitation, energy, communication), tools and technology (tools and equipment for production, seed, fertilizer, pesticides, traditional technology).

5) Financial capital, e.g., savings, credit and debt (formal, informal), remittances, pensions, wages.

2.1.2.2 Vulnerability context

Vulnerability is characterized as insecurity in the well-being of individuals, households, and communities in the face of changes in their external environment. Vulnerability has two facets: an external side of shocks, seasonality, and critical trends; and an internal side of defenselessness caused by lack of ability and means to cope with these. The vulnerability context includes:

1) Shocks, e.g., conflict, illnesses, floods, storms, droughts, pests, diseases.

2) Seasonality, e.g., prices, and employment opportunities.

3) Critical trends, e.g., demographic, environmental, economic, governance, and technological trends.

2.1.2.3 Policies and Institutions

Livelihood strategies and outcomes are not just dependent on access to capital assets or constrained by the vulnerability context; they are also transformed by the environment of structures and processes. Structures are the public and private sector organizations that set and implement policy and legislation; deliver services; and purchase, trade, and perform all manner of other functions that affect livelihoods. Processes embrace the laws, regulations, policies, operational arrangements, agreements, societal norms, and practices that, in turn, determine the way in which structures operate. Policy determining structures cannot be effective in the absence of appropriate institutions and processes through which policies can be implemented. Processes are important to every aspect of livelihoods. They provide incentives that stimulate people to make better choices. They grant or deny access to assets. They enable people to transform one type of asset into another through markets. They have a strong influence on interpersonal relations. One of the main problems the poor and vulnerable face is that the processes which frame their livelihoods may systematically restrict them unless the government adopts pro-poor policies that, in turn, filter down to legislation and even less formal processes.

2.1.2.4 Livelihood strategies and outcomes

Livelihood strategies aim to achieve livelihood outcomes. Decisions on livelihood strategies may invoke natural-resource based activities, non-natural resource based and off-farm activities, migration and remittances, pensions and grants, intensification versus diversification, and short-term versus long-term outcomes, some of which may compete. Potential livelihood outcomes can include more income, increased well-being, reduced vulnerability, improved food security, more sustainable use of the natural resource base, and recovered human dignity, between which there may again also be conflict.

2.1.3 Agricultural land use intensity

Lindenmayer et al. (2012) defined land use intensity as "the increased intensity of human use of the land in a given area or the increased number of areas dedicated to a given form of (productive) human land use across a landscape." While Rudel, et al., (2009) stated that land use intensification generally refers to the intense use of land for modern agriculture dependent upon high yielding varieties with high inputs of fertilizers and pesticides. Land use is a broad topic which is covers many categories. In Laos, land is classified into 8 categories; there are agricultural land, forest land, water area land, industrial land, communication land, cultural land, land for national defense and security, and construction land (National Assembly of Laos, 2003). In this study, only agricultural land is emphasized for discussion.

Agricultural land use intensity is the degree of yield amplification caused by human activities (Dietrich J. , et al., 2012). Intensive use of agricultural land is driven by increasing demand for agricultural products as the population grows and reduction of agricultural land (Hao & Li, 2011), changing dietary habit (Dietrich J. , et al., 2012; Pingali, 2007; Von Braun, 2007), increasing in the use of land for non-agriculture, and environmental issues such as soil erosion also lead to intensifying in agriculture (Rudel, et al., 2009). Agricultural intensification sets in motion two countervailing forces – increases and reduces cultivated areas. Initially, intensified production provides farmers with higher yields per hectare and growth in their gross income. This prospect may induce them to expand the area for cultivation. If demand for the products is relatively inelastic, the increase in supply that results from the aggregation of individual farming decisions will result in a decline in crop prices. This will dissuade farmers from expanding the area for crops cultivation (Rudel, et al., 2009).

Many countries worldwide applied the approach of intensification which is believed that when the land is intensified, farmers will not expand area for cultivation and there will be spare land for other use (Rudel, et al., 2009). However, there are arguments that land use intensification could not spare land when there's strong demand on products and inelastic price of products, and it does not ensure that an environmentally sustainable landscape will be maintained (Rudel, et al., 2009). Also there is debate that land use intensification causes the decline of plant species diversity and effects human well-being in form of impacting on delivering ecosystem services (Allan, et al., 2015).

2.1.4 Land sharing versus land sparing

Land sharing integrates the objectives of agriculture and benefits to wildlife on the same land, while land sparing separates intensive farming areas from protected natural habitats at larger scales (The Pariamentary Office of Science and Technology, 2012). The concept of "land sharing" and "land sparing" is the result of argument on how to combine the goals of biodiversity conservation, rural development, and global food security, and the concept of investments in high-tech industrial agriculture which would lead to more efficient land use and allowing for increased food production while sparing land for wild nature, as well as some argument that agriculture and nature need to share the same space, stressing the need to invest in smallholder, environment friendly farming (Kusters, 2014).

Land sharing attempts to meet both agricultural and conservation needs within the same area (Green, Cornell, Scharlemann, & Balmford, 2005), this approach aims to make existing farmland as hospitable to wildlife as possible by reducing pesticide and fertilizer inputs and retaining habitats such as trees, hedges and ponds. Land sharing aims to create a multifunctional landscape that attempts to integrate food production, nature conservation, biofuel production and other ecosystem services. However, it can limit yields, so more land area is required to produce a given amount of food (Fischer, et al., 2008).

One approach to meet the rapidly increasing global demand for agricultural products without causing biodiversity loss is to further intensify and mechanize agricultural production (Kusters, 2014). It is claimed that this will not only raise production but also protect biodiversity, as it ensures more efficient use of scarce lands. It implies setting aside and giving protected status to as many intact ecosystems as possible, while intensively growing crops in industrial agricultural systems on the remaining land. Crop diversity in these farming systems is usually low, individual

fields are large, and there is heavy reliance on external inputs. But this form of agriculture has its own critics. It could bring opposite consequences, such as the heavy use of agrochemical can cause problems on land or soil degradation. Also, when intensification attracts a growing number of migrants and creates new business opportunities it may have opposite effect (Kusters, 2014).

2.1.5 Spatial analysis

Spatial analysis is the process of analyzing physical geographic spatial pattern applying any of formal techniques for investigating surface feature entities using topological, geometric, or geographic properties. Spatial analysis is a type of geographical analysis which seeks to explain patterns of human behavior and its spatial expression in terms of mathematics and geometry, that is, locational analysis (Dartmouth College Library, 2017). The spatial analysis could be classified into two broad processes: (1) geospatial data generation and (2) geospatial analysis. Geospatial data generation is the process of generating data from data sources such field survey or remote sensing sources including aerial photograph and satellite imageries. The output is often in form of map of spatial pattern with attribute data of the interested area. Geospatial analysis is the process to bring understanding about spatial pattern characteristic and their relationship. Spatial analysis is the core task of geographic information system (GIS), it also involve digital image processing of remote sensing science.

2.1.4.1 Geographic information system (GIS)

Geographic information system is a computer system for capturing, storing, querying, analyzing, and displaying geospatial data which are the data describe both locations and the characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geospatial data distinguishes GIS from other information systems. GIS has been important in natural resource management, including land use change analysis, land use planning, natural hazard assessment, wildlife habitat analysis, riparian zone monitoring, and timber management (Chang, 2006).

2.1.4.2 Digital image processing

Digital image interpretation and analysis or digital image processing involves the manipulation and interpretation of digital images with the aid of computer. The results form a new digital image that may be displayed or recorded in pictorial format or may be further manipulated by additional programs. The processes of digital image processing may involve two or more of the following steps of computer-assisted operations (Lillesand, Kiefer, & Chipman, 2007).

Image rectification and restoration

These operations aim to correct distorted or degraded image data to create a more faithful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortions, to radiometric calibration, and to noise elimination. Image rectification and restoration procedures are often termed "preprocessing" operations because they normally precede further manipulation and analysis of the image data to extract specific information.

Image enhancement

These procedures are applied to image data in order to more effectively display or record the data for visual interpretation. Normally, image enhancement involves techniques for increasing the visual distinctions between features in a scene of image. The objective is to create new images from the original image data in order to increase the amount of information that can be visually interpreted on a monitor.

Image classification

The objective of these operations is to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. This normally involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image. The intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes. These categorized data may then be used to produce thematic maps of the land cover present in an image or produce summary statistics on the areas covered by each land cover type.

There are two type of image classification – supervised and unsupervised classification. In supervised classification, the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene. To do this, representative sample sites of know cover type, called "training area", are used to compile a numerical "interpretation key" that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it looks most like.

Unsupervised classification procedures are applied in two separate steps. The fundamental difference between supervised and unsupervised classification is that supervised classification involves a training step followed by a classification step. In the unsupervised approach the image

data are first classified by aggregating them into the natural spectral groupings, or clusters, present in the scene. Then the image analyst determines the land cover identity of these spectral groups by comparing the classified image data to ground reference data.

Data merging and GIS integration

These procedures are used to combine image data for a given geographic area with other geographically referenced data sets for the same area. These other data sets might simply consist of image data generated on other dates by the same sensor or by other remote sensing systems. Frequently, the intent of data merging is to combine remotely sensed data with other sources of information in the context of a GIS.

2.2 Related studies

Globally, the study on the impacts of the roads mainly focused on the expansion of road in urban areas. Some papers addressed the impact of the road construction on ecology such as Forman and Alexander (1998). The study led to conclusion that the major ecological impacts of a road network at the landscape scale are the disruption of landscape processes and loss of biodiversity, same as Harris, et al., (1996) who stated that roads interrupt horizontal natural processes, such as groundwater flow, stream flow, fire spread, foraging, and dispersal, fundamentally alters the way the landscape works. Mo, et al., (2017) studied the impacts of road network expansion on ecological risk in the urban landscape in a megacity of China, a case study of Beijing by employing spatial analysis toolset of Geographic Information System technology. The study showed that there was dynamic change in landscape pattern, and the changes in landscape were relate to land use type. The changes in a time series, the expansion of the road kernel area was consistent with the extension of the sub-low-risk area in the urban center, but there were somedifferences during different stages of development. For the spatial position, the expanding changes in the road kernel area were consistent with the grade changes of the urban central ecological risk. The influence of road network expansion on the ecological risk in the study area had obvious spatial differences, which may be closely associated with the distribution of ecosystem types.

There are few researchers interested in studying the impact of the road expansion on the overall natural landscape structure. In 2008, Liu, et al., brought this view into the discussion through the study of the influence of roads on landscape within Lancang River Valley of Southwest China. The results showed that forest and shrub land decreased while farmland and constructed land increased in the past 20 years in the study area. Also, the ecosystem's change rate near roads

increased while the diversity evenness, patch density and human disturbance indices all decreased. Different aspects of road development had different negative consequences for the environment.

In Laos, there are few studies on the impact of the road expansion and most of papers published are focus raising the positive effects of the road project on livelihood in terms of transportation or accessibility, such as Warr, (2006) studied the impact of road development on poverty in the Lao PDR based on evident suggesting that road improvement in rural areas can contribute significantly to lowering the incidence of poverty, improving educational participation of primary school aged children, and reducing rates of illness. He pointed that the most important form of road improvement to effect poverty reduction is conversion of dry season access roads to all season access. The same as Syviengxay Oraboune (2008) also said that the improvement of all-weather road in Lao PDR has significantly contributed to poverty reduction as the consumption expenditure increased. The rural roads provide opportunities to access to market by peasants. Accessing to market could help peasants diversifying their income sources. In terms of farming system could also be improved when accessing to market is available. He believes that this ensures a stable income; improve living standard, and reducing poverty. Pearse, (2006) studied the social and economic impact of the construction of the Nam Ham and Nam Ven roads, Huaphan province, Lao PDR to investigate the benefits provided by good accessibility to the village. The study found that the livelihood had great improved since the roads were built. The main reasons were ease of travelling, reducing travel time, availability of bus services, personal transport, etc. The research also found that good accessibility by the roads brought villages out of isolation, supported off-farm employment opportunities.

Our case study aimed at analyzing the impacts of the roads construction on natural landscape structure by focusing on the changes in land use and land cover composition and the impact of those change in landscape on local livelihood in remote area where villagers rely on agricultural-based economy. Therefore, the core context was on the relation of agricultural land use and agricultural production practices on livelihood.

There are several study that were used to shape our conceptual framework such as the study by Lambin, et al., (2001) studied the causes of land use and land cover change by examining each classes, namely, tropical deforestation, rangeland modification, agricultural intensification, and urbanization. His study revealed that neither population nor poverty alone constitute the sole and major underlying causes of land-cover change worldwide, but peoples' responses to economic opportunities drive land-cover changes. The opportunities and constraints for new land uses are

created by local as well as national markets and policies. Global forces become the main determinants of land-use change, as they amplify or attenuate local factors. A research studied by Thongmanivong and Fujita (2006) on land use and livelihood transition (1993 to 2000 in 4 Northern provinces of Lao PDR: Luang Prabang, Oudomxay, Bokeo, and Luang Namtha) found that agro-ecological landscape of the upland areas was undergoing rapid transformation from subsistence and Swidden-based landscapes to commercial and multifunctional use of the uplands. The government policy of restricting the expansion of shifting cultivation has induced farmers to seek alternatives, which has been further driven by integration into the market economy and the development of road networks. As the road links are improved and regional trade is institutionalized, it could be foresee the increased commercialization of agricultural production and natural resource use in northern Laos. As well as Keophoxay, et al., (2011) studied on the impact of maize expansion on household economy and production system in Xiengkhor district (Huaphan Province) and in Kham and Nonghet districts (Xiangkhuang Province), northern Lao PDR. His study revealed that maize had rapidly spread in the areas because of government policies and investment in infrastructures and pulled by the growing Vietnamese market. Maize become the main source of income and had tremendous impact on local communities, widening farmer's differentiation and changing in social networks in favor of powerful middlemen and traders. Besides, it leaded to the spread of credit system and emerging of local institutions. And Castella, et al., (2016) investigated the impact of maize expansion on the household economy by analyzing the contribution of maize to local incomes using 2 household data series surveyed in 2003 and 2009. The research revealed that with tillage system, the use of herbicides, pesticides and hybrid seeds, farmers could significantly reduce the time spend in the fields. Maize expansion presented gradual homogenization of landscapes and agriculture production, by this path, farmer become more vulnerable to land degradation, agrobiodiversity loss and price fluctuation.

2.3 Conceptual framework

This study focuses on the balance between livelihood outcome indicators which has been driving by cash crop livelihood strategy. Maize is the important cash crop in the study area which is promoted by government aiming at reducing poverty for rural residences and enhance sustainable economic development. However, maize production constrains were (1) the lack of production areas that farmers have to cultivate in slope remote upland areas, and (2) the sparse of road network for transporting products. These led to feeder road construction.

Subsistence agriculture & poverty

Market-oriented Agriculture Policy

Promote cash crop production

Promote market

Cash crop productions

Maize production

Contract farming

Feeder road construction
- Access to remote production areas
- Facilitate products transportation

Livelihood outcomes

Income

Well-being

Vulnerability

Sustainable of natural resources

Assets and agricultural change

Farmers' perception

Spatial changes
- LULCC
- Forest change
- Land use intensity

Figure 2-2 Conceptual framework

Chapter 3 General information of the study area

This chapter presents essential background data of the study area including, Geographic feature, population, infrastructure, institutes, and agriculture in the study area.

3.1 General information of the study area

3.1.1 Location

The study site is in Natong village cluster (Kumban or group of village), Xiengkhor district, in northern of Huaphan province, which is one of the northern province of Laos, located between 19°48'N and 103°00'E. It is an old community of the country which has been existed since Lanxang Kingdom era. Huaphan is bordered by 3 provinces of Vietnam, namely, Son La to the North, Thanh Hoa to the East, and Nghe An to the Southeast; and 2 domestic provinces of Laos, namely, Louangprabang to the West, Xiangkhuang to the Southwest. The terrain is mountainous ranging from 200 to 2,300 m ASL and covers an area of 16,500 km^2, consists of 10 districts, namely, Xamneua, Xiengkhor, Xon, Viengxay, Houameuang, Xamtay, Sopbao, Add, Kuan, and Hiam district. There are 90 village clusters, 716 villages. The province is the home to 9 ethnic groups or about 289,400 populations in 2015 (Lao Statistics Bureau, n.d.; Huaphan Province, n.d.).

Natong village cluster is located in the north of Xiengkhor district. The 5 villages of our case study are located in the northwest of the village cluster and occupy total area of 5,190 ha[1] (Natong 1,600 ha; Phouk 1,426 ha; Nanong 460 ha; Xiengdaen 920 ha; Nadeua 785 ha). The terrain of these five villages are characterized by mountain which covers about 98%, while flat area is paddy rice field covers 2% of total area. The highest elevation within these villages is about 1,179 meters and the lowest elevation is about 262 meters[2].

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[1] The area was calculated using GIS software. The boundaries of the villages are based on the previous study and they were participatory checked and updated with village authorities during field work in the study site based on their agreement on village land administration.

[2] Elevation is based on ASTER GDEM2 (ASTER-Advanced Spaceborne Thermal Emission and Reflection Radiometer; GDEM2-Global Digital Elevation Model Version 2). ASTER GDEM2 is available from **www.glovis.usgs.gov** (the U.S. Geology Survey).
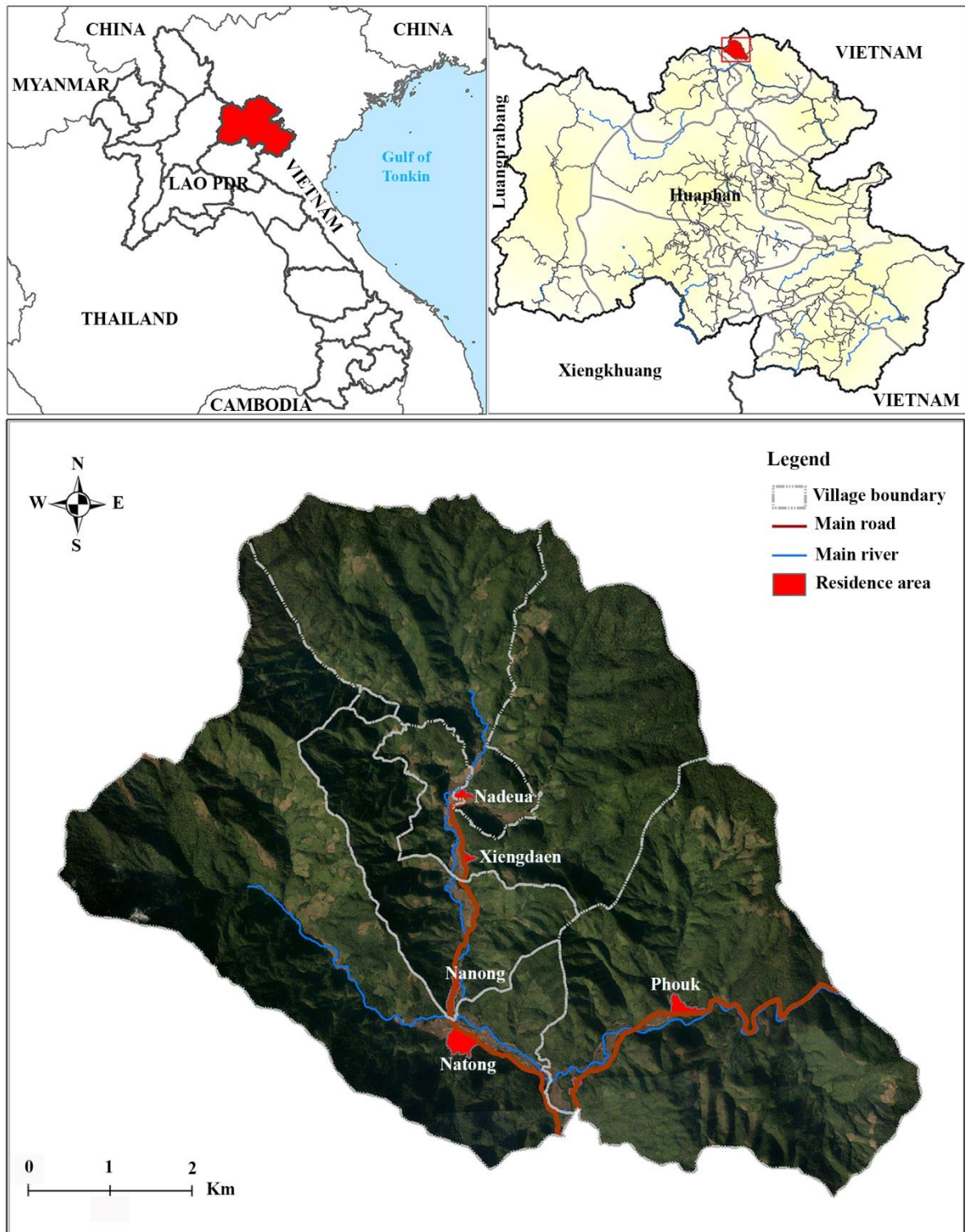
Figure 3-1 Location of the study site

3.1.2 Population

Before inception of Lao's People Democratic Republic in 1975, there were 11 hamlets within this study area (Figure 3-2) which were the homes of four tribes: Tai Dam, Ksing Mool, Khmu, and Yao (Viau, Keophosay, & Castella, 2009).

Tai Dam is a minor group of Lao-loum[3], Tai Dam lived in four villages (Natong, Nanong, Nakiu, and Phouk). Ksing Mool and Khmu are minor groups of Lao-therng[4]; Ksing Mool lived in three villages (Natia, Bui, and Ho), Khmu lived in three villages along the Dea, Hit, and Niup stream and the villages were named according to the streams. Yao, a minor group of Lao-soung[5], lived in Phoukang village in the North.

After establishing Lao People's Democratic Republic in 1975, the government integrated mountainous hamlets by relocating them to accessible lowland and form a larger community in order to ease development and providing services. In 1975, according to Viau et al. (2009), three Khmu hamlets (Dea, Niup, and Hit) were moved and merged together in new settlement named Nadeua village. Phouk village was also created that year by merging the old Phouk village which was the Tai Dam hamlet, two Ksing Mool hamlets (Bui and Ho) together. The succession of resettlement policy in inception of Laos led to new movements of population. In the mid-1990s, the Yao community was moved from high land to merge to Phouk village, and Ksing Mool community in Natia merged with Natong village. As most villagers from the area are from Tai Dam ethnic group they can easily communicate in their local language with people from the same ethnic group who live in Vietnam at the other side of the border. They have many commercial and cultural interactions with neighboring villages in the Vietnam side.

Current population according to data from field survey in April 2016, there are total 349 households in five villages (Natong 109 HH, Nanong: 48 HH, Xiengdaen: 35 HH, Nadeua: 50 HH, and Phouk: 107 HH); Total population is 2,170, female 1,087 (Figure 3-4). All household rely on agriculture, and maize is the main income source for mainly households.

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[3] Lao-loum (low-land Lao) refers to Lao people who live in lowland. This group mainly does agriculture in lowland, in particular paddy rice production, but they also grow upland rice when the rice from paddy is not sufficient for living.

[4] Lao-therng (mid-land Lao) refers to Lao people who live in between lowland and mountains. These people live lower than Lao-soung.

[5] Lao-soung (high-land Lao) refers to Lao people who live in the mountains.
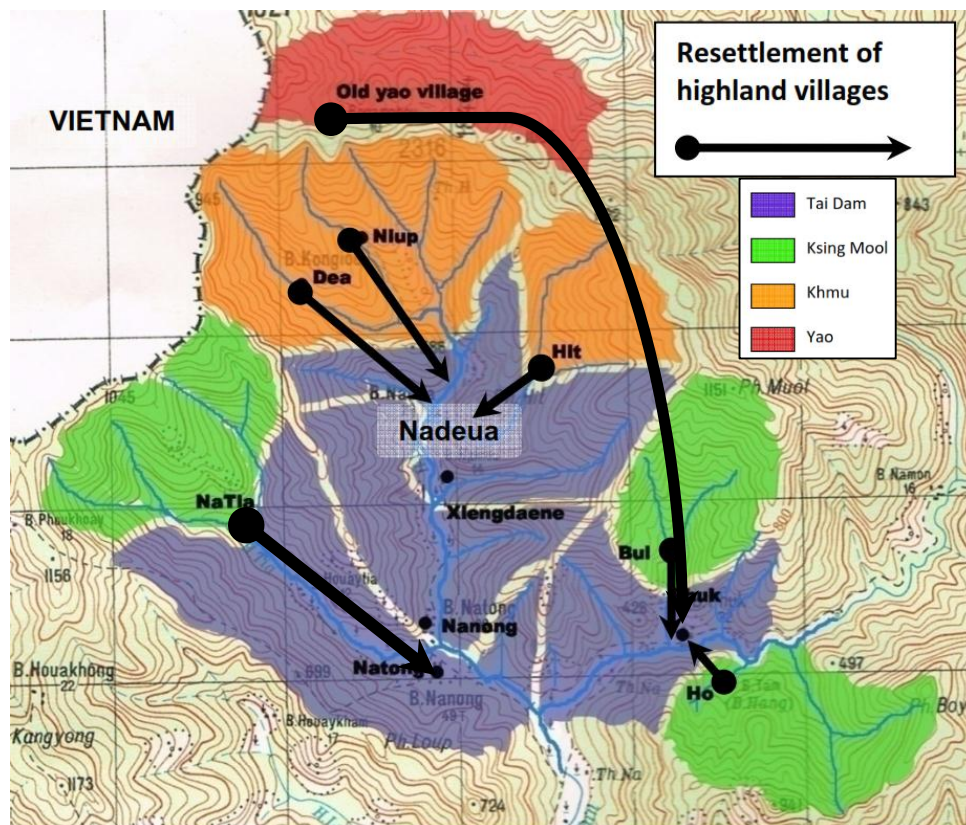
Figure 3-2 Population movements in the study area after the inception of Lao PDR in 1975

Source: (Viau, Keophosay, & Castella, 2009)
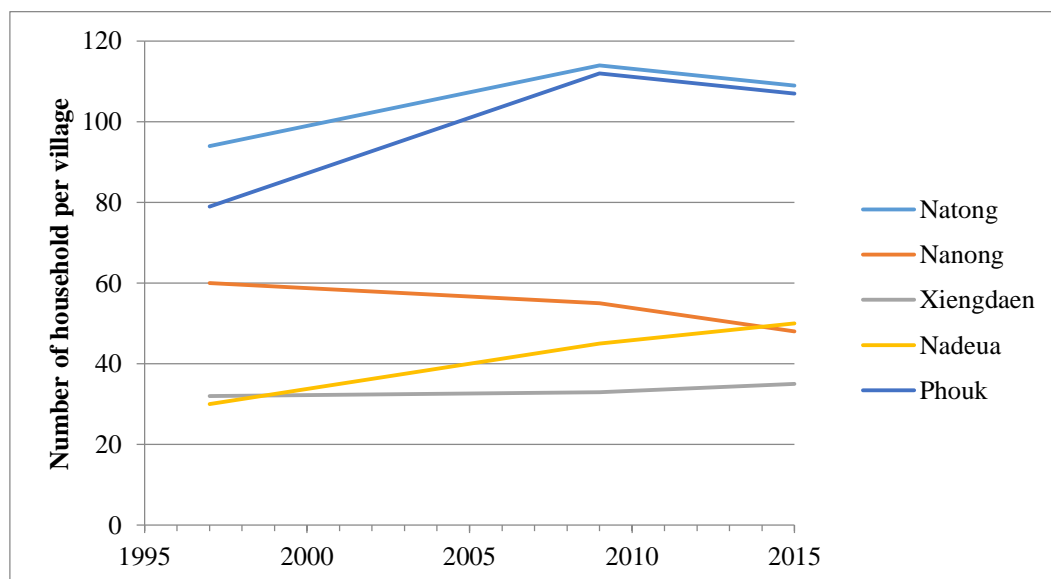
Figure 3-3 Population changes in the study area 1997-2009-2015
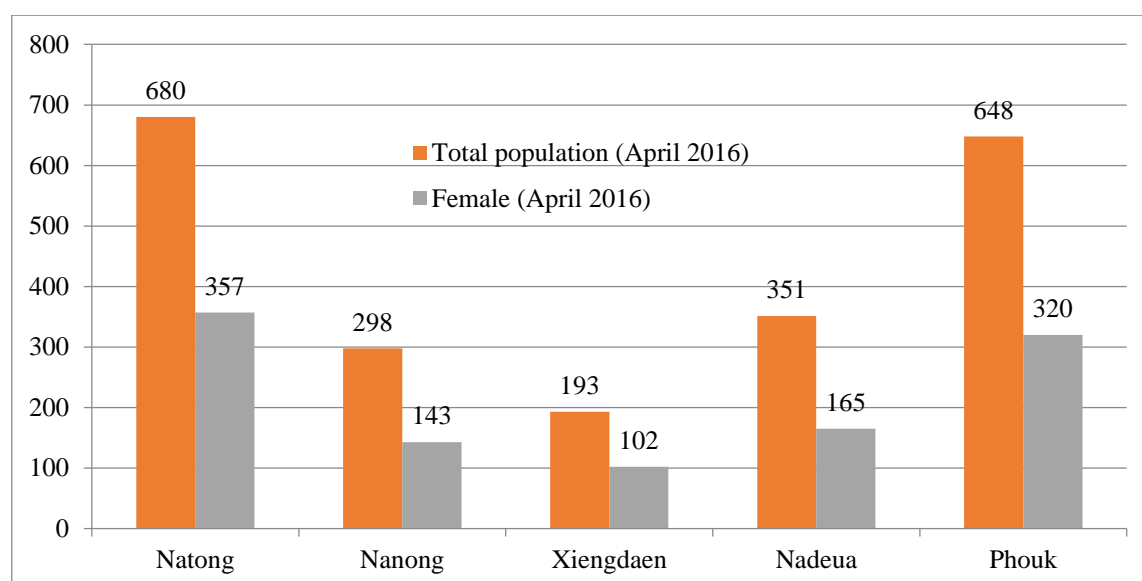
Figure 3-4 Population in the study area in April 2016

3.1.3 Infrastructure

Roads. There is a main road from Xiengkhor through part of Natong and Phouk villages to Vietnam and a road to Natong valley: access to Natong, Nanong, Xiengdaen, and Nadeua villages (Figure 3-5). The road to Natong valley is connected to the main road. All roads including roads accessing Natong valley and the main road through Phouk to Vietnam are currently unpaved. However, access to these villages is possible in all seasons, which is good in term of development opportunity. Being located at the border with Vietnam, the study area is highly influenced by market demand from the neighboring country. This was especially the case for maize expansion as the large demand from Vietnam for transformation in animal feedstock as largely influenced agricultural changes in the past decade.

In 2003, Xiengkhor district entered the list of the 47 poorest districts in Laos. This list was made so funds could be concentrated in the poorest areas, especially in the uplands. Between 2003 and 2008, the PRF (Poverty Reduction Fund), a national agency that is partly financed by the World Bank, improved road access, making the roads accessible for trucks, built water supplies, built schools, financed nurses' formation, financed concrete irrigation and built a bridge across the river (which can be crossed on motorcycle only). This infrastructure dramatically changed local livelihoods. Children could go to school in the village up to the third year of secondary school). Services (market, health dispensary, secondary school, gas station) in the district capital Xiengkhor could be reached in 30 minutes by motorcycle; previously, it took half a day. Infrastructure

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investment was not the only external factor. The district government decided to improve market access by reducing taxes on exports to Vietnam and by exempting Vietnamese traders from paying a specific tax on foreign investment. However, more than that administrative move, regional trends in commodities and the cheapness of Lao commodities are responsible for the introduction of cash crops in the study area. Previously, cash crops such as maize, vegetables or even cotton were grown in very small quantities. The possibility of finding traders who could buy directly in the village allowed farmers to focus more on cash crop production. The first attempts were made with soya bean production between 2003 and 2004, followed by maize in 2005; at this point, every household started to shift their production system from subsistence to commercialization.
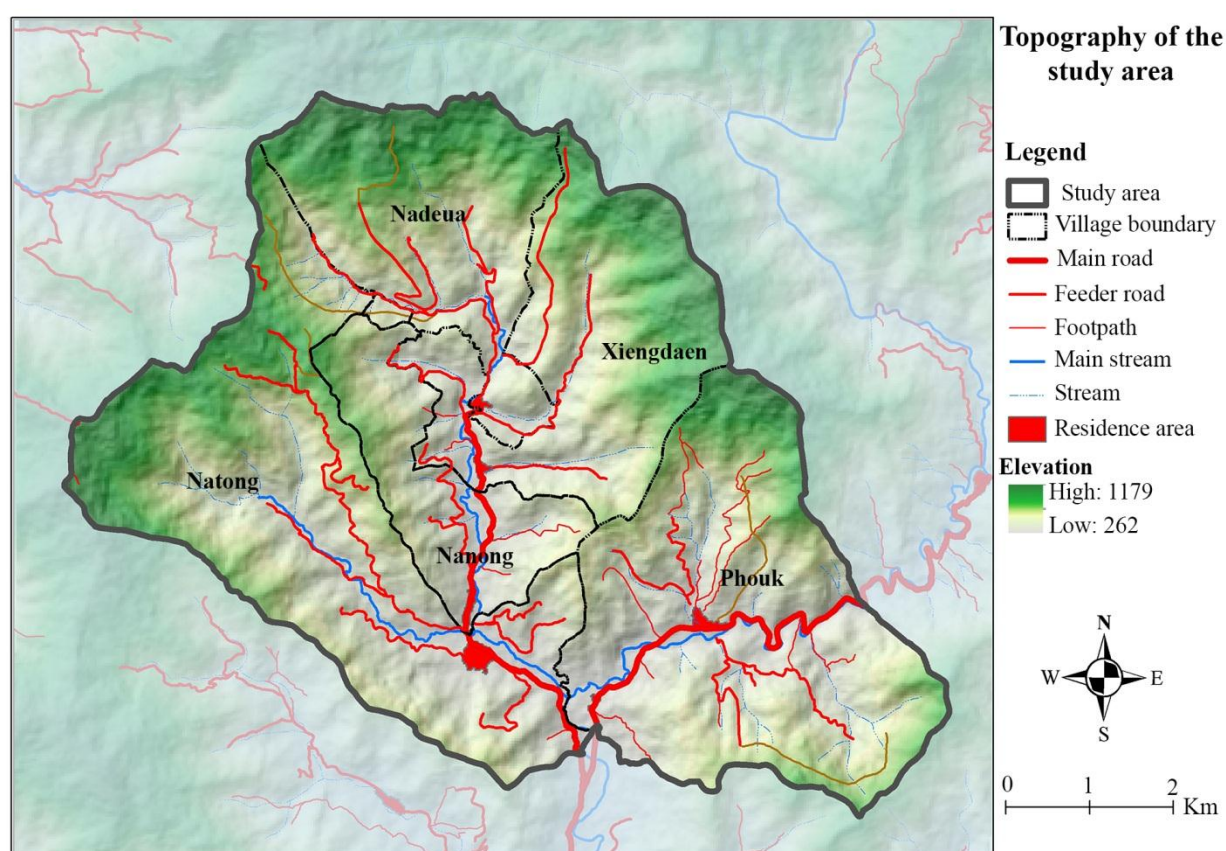
Figure 3-5 Topographic of the study area

Electricity: The four villages in Natong valley (Natong, Nanong, Xiengdaen, and Nadeua) were connected to the national power grid since 2013, while Phouk was connected in 2014.

Water supply system is now sufficient for domestic use in 4 villages, except Natong. There is occasional water shortage in Natong village, but that is not the problem. The number of the water points are different in each village depending on the number and density of households, i.e.,

there are 5 points in Nadeua and Xiengdaen, 6 in Nanong, and 11 in Natong and Phouk which are the larger villages in terms of population size (Table 3-1).

Table 3-1 Water points in the study area

Village name	Population	Number of water points	Number of house with pipes
Nadeua	351	5	10
Xiengdaen	193	5	0
Nanong	298	6	25
Natong	680	11	50
Phouk	648	11	40

Because there are closed-water sources that they can use instead of water points (Figure 3-5). There is only Phouk village that suffers the lack of water for irrigation.

3.1.4 Local institutions

Village authority organizations in these five villages have the same structure. The organization is composed of 21 village-committee members and divided into 7 units as follows:

1) Village front: composed of 3 members; a head of the village front and 2 deputies.
2) Village committee: composed of 3 members; 1 head of the village and 2 deputies.
3) Village youth union: composed of 3 members; 1 head and 2 deputies.
4) Village woman union: composed of 3 members; 1 head and 2 deputies.
5) Village security unit: composed of 3 members; 1 head and 2 deputies.
6) Village defense unit: composed of 3 members; 1 head and 2 deputies.

Each village also divides the households into smaller "village unit", in order to manage easily. In each group there are 1 head and 2 deputies of village units.

Collective works in these five villages are similar. The common works consist in fixing & cleaning the village road, cleaning the village and school, and fixing & cleaning the water supply system. The data in Table 3-2 shows that cleaning the village and school is the major task of collective work. They spend more time with this activity than others.

Table 3-2 Collective works in the study area

Village name	Fixing & cleaning the village road (man-days/year)	Cleaning the village and school (man-days/year)	Fixing/cleaning the water supply system (man-days/year)
Nadeua	100	200	150
Xiengdaen	70	490	420
Nanong	144	336	48
Natong	436	2725	1308
Phouk	428	1605	1284

Financial resources refer to the funding mechanism for social help in the villages. Only Natong, Phouk, and Xiengdaen have this kind of units. There is a rice bank in Xiengdaen village that was created in order to use rice for payment of any collective activities in the village and also to help the household who suffers the lack of rice for consumption. Phouk and Natong have the same funding system named "Korng Theun Suay Leua Seng Kan Lae Kan (the Fund for helping each other)" which was supported by the Poverty Reduction Fund project of the Lao government.

Village awards are the certificates delivered by district line agencies indicating the achievement of the village on implementing the district's development goals. The award, through its appraisal mechanism encourages villager to comply with the government policies implemented by the local administrations. There are many programs running in this area such as cleaned-village, no crime - no case, healthy, cultural, all household-heads finished primary school, all household-heads finished secondary school, strength-youth, developed-village, good women union, stopped shifting cultivation, etc. Some programs are annually awarded, but some awards are one time award, i.e., stopped shifting cultivation. The Table 3-3 shows the date deliverance of different awards to the study villages.

Table 3-3 Awards indicating the achievement development programs

Awards	Awarded-Year				
	Phouk	**Natong**	**Nanong**	**X-dane**	**Nadeua**
Clean village	2005	2013	2013	2005	2013
No crime - no case village		2008	2010	2013	
Healthy village	2016	2013	2013	2013	2013
Cultural village		2015	2013	2015	
All household heads completed primary school	2013	2013	2010	2002	2013
All household heads completed secondary school	2015	2011	2013		
Youth strength		2012	2013		2013
Developed village		2013	2013	2015	
Good women union	2015	2012	2013		
Stopped shifting cultivation		2015	2013		

3.1.5 Agriculture

Before 1975, upland rice production was the main agricultural activity in the area. The Ksing Mool, Yao and Khmu ethnic groups traditionally grew upland rice. The Tai Dam are lowland farmers and started terracing paddies more than one century ago, but the paddy area was not sufficient to feed everyone and they continued to grow upland rice. During the last two decades, the Tai Dam gradually extended their individual paddy field (Nati) even by buying in Nadeua village. Rice and livestock are the only mean to get cash. The economy was based on subsistence crops until a road was built in 2003 that allowed commercial exchanges. In 2005, the maize production started and in 2007 all of the households produced maize. In parallel with this shift to a commercial economy a minority of household stopped the upland rice production and the majority reduced their field's area as they had limited labor force available to attend to their upland rice fields.

3.1.5.1 The 3 main crops

Maize is the most important cash crop in the study area, as every household grows maize in 1, 2 or 3 fields without rotations. Sometimes pumpkin or chili is associated in the maize fields but mainly for self-consumption (100-200 Kg).

In 2005, a relative of Natong village's head who lived in Xiengkhor gave him 40 kg of maize seeds who then gave 20 kg to someone in Nadeua. In Xiengdane, only one farmer tried to grow maize in 2005. All of them got a good production and then sold to traders who came in the villages to buy. In 2006, a lot of people in Natong, Xiengdane, Nadeua but few in Phouk produced maize. At this time Vietnam traders started to provide seeds to farmers by contracting local middlemen.

All households gradually engaged in maize production on their upland rice fallows, pushing upland rice away from the feeder roads that rapidly spread all across the landscape. Farmers build storage huts in their field near the maize feeder roads. The traders come 10-20 days after the harvest to thresh the maize cobs and load the bags of maize grain in their trucks for transportation out of the village. Rats and wild pigs are seen as the most important threat to maize production. Then some weather problems such as droughts, storms or coldness are also mentioned. Then soil fertility and germination problems. Since 2007/2008, the majority of the maize's fields are situated along the maize feeder roads.

Upland rice is produced through shifting cultivation. Upland rice fields are usually located up the hills, above the maize fields or in remote areas. A 2 to 3 years fallow rotation system is used since more than 10 years. In 1975, fallows were 6 to 7 years long. Diverse crops are associated with upland rice in the same shifting cultivation field, such as cucumber, watermelon, sugarcane, chili, pumpkin, eggplant and traditional maize. The quantities range from 5 to 200 Kg for each. Weed control is considered as an important constraint to upland rice production especially as the fallow length is gradually decreasing.

Paddy rice is produced during two successive cycles (spring and rainy season) since 1975. Not all the area can be used two seasons, mostly because of water shortage for irrigation. Weather conditions (coldness) and water quantity are seen as the most important limitation of the spring rice production. The harvest takes place during the raining season, which leads to losses in production. In case villagers do not grow spring rice, they usually grow winter vegetable in their paddies after the harvest of the rainy season cycles (mostly in Phuk and Natong). Buffaloes were traditionally used for land preparation but they have been gradually replaced by hand tractors when farmers got enough cash to buy this equipment. In Natong, Phouk and Xiengdane, paddy land is owned collectively like in many other parts of Houaphan province. This collective tenure system is called Na Muang. The Na Muang area is reallocated every 5 years (or 3 years in some villages) to individual households according to the size of the household based on the follows rules: 1 People > 10 Years old = 1 unit / 1 People < 10 Years old = 0.5 unit. Each family gets an area according to its number of units. This area is a new one every 5 years and the newly formed couples/household doesn't get a part of the Na Muang of their parents but a new one. The overall collective land is then divided by the number of unit to compute how many square meters will be allocated to each household according to its size (i.e. number of units): Natong households get 300 m^2/unit, Xiengdane households get 500 m^2/unit and Phouk households get 262 m^2/unit.

Only in Natong there is a different rule for spring rice (200 m^2/unit) so that everybody can grow rice during the spring season. In Xiengdaene and Phuk there is a rotation of the land, the farmer who can do just 1 season will get a field with 2 seasons at the next allocation. In Nadeua, when they created the village in 1975, they created a Na Muang, but the area is too small (81 m^2) and, so, there has been no change of the use (no rotation) since this time, but farmers are not allow to sell. As consequences, it is very difficult for a young couple in Nadeua to get access to a Na Muang.

Apart from those communal lands that somehow buffer the disparities between households, there are also individual paddy fields (Nati). Those fields have been built by farmers themselves or bought from someone else. The majority of the Nati have been built during the period from 1980 to 2000. Generally, farmers build a small area with irrigation and then extend every year. Nati are the only lands which can be sold between villagers. Those fields are away from the villages, along small rivers, and sometimes farmers choose to build a 2nd house close to it.

3.1.5.2 Livestock

Villagers raise cows, buffaloes, goats, pigs, chicken and duck in all villages. Large livestock are considered as living capital that can be sold in case of problem. A few buffaloes are still used for paddy land preparation but they have been rapidly replaced by cattle in the recent years after some animals had been stolen when roaming in the remote forests around the village. Cows and buffaloes are sold in the villages to other villagers or traders. Cows and buffaloes are kept in 1 or 2 livestock areas in each village, with fences around between April and November, and then they are left roaming after the crop harvests are completed. As there is no fence around the paddy fields nor upland crop fields, livestock owners are responsible for damages their animals may cause to the crops and would have to pay for losses incurred. The pigs are kept in pigsty near the houses all year long. Farmers feed them with cassava, banana trunk, banana, traditional maize, leaf and vegetables. For each litter they sell half of the piglets at 10 Kg and keep half to feed them and sell them at more than 100 Kg (3 years old). Traders come to the villages to buy. They do no vaccinate their animals but they reported only few losses from diseases. Every households breed chicken. They have between 5 to 10 mothers in each household. They don't eat eggs. Chickens eat rice bran, cassava and kitchen waste. Few households breed ducks. They always complain about the difficulty to breed ducks compare to chicken. So they prefer to eat or sell the eggs.

3.1.5.3 Non-timber forest products

The 3 main products collected are Phak No, Phak Waen and bamboo shoots, mostly for the family consumption. Phak No and Phak Waen are found in paddy field, bamboo shoots in fallows or open forests. The other products collected are mostly found in upland fallows and along the rivers. Some households in Natong or Phouk sell those products, but no one in Xiengdane and Nadeua, where it is exclusively collected for household consumption.

In every village there is a production forest, where the villagers find timber for their houses and firewood in addition to their fallow fields. Hunting is limited to small animals, birds and rats in maize fields. Some households have a fishpond (60 to 150 Kg/Year). In Natong and Phouk they fish in the river (10 to 20 Kg/Year). In all the 4 villages they collect frogs during the rainy season. No hunting of big wild animals has been reported.

3.2 General information of feeder roads in the study area

3.2.1 Expansion patterns of feeder roads

After maize harvesting in 2006, the Vietnamese maize trader offered opening the feeder roads to production areas in order to promote maize production. The first two feeder roads were opened in Nanong village. These first two roads costed 28 million Lao kip (MLAK). In 2007, Nadeua village invested about 25 MLAK to open a road to one of their production areas. Then, in 2008, there was a big investment in opening feeder roads, four roads were opened in Natong village for a total cost of 102 MLAK and three roads for 40 MLAK in Xiengdaen village. At the same time, Phouk village invested 68 MLAK to open four roads, for 10.5 MLAK per km. But three of the roads built in Phouk village which costed 55 MLAK were not reimbursed by villagers because the contract was canceled as the trader did not come to buy maize from villagers.

In 2009, Natong village opened two more roads. A road cost 24 MLAK, while another met contract breaking condition as it was not maintained by the company as per contract agreement. In 2012, Natong invested in two more roads which cost 31 MLAK. In 2013, Nadeua invested in opening one more road after long period use of land along their first feeder road built in 2007, this new-road cost 15 MLAK. There was a break between 2013 and 2015 as no new-road was constructed. In the early of 2016, 5 new-roads are being constructed: 2 roads in Xiengdaen, 3 roads in Nadeua, see Figure 3-6.

In the short future, Natong village plans to open 2 more roads to access to the rest of their production areas, Phouk village plan to open 2 roads, and Nadeua plan to open one more road so

that every production areas are accessible. Nanong has already expanded feeder roads to its maximum length with only two roads because their production areas are limited.
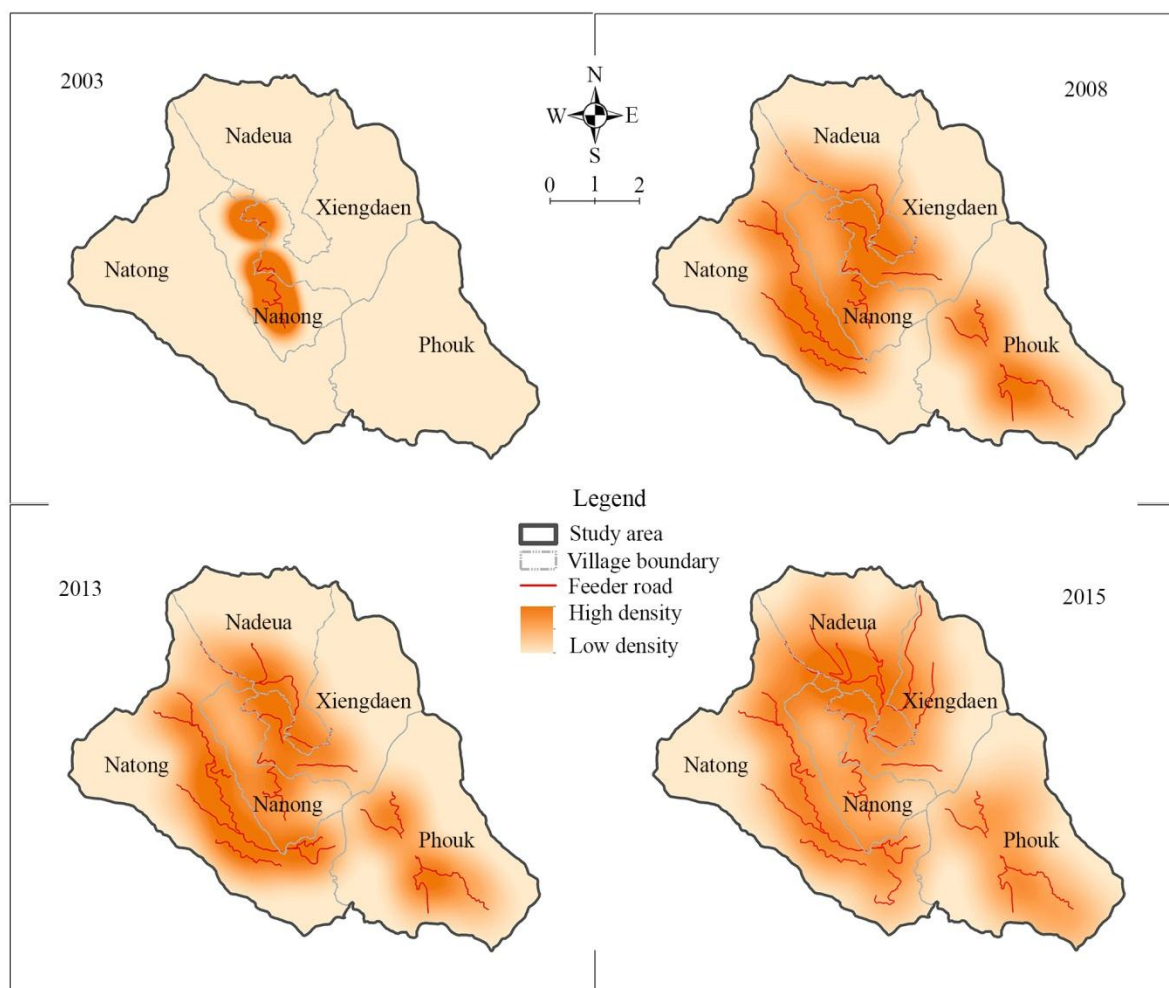
Figure 3-6 Feeder road expansion

Since constructing the first feeder road until 2015, villagers invested more than 300 MLAK in building feeder roads along the hillsides to reach their production areas. As shown in Figure 3-7, there were two main periods of road construction: at the initial time of the maize boom, between 2007 and 2008 and more recently, 2015, which may mark as a second wave of maize expansion.
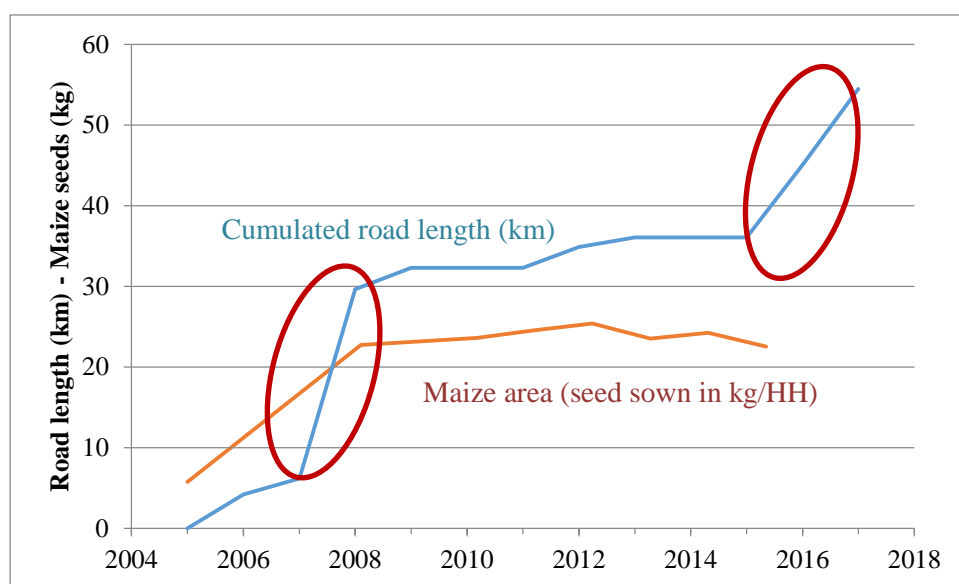
Figure 3-7 Cumulative length of feeder roads and expansion of maize areas

In summary, most of feeder roads were constructed before 2009 accounting for about 29 Km (villagers reported 19 Km). Between 2009 and 2015, there were some additional road construction with total length about 6 Km (villagers reported 4 Km), and then more roads were constructed after 2015 estimated to account for about 18 Km (Table 3-4).

Table 3-4 Summarized feeder roads statistics in the study site

Time periods	No of roads	Calculated length* (km)	Reported length** (km)
Before 2009	**16**	**29.65**	**19.81**
2006	3	4.22	2.30
2007	1	1.97	2.18
2008	12	23.45	15.33
2009 - 2015	**5**	**6.41**	**4.27**
2009	2	2.66	0.00
2012	2	2.59	3.10
2013	1	1.16	1.17
After 2015	**10**	**18.42**	**7.00**
2016	5	9.02	7.00
Plan	5	9.42	0.00
Total	**31**	**54.50**	**31.08**

*Calculated length using GIS software: is the length calculated based on participatory mapping during field work.

** Reported length: is the length reported by key informant during group discussion in field work

3.2.2 Feeder road construction processes

Villagers usually agree on which plot they would like to grow maize and then decide where they would like to open a feeder road and the design. Next, villagers who have land around this production area contact the trader to present their plan and negotiate a price. Then, the road project is further presented to the village head and committee who may survey the area planned for road construction together with the trader to agree on a price. After that, the village head introduces the project to 3 district services: Department of Public Work and Transportation, Department of Natural Resources and Environment, Department of Agriculture and Forestry. The district authorities may ask for a field survey of the area where the villagers propose to construct the road to insure that the road will not run through protected areas (Figure 3-8). After receiving an official agreement from the three departments, the village head is allowed to sign a contract with the maize trader on behalf of the villagers' group.
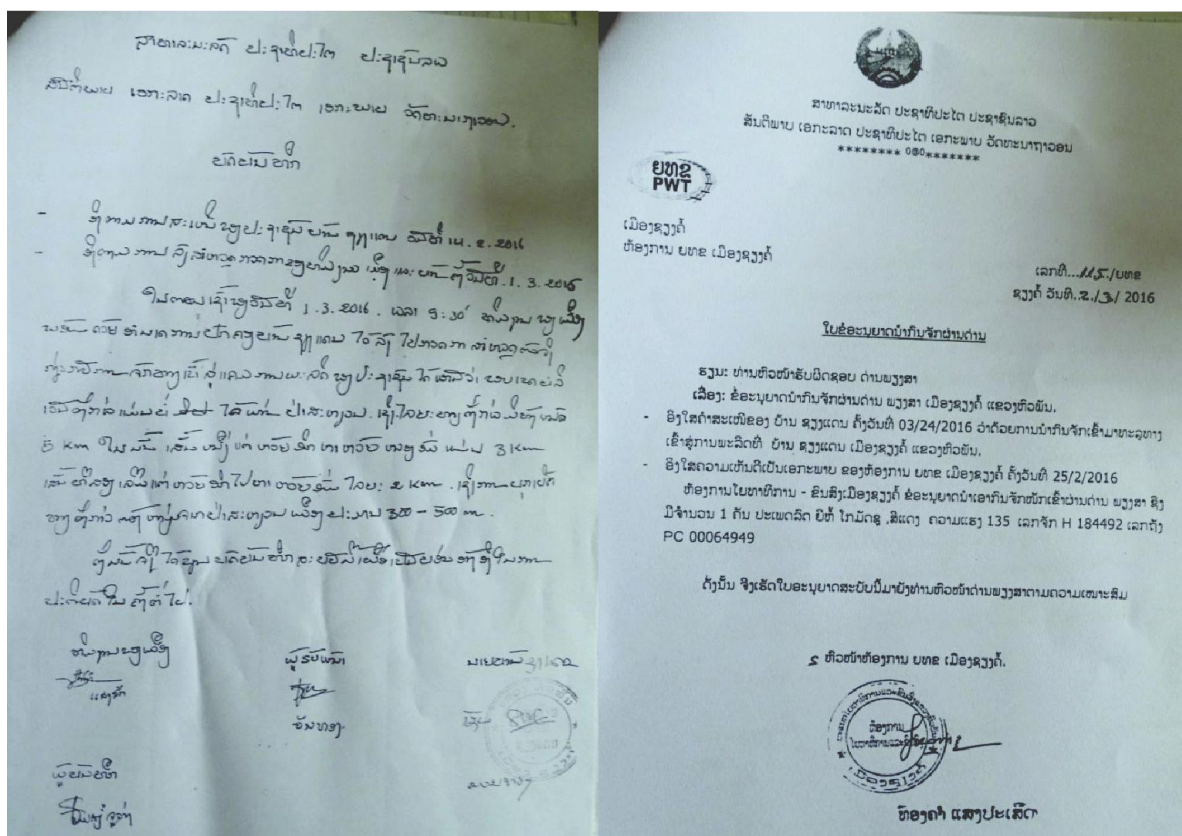
Figure 3-8 Feeder road authorization documents for Xiengdaen village, March 2016

Left: Report about checking feeder road project proposed by Xiengdane village in order to ensure that the road will not pass through protected forest (dated 1/3/2016)

Right: Letter from the District Public Works and Transportation to the border check point for importing excavator from Vietnam in order to repare existing feeder roads and openning new feeder road in Xiengdaen (dated 2/3/2016)

The conditions are presented in the contract: the trader constructs the road with his own equipment or rent equipment from private owners or construction companies. The road should be finished before the beginning of the rainy season. The trader commits to repair the road every year at the end of the rainy season to facilitate the harvest. The villagers will sell all their production to this trader for 3 or 5 years depending on how difficult the road open is and will sell their maize at a reduced price (100 LAK/kg) from the market price.

These official rules are provided by the department in charge at the district level, but in reality the roads are often opened before receiving the official agreement and in many cases an official request is not sent to the offices in charge. This leads to a large discrepancy in available data depending on the sources of information: 45km through participatory mapping and measurements with GPS and Remote sensing tools, 31km through focus group discussions at village level and 7 km at the district office for officially registered roads (only since 2014).

Furthermore, the conditions negotiated between the different parties vary very much from village to village and period to period depending on the information level of the different parties, their previous experience and bargaining power and whether the conditions of the agreement are written down in a contract or remain oral (Box 1).

Box 1 History of road negotiations in Xiengdaen village

In 2008, villagers paid their first roads in cash according to the cost agreed upon per km. The total amount was divided among all households according to the number of household members. They paid once a year after harvest time during 3 years.

In 2016, Xiengdaen villagers decided to open two more maize roads. One about 5 km and another one only opened on 2km at the time of the survey but has surely been extended since then. The village committee discussed about the roads and their location then invited all villagers (35 households) to survey the area. Villagers were all offered to select a field close to the future road. For each section of the road, the village head would ask who is interested to get his/her field at the right and left side of the road. Those who then raised their hand would get allocated a field to grow maize.

Once the road construction was decided, the village committee discussed with the trader about the conditions. This year, the negotiated contract stipulates that the villagers will have to sell exclusively to this trader; that they will get paid 100LAK/kg less for the maize collected along the new roads than the one collected along the old feeder roads. The reference price for the old roads will be the market price. The problem is that villagers do not know the cost of the new roads. As per the contract, they will have to pay 100LAK/kg maize harvest along these roads for the next 5 years. In case they would like to reimburse in cash (like for the first set of roads in 2008) and not with maize, it is not clear how much they would have to reimburse as the road cost is not known. The contract is then sent to the district officers who check it and modify if necessary. It should go

through the District Agriculture and Forestry Office (DAFO), District Office of the Natural Resources and Environment (DoNRE), Industrial and Trade, and the District Public Work & Transportation Offices. DAFO and DoNRE staffs have already surveyed the area before the road was built to avoid problems with a road that would go through conservation forest or other land use types that are not allowed to convert into maize.

The previous roads built in 2008 caused a number of problems to both the trader and villagers. The new regulations with stronger involvement of the district authorities and formally written contract are based on the past experiences. One year after building the road, the villagers in Xiengdane decided not to grow maize and therefore no reimbursing the road by selling their maize. It took a long negotiation for the trader to get reimbursed in cash by villagers who were not growing maize. On the other hand, the traders wrote in one contract that the maize price would be fixed to 700LAK/kg for villagers who benefited from the newly built road. But the price was fixed, whatever the market price of maize would be. As a result villagers were receiving 700 LAK/kg even when the market price was 1000 or 1200 LAK/kg; a deal that was highly benefiting the trader. As a consequence, a price decreased of 100LAK/kg from the market price was decided in the next contracts. The quality of the contracts and the quality of the negotiators therefore improved gradually through the successive experiences they went through. A compromise was found between the three main actors of the negotiation: the villagers, the traders, and the officers of the district line agencies.

Chapter 4 Impacts of feeder roads on livelihoods

This chapter presents the changes in livelihood outcome looking through changes in income generation pattern, assets, and agricultural practices.

4.1 Data and methods

Analyzing the impacts of feeder road on livelihood is to explore the livelihood outcome from feeder roads investment to support maize production. In this section we focused on quantifying changes in some livelihood outcome indicators, namely, income, well-being by investigate changes in assets, food security by investigate changes in agriculture, and investigate vulnerability through analysis farmers' perception on their natural resources and environment in their villages. Data use to support analysis in this section include primary and secondary data as describe below.

4.1.1 Data collection

Socio-economic data was collected by variety methods in order to capture and analyze the impacts of the feeder road on livelihoods, as well as to support spatial analysis. The secondary data obtained from Catch-Up project in 2009 (**www.asia-uplands.org/Catch-Up/index.php**). The primary data was collected during field survey from the 27th of March to the 4th of April, 2016. Data was mainly collected through focus group discussion, observation in the fields, and interviewing the key persons, e.g., the village heads and members of the village committee.

All households, totally 368 households, were included in rapid survey to collect data about household composition, agricultural practices, assets, and income. Data derived from rapid survey provided general situation. We then collected more details about household composition, agricultural practices, assets, and income from sample population totally 118 or about 30% of the study population (Table 4-1).

Table 4-1 Participants involved in data collection

Villages	Total HH in the village (registered)	Number of the village organization committee	Focus Group	Rapid Survey	Details Survey
Nadeau	50	18	8	59	30
Nanong	48	18	0	47	24
Natong	109	18	7	113	24
Phouk	107	18	7	112	21
Xiengdaen	35	18	8	37	19
Total	349	90	30	368	118

Then we conducted focus group in each village in order to collect data about development trajectory, general information of the village, cropping system, livestock system, contract farming, feeder road development, and perspective on the value of natural resources in the village (Table 4-2).

Table 4-2 data collected and methodology

Data collected	Purpose	Methods
History of the village	Understand dynamic or development trajectory.	Focus group
General information of the village	Understand current situation of the village	Focus group
Cropping system	Understand cropping practice	Focus group + Playing game
Livestock system	Understand livestock husbandry system	Focus group + Playing game
Contract farming	Understand contract farming situation and processes	Focus group
Opening road to production areas	Understand situation and processes in opening roads	Focus group
Land use/land cover valuation	Understand the values given to land use land cover by villagers in terms of ecosystem services.	Focus group + Playing game
Household survey: Rapid & Details survey	Understand the change in agricultural activities and well-being.	Focus group

4.1.2 Data analysis

As presented in chapter 3, the 54km feeder road network built over the years came with a direct cost for the local population, estimated at about 300 MLAK and indirect costs in terms of forest loss and land degradation. It also came, of course, with direct benefits for the local population in terms of income generated through maize cultivation and indirect benefits depending on how the maize money was reinvested by villagers into other income generating activities.

Therefore, we analyze the impacts of maize expansion on livelihood based on some livelihood outcome indicators such as income generation, household assets to indicate well-being, and agriculture practices. The results are based on the analysis of exhaustive household surveys, i.e. all 350 households in the 5 target villages responded to a rapid quantitative survey in 2009 and then again in 2016, and a more detailed survey involving 73 households in the 4 villages of Natong, Phouk, Xiendane and Nadeua who responded to a detailed questionnaire in 2009 and then again in 2016. Besides, thematic focus group discussions were conducted in the four latter villages and provided more qualitative perspectives on the topics addressed by the two other questionnaires.

For farmers' perception on the environment is analyzed using frequency analysis based on their perception provided to all aspects of questions about environment. The perception on

environmental change is evaluated based on 5-scale, namely, (-2) sharp decrease, (-1) decrease, (0) stable, (+1) increase, (+2) large increase. Pivot-table and pivot-chart was used to summarize the perception of the villagers on the values of land use and land cover for local livelihood and natural environment.

4.2 Changes in income generation patterns

Faced with decreasing maize yields due to land use intensification in the uplands (i.e. shortening of the rotational systems), villagers are currently faced with three strategic options:

1.   Transforming their cropping systems towards more sustainable ones. So far they have introduced herbicides and fertilizers to compensate for weed infestation and fertility losses but these changes reduce their economic margin and make the maize production not economically sustainable. Other practices such as conservation agriculture have been tested in the area, but not adopted by villagers because they were not under pressure to change their practices at the time they were invited to experiment some sustainable cropping practices,

2.   Expanding the feeder road network to expand maize to more remote and more fertile fields within the village territory. This option consists in temporarily moving the problem to another place so that farmers can continue growing maize. But this will be the last time such a 'geographic shift' will be possible because this second batch of road expansion that has occurred between 2015 and 2017 as reached the limits of the village territory,

3.   Diversifying on-farm and off-farm income generation activities has been mentioned many times by respondents during focus group discussions. Diversification of agricultural activities concentrates on livestock at the moment as the market for fruit trees is still limited. Many villagers plan to turn their maize fields into improved pastures to raise cattle. This change as already started during the period from 2009 to 2016 as shown in Figure 4-1. While crops still generate the bulk of income there is a clear trend of diversification towards livestock and off-farm activities (see arrows in Figure 4-2).
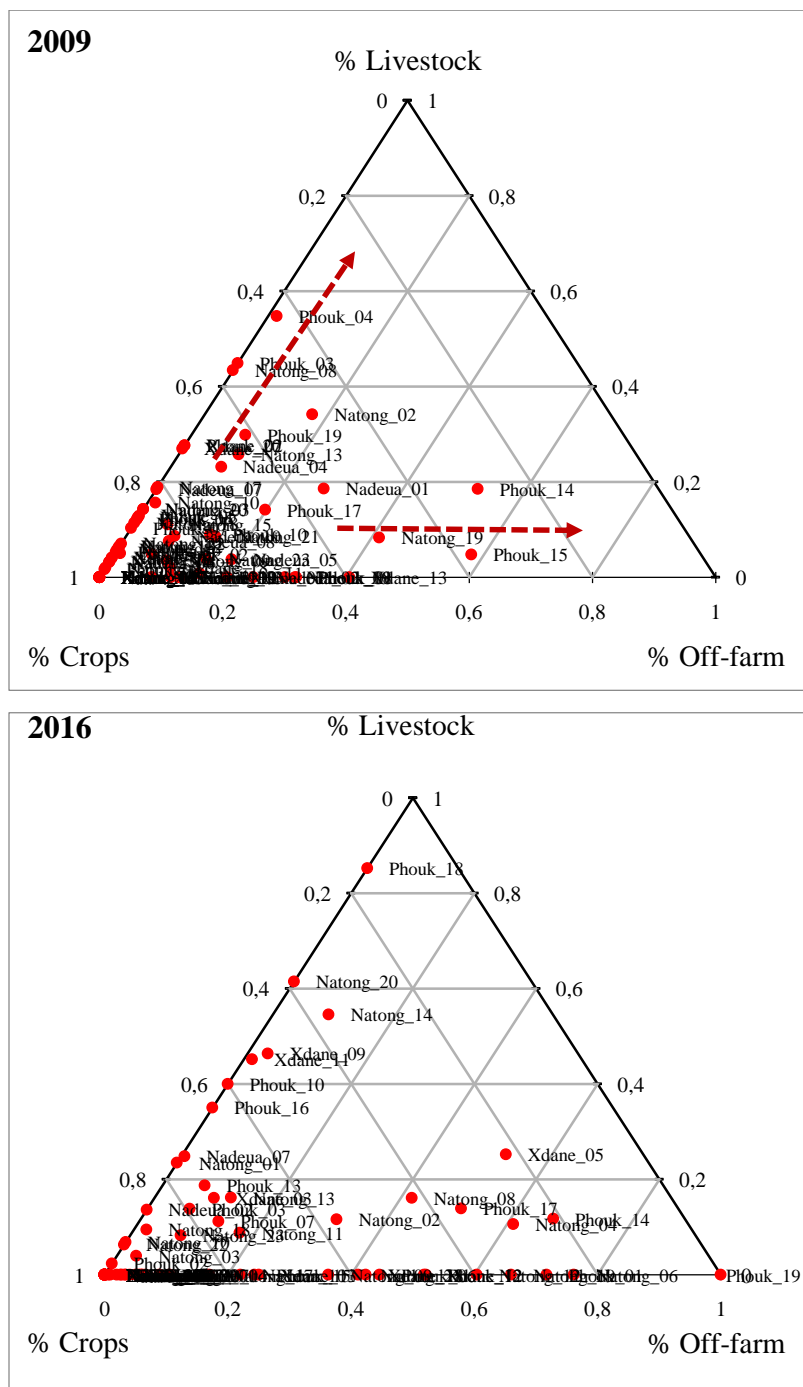
Figure 4-1 Relative contribution of crops, livestock and off-farm activities in household incomes in 2009 and 2016
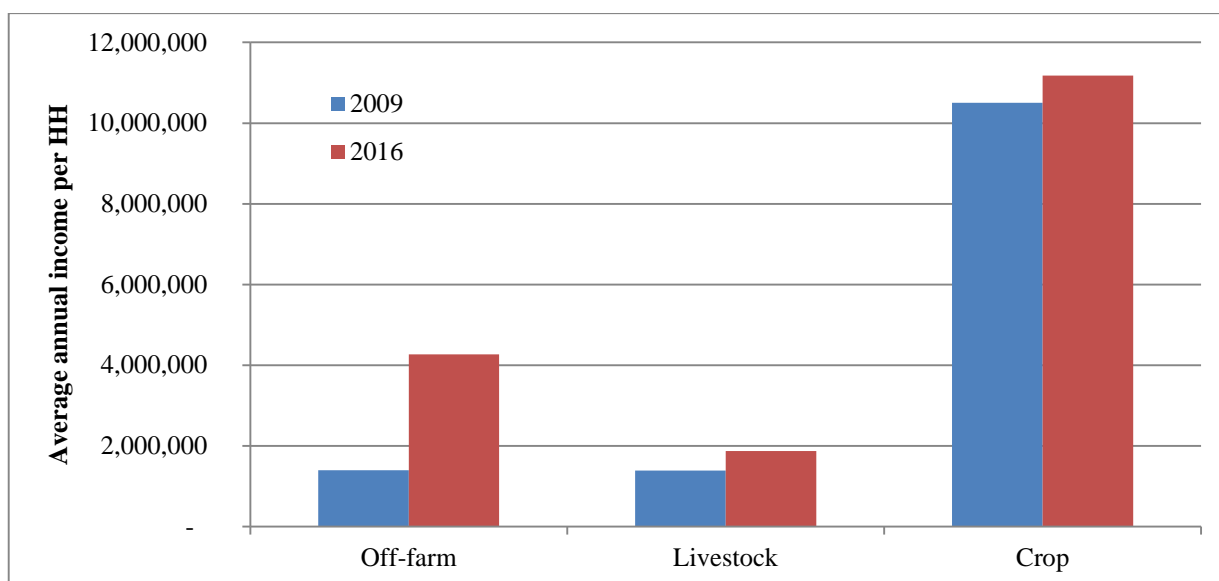
Figure 4-2 Main income sources between 2009 and 2016

Looking in more detail at the pattern of activities that generate incomes in the study area we ranked in Figure 4-3, below, the same 73 households surveyed in 2009 and 2016 according to their total annual income. From there, we found that while 50% of the households owned less than 20MLAK in 2009, the lowest 50% of the households earned less than 15 MLAK in 2016. The median income has been reduced by 5MLAK within a few years, which may explain why villagers are so much in search of alternative income sources. From the comparison of income distribution in 2009 and 2016, one can also observe that income from NTFP and gardens has almost completely disappeared with the rapid spread of maize areas. There are less NTFP in the remaining degraded forest and villagers have less time than before to collect and sell them because they are busy maintaining their declining maize-based system by using more inputs that reduce their economic margin or expanding to new forested area which is detrimental to forest resources as an economic safety net for the poorest household as it used to be.
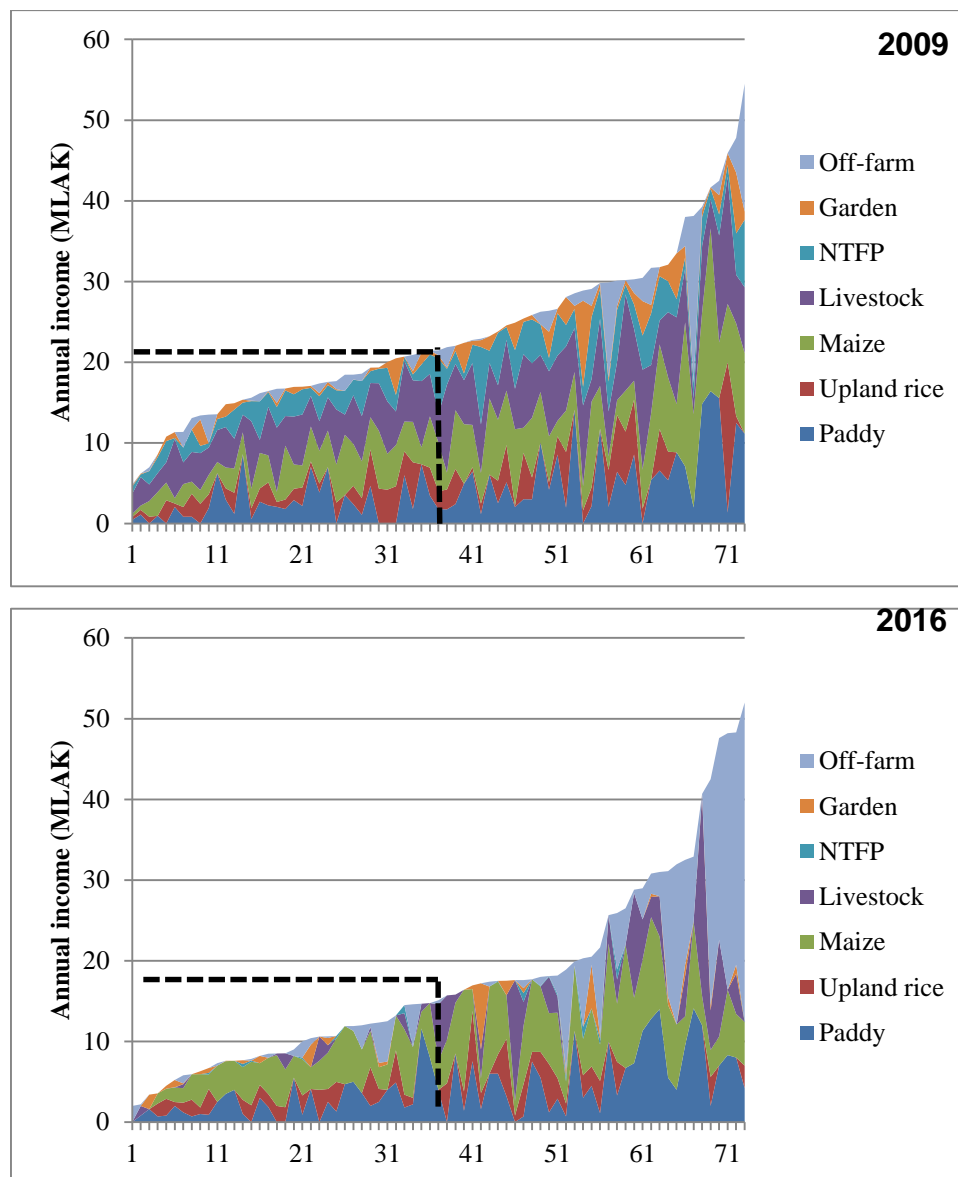
Figure 4-3 Income composition of the same 73 households surveyed in 2009 and 2016

As a consequence, the share of off-farm activities in the income of the 50% richer households has increased tremendously. Farmers who could accumulate sufficient capital from maize cultivations are now turning to other activities such as livestock and off-farm. The poorest ones are poorer than before because they do not have access to NTFP products anymore and are stuck with maize production in a context of decreasing yields. They have somehow compensated these losses through the second expansion of feeder roads 2013-2016 but this further exploitation of the natural resource based will provide only temporary benefits. Indeed, the maize yields are expected to drop again in the coming years through the same mechanisms as the one that took place between 2006 and 2009 for the first batch of feeder roads.

4.3 Change in assets

Changes in assets were induced by both the *opportunities* provided by maize benefits that allowed farmers to invest in new equipment and the *constraints* imposed by maize expansion on the family labor force available on the farms that required some level of mechanization or input use to expand maize area and maintain yields beyond the initial boom period, i.e. 2006-2008.

The Figure 4-4 below shows that the first wave of equipment bought by villagers in relation with the maize boom was first rice mills, then motorcycles and finally hand-tractors. The steep slope on the motorcycle and hand-tractor curves in Figure 4-4 during the period 2006-2008 confirms the statements of the surveys' and focus groups' respondents that the maize money was rapidly invested in livelihood improvements such as renovating houses and paying for the study of the children but also time saving equipment such as motorcycles and hand-tractors. Both needed feeder roads to easier transportation to production areas in the village landscape, so the purchase of transportation equipment further accelerated the construction of new feeder roads.
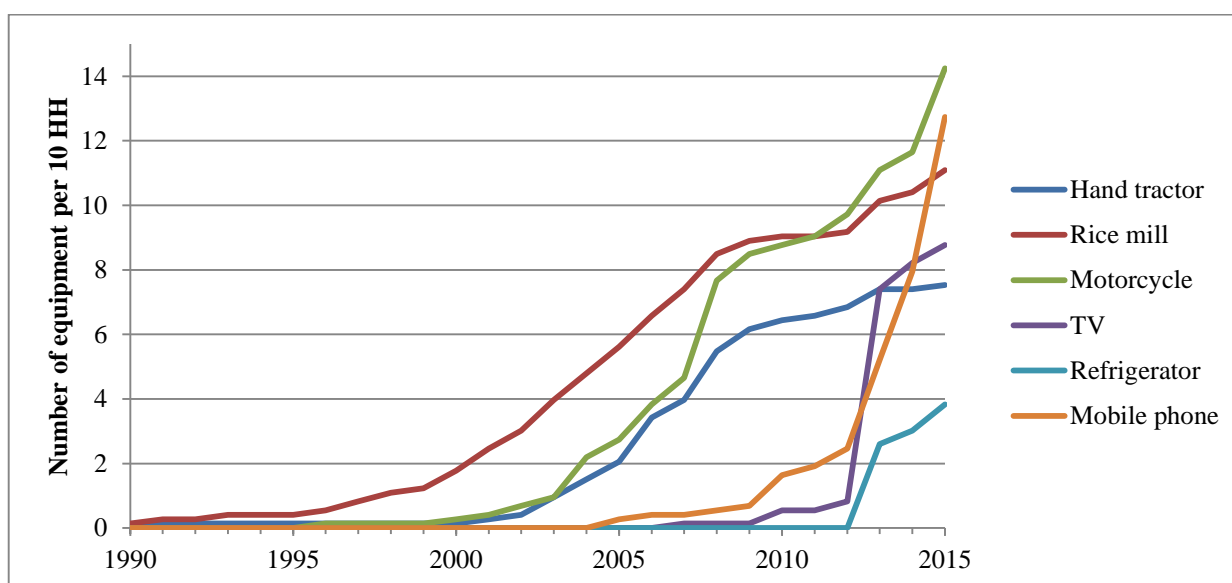
Figure 4-4 Time of equipment purchase by households in the study area (cumulative values)

The second wave of investments took place in 2012 and 2013 at the time the village got connected to the electricity grid. Contrary to the first batch of investment, this one was less oriented towards agricultural production and transportation and more in communication as it mainly consisted in buying TV and mobile phones, and more recently, refrigerators.

The number and value of assets each household own increased significantly between 2009 and 2016 as displayed in Figure 4-5 below. One can thus conclude that livelihoods improved thank to maize money.
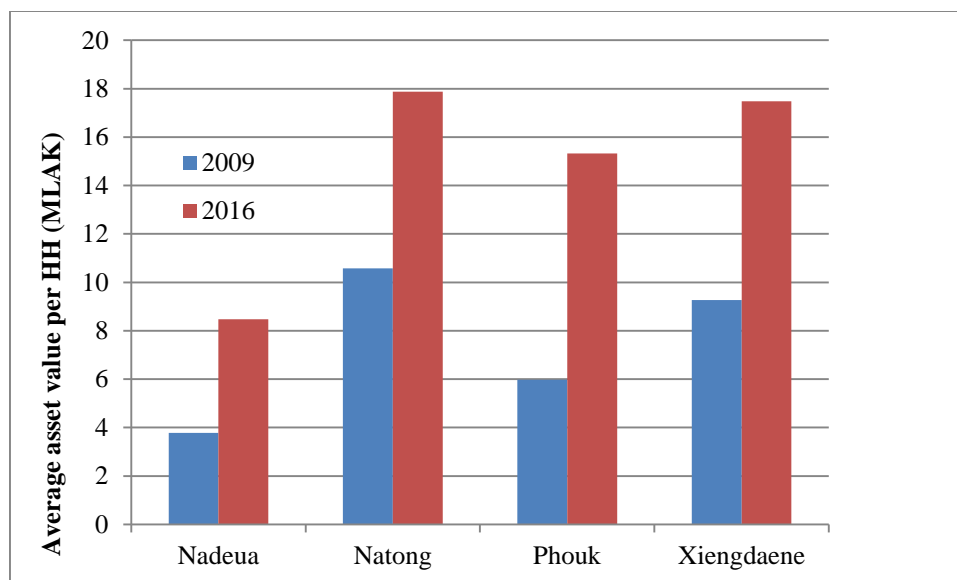
Figure 4-5 Average household asset value per HH in each village in 2009 and 2016

4.4 Changes in agriculture

4.4.1 The maize boom

Most livelihood changes happened in relation with the maize boom that started in 2006 in the study area. This rapid increase in maize cultivation marked a shift from **subsistence based agriculture** with villagers depending (i) on paddy land and upland fields to cultivate their staple food: rice, and (ii) livestock (mainly buffaloes) and forest products to provide limited amount of cash, to **market-oriented agriculture** involving the use of more inputs for production, indebtedness, land use intensification and diversification of income generation sources. We detail these multiple aspects of agricultural changes in the successive graphs based on analysis of household surveys.

Figure 4-6 below shows the gradual expansion of the three main crops produced in the study area, namely paddy rice, upland rice and maize, expressed as average quantity of seeds sown per household. In relation to the sharp increase in maize cultivation that replaced many fallow plots of

the upland rice sifting cultivation system one observe an overall decrease in upland rice cultivation since 2007. This reduction of shifting cultivation has been compensated by an increase in paddy rice production, not so much as an expansion of paddy areas as shown in the previous section by as an intensification of the production through generalization of the 2 cycle rice production while spring rice was cropped only on some plots before maize expansion.
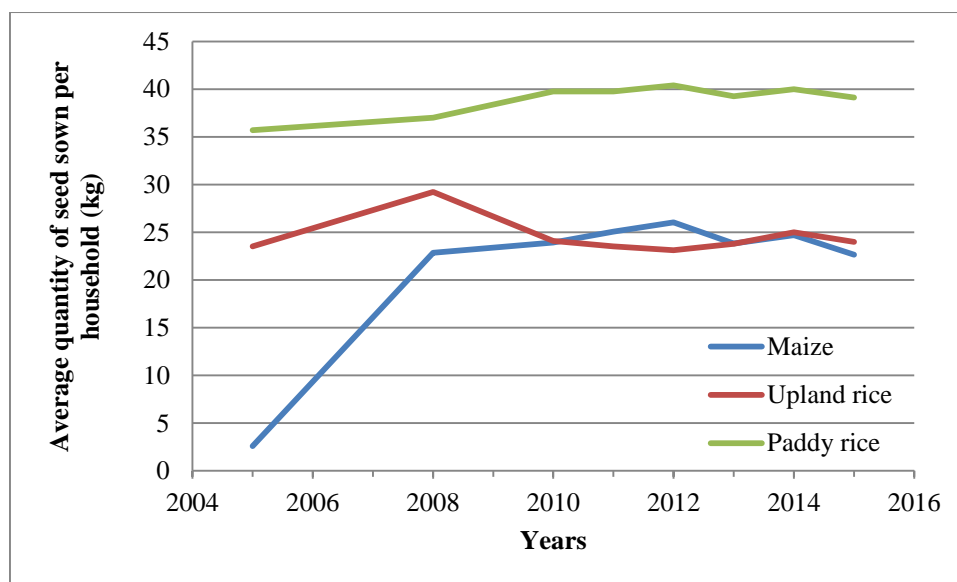
Figure 4-6 Change in the three main crops from 2005 to 2015

The Figure 4-7 confirms the trends presented above about the limited expansion of agriculture after the initial increase in maize areas in 2006-2008. The change in the average level of production per household has not evolved significantly between 2009 and 2016.
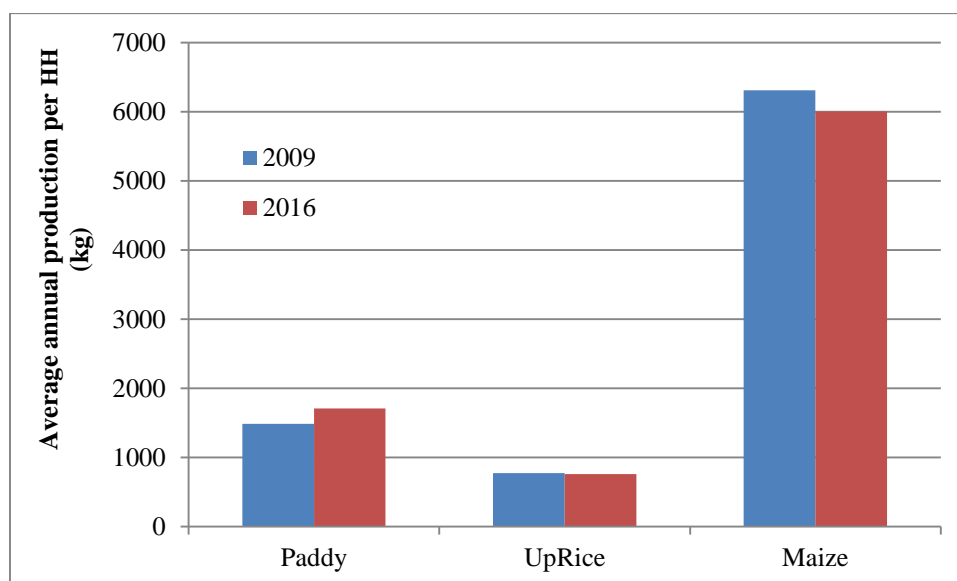
Figure 4-7 Change in production of the three main crops between 2009 and 2016

4.4.2 Livestock changes

Over the same period, major changes have been observed in relation to livestock. Buffaloes were gradually replaced by hand tractors for plowing the paddy land as villagers could afford to buy machinery with the money they earned from maize in 2007-2008. Also, some buffaloes that used to roam freely in remote forests when the maize largely spread in the uplands got stolen or disappeared because were roaming too far away, leading villagers to sell the remaining ones to avoid further losses. They then decided to buy more cattle as they had a faster reproduction rate than buffaloes but decided to delineate livestock areas closer to the villages to avoid further losses, and damages to upland crops, especially during the rainy season. As there are no fences in the village territory, the livestock need to be tended or parked in fenced livestock areas to avoid damages on crops by domestic animals.
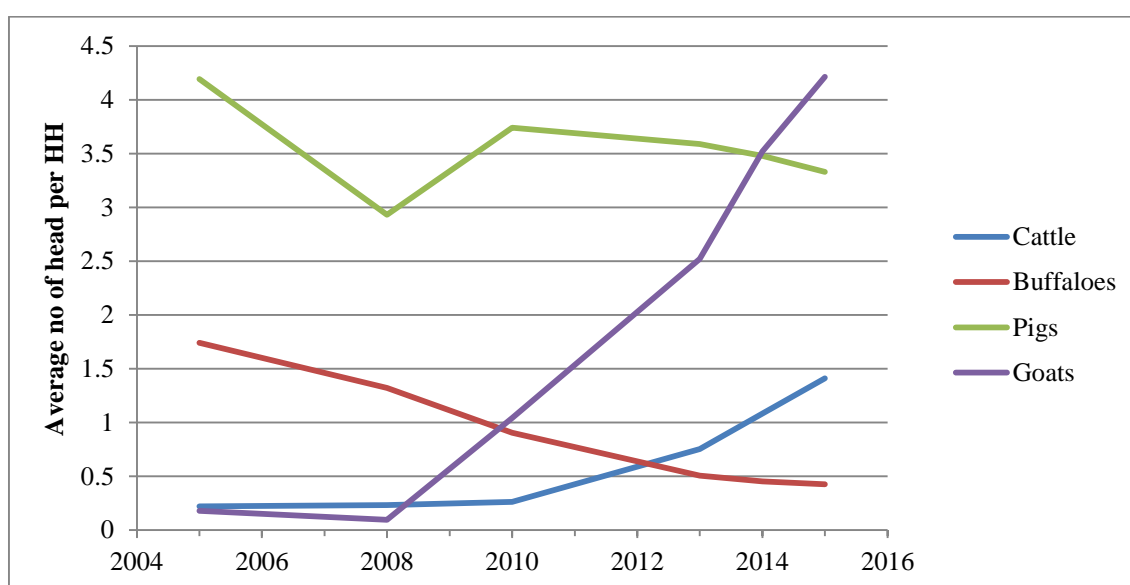
Figure 4-8 Livestock changes

The villagers started raising goats in 2010 and the number of heads increased sharply over the recent years. Goats spend the night in sheds. Owners alternate to take care of the animals that tended at all time and are usually brought to the fallow areas for grazing.

Livestock owners are responsible for damages their animals may cause to the crops as there is no fence in the village except around the livestock areas. Whenever animals get out of the livestock area the livestock owner is responsible for any damage cause by its animals. This local institution emerged in 2006 when a large proportion of villagers started growing maize in the village. Maize expansion therefore triggered a major change in livestock management style with a shift from free roaming to collectively managed livestock areas.

4.4.3 Drivers of agricultural change

The *population* (359 HH in 2009 and 368 HH in 2016) did not change much over the recent years and was therefore not a major driver of changes. No *land use plan* implemented so far by the district authorities in the study area. An initial plan was designed by the villagers themselves in 1997 (see report Viau et al., 2009) and the Poverty Reduction Fund did a plan about forest use in 2010. They delineated village protection forest, located above the village to protect against landslides and at the border with Vietnam, village production forests and sacred forests. In 2015 DAFO delineated livestock areas with villagers. These areas already existed since 2009, set up by villagers themselves but were formalized in 2015 only (Figure 4-9).

Many fruit trees (mango, tamarind, etc.) were planted from 2003 to 2005 with the support of development projects but traders did not come to buy the harvests. From 2003 to 2006 almost all villagers also grew soybean, but they stopped when they started growing maize because of labor shortage and limited market opportunities for alternative crops such as fruit trees, vegetable or soybean.

The main drivers of change were the expansion of feeder roads that allowed the expansion of maize fields in 2006-2008, the improvement of the main access road to the village in 2009 that brought the traders to the village and offered market opportunities, and then the connection to the electricity grid in 2013.
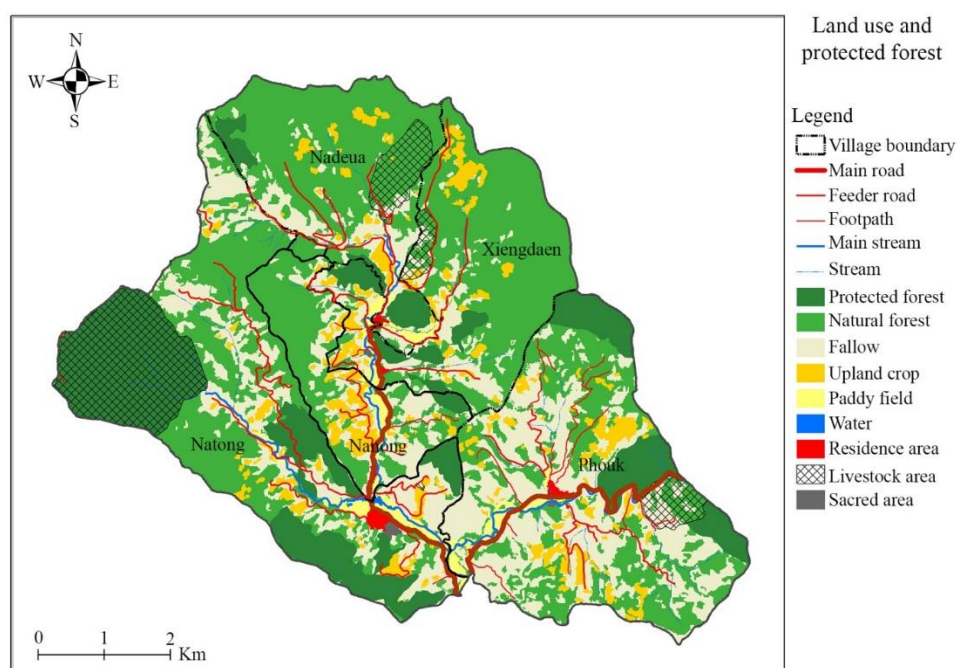
Figure 4-9 Land use in the study area in 2015

4.4.4 Change in agricultural practices

Maize expansion also brought other changes that may not be considered as positive in terms of livelihood impacts. Due to shortening maize-based rotational system farmers faced more and more problems with weed control that used most of their labor force and therefore reduced their capacity to expand the crop or to intensify cultivation in the lowland due to labor shortage.

Farmers first used herbicides in 2014. The first year they hired Vietnamese people to spray as they did not know how to do. Then villagers sprayed themselves. Many households also started using chemical fertilizers at the same time as herbicides, on maize and upland rice. They also started using urea in paddy since 2014. Since then, the few households who were using animal manure as fertilizer in the paddies stopped doing so as applying chemical fertilizer was considered more convenient despite the cost: urea is sold 190.000 LAK/bag.

But these new practices, developed as a response to decreasing yields, had negative effects on the household economy. They increased indebtedness of the households with the maize traders and middlemen forcing them to continue growing maize despite decreasing economic margins due to (i) increasing production costs due to: price of hybrid seeds (from 42.000 to 55.000 LAK/kg), chemical fertilizers and herbicides, used to compensable (ii) decreasing yields due to weed infestation, soil erosion and land degradation on hill slopes cropped continuously with maize.

As a consequence, farmers are searching alternative to what is now considered as unsustainable production systems. Indeed, intensive rotational systems on the hillsides are not sustainable as they are associated to soil fertility depletion. Depending on the villages, the soil quality and the household four main rotational systems are used in the study area, either with separate maize and upland rice fields (options 1 and 2) or mixed systems (options 3 and 4):

1. Maize – maize – maize – fallow – fallow – fallow (maize can be cropped up to 7 years on the same plot)
2. Rice – fallow – fallow – fallow (usually only one year cropped)
3. Rice – rice – maize – maize – maize – fallow – fallow – fallow (most common succession)
4. Rice – maize – maize – maize – fallow – fallow – fallow.

Options	Years							
	1	2	3	4	5	6	7	8
1	M	M	M	F	F	F		
2	R	F	F	F				
3	R	R	M	M	M	F	F	F
4	R	M	M	M	F	F	F	

Description	
F	Leave as fallow
M	Growing maize
R	Growing rice

Figure 4-10 Land use for cropping in upland area

In 2016, many villagers have decided to cut maize production by half and to raise more animals on natural grass left on former maize fields. This gradually increasing disinterest for maize also comes from strict conditions imposed by the companies on maize quality as the production conditions are degrading. If the quality is not good the company informed that it will not buy the harvest. When maize prices were high on the international market, the company committed to provide the seeds, buy the whole production from the village and to maintain the feeder roads. But some problems occurred with the company in 2014, in a context of low maize price, as they did not fix the road properly and the truck could not reach some areas. As a result they did not collect some maize areas, therefore increasing the tensions with maize producers.

Finally, respondent all agreed that 2008 was the best maize year in the village. They could sell a good harvest (high yields on relatively good soils at the initial stage of the maize boom) at a good price 1400 LAK/kg as compared to 900 to 1000 LAK/kg in 2016. The maximum cropped area in the village was reached in 2013 in an attempt to compensate gradual land degradation and therefore decreasing yields by expanding maize to new, more fertile fields. Indeed, 2013/2014 is a turning point in the history of the study area with the decrease in maize production and the massive investment in goats and cattle as an attempt to diversify income generation sources. In 2016 villagers decided to expand the maize roads so that they can open new fields further away from the village and fallow the old fields that have been cropped for many years.

4.5 Farmers' perception of environmental changes

4.5.1. Perception of natural resources

Perception of environmental changes indicate understanding of unsustainable of natural resources. Farmers' decisions on land use also depend on their perception of the negative impacts of their practices on the environment. The results of the household survey conducted on 118 households of the study area in 2016 show that farmers perceived a decrease in soil fertility over

the past decade. Many of them agreed that soil fertility has been decreasing very much (Figure 4-11). They are also concerned about the reduction of forest areas and related changes in volume of water in the streams as these resources have been decreasing, as well as availability of NTFP in the forest.
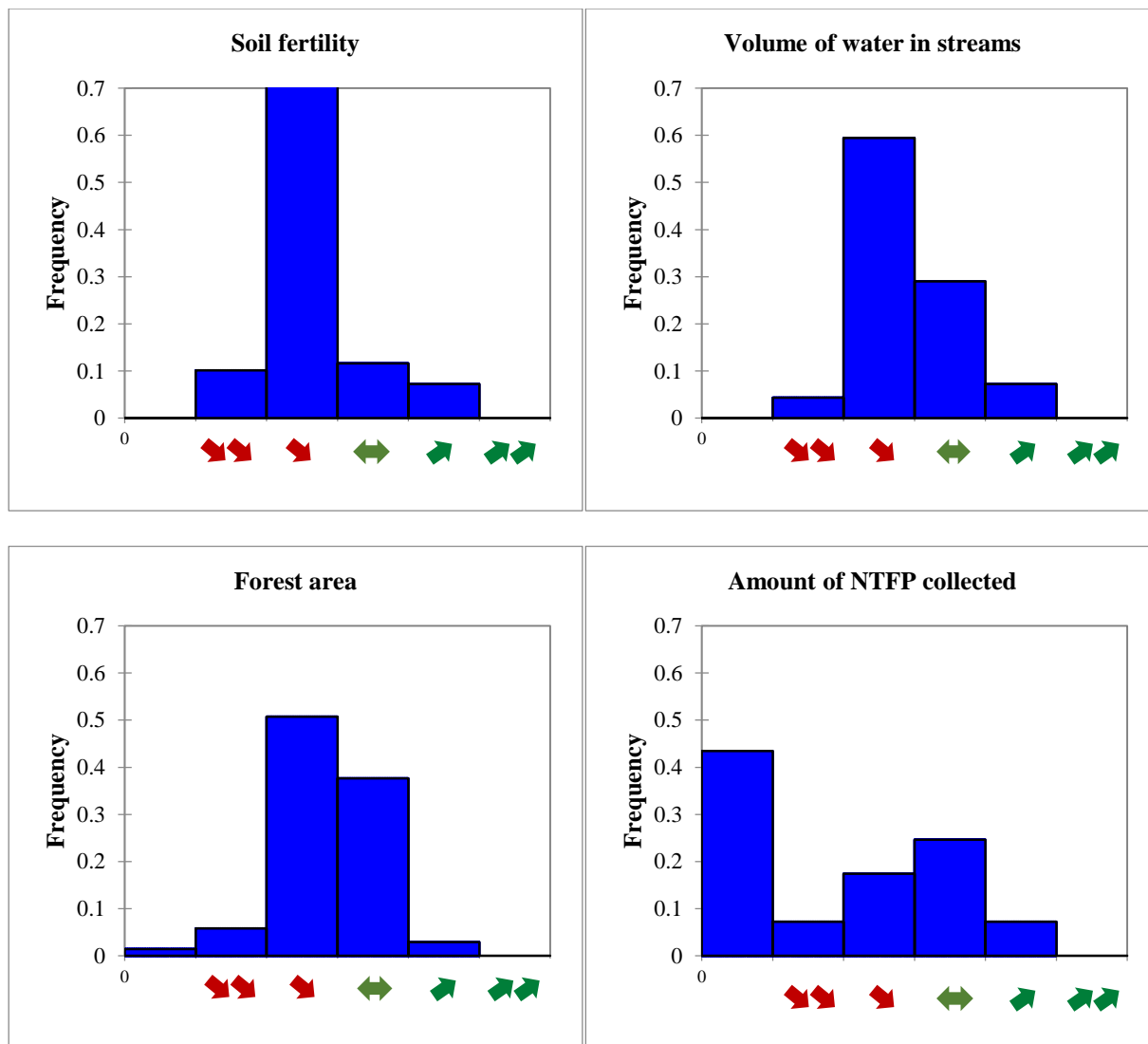
NB: bars from left to right correspond to: no answer, sharp decrease, decrease, stable, increase, large increase.

Figure 4-11 Distribution of responses to questions on the perception of environmental changes over the past decade from 118 households surveyed in 2016

4.5.2. Perceived value of the different land use types

Farmers perceived that different land use and land cover provided different services to their livelihood. The provisioning services from different land use and land cover categories in the study area could be classified into four categories, namely, cultural value, medicine or related health care, income generation, and consumption. Farmers perceived that paddy field and upland field rice in subsistence agriculture system are important in terms of consumption as they obtained food from these land (Figure 4-12). Upland rice field could also provide resources for health care through herbal products. Maize fields were concentrated only for income generation. Fallow and conservation forest played quite the same important roles that they provided products for consumption, income, and medicine or health care. Forest was very important as it implicated with their traditional and culture (Figure 4-12).
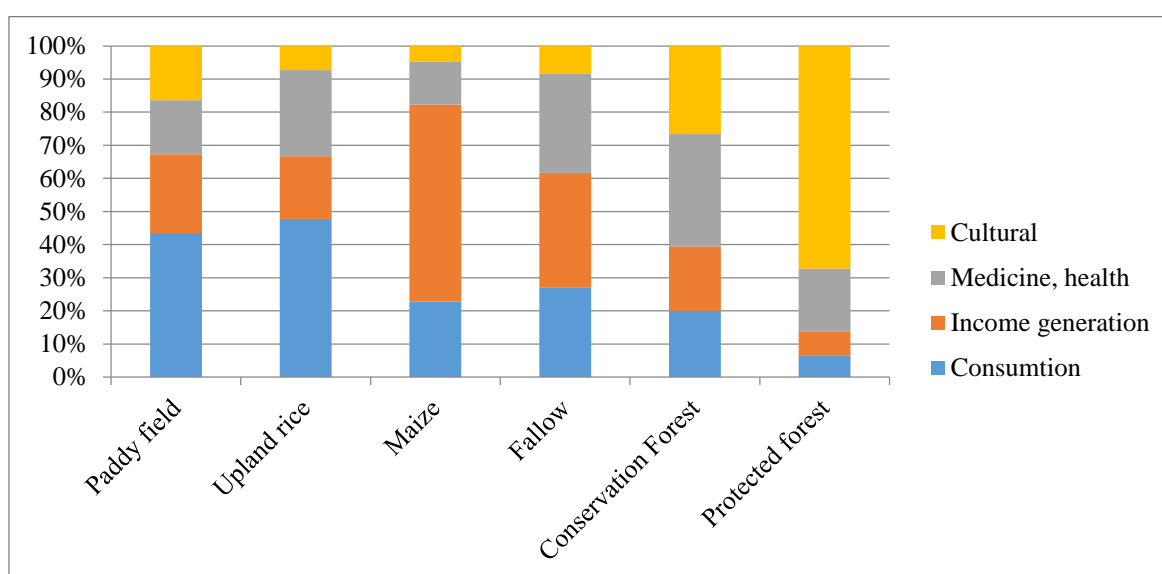
Figure 4-12 Perceived value for local livelihoods of the different land use types present in the study area

4.5.3. Perceived value for the natural environment

They often use arguments related to the environment to justify their choice to move away from maize cultivation towards livestock related activities (Figure 4-13). Villagers are thus willing to change towards more sustainable practices and they are already exploring alternatives such as livestock and off-farm activities. They are clearly in search of agricultural activities that would have a high level of market demand while preserving the environment.
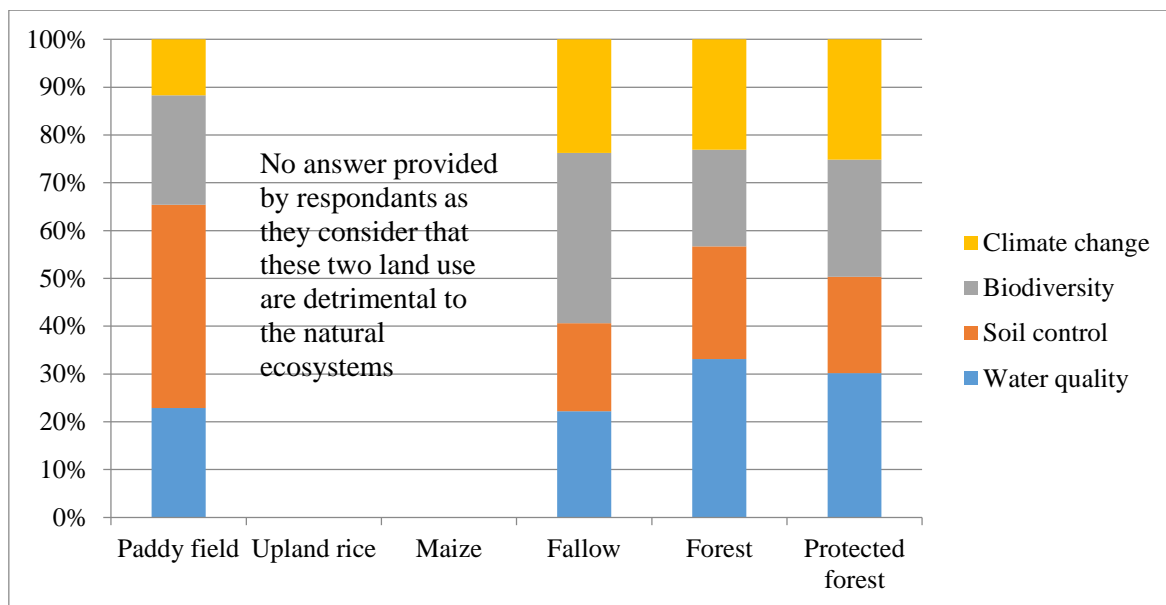
Figure 4-13 Perceived value for the natural environment of the different land use types

Chapter 5 Impacts of feeder roads expansion on landscapes

This chapter presents expansion trajectory of feeder roads including expansion pattern and construction processes, changes in spatial pattern in aspect of land use and land cover, dynamic of upland agriculture and forest, land use intensity.

5.1 Data collection

Geographic spatial data was used to quantify the impacts of the feeder road construction on landscape, especially in land use and land cover between the years 2003 to 2015. Landsat satellite images derived from USGS (The United States Geological Survey) were used to generate land use and land cover maps. Since this study aimed at investigating the changes in landscape between 2003 and 2015, Landsat imagery from different sensors such as TM (Landsat 5), ETM and ETM+ (Landsat 7), and OLI (Landsat 8) were used. The clear images from Global Visualization (Glovis) satellite platform of the USGS, for the study period, are rarely available. Only images between February and April of each year are free of cloud. Therefore, most of images used in this study are of the date between February and April. The spatial resolution of the image is 30 meters (Table 5-1).

Table 5-1 List of satellite images used in this study

| Year	Satellite/Sensor	Acquisition date	SLC	Sources of images
2003	Landsat 7/ETM+	2003/04/10	on	glovis.usgs.gov
2008	Landsat 7/ETM+	2008/01/02	off	glovis.usgs.gov
2013	Landsat 7/ETM+	2013/03/20	off	glovis.usgs.gov
2015	Landsat 8/OLI	2015/03/18	on	glovis.usgs.gov

Note: Landsat imageries in 2008 and 2013 are SLC-off (Scan Line Correction off) scenes. The gaps in these images were filled using other scenes acquired very close to the date of acquisition of these two images. For Landsat 2008, only one scene acquired on the 1st of December 2007 was found appropriate to use filling gaps, and Landsat on the 5th of April 2013 was used to fill gaps in Landsat image of 2013.

SPOT image and aerial photograph were also used in order to support the classification processes and field works. Google Physical and Google Satellite image also covers large part of the study site. Therefore it was also used through OpenLayers, a function of QGIS (Table 5-2).

Table 5-2 List of supporting images used in this study

Type of image	Acquisition date	Sources
SPOT7	2015/03/31	EFICAS project in Lao PDR
Aerial Photo	2014	National Geographic Department in Lao PDR
GoogleEarth	2014/05/15 & 2013	GoogleEarth and OpenLayers in QGIS

5.2 Data analysis

5.2.1 Feeder roads construction

The expansion of the feeder roads is described base on statistic data obtained from group discussion and interviewing key informants of each village. We analyzed contents from interviewing key informants and in charge district authorities, from focus groups, and from official documents related to feeder road construction.

5.2.2 Impact of the feeder roads on landscapes

5.2.2.1 Generating land use and land cover maps

To analyze the impact of feeder roads on landscape, we first generated land use and land cover maps from Landsat satellite images using combination of supervised and unsupervised classification technique. The images used in this study are level 1G product of Landsat 5, 7, and 8. Land use and land cover categories are adjusted from the top-level categories suggested by Intergovernmental Panel on Climate Change (IPCC, 2003) with some additional sub-divisions of forest land (FAO, 2004) (Table 5-3).

Table 5-3 Land use and land cover categories

Code	Categories	Description
1	Dense forest	This refers to forest land of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.
2	Open forest	This refers to area of forest regenerated largely through natural processes after significant human or natural disturbance of the original forest vegetation. This category includes the areas of mix woody with bamboo and old fallow.
3	Fallow	This refers to vegetation types where the dominant woody elements are shrubs i.e. woody perennial plants, generally more than 0.5 meters and less than 5 meters in height at maturity and without a definite crown. This category includes clear bamboo which the spectral reflectance is close to the features classified as fallow.
4	Upland crop	This category refers to land area in higher slope which is mainly used for dry cropping such as upland rice, maize, etc.
5	Paddy field	This category refers to paddy fields both dry-season and wet-season paddy fields.
6	Water	This category includes land that is covered or saturated by water for all or part of the year and that does not fall into the forest land, cropland, grassland, or settlements categories. It includes reservoirs, natural rivers, and ponds.
7	Residence area	This category includes all developed land, including transportation infrastructure and human settlements of any visible size.
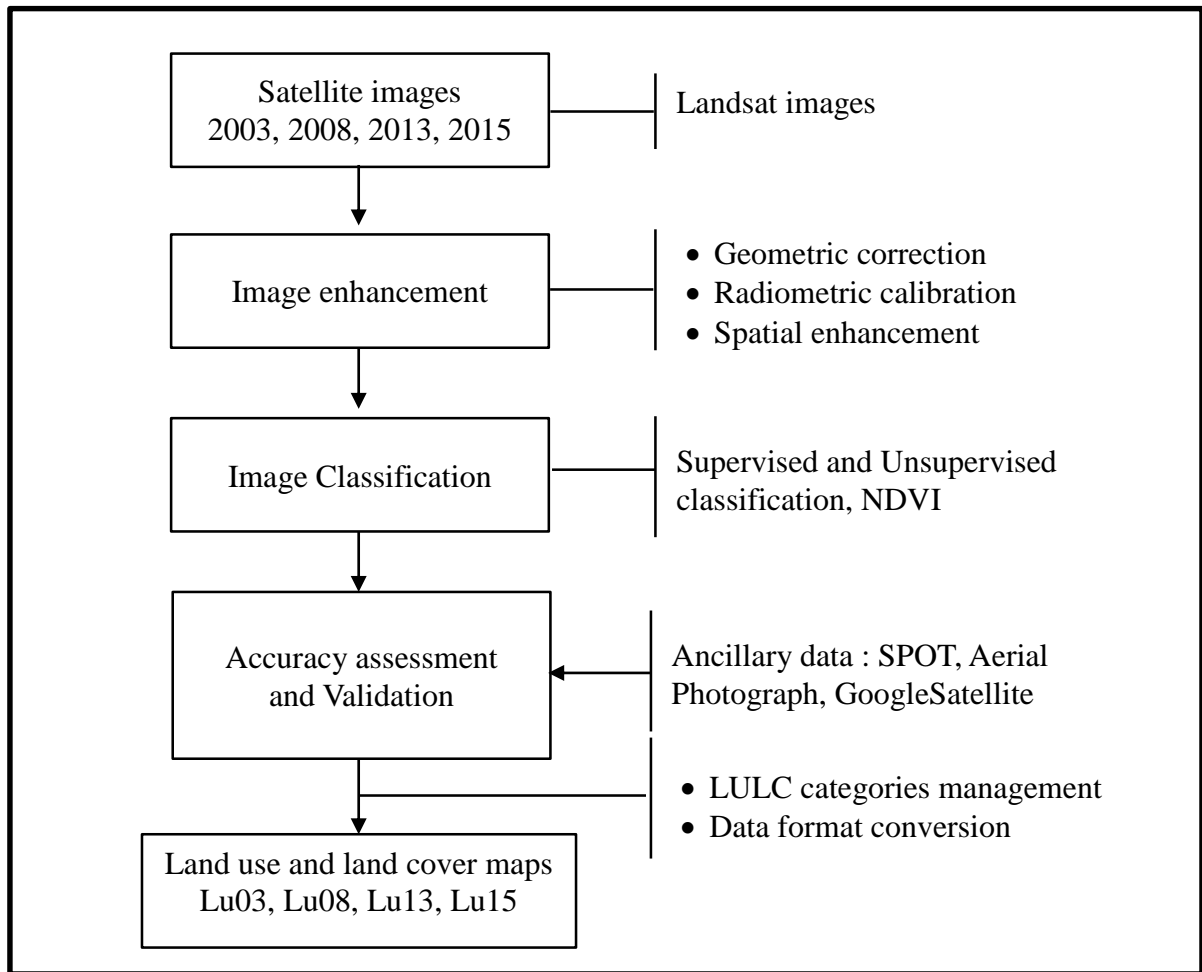
Figure 5-1 Image processing processes

Accuracy assessment for image classification is available only 2015 based on reference data from aerial photograph, SPOT image, and reference data from the field. Aerial photograph is of the year 2014, the SPOT image is of March 2015, data from field work during March – April 2016. The number of reference data is defined by multiply the number of land use and land cover categories by 40 - base on FAO (2016), the minimum sample size should be at least 20 to 100 samples per class. The reference point is randomly generated. As a result, each category has different reference points (Table 5-4).

Table 5-4 Result of accuracy assessment for land use and land cover map of 2015

Classified Data	Reference Data							C-Total	Num. Correct	PA (%)	UA (%)	(K^) stat.
	DF	OF	YF	UC	PA	WA	RI					
DF*	30	3	1	0	0	0	0	34	30	96.77	88.24	0.86
OF	1	93	9	2	0	0	0	105	93	86.92	88.57	0.81
YF	0	9	62	0	0	0	0	71	62	74.70	87.32	0.81
UC	0	2	11	34	0	0	0	47	34	94.44	72.34	0.68
PA	0	0	0	0	15	0	1	16	15	100	93.75	0.93
WA	0	0	0	0	0	2	0	2	2	100	100	1
RI	0	0	0	0	0	0	5	5	5	83.33	100	1
R-Total	31	107	83	36	15	2	6	280	241	90.88	90.03	0.81
Overall Classification Accuracy = 86.07%												

* DF=Dense forest; OF=Open forest; YF= Young fallow; UC=Upland crop; PA= Paddy field; RI= Residence area; WA=Water; R-Total= Reference Total, C-Total= Classified Total, PA= Producer Accuracy, UA= User Accuracy.

5.2.2.2 Analysis land use change and measuring land intensity

Land use changes between dates were analyzed using GIS software based on land use maps obtained for each date. Two main processes of land use change were investigated, namely (i) forest regeneration and deforestation and (ii) upland crop expansion, as they account for most of the changes over the study period.

Changes in forest cover:

Three categories were investigated:

1) Forest regeneration: Others land use and land cover types in previous date become dense forest and open forest in the later date.

2) Unchange: One land use and land cover type in previous date overlap the same type in the later date.

3) Deforestation: Dense forest and open forest in previous date become others land use and land cover types in the later date.

Table 5-5 Forest regeneration and deforestation

	LULC	Forest change						
		DF	OF	FA	UC	PA	RI	WA
Previous date	DF	Unchange	Unchange	Deforestation	Deforestation	Deforestation	Deforestation	Deforestation
	OF	Unchange	Unchange	Deforestation	Deforestation	Deforestation	Deforestation	Deforestation
	FA	Forest regeneration	Forest regeneration	Unchange	Unchange	Unchange	Unchange	Unchange
	UC	Forest regeneration	Forest regeneration	Unchange	Unchange	Unchange	Unchange	Unchange
	PA	Forest regeneration	Forest regeneration	Unchange	Unchange	Unchange	Unchange	Unchange
	RI	Forest regeneration	Forest regeneration	Unchange	Unchange	Unchange	Unchange	Unchange
	WA	Forest regeneration	Forest regeneration	Unchange	Unchange	Unchange	Unchange	Unchange

XX= impossible for this change. This must not happen in reality.

Land use and land cover
DF   Dense forest
OF   Open forest
FA   Fallow
UC   Upland crop
PA   Paddy field
RI   Residence area
WA   Water

Forest transition
■ (green) Forest regeneration
■ (grey)   Unchange
■ (red)   Deforestation

Changes in upland crops:

 Four main land use conversions were investigated:

1) Upland crop from dense forest: the conversion from dense forest to upland crop.

2) Upland crop from open forest: the conversion from open forest to upland crop.

3) Upland crop from fallow: the conversion from fallow to upland crop.

4) Upland crop from upland crop: cropping in upland crop area in the previous date.

Table 5-6 Changes in upland crops

	Upland crop		
	2003-2008	2008-2013	2013-2015
Dense forest			
Open forest			
Fallow			
Upland crop			

Land use intensity:

The land use intensity was calculated only for upland crops as they accounted for most of the agricultural changes over the study period. All areas that were classified as upland crop in any of the 4 years of the study were assigned a different color depending on how many years they appear as upland crop on the successive land use maps. The resulting map reflects land use intensity with respect to the frequency of upland crop cultivation in the landscape.

Table 5-7 Land use intensity

Color code	Categories	Description
	Upland crop 1 date	The upland crop areas appear only in a land use map.
	Upland crop 2 date	The upland crop areas appear in two land use maps in the same location.
	Upland crop 3 date	The upland crop areas appear in three land use maps in the same location.
	Upland crop 4 date	The upland crop areas appear in four land use maps in the same location.

5.2.2.3 Quantifying impacts of the feeder roads on landscape

In order to quantify the impact of the feeder roads on landscape composition, we generated buffer along the roads with the extent of 200 meters. The extent of buffer is set based on the spatial analysis of upland crop distribution along the roads. The analysis showed that 200 meters (by average) from roads are possibly to be used for cropping.

In an attempt to relate feeder roads to other components of the landscape a spatial analysis was conducted within and outside of buffer zone to relate the intensity of changes to the presence of the roads in the form of forest regeneration and deforestation since 2003 to 2015.

5.3 Land use and land cover changes

Figure 5-2 and Figure 5-3 presents the changes in land use and land cover in each year. Open forest covered large proportion in each year, followed by fallow land and dense forest.

Forest covered large proportion in the study area in the early 2000s, but it decreased continuously both in dense forest and open forest areas over the past decade. Open forest, the largest land cover category, decreased dramatically from 74% in 2003 to 54% in 2015. Fallow areas increased inversely to open forest. Upland crop areas, essentially upland rice prior to the maize boom in 2006 and then a mix of upland rice and maize, increased continuously in the recent years.
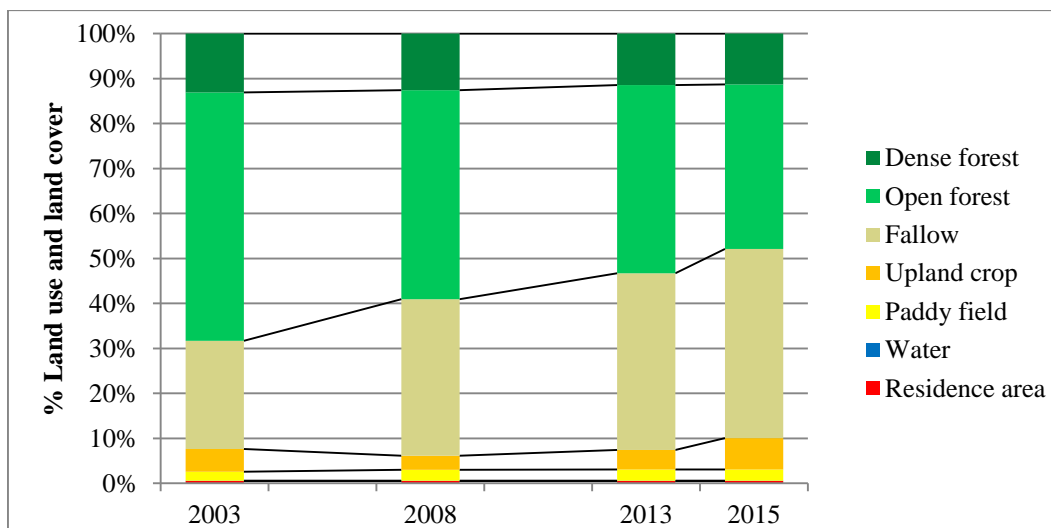
Figure 5-2 Land use and land cover between period of the study

Most of land use changes occurred in upland crop areas. It was almost unnoticeable for change in paddy field and residence area. Therefore, the analysis of land use change was focused on the change pattern in upland crop areas, in particular the expansion of upland crop areas.

Between 2008 and 2013, all households in the study area engaged in the production of hybrid maize and many feeder roads were opened. The roads were necessary for maize expansion as farmers could not carry back the heavy harvest from scattered fields on their back as they use to do with upland rice. When they harvest one tone per hectare of upland rice in average, the maize yield is about 5 times higher, which would require to carry down the hills 5 tons per hectare cultivated with maize. The feeder roads allowed the hand tractors to get closer to the fields and facilitated the transportation of the harvest and circulation within the village territory. It is considered by villagers as a considerable improvement of their workload and their lifestyle.

Upland crop area decreased between the transforming from subsistence agriculture to the beginning of introduction of cash crop between 2003 and 2008. Rice was the main crop grown before adoption to maize as a cash crop in 2005. In rice cultivation, upland rice patches scatter over the village area as since farmers did not consider about selling outlet.
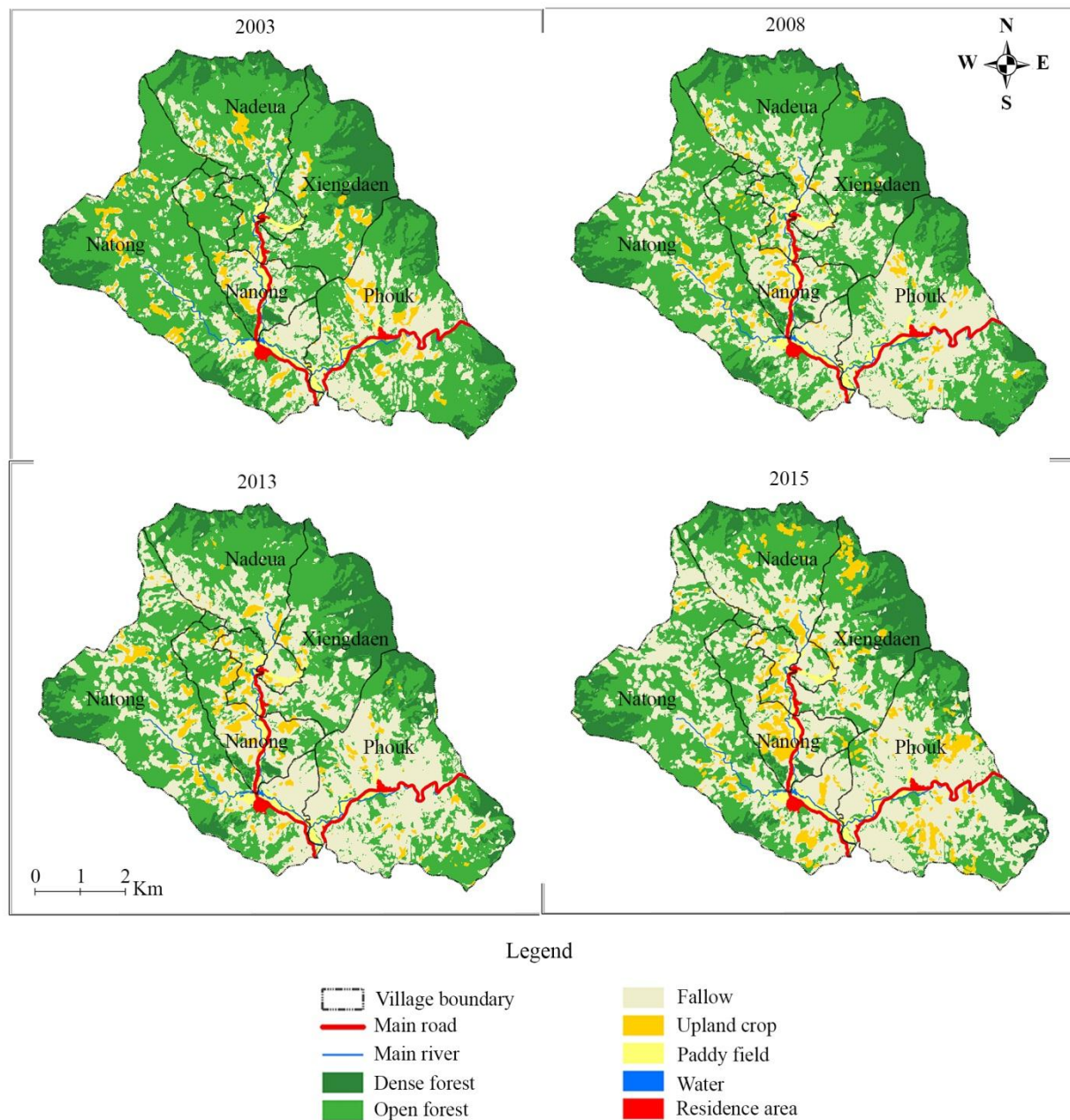
Figure 5-3 Land use maps 2003, 2008, 2013, 2015

Expansion of maize crop transformed dramatically the agricultural landscape as the rotational system was shortened as compared to upland rice-based shifting cultivation systems. While upland rice cultivation was usually followed by 5 to 7 years of fallow and forest regeneration before returning to the same plot for cultivation, maize rotational systems involved only 2 years of fallow and in most accessible areas close to the feeder roads farmers were cropping their plots almost continuously. There is therefore a gradient of land use intensity from remote areas towards more

accessible areas in the landscape, with decreasing proportion of fallow in the rotational agricultural system as it is located closer to the feeder road network.

Figure 5-4 shows upland crop expansion which was the main land use change in the study area, with a continuous increase over the study period.
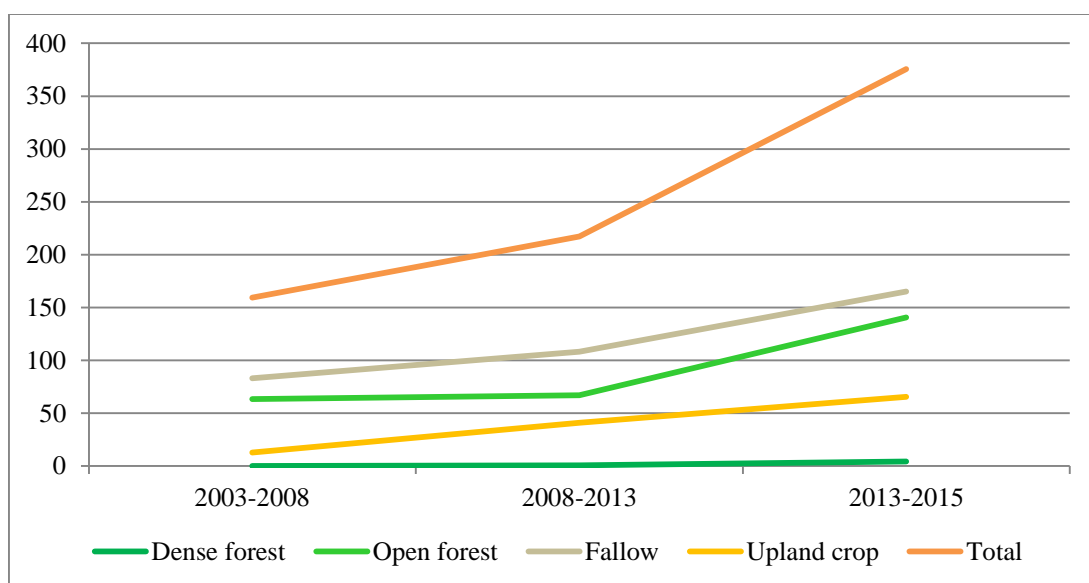

Figure 5-4 Upland crop expansion between 2003 and 2015

5.4 Forest regeneration and deforestation

As a result of maize expansion, large areas of forest land, both dense and open forest, were converted to upland rotational agriculture (or shifting cultivation): represented by the upland crop and fallow land use categories in Figure 5-5. The natural forest regeneration involved in the traditional shifting cultivation system could not compensate anymore for the forest degradation induced by upland crop expansion and shortening fallow periods leading to an overall degradation of the forest cover. This forest change had further consequences on water cycles and availability in the streams and river, on land degradation, erosion and fertility decrease and on the availability of non-timber forest products that used to be a major component of farmers' livelihood systems in the area.
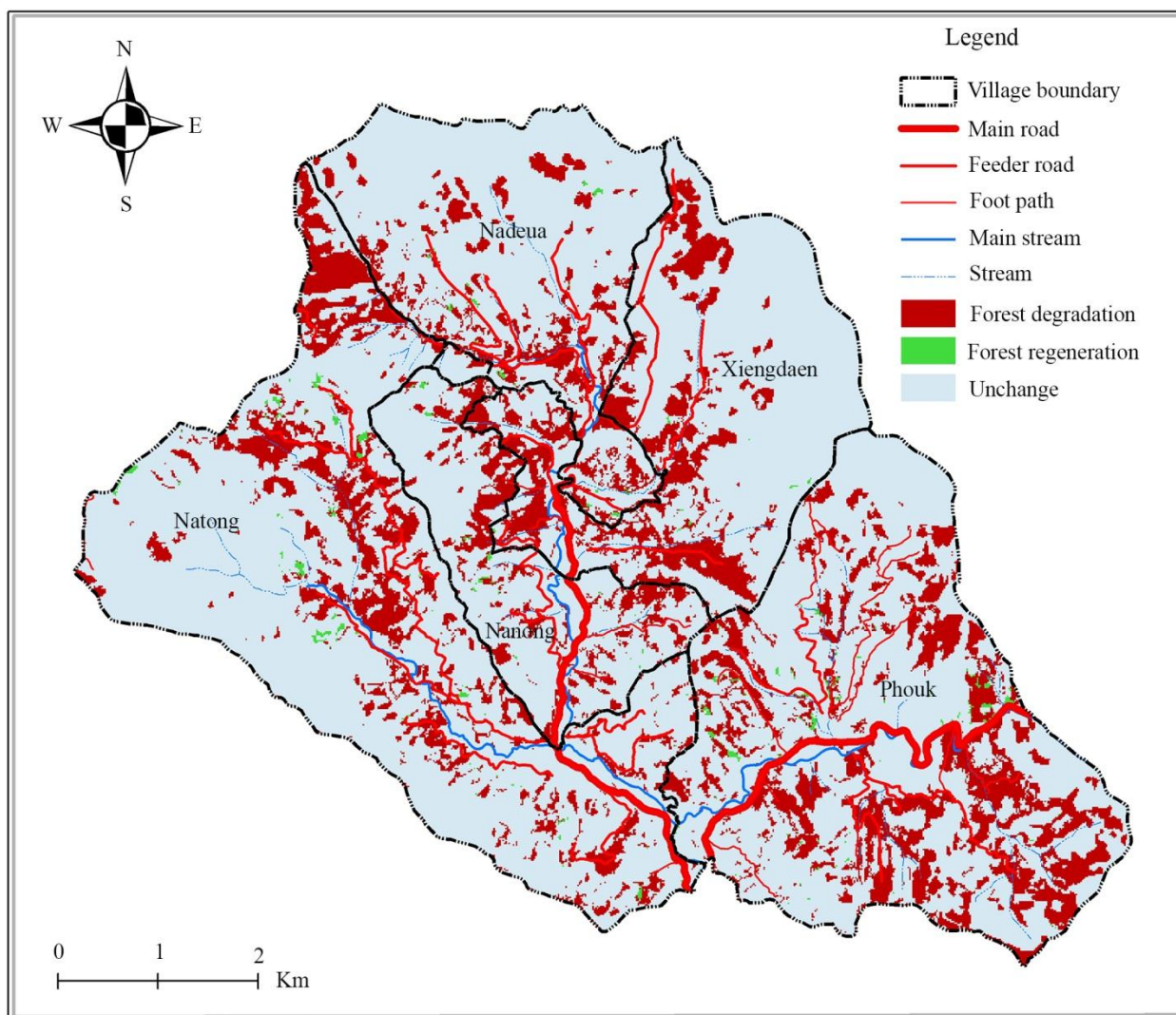
Figure 5-5 Land use change 2003 – 2015

The roads are necessary for the maize expansion and on the other hand maize production pays for the roads. Both processes are therefore intimately related and feeder roads can be considered as an instrument of maize expansion. We have shown in the previous section that maize expansion comes with many other land use changes that have major impacts on local landscapes and livelihoods. In an attempt to relate feeder roads to other components of the landscape, a spatial analysis was conducted within and outside of a 200 meters buffer area around the feeder roads to relate the intensity of changes to the presence of the roads (Figure 5-6).

Legend

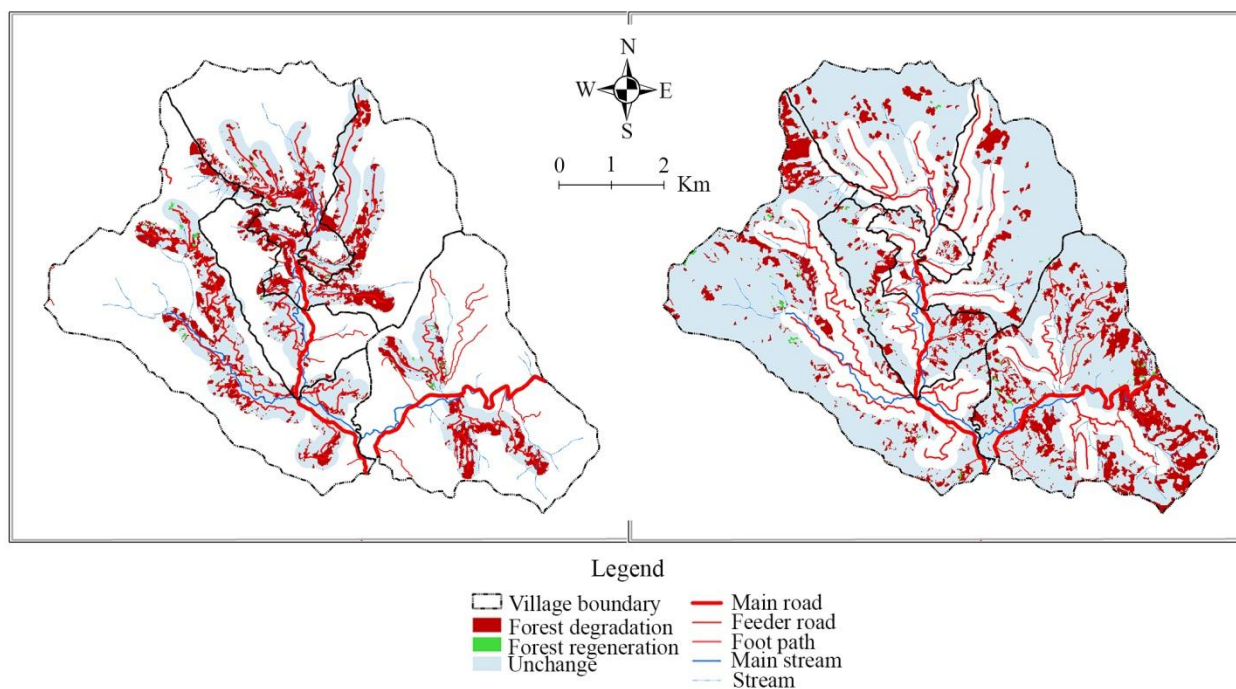|			
⬚ Village boundary	━━ Main road		
■ Forest degradation	─ Feeder road		
■ Forest regeneration	─ Foot path		
▦ Unchange	─ Main stream		
	┄ Stream		

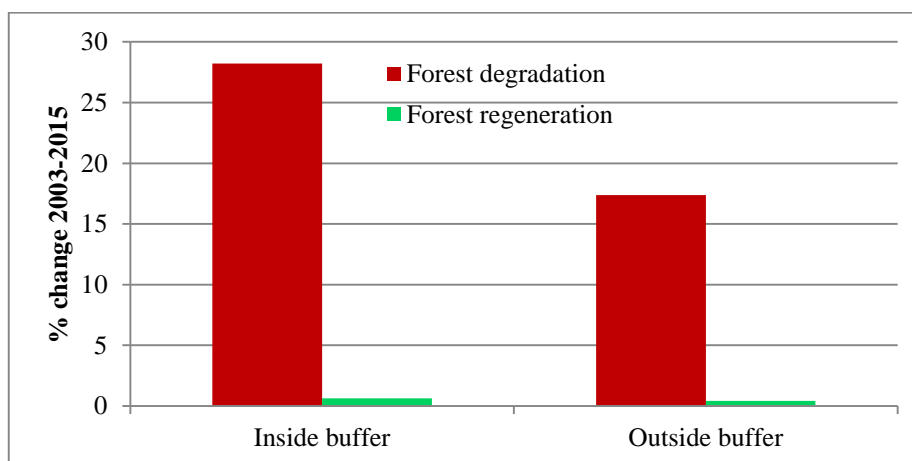Figure 5-6 Land use changes 2003-2015 induced by feeder roads within a 200m buffer area

Figure 5-7 Percentage of forest degradation and regeneration inside/outside a 200m buffer zone around the feeder roads

The study clearly shows that most of the forest degradation happened within the buffer area. But looking more closely at the expansion of upland crops during the successive periods we could also show that while the crop expansion concentrated around the feeder road network during the period from 2003 to 2008 and from 2008 to 2013, it mostly happened away from the feeder roads during the period 2013-2015 (see northern part of the map in Figure 5-8). Open forests were then converted to upland crops in a new movement of agricultural expansion. Then, the same years new feeder roads were constructed to reach these new maize production areas.
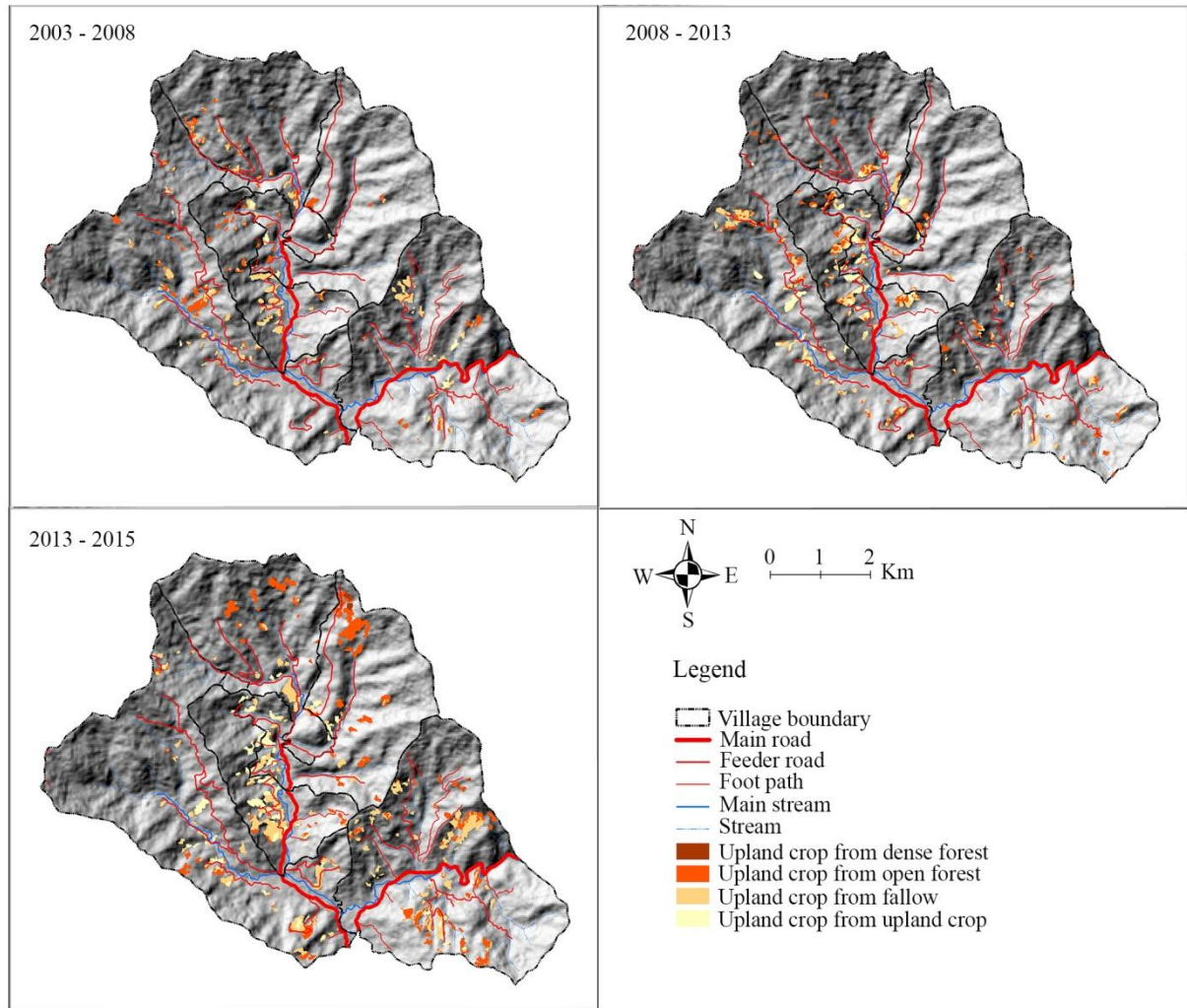
Figure 5-8 Conversion of different land use types to upland crops over the 3 successive periods

These results are confirmed by the analysis of land use change done within and outside the buffer areas during the 4 successive years that show most of the upland crops within the buffer in 2008 and 2013 while they were mainly outside of the buffer in 2015 (Figure 5-8).
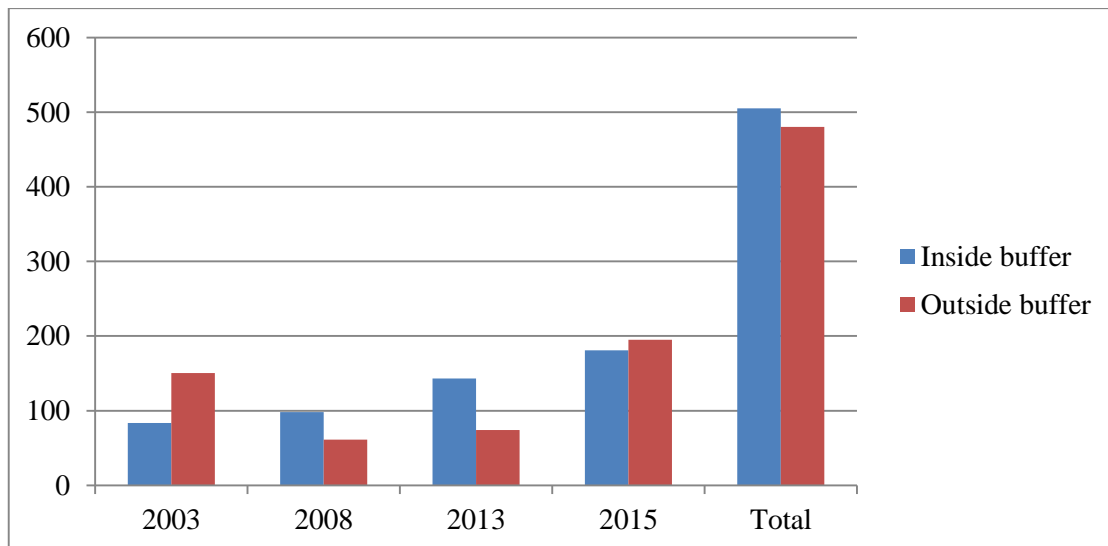
Figure 5-9 Upland crop area inside and outside of feeder road buffer (area is in hectare)

5.5 Land use intensity

Upland crop intensity was further analyzed as the number of times each pixel was classified as upland crop during the 4 dates of our study (2003, 2008, 2013, and 2015). This further investigation showed that upland crops were still largely rotating within the study area with few areas where upland crops had been cultivated more than two times over the study period Figure 5-10. It also confirmed that the most intensive land uses (i.e. cultivation of upland crops more than twice over the study period) were systematically located along the feeder roads, within the buffer area (Figure 5-11). A comparison of our study site with the large upland crop area located at the northwestern part of the landscape in Figure 5-11 show how the study area may evolve in the future if land use intensity further increases. This maize production area is located across the border, in Vietnam, where maize has also spread very rapidly in the recent decade.
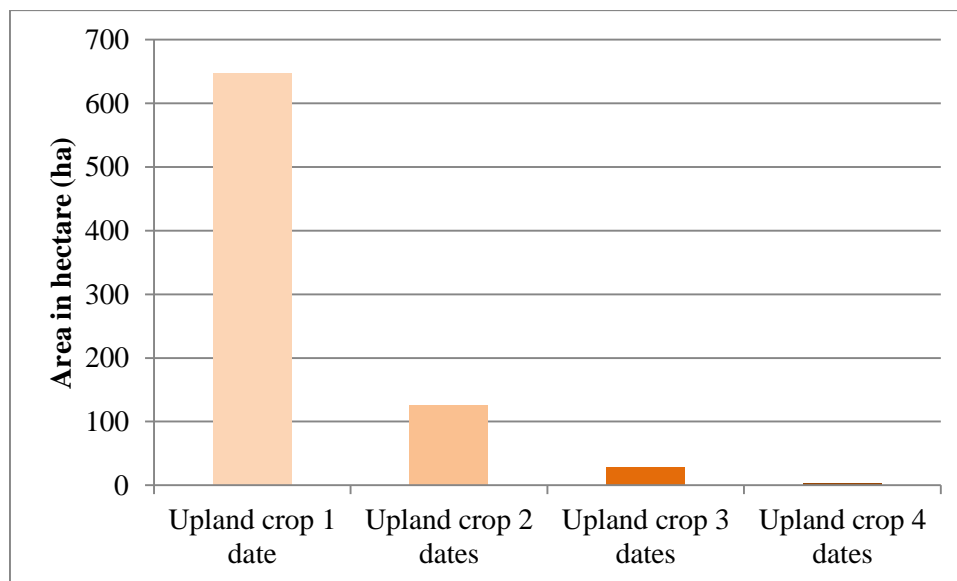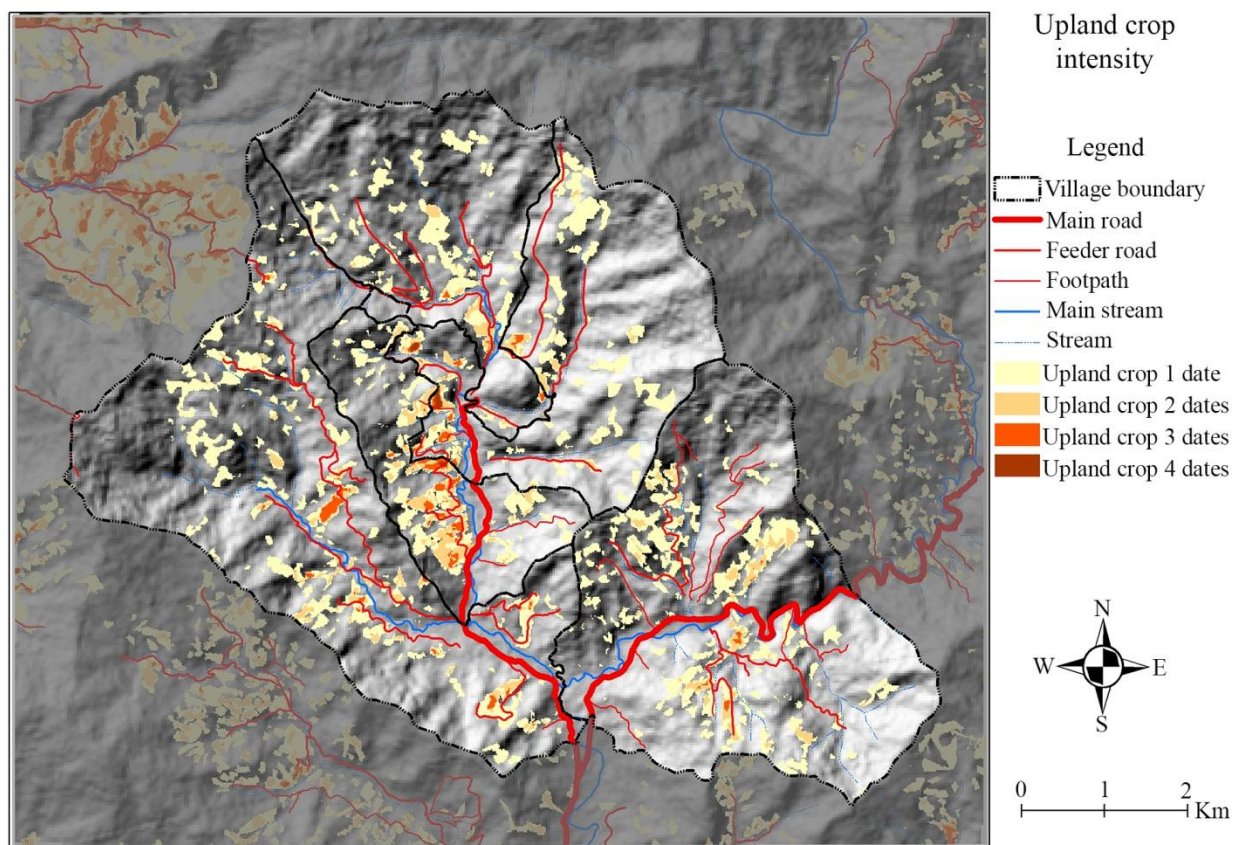
Figure 5-10 Upland crop intensity

Figure 5-11 Upland crop intensity distribution

Chapter 6 Conclusion, Discussion, and Forward Looking

This chapter puts the study into a larger perspective, and responds to the initial question about the impacts of feeder roads on the landscapes and livelihoods in the northern uplands of Lao PDR.

6.1 Conclusion

This research analyzed the patterns of maize expansion in Huaphan, a northeastern province of Lao P.D.R., in relation with the construction of feeder roads to reach maize production areas with hand tractors or small trucks. The study concentrated on some of the villages of Natong cluster including Nadeua, Xiengdaen, Nanong, Natong, and Phouk villages which started growing maize as a cash crop for income generation since 2005. The study assesses the impact of the feeder roads constructed in the period from 2006 to 2008 on the subsequent period from 2009 to 2016 through the analysis of a chronological series of remote sensing data combined with repeated household surveys in 2009 and in 2016. The objective of this study was to quantify the impact of the feeder road construction on socio-economic context and spatial pattern in the study area using combination analysis of data related to social and economic contexts and spatial patterns. The study of the impact of the feeder roads on livelihood was evaluated through statistical analysis. The data used include primary data from field work in the beginning of 2016 and secondary data from Catch-Up project in 2009 (www.asia-uplands.org/Catch-Up/index.php). The impact of the feeder roads on spatial pattern was implemented based on spatial analysis employing Geographic Information System (GIS) and Remote Sensing Techniques. The data used include Landsat imageries (2003, 2008, 2013, and 2015), SPOT image of 2015, aerial photo of 2014, data from ground survey in 2016, and other related GIS data. The study revealed that:

3) The impacts of the feeder roads expansion on livelihood were both positive and negative. The positive impact was that it eased accessing to production areas, reduced the constrains in production in terms of time spent in the fields and products transportation, allowed engaging remote communities into the market economy through intensive cropping of maize. They could invest in basic livelihood assets such as better house, motorcycles for transportation, send children to schools, etc. and also invest in off-farm activities that provide a significant part of their income at present. However, these maize-driven land use changes also came with negative impacts such as reduction of income from NTFP, soil erosion and land degradation that reduce the yields in the upland fields and force villagers to use more inputs, to contract more debts and engage in more economically risky activities as compared with the previous decade.

4)   Feeder road expansion in order to support maize production led to changes in spatial pattern arrangement. It caused decreasing of natural forest cover in every year. Agricultural land, in particular upland crop system, increased inversely to open forest. The expansion of agricultural land seemed to move towards to forest areas. Land use intensity gradually emerged along the feeder roads and land sparing appeared as at the beginning state.

As we have seen, the consequences on local livelihoods of such changes in landscapes are dramatic as the forest does not provide NTFP anymore which used to be an important component of the household economy, as the soil is eroding rapidly and losing the fertility that used to be maintained by the fallow system and that is now substituted by intensive use of herbicide and chemical fertilizer to artificially maintain reasonable level of fertility. But intensive use of agricultural inputs come with debts and reduced economic margins up to a level that makes maize production not sustainable anymore.

6.2 Discussion

In subsistence agriculture that prevailed before 2005, rice was the main crop grown in the study area both in low land and upland area. Lowland expansion was limited by mountainous topography. Therefore, the main source of additional rice was from upland fields. Upland rice was produced through shifting cultivation. As a result, upland fields were scattered over the areas within village boundary as shown in 2003 land use and cover map. In 2008, upland crop areas were subtracted to the feeder roads which started constructing in 2006 and expanded to every villages in 2008, and it appeared that villagers cultivated upland crop in the same region, rather than separated the fields as shown in 2003. At the beginning stage of the conversion from upland rice as a main upland crop to growing maize as a cash crop, there were obvious changes in landscape that upland crop area decreased because of an unsure about new crop and new cropping practice from individual to group cultivation. When villagers were confident about the benefit from maize, they expanded their production area as well as quantity of seed based on labor forces of their households. The combination of convenient access to production areas and labor forces drove upland crop expansion between 2008 and 2015. Agriculture practice also changed from annual rotation cropping system to continuous cropping for 3 to 5 years system. Because of such cropping practice, there was no expansion in feeder road after first batch between 2006 and 2009. Within a period of 7 years, from 2009 to 2016, the landscape and the local livelihoods have been completely transformed through an overall process of land use intensification as described in Figure 6-1. The resulting landscape is characterized by more degraded land along the feeder roads

due to intensive farming without erosion control and fertility management. The whole agricultural activity has concentrated on these areas during the 5 years that followed the opening of the feeder roads and as a result the forest somehow regenerated in remote areas at the periphery of the village territory. But as the land along the feeder road was degrading some farmers started growing upland rice in more remote and more forested areas, then they managed to convince the village community to expand the feeder roads to these new areas, moving the land degradation problem to these new places until the forest limit is reached. Two successive periods can be described in relation with opening of the feeder roads:

- a first one of *contraction of the agricultural space* along theses feeder roads that provide easy access to formally remote fields combined with and *intensification of land use* in these new agricultural areas until land degradation reach a level that makes the cultivation system not profitable anymore, and then
- a second one of expansion of the feeder roads to more remote, forested environments that were relatively preserved during the previous period and where a similar process of contraction and intensification of land use starts as for the first batch of feeder roads.

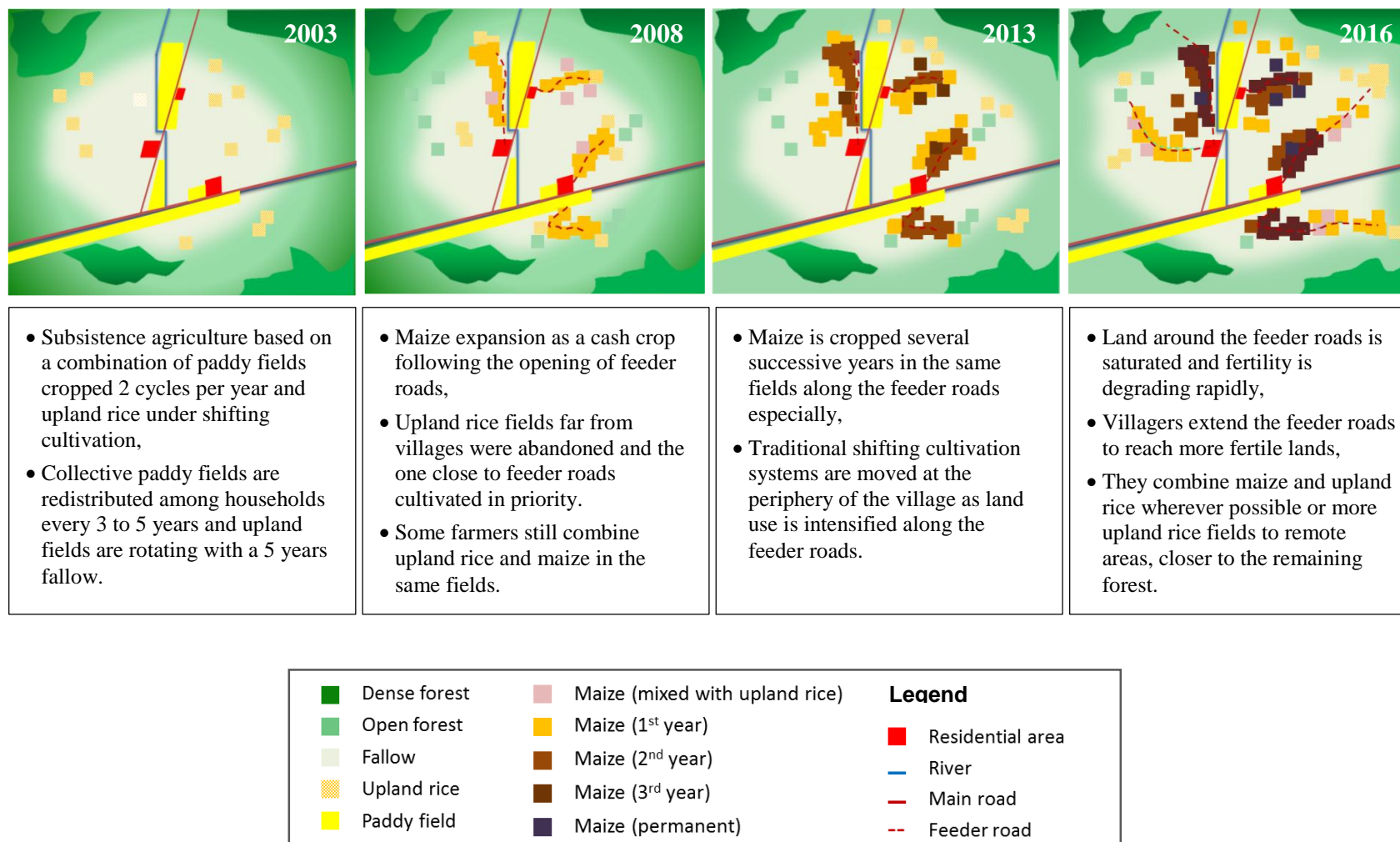| 2003	2008	2013	2016
• Subsistence agriculture based on a combination of paddy fields cropped 2 cycles per year and upland rice under shifting cultivation, • Collective paddy fields are redistributed among households every 3 to 5 years and upland fields are rotating with a 5 years fallow.	• Maize expansion as a cash crop following the opening of feeder roads, • Upland rice fields far from villages were abandoned and the one close to feeder roads cultivated in priority. • Some farmers still combine upland rice and maize in the same fields.	• Maize is cropped several successive years in the same fields along the feeder roads especially, • Traditional shifting cultivation systems are moved at the periphery of the village as land use is intensified along the feeder roads.	• Land around the feeder roads is saturated and fertility is degrading rapidly, • Villagers extend the feeder roads to reach more fertile lands, • They combine maize and upland rice wherever possible or more upland rice fields to remote areas, closer to the remaining forest.

Figure 6-1 Graphic representation of the process of land use intensification induced by maize expansion in the study area

A similar process was observed across the border to Vietnam in an area located at the north-west of our study area (Figure 6-2). Within a decade, the forest completely disappeared from the uplands in this area, the feeder roads gradually progressed up the hills until the whole area was cultivated permanently with maize.
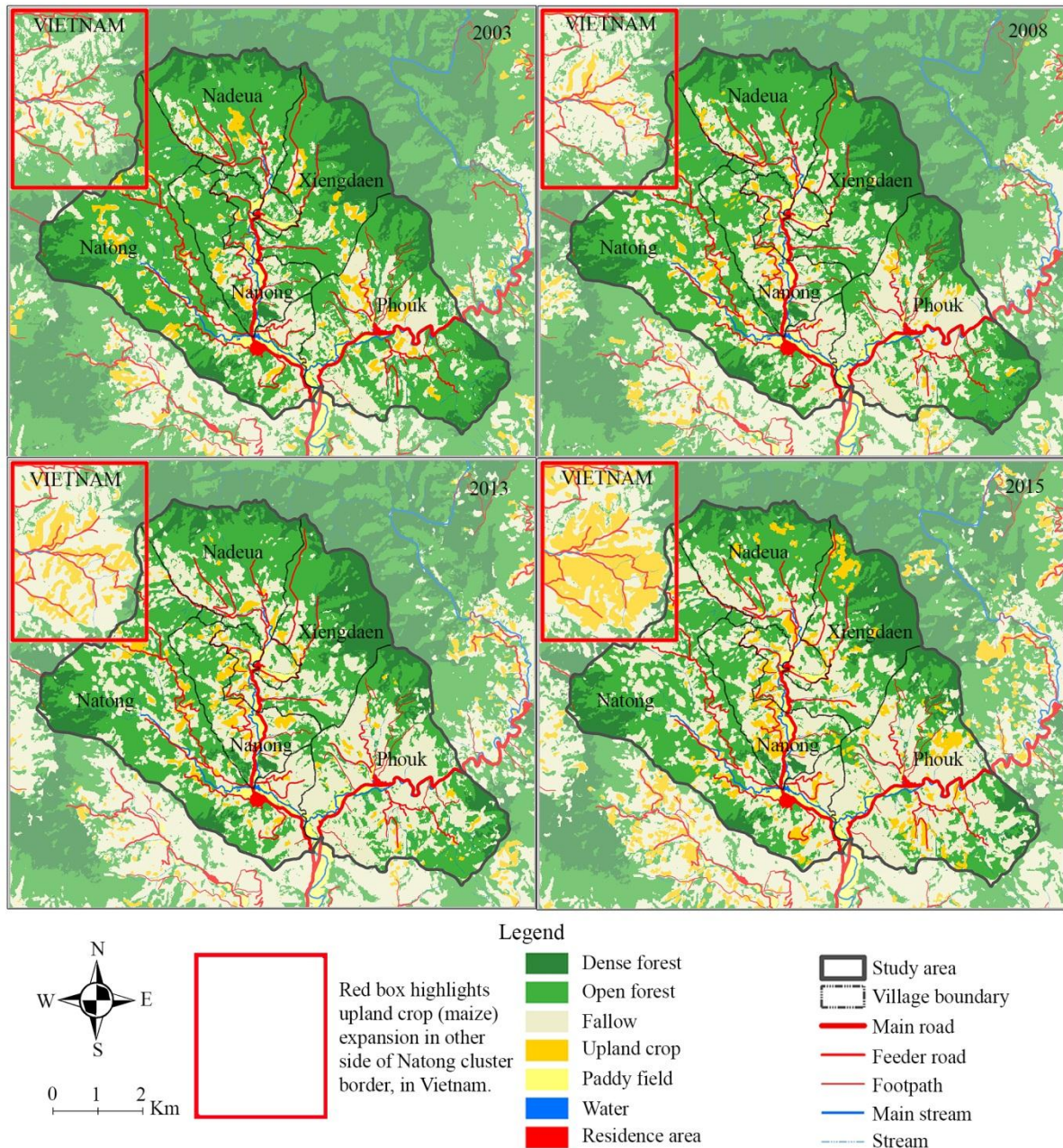

Figure 6-2 Highlights land use change across the border to Vietnam 2003 - 2015

This confirms the perspective of (Rudel, et al., 2009) that land use intensification does not necessarily ensure that an environmentally sustainable landscape will be maintained when there's strong demand on products and inelastic price of products. However, increasing land use intensity in the study region tends to reduce variety of land use types in the landscapes as stated by Allan, et al., (2015) land use intensification causes the decline of plant species diversity. This change in landscape impacts human well-being through erosion of ecosystem services such as NTFPs and climate change.

6.3 Implications

In a context of high environmental and economic pressure what are the possible options for local communities to maintain their livelihood status? A number of options have already been explored by villagers that we classify into 2 sub-groups: one within the maize production realm and the other one based on diversification processes away from maize.
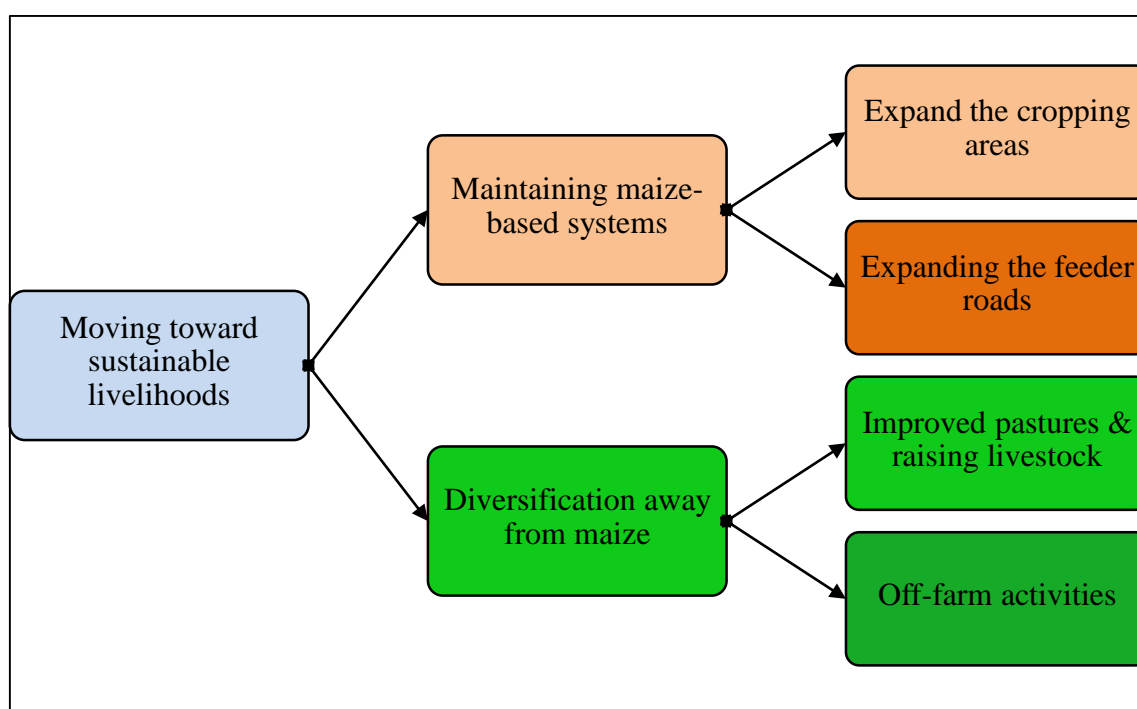

Figure 6-3 Scenarios exploration towards more sustainable livelihoods

6.3.1 Maintaining maize-based systems

1. The first option explored by maize farmers when they faced decreasing yields due to land degradation was to expand the cropping areas so that they could maintain the same level of production despite lower soil fertility. But to expand the area with the same labor force, they needed to overcome the main production bottleneck which is the labor force needed for

manual weeding operations. In 2014, they started using herbicide to expand their maize areas and fertilizers to maintain some level of production in the permanently cropped fields.

2. The second option consists in expanding the feeder roads in an attempt to move their production areas to more fertile lands. But they just recreate the same conditions as for the 1st batch of feeder roads further away in the landscape. They somehow delay the time they will have to stop their unsustainable practices by moving them temporarily to new areas at the periphery of the village territory.

6.3.2 Diversification away from maize

1. Another option explored by farmers who could accumulate capital during the maize boom consists in gradually turning the maize fields into pasture land and to buy livestock that will graze on these improved pastures. Many villagers in the study area are preparing to this major change and are only limited by the capital available to invest in livestock. Some of them therefore invest in goats that require less capital to start with before they turn to cattle ranching.

2. Off-farm activities are providing an increasing share of the household incomes as villagers who could accumulate capital invest in new activities such as small trade or purchase a truck for transportation of agricultural products, etc. Those who could not accumulate capital are employed by the richest villagers to work in their fields as daily wage workers once the latter have moved to off-farm activities.

All villagers would be ready to produce other cash crops as soon a market opportunities raise. They are prompt to engage in producing new crops as shown by the recently introduced Sacha inchi (2015) or the rapid development of fruit tree orchards in 2003-2004 that are still handicapped today by a highly uncertain market demand that dissuade many household from engaging into these income generating options.

We should also mention past attempts by development projects to introduce alternative production techniques as a basis for sustainable maize cropping systems. Combination of legume crops with maize was tested in 2009 as a way to control weeds with a permanent soil cover and increase soil fertility with legume residues. However, it was difficult to convince farmers at that time of the benefits of conservation agriculture as they were at the peak of the maize boom and had not experience yet the yield decreases that they are facing nowadays. It would therefore be interesting to test this option again as farmers would now be more receptive as they were before.

6.4 Limitations

Despite the constraints imposed by revisiting the same site and same villagers 7 years after a similar study was conducted in the same group of villages, the proposed longitudinal study brought precious knowledge about the drivers of the land use changes that occurred during the period between 2009 and 2016 and their impacts on local landscapes and livelihoods. Many collected data could not be analyzed in the limited time allocated to this M.Sc. research but will be published in subsequent document relying on the large database developed by the EFICAS project over the years in the study area.

The analysis of impact of the feeder road on landscape was limited by resolution of satellite images. The images used to generate land use land cover maps are Landsat multispectral which resolutions are quite low for our study focusing on village level. Hence we did pan-sharpening in order to obtain fine resolution images. An increased number of dates for land use maps over the study period may have compensated for the limited resolution of the remote sensing data, but the processing of a larger number of dates (i.e. beyond the 4 dates that were included in the study) would have been too time consuming for the limited time allocated to this research.

6.5 Forward looking

A number of alternative livelihood options have been explored, such as development of improved livestock systems. These could be further supported by development projects that would reorganize the complex interactions between different land use types that make up the village landscapes, namely: the paddy fields in the lowlands, the cultivated hillsides that may be turned into livestock areas and perennial tree plantations in the future if villagers cannot adopt some sustainable land management practices on the slopes to continue cropping annual crops such as upland rice and maize, and the forests that would provide a safety net thanks to the many NTFP and would regulate water cycles for the benefit of the whole community and ecosystem.

This longitudinal study may be further continued so as to check in the future if the foresights we propose in this report, such as the same land use intensification trends happening in the future around the 2nd batch of feeder roads (2015-2017), will actually take place or if the village communities to be engaged, with the support of research-development projects, in designing more desirable landscapes and livelihoods towards a sustainable development.

Also, this study was conducted under the time constrain to include all aspects regarding effects from the feeder road expansion such as impacts of the feeder roads on ecosystem service, which

could provide comprehensive perspective on linkages between livelihood and landscape composition. It is interesting to investigate the impact on ecosystem services, modeling scenario of land use and land cover change, and landscape mosaic analysis which could confirm land use transition at the landscape level.

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Acknowledgements

Appendix

Digital image processing for this research

1) Image rectification

The Landsat level 1G products from USGS is a geometrically corrected of Level 0R image. The WGS84 ellipsoid is employed as the Earth model for the Universal Transverse Mercator (UTM) coordinate transformation (NASA-National Aeronautics and Space Administration, 2011). It is not necessary to convert to local projection. Therefore, the images were used directly without re-projection after checking snapping between the scenes.

2) Radiometric calibration

The Landsat level 1G products from USGS is a radiometrically corrected of Level 0R image. During Landsat 7 level 1G product rendering image pixels are converted to units of absolute radiance using 32 bit floating point calculations. Pixel values are then scaled to byte values prior to media output (NASA-National Aeronautics and Space Administration, Landsat 7 Science Data Users Handbook, 2011). To analyze the changes in landscape, it is necessary to use physical quantities such as spectral radiance (surface or top of atmosphere-TOA) and spectral reflectance (Irish, 2008). Therefore, all images used in this study were converted from digital number (DN) to spectral reflectance. To convert DN, Landsat ETM+ requires two steps − DN to radiance and radiance to reflectance.

The following equation is used to convert DN's in a 1G product back to radiance units (NASA-National Aeronautics and Space Administration, Landsat 7 Science Data Users Handbook, 2011):

$$L = Grescale * QCAL + Brescale$$

which is also expressed as below:

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda) / (QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN_\lambda$$

Where: L_λ = Spectral Radiance at the sensor's aperture in watts/(meter squared * ster * μm)

Grescale = Rescaled gain (the data product "gain" contained in the Level 1 product header or ancillary data record) in watts/(meter squared *ster * μm)/DN

Brescale = Rescaled bias (the data product "offset" contained in the Level 1 product header or ancillary data record) in watts/(meter squared *ster * μm)

QCAL = the quantized calibrated pixel value in DN

LMAX$_\lambda$ = the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * μm)

LMIN$_\lambda$ = the spectral radiance that is scaled to QCALMAX in watts/(meter squared * ster * μm)

QCALMAX = the minimum quantized calibrated pixel value (corresponding to LMIN$_\lambda$) in DN

= 1 for LPGS (Level-1 Product Generation System) products

= 1 for NLAPS (National Landsat Archive Production System) products processed after 4/4/2004

= 0 for NLAPS products processed before 4/5/2004

QCALMIN = the maximum quantized calibrated pixel value (corresponding to LMAX$_\lambda$) in DN = 255

The LMINs and LMAXs are the spectral radiances for each band at digital numbers 0 or 1 and 255 (i.e QCALMIN, QCALMAX), respectively. LPGS used 1 for QCALMIN while NLAPS used 0 for QCALMIN for data products processed before April 5, 2004. NLAPS from that date now uses 1 for the QCALMIN value. Other product differences exist as well. One LMIN/LMAX set exists for each gain state. These values will change slowly over time as the ETM+ detectors lose responsivity. Table 5 lists two sets of LMINs and LMAXs. The first set should be used for both LPGS and NLAPS 1G products created before July 1, 2000 and the second set for 1G products created after July 1, 2000. Please note the distinction between acquisition and processing dates. Use of the appropriate LMINs and LMAXs will ensure accurate conversion to radiance units. Note for band 6: A bias was found in the pre-launch calibration by a team of independent investigators post launch. This was corrected for in the LPGS processing system beginning Dec 20, 2000. For data processed before this, the image radiances given by the above transform are 0.31 w/m2 ster um too high (NASA-National Aeronautics and Space Administration, Landsat 7 Science Data Users Handbook, 2011).

Table 0-1: ETM+ Spectral Radiance Range watts/(meter squared * ster * µm)

Band Number	Processed Before July 1, 2000				Proccessed After July 1, 2000			
	Low Gain		High Gain		Low Gain		High Gain	
	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX
1	-6.2	297.5	-6.2	194.3	-6.2	293.7	-6.2	191.6
2	-6.0	303.4	-6.0	202.4	-6.4	300.9	-6.4	196.5
3	-4.5	235.5	-4.5	158.6	-5.0	234.4	-5.0	152.9
4	-4.5	235.0	-4.5	157.5	-5.1	241.1	-5.1	157.4
5	-1.0	47.70	-1.0	31.76	-1.0	47.57	-1.0	31.06
6	0.0	17.04	3.2	12.65	0.0	17.04	3.2	12.65
7	-0.35	16.60	-0.35	10.932	-0.35	16.54	-0.35	10.80
8	-5.0	244.00	-5.0	158.40	-4.7	243.1	-4.7	158.3

Source: Landsat 7 Science Data Users Handbook, 2011.

Table 0-2: The parameters of all Landsat ETM+ images used for DN to Radiance conversion in this study

IMAGES	Band used	GAIN	LMAX	LMIN	QCALMAX	QCALMIN
LE71280462003100BKT01	1	H	191.6	-6.2	1	255
	2	H	196.5	-6.4	1	255
	3	H	152.9	-5.0	1	255
	4	L	241.1	-5.1	1	255
	5	H	31.06	-1.0	1	255
LE71280462008002EDC00	1	H	191.6	-6.2	1	255
	2	H	196.5	-6.4	1	255
	3	H	152.9	-5.0	1	255
	4	H	157.4	-5.1	1	255
	5	H	31.06	-1.0	1	255
LE71280462013079EDC00	1	H	191.6	-6.2	1	255
	2	H	196.5	-6.4	1	255
	3	H	152.9	-5.0	1	255
	4	L	241.1	-5.1	1	255
	5	H	31.06	-1.0	1	255

Source: metadata file of the images

The following equation is used to convert radiance to reflectance values (Irish, 2008):

$$\rho_p = \pi * L_\lambda * d^2 / ESUN_\lambda * \cos(\vartheta)_s$$

Where:

ρ_p = Planetary TOA reflectance (unitless)

π = Mathematical constant approximately equal to 3.14159 (unitless)

L_λ = Spectral radiance at the sensor's aperture

d = Earth-Sun distance in astronomical units from nautical handbook or interpolated values

$ESUN_\lambda$ = Mean solar exo-atmospheric spectral irradiancegenerated using the solar spectrum generated by **Thuillier** (Table 7)

$(\vartheta)_s$ = Solar zenith angle in degrees

Table 0-3: ETM+ Solar Spectral Irradiances

Band	watts/(meter squared * µm)
1	1997
2	1812
3	1533
4	1039
5	230.8
7	84.90
8	1362.

Table 0-4: The parameters of all Landsat ETM+ images used for Radiance to Reflectance conversion in this study

IMAGES	d	Solar zenith $(\vartheta)_s$ (90° - Sun Elevation)	$\cos(\vartheta)_s$
LE71280462003100BKT01	1.0017175	29.03085329	-0.72722947
LE71280462008002EDC00	0.9833042	50.78433891	0.868386818
LE71280462013079EDC00	1.0166408	33.15219282	-0.164715887

Landsat 8 Images are processed in units of absolute radiance using 32-bit floating-point calculations. These values are then converted to 16-bit integer values in the finished Level 1 product. These values can then be converted to spectral radiance using the radiance scaling factors provided in the metadata file (NASA-National Aeronautics and Space Administration, Landsat 8 Data Users Handbook, 2016):

$$L_\lambda = M_L * Q_{cal} + A_L$$

Where:

L_λ = Spectral Radiance (W/(meter squared * ster * μm)

M_L = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata)

A_L = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata)

Q_{cal} = L1 pixel value in DN

Similar to the conversion to radiance, the 16-bit integer values in the L1 product can also be converted to TOA reflectance. The following equation is used to convert Level 1 DN values to TOA reflectance:

$$\rho\lambda = (M\rho * Q_{cal} + A\rho)/\sin(\Theta_{SE})$$

Where:

$\rho\lambda$ = TOA Planetary Reflectance (Unitless)

$M\rho$ = Reflectance multiplicative scaling factor for the band (REFLECTANCE_MULT_BAND_n from the metadata)

$A\rho$ = Reflectance additive scaling factor for the band (REFLECTANCE_ADD_BAND_n from the metadata)

Q_{cal} = L1 pixel value in DN

Θ_{SE} = Loal sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION)

Table 0-5: The parameters of Landsat 8 used for DN to Reflectance conversion in this study

IMAGES	Band used	M_L	A_L	$M\rho$	$A\rho$	$\sin(\Theta_{SE})$
LC812804620 15077LGN00	1	0.012678	-63.39056	0.00002	-0.100000	0.261902421
	2	0.012983	-64.91271	0.00002	-0.100000	0.261902421
	3	0.011963	-59.81651	0.00002	-0.100000	0.261902421
	4	0.010088	-50.44065	0.00002	-0.100000	0.261902421
	5	0.0061734	-30.86716	0.00002	-0.100000	0.261902421

Source: metadata file of the images

3) Spatial enhancement

Pan-sharpening was applied to improve spatial quality of Landsat images. Landsat data are acquired at three different resolutions. The multispectral bands (bands 1-5, 7) are collected at 30 meters, the thermal band (band 6 for Landsat 7; band 10&11 for Landsat 8) is collected at 60 meters for Landsat 7; 100 meters for Landsat 8, and the panchromatic band (band 8) is collected at 15 meters. The multispectral bands do not have fine spatial resolutions required for small scale of study site, while the panchromatic layer is more appropriate in terms of spatial resolution, but lack detailed spectral information. Thus, pan-sharpening technique is a choice for producing higher resolution image by merging high-resolution panchromatic data with medium-resolution multispectral data to create the 15 meters resolution multispectral images. The pan-sharpened

images then could be used with supports of the very high resolution SPOT image and aerial photograph.

4) Images Classification

Images classification is conducted using unsupervised classification technique with ERDAS IMAGINE Software. Unsupervised Classification is the process of creating thematic raster layer by letting software identifies statistical patterns in the image data without using any ground truth data. ERDAS IMAGINE uses the ISODATA algorithm to perform an unsupervised classification. ISODATA stands for Iterative Self-Organizing Data Analysis Technique. It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. Self-Organizing refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or the means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. K-Means method was specified as algorithm of classification to prevent cluster deletion, splitting, and merging between iterations.

5) Post-classification

Classified data often manifest a salt-and-pepper appearance due to the inherent spectral variability encountered by a classification when applied on a pixel-by pixel basis (Lillesand, Kiefer, & Chipman, 2007). It is often desirable to "smooth" the classified output to show only the dominant classification. In this research, the smoothing process was not conducted through direct filtering, but it was conducted using eliminate function. This function performs a Focal Majority filter on the input file in an iterative fashion, so that the data value of the large clumps overwrites the data value of the small clumps. With iteration each time, the one-pixel-width outer edge of the small clump is replaced with values from the surrounding larger clumps. The iteration continues until all the small clumps have been completely removed. The final clumps are then recoded using the "Original Value" attribute so that the output values of the remaining clumps are in the same range as the values in the original file which was the input to Clump (Intergraph Corporation, 2013).

6) Accuracy assessment

Accuracy assessment is the process to assess the result of image classification comparing to geographical data that are assumed to be true, which is called "reference data". The reference data normally derive from field survey or ground truth checking or derive from the high resolution images such as aerial photograph (Lillesand, Kiefer, & Chipman, 2007). It is not practical to do

ground truth checking or test every pixel of a classified image. Therefore, a set of reference pixels is usually used. Reference pixels are points on the classified image for which actual data are (or will be) known (Intergraph Corporation, 2013). The reference pixels are randomly selected. The number of reference pixels is an important factor in determining the accuracy of the classification. The minimum sample size should be at least 20 to 100 samples per class (FAO: Food and Agriculture Organization, 2016).

The reference data used to assess the accuracy of current land use map of 2015 derived from aerial photograph taken in 2014 and SPOT7 taken March 2015 - the same month of Landsat image that used to generate the last land use map for this study.

The Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a standardized index for displaying vegetation greenness (relative biomass). This index is calculated using two bands from a multispectral raster dataset—the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band. NDVI is often used worldwide to monitor drought, monitor and predict agricultural production, assist in predicting hazardous fire zones, and map desert encroachment. The NDVI is preferred for global vegetation monitoring because it helps to compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors (Lillesand, Kiefer, & Chipman, 2007).

The differential reflection in the red and infrared (IR) bands enables image analyst to monitor density and intensity of green vegetation growth using the spectral reflectivity of solar radiation. Green leaves commonly show better reflection in the near-infrared wavelength range than in visible wavelength ranges. When leaves are water stressed, diseased, or dead, they become more yellow and reflect significantly less in the near-infrared range. Clouds, water, and snow show better reflection in the visible range than in the near-infrared range, while the difference is almost zero for rock and bare soil. The NDVI process creates a single-band dataset that mainly represents greenery. The negative values represent clouds, water, and snow, and values near zero represent rock and bare soil. The equation of NDVI is as follows:

$$NDVI = ((IR - R) / (IR+R))$$

Where: IR = pixel values from the infrared band

R = pixel values from the red band

This produces a single-band dataset, mostly representing greenness, where any negative values are mainly generated from clouds, water, and snow, and values near zero are mainly generated from rock and bare soil. This index outputs values between -1.0 and 1.0. Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8) (ESRI, 2016).