AGRARIAN TRANSITIONS IN SWIDDEN CULTIVATION IN MYANMAR：CASE STUDIES IN BAGO MOUNTAINS AND SOUTHERN SHAN HIGHLANDS

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CONTENTS

LIST OF TABLES

LISTS OF FIGURES

LIST OF APPENDICES

SUMMARY

Swidden is an old agricultural system, mainly practiced by the ethnic minorities in mountainous areas. Recently, the persistence or demise of swidden agriculture was being debated among the governments and academia. The dynamic and complex nature of all swidden agriculture makes it difficult to detect the area from satellite images and Landsat-related methodologies in many studies. Some of the articles mainly highlighted the problem of defining and measuring the spatial and demographical extent of swidden. Despite the swidden agriculture still remains as a safety net for some ethnic minorities (ethnic minorities mean subgroup which differ from main dominant groups in terms of culture, religious, language, color and race) the transformation into other agricultural practices have occurred, especially in Mainland Southeast Asia (SEA). However, attempts to bridge the gaps between the swiddening related information and sustainable land use strategy for the mountain area development were still limited to promote the swiddener's livelihoods sustainability. This study aimed at understanding the agrarian transition and its impacts on the local livelihoods in two traditional swidden cultivation areas in Myanmar to contribute towards sustainable agricultural land use in two traditional swidden cultivation areas in Myanmar. Therefore, this study was conducted to investigate the characteristics of upland soil, to clarify the changing trend of swidden and to contribute to find the feasible alternatives to secure the future sustainability of upland farmers.

Chapter 2 revealed the investigation of the characteristics of upland soil from three Mountainous areas; Bago Mountains, Puanglaung, and Pinlaung areas in southern Shan Highlands, aiming at to contribute for well understanding of soil characteristics of

swidden land use areas and to provide the basic information needed to find feasible alternatives to swidden agriculture in future. Soil morphological characteristics and soil physicochemical properties were reported for two representative soil profiles from each of the study sites, and soil classification was done according to the keys to soil taxonomy 2014 in USDA system. The soil-forming environment of Bago Mountains were characterized by the history of the emergence of marine deposit and contemporary dry climate. Carbonates were still detected in the soils in the low elevation areas. Slightly acidic soils, potentially equivalent to Alfisols, were dominated in this area, though the most of soils were actually classified as Inceptisols due to steep slopes and possibly limited time for formation of the argillic horizon. Besides, the soil depths were consistently deep in Bago Mountains, which was potentially advantageous for continuous cropping on steep slopes in the future.

On the other hand, the soils in Paunglaung and Pinlaung in southern Shan Highlands exhibited similar characteristics with upland soils in northern mountainous regions of SEA such as Thailand, Lao, and Vietnam in that sedimentary rocks, including limestone have developed soils with slightly to moderately acidic soils under the ustic soil moisture regime. Although many soils were actually classified as Inceptisols due to the limitation of time for soil development on steep slopes, the physicochemical properties of soils were essentially similar to Alfisols or Ultisols under the presence or absence of the influence of limestone, respectively. Soil depths in the southern Shan Highlands were not deep as those in Bago Mountains, generally shallow as 79.8 ± 37.7 cm (SD) as the average of 62 points. Rocks and limestone were sometimes exposing even on the land surface in some locations. This information could be utilized as a basis for developing modern agriculture in these mountainous slope lands.

Chapter 3 revealed the development of mapping methods for current agricultural land use and swidden land use detection methods from freely available time-series satellite images, integrated with detailed information of ground truths and interview surveys in order to contribute to sustainable land use management for legally unrecognized swidden in Myanmar. Satellite images were classified by using the NDVI break value method and maximum likelihood method, which were then specified with the multiple criteria of ground truths such as the elevation and size of swidden fields. The accuracy of these methods was examined with actual ground truth data collected in 2016. As the maximum likelihood method showed better accuracy to detect the swidden fields, it was, therefore, selected. The accuracy test revealed that over 70 % of the actual swidden plots were detected, and the failures of such detection were mainly caused by incomplete burned fields and small-sized swidden plots as well as the topography. However, the developed method is applicable for swidden land use detection at the plot level with preferable accuracy in undulating hilly regions. In this study, a relatively accurate mapping method for swidden land-use detection was established by using freely available satellite images with relatively low resolutions. The method developed in this study detected more than 80 % of the actual swidden plots, enabling them to show changing trends of such fields on sloping land at the local level in tropical countries. Owing to the complexity and dynamic nature of swidden, it is difficult to detect the spectral signature of such plots in steep areas, especially when swidden fields were not burned completely during the burning phase, it is difficult to identify such plots clearly. Compared to previous remote sensing-based studies for such detection using low-resolution images, this method revealed the better accuracy to identify these swidden fields for the further time-series swidden land use detection in sloping areas.

Chapter 4 reported the agrarian transition and its impacts on the local livelihoods on Bago Mountains. The agricultural activities of swidden agriculture in the Bago Mountains have gradually been in transition from the traditional swidden practices to permanent agriculture. In this study, recent trends of swidden agriculture and the introduced permanent agriculture were assessed by using not only satellite image assessment but also interviews and socioeconomic surveys. The findings showed that the extent of swidden area gradually decreased after the introduction of the permanent agriculture in SN and KC village. The demise of swidden was found in GS village because of the advantage of low land availability. Land use conflicts, lowlander migration, labor, and agricultural input availability were the major underlying causes for agrarian transition. Although the newly introduced permanent agriculture may have significantly contributed to local livelihoods, more research must be conducted in order to find out the suitable agricultural land use for the future sustainability of swiddeners' livelihood.

Chapter 5 highlighted the agrarian transition before and after the hydropower dam construction in Paunglaung (the 2nd study site) reserved forest. Agrarian transition was conducted by using GeoEye images taken in January — February of 2011 and 2018. The permanent farmlands of the local farmers were confiscated, with the reduction of farmland from 277.96 ha in 2011 to 35.51 ha in 2018, accounting about 11.05% in 2011 to 1.41% in 2018 due to dam construction. The farmland area largely changed into water bodies. I also examined the socioeconomic condition after the dam construction by using the PCA analysis and found that local communities, especially the land-lost farmers, engaged in random jobs for their daily consumption. This study highlighted the urgent needs of sustainable land use planning, and the findings contributed to find the alternative choices for ensuring the long-term sustainability of local farmers.

Chapter 6 described the development of paddy fields in the Bago Mountains and land sue suitability assessment for it. Paddy field development was the wise utilization of surface soil nutrients carried by the surface runoff from the upper part of the slope. The number of households engaged in practicing the permanent agriculture incased yearly in all three villages. Therefore, an attempt is necessary to map how much extent of paddy fields have been introduced and how much extent is still available and where is the best are to open the paddy fields in the future. This study was conducted to analyze the suitability land use map for the paddy field development to contribute towards the effective selectin for paddy fields development two traditional swidden cultivation areas in Myanmar. Development paddy fields was one of the feasible alternatives to secure the future consumption of the swiddeners. It was the effective utilization of nutrients carried down by the surface runoff from the upper portion of the sloping land and mountains. Therefore, an accurate mapping for the development of paddy fields was done in three villages of the Bago Mountains with proper accuracy. The best and moderate land use suitability class could be utilized for the development of paddy fields in Bago Mountains. Available lands for the development of paddy were still available in SN and KC village. In GS village, the introduction of permanent agriculture reached the maximum stages, and villagers opened some of the permanent agricultural fields, even the challenging suitability class. Forest tree species, perennial and annual plants should be maintained in the difficult and useless suitability classes to reduce the soil erosion in sloping land.

Chapter 7 presented the general discussion and conclusions. Detection methods form different satellite images were assessed, and the applicability and validity of each method were also reported in this chapter. This study provided a clear insight of agrarian transitions and socioeconomic conditions of swiddeners under different stresses of swidden transformations in two different study sites. The combined inferences based on the soil type, climate, topology, and socioeconomic condition, feasible land use suitability map, and agricultural practice was clarified, and some policy measures were also reported in this study. Further research needs to be conducted to determine crop suitability to secure the sustainable livelihoods of upland farmers. In conclusion, it is better to take into account the land use right of the farmers in the forest, and the results based on this study will contribute toward future National Land Use Planning of the Myanmar.

CHAPTER 1 GENERAL INTRODUCTION

1.1 Theoretical Backgrounds

Agriculture is an important activity for large population of the developing world. Among the various agricultural systems, swidden is an old agricultural system, and the common features of swidden agricultural system are clearing a patch of vegetation by the slash-and-burn method, growing different varieties of crops in the cleared land for one or two seasons, and then moving to a new plot of land on a rotational basis (Ruthenberg 1971; Rasul and Thapa 2003). The traditional swidden cultivation practices were highly complex and involved a variety of crops with low or zero tillage (Nath *et al.,* 2016). Decades of scientific debate on the pros and cons of swidden have not brought about the much agreement in this land use system. Even though previous research has argued that swidden practice reflected an example of 'land sharing' that can deliver both conservation and livelihood benefits across landscapes, i.e., "the two pressing global issues: the need to protect ever-decreasing forest lands, and the imperative to feed the growing human population" (Padoch and Sunderland 2014; Dressler *et al.,* 2017). Moreover, Fan (1998) viewed the swidden as an important provider of environmental services as a large carbon sink when compared to the alternative land use systems. Across the (SEA), the number of shifting cultivators has been estimated to lie between 14 and 34 million people (Mertz *et al.,* 2009).

Even though swidden remains the mainstay of local livelihoods, it is undergoing rapid transition into other forms of land uses (Mertz 2009). According to Padoch *et. al.* (2007) and Takeda *et al.* (2006), prohibitive government policies and rigid land development aimed at eradicating swidden cultivation and forcing intensive commercial agriculture. Development projects such as dam construction are also inducing the agricultural land loss and resulted in the swidden transition. Forced displacements and farmland loss were also one of the major issues induced by the hydropower dam constructions in Sri Lanka, and West Java of Indonesia (Manatunge *et al.,* 2009). Resettlements and farmland loss under the hydropower dam construction were commonly found in China, Sri Lanka, Vietnam (Galipeau *et al.,* 2013; Rousseau *et al.,* 2017; Zhao *et al.,* 2010; Jackson and Sleigh, 2000). Padoch *et al.* (2007) also mentioned that the combined forces of agricultural, forestry, and conservation policies and population growth are still stressing for swidden transformation to more intensive permanent agriculture in many parts of SEA. Swiddeners in SEA were participating in more fully an improved road system and market economy and endeavored to secure their land use right as farmer (Van Vliet *et al*., 2013; Padoch *et al*., 2007; Hansen and Mertz, 2006). Some previous studies predicted that swidden would disappear in the next few decades in SEA (Padoch *et al.*, 2007; Van Vliet *et al.*, 2013).

The current situation of swidden is under pressure and rapidly being transformed into other land uses in many parts of forest-frontiers of the tropics, especially in the mainland of SEA. Therefore, proper land use planning and considering the feasible alternatives to promote the sustainable agricultural land use became a major concern to secure the livelihoods of upland farmers.

1.2 Rationale

Swiddening is a way of life associated with cultural traditions that provide valuable subsistence products to local farmers, especially the poor ethnic minority groups (van Noordwijk *et al.*, 2008; Li *et al.*, 2014). Globally, people living in 40 - 50 countries are still practicing the swidden cultivation, despite the compression of agricultural transformation into more intensive agriculture by each government in each country (Mertz, 2009; Li *et al.*, 2014). Jackson (1995) stated that an estimate of 500 million people, 10 percent of the world's population at that time, was living on the tropical mountainous regions, and in 2020, conservative estimates showed that upland watershed populations might increase by as many as 60 million people.

Myanmar is characterized by several mountain ranges including the Bago Mountains, the Rakhine Mountains, the Tenasserim Hills, and the Shan Hills. The mountains within the country run north to south from the Himalayas. Each mountainous region has diverse topographic and climatic conditions and characterized by diverse flora and fauna. However, nowadays, the mountain region continues to face several threats of human activities, especially the land use and land cover changes. Swidden agriculture mainly prevails on the mountainous region and is practiced by the smallholder farmers in 64 developing countries from the discourage the swiddeners and forced them to change into diverse market-oriented land use types since 1990 in SEA (Padoch *et al.*, 2007; Fox *et al.*, 2009; Li *et al.,* 2014; Cramb *et al.,* 2009).

Recent political stress for mitigation of swidden, country development project, land use conflicts among the local government and local upland farmers, and agrarian transition into a more permanent form of agriculture are threatening the mountain ecosystem. Land use conflicts between the prevailing ethnic groups and the government, loss of traditional land use practice especially swidden, and the transformation into a more permanent form of agriculture are threatening the mountain ecosystem services (Tovar *et al.,* 2013). Besides, researches indicated that topographic factors such as elevation, slope, aspects and climatic factors such as rainfall, temperature, and water availability and drainage density were also important factors that are influential for land use pattern changes and spatial distribution (Liu *et al.,* 2017). Under this condition, it urgently needs to consider the sustainable land use management that is economically acceptable, socially equitable, and environmentally viable. Therefore, there is a need to capture the well understanding of current saturation of agricultural land use and to those land use changes with the topographic factors and of mountain dwellers.

In order to clarify the possible strategies for sustainability of swidden, well understanding of soil type, climatic factors, topographical factors, current land use condition, and socioeconomic assessment area are essential to promote sustainable agriculture in those traditional swidden cultivation areas.

Although the swiddening is still maintained as the mainstay of their local livelihoods, swiddening is undergoing rapid transformation and sometimes forced transition to other forms of land uses (Mertz, 2009). Padoch *et al.* (2007) also suggested that having reliable information about changes in upland farms will facilitate the identification of the process that accounts for these shifts and makes possible understanding of their consequences and further implications.

In many previous studies, various attempts have been conducted on the land use and land cover changes with the special focus on the forest land, agricultural land and other categories. However, no attempt was made to assess the accurate estimates of the swidden extent of swidden because of the dynamic and complex nature of swidden (Schmidt-Vogt *et al.,* 2009). Therefore, land use maps and statistical records of swidden area were rarely reported in many previous studies. However, Padoch *et al.* (2007) reported that a wide range of remote sensing-based techniques are available for the assessment of local level changes in swidden land use. Hansen and Mertz (2006) and Messerli (2009) analyzed the swidden land use changes in Sarawak, Malaysia and Lao PDR by using the satellite images, respectively. Li *et al.* (2014) mentioned that the monitoring of swidden agriculture will greatly contribute to implementing and managing the REDD projects because forty-five developing countries in Africa, Latin America and South/Southeast Asia, where smallholder farmers mainly practice swidden, are parts of the United Nations collaborative initiative on Reducing Emission from Deforestation and Forest Degradation (UN-REDD Programme) partner countries. Likewise, few assessments have been done whether new changed agricultural technology contributed to the local livelihoods instead of siwdden agriculture. In accordance with several previous works (Sakai, 2002; Heinimann *et al.,* 2017; and Padoch *et al.,* 2007), any attempts for clarifying upland land use changes for sound evidence can greatly contribute to the future climate projection, and statistical data related to slash-and-burn in a region is a basic need for environmental monitoring and conducting various investigation on forest conservation and agricultural development. In this condition, accurate mapping and reliable information on swidden land use in the traditional swidden cultivation area is of paramount importance for food security for the swiddeners. Developing the accurate mapping method based on local case studies is crucial. It remains as the best approach for accurate current land use mapping in order to implement the adaptation policies and land use strategies in line with the local needs, especially for the future sustainability of the swiddeners.

Impacts of agricultural intensification into a more permanent form of agriculture were not well documented in many previous studies. Likewise, few assessments have been done whether the new changed agricultural technology contributed to the local livelihoods indeed instead of siwdden agriculture. Moreover, village-level socioeconomic data are urgently needed for reforming the land use policy, pertaining to the land use rights for the swiddeners. Li *et al.* (2014) also stated that there is very limited information on the basic geographical data of swidden, and agricultural, socioeconomic and biophysical effects of these transformations. Padoch *et al.* (2007) also suggested that having reliable information about changes in swidden will facilitate the identification of the process that accounts for these shifts and makes possible understanding of their consequences and further implications. Moreover, in Myanmar, *de facto* land policies were practiced since after the independence. Thus, one of the main challenges of the Government is to reform the land use policy considering the land use right for the ethnic minorities, especially the swiddeners. In such an undeveloped mountainous area, sustainable land use management needs to be undertaken to fulfill the goal of poverty reduction and zero hunger for the mountain dwellers.

Moreover, village level socioeconomic data are urgently needed for reforming the land use policy, pertaining to the land use rights for the mountain dwellers. The socio-economic factors associated with swidden and intensified agriculture need to be studied, and the impacts of landscape change on local livelihoods needed to be clarified too. Therefore, this study was conducted to fulfill the knowledge gap for general soil information of two traditional swidden cultivation areas, swidden land cover information at village level, and socioeconomic assessments of swiddeners in order to reach the sustainability goals of swiddeners, especially remote and impoverished areas of a developing country.

1.3 Literature Review

1.3.1 General aspects of swidden agriculture

Agriculture is an important activity for a large population of the developing world. Among the various agricultural systems, swidden is an old agricultural system, and the common features of swidden agricultural system are clearing a patch of vegetation by the slash-and-burn method, growing different varieties of crops in the cleared land for one or two seasons, and then moving to a new plot of land on a rotational basis (Ruthenberg, 1971; Rasul and Thapa, 2003). The traditional swidden cultivation practices were highly complex and involved a variety of crops with low or zero tillage (Nath *et al.,* 2016). Decades of scientific debate on the pros and cons of swidden have not brought about the much agreement in this land use system. Even though previous research has argued that swidden practice reflected an example of ”land sharing” that can deliver both conservation and livelihood benefits across landscapes, i.e., “the two pressing global issues: the need to protect ever-decreasing forest lands, and the imperative to feed the growing human population” (Padoch and Sunderland, 2014; Dressler *et al.,* 2017). Moreover, Fan (1998) viewed the swidden as an important provider of environmental services as a large carbon sink when compared to the alternative land use systems. Across the SEA, the number of shifting cultivators has been estimated to lie between 14 and 34 million people (Mertz *et al.,* 2009). The current situation of swidden is under pressure and rapidly being transformed into other land uses in many parts of forest-frontiers of the tropics, especially in the mainland of SEA. Even though swidden remains the mainstay of local livelihoods, it is undergoing rapid transition into other forms of land uses (Mertz, 2009). According to Padoch *et al.* (2007) and Takeda *et al.* (2005), prohibitive government policies and rigid land development aimed at eradicating swidden cultivation and forcing intensive commercial agriculture. Padoch *et al.* (2007) also mentioned that the combined forces of agricultural, forestry, and conservation policies and population growth are still stressing for swidden transformation to more intensive permanent agriculture in many parts of SEA. In fact, swiddeners in SEA were participating in more fully an improved road system and market economy and endeavored to secure their land use right as farmer (Van Vliet *et al.,* 2013; Padoch *et al.,* 2007; Hansen and Mertz, 2006). Some previous studies predicted that swidden will disappear in the next few decades in SEA (Padoch *et al.,* 2007; Van Vliet *et al.,* 2013).

1.3.2 Extent and demography of swidden agriculture

Swidden was found throughout the uplands of SEA (Schmidt-Vogt *et al.*, 2009; Li *et al.,* 2014) but often does not show the swidden land use category on land use map and in statistical records (Padoch *et al.,* 2007; Li *et al.,* 2014; Schmidt-Vogt *et al.,* 2009). It is because, in remote sensing technology, the complex and dynamic nature of swidden create the difficulties in delineating and mapping (Schmidt-Vogt *et al.,* 2009; Li *et al.,* 2014). In the mid-1980, according to Uhlig *et al.* (1994), the estimated swidden area was about 1 million ha in Thailand (Li *et al.,* 2014). In Lao PDR, larger extent swidden was found than other countries in SEA, and the most recent data for swidden cultivation landscape was 28.2% of Laos or 6,500,000 ha (Messerli, 2009; Li *et al.,* 2014). According to Hansen and Mertz (2006), the estimated population engaged in swiddening were 300,000 families or 1.8 million people in the early 1990s in Laos. Official attempts to categorize or map the extent of swidden in Vietnam, Philippines, and Myanmar and the available figures are also extremely variable (Schmidt-Vogt *et al.,* 2009). Swidden land have been transformed into permanent agriculture in Peninsular Malaysia and the estimate of swidden land in Indonesia was about 11,402,300 ha in 1980s (Schmidt-Vogt *et al.,* 2009).

The extent of swiddening and pattern of changes of swidden in SEA was assessed by Schmidt-Vogt *et al.* (2009), depending on the regional and national sources for nine countries, and on the basis of 151 cases culled from 67 articles (Table 1-1). Additionally, Mertz *et al.* (2009) examined the estimates of the number of swidden cultivators worldwide based on the available regional and local data from SEA (Table 1-2). However, all these attempts are to identify the gaps in data and research is needed to arrive at a reliable estimate for each region, but it is not fully satisfactory figures until now.

Table 1-1 Regional and national estimates of land covers under swidden in SEA

Country	Estimate	Source of data	Reference
Thailand	1.0 million hectares	Based on FAO/UNEP study, data from early 1980s	from the early 1980s Uhling *et al.* (1994)
Laos	2–2.5 million hectares	Assessment based on census data	Hansen (1998)
	4.8 million hectares	1981-82 ~1988-89 aerial photographs of the Forest Inventory and Management Office	Chazee (1994)
	6.5 million hectares	2002 SPOT satellite images	Messerli *et al.* (2009)
Cambodia	349,000 ha	JICA dataset 2002	SCW (2006)
Vietnam	1 fifth of total land area	General Department of Land Administration, 2001	Nicolic *et al.* (2008)
Yunnan	No estimates		

Country	Estimate	Source of data	Reference
Myanmar	2.43 million hectares	Estimate based on forest inventory data from the early 1990s	Ministry of Forestry (1995)
	5.32 million hectares	Analysis of Satellite imagery 1995– 2000	Forest Department (FD) 2000 (cited in Hlaing, 2004)
	10.18 million hectares	Estimate based on forest inventory data from the early 2000s	FD 2003 (cited in Htun, 2007)
	0.29 million hectares	Unpublished data circulated within the Department	Planning and Statistics Division, FD Myanmar (2008)
Malaysia	Sarawak, 2.3 million hectares and Sabah, 1.4 million hectares in 1980	Malaysian Department of Statistics	Uhlig *et al.* (1994)
Indonesia	Sumatra 3,428,600 ha, Kalimantan 5,457,400 ha, Sulawesi 526,900 ha, Maluku 216,400 ha, Papua 1,287,300 ha, NTB 63, 600 ha, NTT 323, 500 ha, E- & W-Timor 98,600 ha, Total (including Timor E and W) 11,402,300 ha	RePPProT data 1982	Weinstock (1990)
Philippines	No estimates		

Table 1-2 The evolution of estimates of the number of swidden cultivators worldwide

Reference	Estimate, million swiddeners	Source of data
Sanchez *et al.* (2005)	37	Cites Dixon *et al.* (2001)—however, the number appears not to be available in this reference
IFAD *et al.* (2001)	Possibly 1,000	Not indicated
Dupriez and de Leneer (2001)	300	Not indicated
Kleimann *et al.* (1996)	>300	(Andriesse and Schelhaas, 1987)
Myers (1994)	300	Cites Denevan (1980), who, however, only provides data for Latin America
Warner (1991)	250–300	Myers (1986); Russell (1988)
Andriesse (1989)	300	Not indicated
Goldammer (1988)	500	Lanly (1985)
Russell (1988)	200 in 1957 300 in 1987	Cites Anonymous (1987) for 1987 number 300
Andriesse and Schelhaas (1987)	300	Not indicated
Anonymous (1987)	300	Fortmann (1986)
Myers (1986)	250	Not indicated
Fortmann (1986)	300	Not indicated
Lanly (1985)	500	Based on the estimate in FAO/UNEP study
Dove (1983)	240–300	Sanchez (1976)
Hartmanns (1981)	300	Not indicated
Sanchez (1976)	250	Hauck (1974)
Hauck (1974)	250	Not indicated
Conklin (1963)	200	FAO Staff (1957)
FAO Staff (1957)	200	Not indicated

1.3.3 Remote sensing and GIS technique for detecting swidden land use changes

Since 1970`s, remote sensing technology was used (Li *et al.,* 2014) to get information on environmental changes and their monitoring. Satellite data that can be used for delineating swidden cultivation are Medium spatial resolution Landsat images such as Landsat TM, Enhanced Thematic Mapper (ETM), and Operational Land Imager (OLI), coarse spatial resolution by MODIS and Synthetic Aperture Rader (SAR). In many previous studies, Medium spatial resolution Landsat images are the most commonly used satellite data in many previous studies (Li *et al.,* 2014), and they are particularly suitable for mapping burned area (Petropoulos *et al.,* 2011; Li *et al.*, 2014). MODIS data and SAR data were seldom reported in mapping swidden land use, possibly because of the temporal changing nature of swidden and limited access of SAR data (Li *et al.,* 2014).

However, it is still difficult for accurate assessment of the swidden land use from the satellite images such as the Landsat TM, Enhanced Thematic ETM+ mapper and Operational Land Imager OLI Landsat (Li *et al.,* 2014). Even though the technological developments have been updated to identify and follow the trends in land use transition, it is still inadequate to analyze the complex, dynamic and fragmented land use system such as the swidden land uses. It is very difficult to detect the complex spectral signature of fields, different fallow lands, permanent agricultural land, timber land, and protected forest area (Mertz, 2009). So far, Landsat related methodologies for detecting swidden area were still conveyed in SEA (Li *et al.,* 2014). Moreover, it is also extremely difficult to access the number of swiddeners. Farmers who rely on swiddening are rarely defined as swiddeners in most census and households survey because these people usually dwell in relatively inaccessible mountains and hilly parts and partially or fully, directly or indirectly, rely on the swidden cultivation (Li *et al.,* 2014).

Scholars have been started to detect the swidden land use change recently. Hansen and Mertz (2006) classified the swidden land use changes by using the maximum likelihood methods in Sarawak of Malaysia, and Takeda *et al.* (2006) also detected the time series swidden land use change by using the NDVI threshold value in the Bago Mountains, Myanmar. But in Laos PDR, Messerli (2009) proposed the national level swidden land use change by using the meso-level spatial scaled landscape mosaics. Schmidt-Vogt *et al.* (2009) reviewed the methods for identifying and quantifying swidden system on a country, and regional basis depending on the 151 cases culled from 67 articles and mentioned the four approaches, i.e., (1) identifying the swidden areas on current map, (2) time series analysis of satellite imagery to identify swidden areas, (3) detection and interpretation of landscape pattern and mosaics, and (4) integration of census information into land use classifications. Li *et al.* (2014) classified the remote sensing technique for delineating and mapping swidden land use. The main categorized approaches are the spectral signature-based approach, phenology features based approach, statistical theory-based approach, and landscape ecology approach. Nevertheless, plot-based field investigation, long-term monitoring of specific plots, and village level household surveys are, therefore, necessary in swidden area investigation (Takeda, 2005; Suzuki *et al.*, 2009).

1.3.4 Stressing factors for agrarian transition in mountainous areas

Although shifting cultivation is a widespread practice in the hilly tropics, government policies have attempted to replace it with other land uses in north-east India (Teegalapalli and Datta, 2016) and still trying to change into forest plantation in the fallow land area. The persistence or demise of swidden cultivation are debated among the governments and academia. Padoch *et al.* (2007) assessed the demise of swidden agriculture and confirmed the disappearance of swidden in many parts of mainland SEA. Swidden transformation is clearly related in complex ways in all aspects such as the in- and out-migration, political factors, social factors, and the introduction of innovative technology and engaged with markets. Swiddening was regarded as a smallholder practice, and national policies in all countries of SEA have tried to mitigate the swidden agriculture and encourage the swiddeners to adopt the permanent agriculture (Padoch *et al.*, 2007). The Laos government-supported land use segregation with agricultural intensification through the regeneration of forest cover and promoted the swiddeners into farm enterprise by allocating the land zoning, agribusiness, contract farming and plantation concessions (Castella *et al.,* 2013). Likewise, Malaysian Government once viewed the swidden agriculture as an obstacle for the development and therefore forced the subsequent conversion to oil-palm plantations in 1960. A shift from extensive swiddening into permanent agriculture has been prompted by the government agencies (Castella *et al.,* 2013). Different outcomes of national policies forced to eradicate the swidden cultivation, to emerge the intensive and commercial agricultural practices (Castella *et al.,* 2013). Schmidt-Vogt *et al.* (2009) also noted that the swidden area in Peninsular Malaysia was negligible because most of the agricultural land have been converted into permanent agriculture and plantations. The relationships among swidden agriculture and forest degradation and global warming have been driven by the policies of the inter-governmental organization at the United Nations Framework Convention on Climate change in 1992 to the Kyoto Protocol in 1999 (Li *et al.,* 2014).

Cramb *et al.* (2009) categorized the political driving factors for swidden transformation into four groups; 1) outright prohibition (ban of swidden farming anywhere at any time), 2) prohibition without permit, 3) prohibition in certain classes of land, especially in reserved forest and protected areas, and 4) tenure-related disincentives such as the non-recognition of customary land use right of swiddens combined with secure land ownership to permanent commercial agriculture. Besides, extension services have also promoted the permanent cropping schemes in Malaysia (Hansen *et al.*, 2006). On the other hand, population pressure led to the limited land availability and thus induced a sequence of shorter fallow period of swidden and resulted in lower yields from the swidden fields in SEA (Bruun *et al.,* 2006; Rerkasem *et al.,* 2009). Moreover, low-landers' migration to the upland area is also an example of an intensification pathway for wet rice cultivation in the inland valley in west Kalimantan, Indonesia (Padoch *et al.,* 1998; Cramb *et al.,* 2009). Boserup (2005) theorized that demographic trends (population growth, population decline, in- and out-migration also induced the agrarian transiting in the upland areas. In Indonesia, government-sponsored in-migration resulted swidden transition into more intensive farming practice (Cramb *et al.,* 2009). Similar studies were conducted in the Central Highlands of Vietnam, where the movement of low landers to the upland areas induced the intensification and commercialization of swidden into permanent agriculture (Cramb *et al.,* 2009).

Schmidt-Vogt *et al.* (2009) reviewed swidden transformation based on the total of 46 articles and 91 cases in SEA, of which in 52 documents, swidden being replaced by tree crops, and plantations such oil palm, rubber, and tea, in 29 documents swidden being replaced by the permanent, annual agriculture and in 11 cases swidden systems being transformed into permanent agricultural fields crops such as maize, cotton, peanuts, fodder crops, opium, and flowers.

1.3.5 Environmental and social impacts of agrarian transition

Rapid decrease of swidden land and replacement of swidden with permanent cropping have been occurred in the mountainous mainland of SEA, adjoining parts of Cambodia, Lao PDR, Myanmar, Thailand, Vietnam, and China (Rerkasem *et al.,* 2009). A decrease in the length of the fallow period may result in the disappearance of fallow land, and it may potentially lead to degradation due to over-intensification in SEA (Burgers *et al.,* 2005; Padoch *et al.,* 2007). Therefore, traditional livelihoods have transformed throughout most of the upland in SEA (Pulhin, 2009). In recent decades, many households have shifted towards more actively managed fallows as a result of changes in the biophysical, social, economic, and political environment (Paul Burgers *et al.,* 2005). Such kind of agricultural land use intensification into a permanent form of agriculture can lead to soil erosion, and such kind of market-oriented agribusiness are unfavorable to practice in steep slope mountainous (Funakawa *et al.,* 2007).

In the Atlantic rainforest, Adams *et al.* (2013) explored the impacts of swidden decline on the livelihoods of Quilombola swidden communities. Country development projects such as hydropower dam construction in the mountainous areas and forced displacement also impacted the agrarian transition of upland swiddeners (Rousseau *et al.,* 2017). Forced displacement under dam construction and farmland loss occurred in Asia, China, Sri Lanka, West Java of Indonesia, and Vietnam (Rousseau *et al.,* 2017; Morimoto, 2013; Manatunge *et al.,* 2009). Local livelihoods have diversified with new alternative income sources and off-farm income and became less reliant on the agricultural activity (Adams *et al.,* 2013; Castella *et al.,* 2005). Moreover, the changes in livelihoods associated with the demise of swidden also induced the implications for food security, nutrition. Moreover, high dependency on the purchased food consequently resulted a rise in price, nutrition transition, such as an increase in stature and a high rate of obesity (FAO, 2015; Adams *et al.*, 2013). However, there is very limited information on the basis of geographical and demographic data of swidden agriculture, swidden transformation, cultural changes of swiddeners, and their impacts on the local livelihoods.

1.3.6 Swidden agriculture in Myanmar

'Swidden cultivation' also known as 'rotational agroforestry,' 'long fallows forest cultivation,' 'shifting cultivation,' 'slash and burn agriculture,' or in Burmese term 'Shwe-Pyaung-Taung-Ya,' which is a common form of traditional subsistence agriculture and large numbers of ethnic minority groups, who live in the rugged hills and mountains. Myanmar is one of the world's most ethnically diverse countries. The ethnic minorities occupied 57% of the total land area, and an estimated 30-40 % of the total population are subsistence farmers and commonly practice the traditional swidden cultivation (Kramer, 2013). In Myanmar, swidden agriculture is mainly practiced by ethnic groups in the Karen, Shan, Kachin, and Chin States of eastern and northern Myanmar and prevails only on the mountainous regions (Win *et al.,* 2005). According to Li *et al.* (2014), the available figures for the swidden agriculture in Myanmar are extremely variable even though provided by the same government agency. The Ministry of Forestry (now Ministry of Natural Resource and Environmental Conservation) estimated the swidden area of 2.43 million ha practiced by 1.5 to 2 million families in 1995, and 10.18 million ha, which was about 15% of the total area of the country in 2003. The most recent estimate based on the analysis of satellite imagery in 2000 was that 0.29 million ha of swidden land is located in the Reserved Forests and Protected Forests and 5.32 million ha of swidden land, including the fallow land (Li *et al.,* 2014). The target areas for this study is a traditional swidden cultivation area practiced by the Karen ethnic minority in the Bago Mountains and swidden practiced by the Shan and Burma ethnic groups in the Paunglaung reserved forest. Locations of each study site were shown in Fig. 1-1.

Figure 1-1 Location of the study sites

1.3.7 Customary land use right and swidden in Myanmar

Swiddening is a traditional and a well-established agricultural system, especially in the mountainous regions, Myanmar, providing the subsistence or supplementary livelihood to many farming families of ethnic minority groups. However, nowadays, a number of drivers of the change in swidden agriculture in SEA have been mentioned in many previous researches, including political and economic pressures as well as economic opportunities and incentives (Cramb *et al.*, 2009; Fox *et al.,* 2009; Castella *et al.,* 2013; Chan and Takeda, 2016). Likewise, in Myanmar, several factors are stressing the swidden systems to transform into more intensive permanent agriculture. Ennion (2015) also mentioned that the relevant factors affecting swidden transformation included the intervention by the government and NGOs. They have encouraged changes from swidden cultivation to more permanent forms of agriculture. As in other tropical countries, swidden cultivation has transformed into other land uses because of population pressure and restrictions on land use (Ministry of Forestry, 2005; Chan *et al.,* 2016). In relation to the political and economic marginalization of swiddeners, few land policies and laws are governing pertaining to access and control of limit areas, where swidden agriculture can be practiced (Fox *et al.,* 2009). In Myanmar, swidden land has not been formally registered and has not been legally recognized as a legitimate use of land. Accordingly, swidden fallows were classified as wastelands, which could be re-allocated (Ennion, 2015). Since 2011, Myanmar has experienced a period of political and economic transition as it moves towards a more democratic government and liberalized economic system. At the same time, the Farmland Law 2012 (Farmland Law, 2012) and the Vacant Fallow and Virgin Lands Management Law 2012 (VFV, Law) were enacted to transform into modernized laws governing agriculture. However, customary land use rights over swiddeners were not addressed in their implementing rules of these two laws (Ennion, 2015). Therefore, customary land management systems managing shifting cultivation have remained relatively detached from overarching frameworks implemented by the State.

1.3.8 Swidden in the Bago mountains

The Bago Mountains is the homeland of the Karen people, where the Karen swiddeners have been practicing the traditional swidden cultivation since many centuries ago (Chan *et al.,* 2016a). They slash and burn the vegetation and typically relies on a large number of crops, planted both simultaneously and successively with the long cropping cycle. *Taungya* (Burmese terms: "*taung*" (hill) and "*ya*" (cultivation)) means temporary cultivation on hilly land (Suzuki 2009; Takeda *et al.,* 2006; Chan *et al.,* 2016b).

In relation to the issues on forest sectors and swiddeners in the Bago Mountains, swidden cultivation was regarded as the constraints of the forest policy by the Ministry of Forestry (1995), as shown in the description such as "discourage shifting cultivation practices, which are causing extensive damage to the forests ... ." Therefore, the Forest Department established teak plantations, where the Karen people could participate in as plantation labors and freely practice Taungya system (Swidden combined with silvicultural practices) in reserved forests in the Bago Mountains (Takeda *et al.,* 2006; Chan *et al.,* 2016a). Private teak plantations were also established in the Bago Mountains since 2007. In addition, the Ministry of Natural Resources and Environmental Conservation tried to stabilize and improve the swidden cultivation and transformed the fallow land of Karen swiddeners into community forest, according to the guidance of

Community Forest Instruction 1995 (CFI, 1995) since 2014. Springate-Baginski (2013) also stated that the Forest Department entered the competition for control of the uplands with swiddeners and sought to restrict them in order to establish the reserve forest for the timber production. Therefore, Karen swiddeners in the Bago Mountains have to face the limited land availability for practicing swidden agriculture. In addition, the most dramatic reform included in the Farmland Law is the introduction of Land Use Certificates (LUCs) (Ennion, 2015). However, swidden land has not been formally registered as farmland under the Farmland Law and land in upland areas of Myanmar is not registered by the Government (Ennion, 2015). On the other hand, the Land Scrutinizing Committee under the Ministry of Natural Resources and Environmental Conservation listed all the villages and their areas in the reserved forests and protected public forests recently. Large villages with over 50 households were approved as villages and village areas, religious land, and permanent agricultural land were removed from the forest land category and transferred to the control under the Ministry of Social Welfare, Relief and Resettlement to notify officially as village areas. In addition, the households which occupy the permanent agricultural land, especially paddy fields, will get the land use certificate approved by the Government.

1.3.9 Swidden in Paunglaung

Like the issues stated above in the Bago Mountains, the village territories of Paunglaung swiddeners also belong to the Paunglaung reserved forest administered by the Forest Department, Ministry of Natural Resource and Environmental Conservation, Myanmar. The Forest Department and some NGOs were also trying to introduce rubber plantation and some orchard tree species, such as coffee, banana, tea. However, swiddening still remains as the main livelihoods and local farmers area practicing the swidden with the customary land use right.

1.3.10 Land use planning in mountainous areas

One of the main challenges of the Government is to reform the land use policy considering the land use right for the ethnic minorities, especially the swiddeners. In such undeveloped mountainous area, sustainable land use management needs to be undertaken to fulfill the goal of poverty reduction and zero hunger for the mountain dwellers. Developing the accurate mapping method based on local case studies is crucial and remains as the best approach for accurate current land use mapping in order to implement the adaptation policies and land use strategies in line with the local needs especially for the future sustainability of the swiddeners. Moreover, village level socioeconomic data are urgently needed for refoming the land use policy, pertaining to the land use rights for the mountain dwellers. To this end, the socio-economic factors associated with swidden and intensified agriculture were studied in this study and impacts of landscape change on local livelihoods were examined in three villages through the interviews with the local people in three Karen villages in the Bago Mountains and the southern Shan Highlands. Therefore, this study was conducted to provide the basic information for finding the possible strategies for sustainable agricultural land use based on a full understanding of current agricultural land use, the topographic factors, climatic factors and general soil type. Although there have been many research works regarding various aspects of swidden agriculture, few studies have been done on the swidden agrarian transition, knowledge on these changing processes at a sub-national scale and impacts of changes on the livelihoods of local people and surrounding environment (Mertz *et al.,* 2009; Schmidt-Vogt *et al.,* 2009). Similarly, there have been limited research about the transformation of Taungya system (swidden cultivation) itself in the Karen area of the Bago Mountains (Takeda *et al.,* 2005). Basic statistical land use data and socioeconomic data at village level are very essential for implementing the proper land use planning for the rural development, especially in the developing countries. Myanmar has been trying to reform land use policy, and therefore research works related to land use transition are very essential for the policy makers.

1.4. Research questions and objectives

This research was conducted by considering the following research questions and research objectives

The following research questions were considered in this study.

a) How could the climatic, soil, and topological conditions of two traditional swidden cultivation areas are evaluated from the agronomic aspects?
b) How different is the changing trend of swidden cultivation in two mountainous areas?
c) What are the main underlying causes of agrarian transition and impacts on the environment and local livelihoods in two mountainous areas?
d) How different are the swiddener's adaptations under the different stress?
e) What are the possible feasible alternatives based on climatic, soil, topological, and social factors?

The specific objectives of this study were:

1. To present the basic climatic and soil information in two traditional swidden cultivation areas
2. To develop the swidden land use detection method and clarify the changing the trend of swidden in two mountainous areas
3. To assess the impacts of agrarian transition on the local livelihoods of swiddeners
4. To explore the possible alternatives based on the climatic, soil, topological and social factors; and
5. To contribute to implementing the sustainable land use planning in traditional swidden cultivation areas.

CHAPTER 2 PROPERTIES OF UPLAND SOILS IN BAGO MOUNTAINS AND SOUTHERN SHAN HIGHLANDS IN MYANMAR

2.1 Introduction

Myanmar is characterized by several mountain ranges, including the Bago Mountains, the Rakhine Mountains, the Tenasserim Hills, and the Shan Hills. Ethnic groups have been prevailing in these landscapes and have been relying on traditional swidden cultivation. However, the mountain region continues to face several threats from human activities, especially from land use and land cover changes. Land-use conflicts between the prevailing ethnic groups and the government, loss of traditional land-use practice of swidden, and the transformation into a more permanent form of agriculture are threatening the mountain ecosystem services and food security of upland farmers (Tovar *et al.*, 2013). In a developing country like Myanmar, recent national land use policy, after decades of isolation, is leading to land-use conflicts among the prevailing ethnic groups in mountainous areas.

On the other hand, swidden has been regarded as the leading cause of deforestation. Therefore, the Forest Department (FD) in Myanmar has been trying to discourage swidden cultivation and to substitute it with community forestry practices, as well as encourage monoculture plantations, especially. Therefore, swidden in Myanmar is also going into demise and has been replaced with forest plantations for forest conservation and a more permanent form of agriculture under increasing political, social, and demographic pressures (Swe and Nawata, 2019). Such an intensification of land-use in upland areas may induce soil degradation, especially surface soil erosion in steep slope areas (Funakawa *et al.*, 2006). Changes in traditional land-use practice, especially swidden transformation into a more permanent form of agriculture and massive monoculture plantation, are threatening mountain ecosystem services and have led to several environmental and socially destructive consequences. Therefore, land management strategies need to be improved to provide long-term sustainable agricultural production. With this background, there is a need for a good understanding of soil characteristics of upland soils to contribute towards finding alternatives to swidden for the sustainable livelihood of upland farmers. Further, it is necessary to understand soil formation and soil type with special reference to the pedogenic factors such as climate and geology. This study was conducted to provide the underlying soil and climatic information for finding future agricultural land-use alternatives. The specific objectives of this study were as follows:

1) to document the basic characteristics of soils under swidden cultivation in terms of profile description and soil physicochemical properties,
2) to characterize the soil pedogenic factors based on the soil profile and physicochemical parameters, and
3) to assess the soil fertility based on the soil profile, physicochemical parameters, and depth, and climate.

2.2. Materials and Methods

2.2.1 Study Area

This study was conducted in two highland areas, namely the Bago Mountains and Paunglaung and Pinlaung regions of southern Shan Highlands in Myanmar (Fig. 2-1). The Bago Mountains are located at an elevation of 250–450 m above sea level and the average annual rainfall was around 1,200 mm from 2008 to 2017 (Fig. 2-2a). The Bago

Mountains are covered with bamboo dominated secondary forests, and the dominant vegetation is *Bambusa polymorpha* (vernacularly, *Kyathaung-Wa*) and *Bambusa tulda* (*Thaik-wa*). The slope ranges from 1 to 46 degrees in the villages that were selected for sampling. The average fallow period was 11 to 12 years in the year of 2016 (Swe and Nawata, 2019). The Bago Mountains are home to the Karen community, where they have been practicing traditional swidden agriculture since several centuries (Chan *et al.*, 2016). They slash and burn the vegetation and typically rely on several crops, that are planted both simultaneously and successively with the relatively long cropping cycle. In this study, three Karen villages (anonymously SN, KC, and GS) of the Bago Mountains were selected as case studies. Administratively, these three villages belong to the Paukkaung Township, the Bago Region. The location of each sample villages and locations soil profile are shown in Fig. 2-1.

Paunglaung and Pinlaung study sites administratively belong to the Pinlaung Township, Southern Shan State (the Pa-O Self-Administered Zone of Shan State, Myanmar), located between 96˚ and 97˚ E longitude and 20˚ and 21˚ N latitude. The Paunglaung site is located inside the Paunglaung reserved forest, which has been classified as a Moist Upper Mixed Deciduous Forest (MONERC). It is located at an elevation of 250–500 m above sea level in Southern Shan State. The average annual rainfall of Paunglaung was 1,643 mm from 1998 to 2018. Three villages, namely TLM, LL, and TPK were selected as sample villages in Paunglaung site. The majority of local people of Paunglaung (second study site) are swiddeners, and mainly grow turmeric in swidden fields. The Pinlaung site is located at an elevation of 500–1500 m above sea level. The average annual rainfall of Pinlaung was 2,202 mm from 1998 to 2018. The average monthly rainfall and temperature of the Bago Mountains, Paunglaung, and Pinlaung, which were collected from the nearest stations, are shown in Fig. 2-2b.

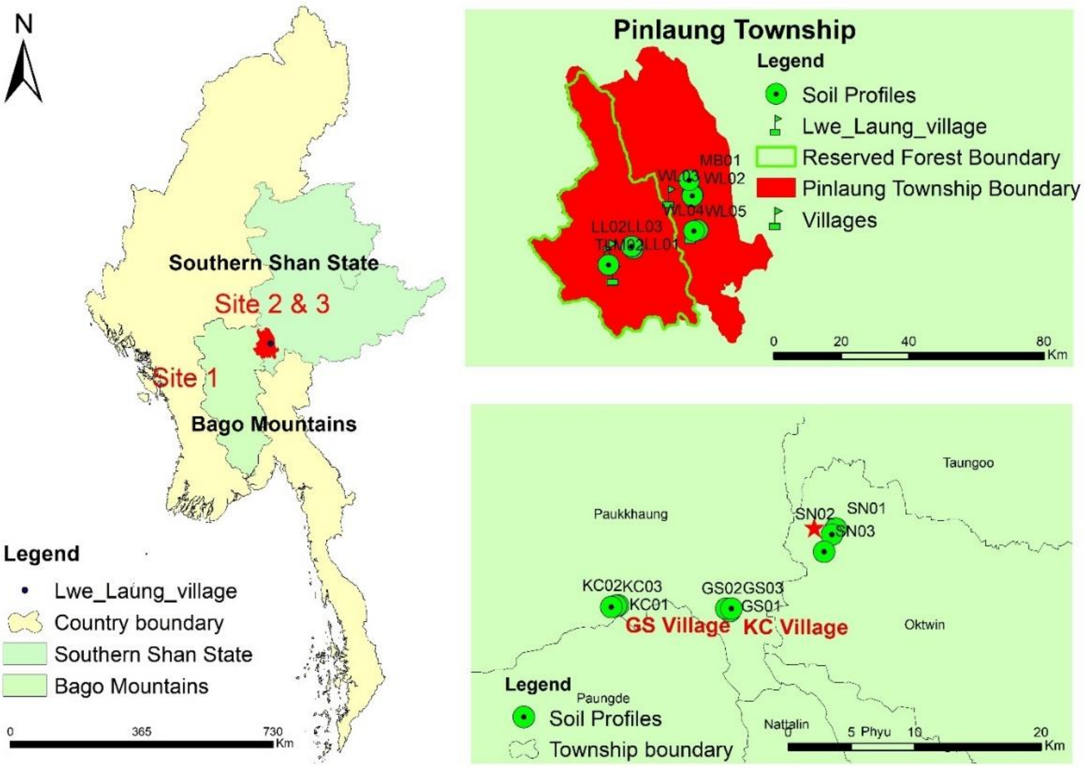

Figure 2-1 Location of study sites and 20 soil profiles in the Bago Mountains, Paunglaung and Pinlaung

2.2.2 Extensive measurement of effective soil depth

In order to assess the potential risk of soil loss through erosion, soil depth and soil-related parameters were measured in the field with an auger from 67 points in the Bago mountains and 53 points in Pinlaung, Shan Highlands.

2.2.3 Intensive Soil Survey

In order to contribute to finding the suitable agricultural land-use practice, soil survey was conducted in these three mountainous areas. Overall, 20 soil profiles were investigated with the aim to understand the general soil information for the three study sites. Nine profiles, with three profiles from each of the three villages in Bago Mountains, and five profiles each from Paunglaung and five profiles form the Pinlaung shan highland area, were investigated (Fig. 2-1).

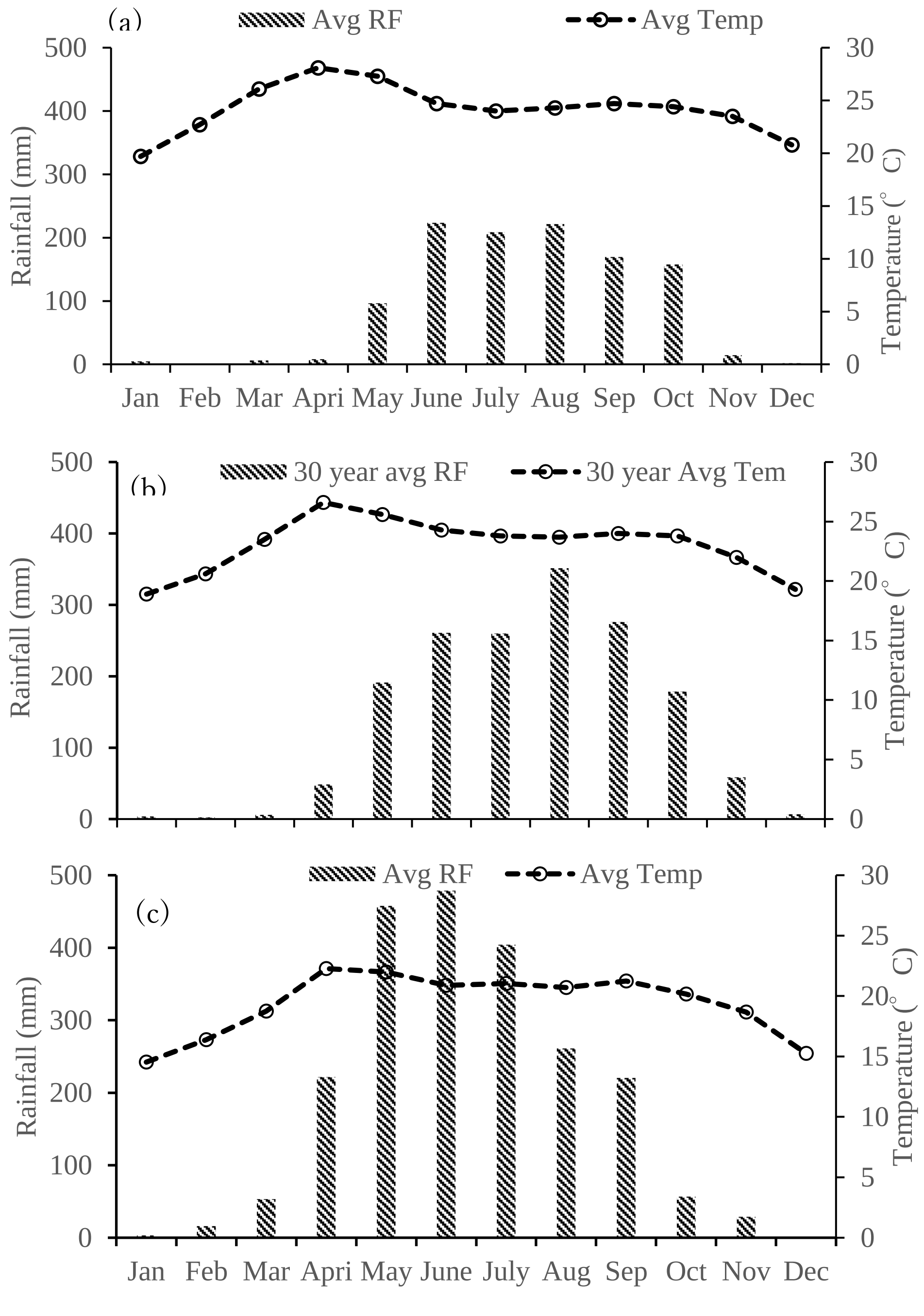

Figure 2-2 Monthly rainfall and temperature in the Bago Mountains over 2008~2017 (a), in the Paunglaung, southern Shan Highlands over 1998~2018 (b), and in the Pinlaung, southern Shan Highlands over 2010 ~2017

(Data sources: Ministry of Agriculture, Livestock and Irrigation (MOALI) for the Bago Mountains and Pinlaung, and https://climatecharts.net/ for the Paunglaung)

2.2.4 Soil Analysis

Bulk density was measured by using the core method. Soil samples were air-dried and gently sieved through a 2-mm sieve prior to the laboratory analysis. Before the Soil texture analysis, soil organic matter was decomposed with H_2O_2, and each component was measured using the combination of the pipette method and sieving method. The Soil pH (H_2O) and pH (KCl) were determined with water and 1M KCL solution at a soil: liquid ratio of 1:5 mixtures by using a glass electrode pH meter (HM-30 P, TOA-DKK, Ltd). Soil EC was also measured by making aliquot with water at a 1:5 ratio in the same method with soil pH. Dry soil samples were finely grinded with a ball mill, and total carbon and total nitrogen were analyzed by using an NC analyzer. Exchangeable cations (K, Na, Mg, and Ca) were extracted with 1 M of ammonium acetate (CH_3COONH_4) solution and measured by atomic absorption spectrophotometer (AAS). Then, the treated soils were washed with ethanol, and the cation exchange capacity (CEC) was determined by using the solution extracted by 10% NaCl on flow injection analysis (FIA). Available phosphorus was determined using the Truog method. Exchangeable aluminum and H^+ were also measured with the titration method after the extraction with 1M KCl solution. Soil carbonate contents were additionally measured for the samples with high pH values by back-titration method as follows: soil samples were firstly treated with excess amounts of hydrochloric acid to completely remove carbonates and then were titrated with sodium hydroxide solution by using an auto-titrator (HIRANUMA COM-1600). Soil profiles were classified to taxonomic order levels according to *Keys to Soil Taxonomy*, (Soil Survey Staff, 2014).

2.3. Results

2.3.1 Overview of soil development

Most importantly, according to the auguring survey from 67 plots in the three villages in the Bago Mountains, gravel layers were not found till 110 cm depth of soils at all the plots surveyed. It was concluded that the soil depth in our survey villages was consistently relatively deep, which may potentially contribute to the resistance to soil erosion to a certain extent in the steep slopes of the Bago Mountains. On the other hand, in southern Shan Highlands, the average soil depth of 62 points was 79.8 cm ± 37.7 cm (SD). Rocks and limestone were sometimes exposed even at the land surface in some locations. The situation seems to be more common in upland soils in mountainous regions of northern Southeast Asia.

2.3.2 Morphological characteristics and physicochemical properties of six representative soils from Bago Mountains and Southern Shan Highlands

GS01, from an upper slope of the lowest terrain of Bago Mountains (166 m above sea level), was characterized by clayey texture and the presence of carbonates in the upper B to the bottom horizons (Tables 2-1 and 2-7 and Fig. 2-3). The soil color was bright, as dull yellowish brown (10YR5/4) to bright yellowish brown (2Y6/6). These indicated that the parent materials of the soil were deposited in a shallow marine environment and that the soil had experienced a relatively short period of time after emergence. Since the carbonate content was not high, if any, as to meet the condition of calcic horizon and the clay translocation in the profile was not clear, the soil was classified as Typic Haplustepts. Since the other two soil profiles from the same village exhibited similar properties, there is a possibility that in the low elevation area of west Bago Mountains, Ustepts strongly affected by the recent marine environment are likely to be distributed widely. Since the properties of the soils were quite different from other major upland soils in the northern region of Southeast Asia in countries such as Thailand, Lao, and Vietnam, it is necessary to survey their distribution pattern.

Figure 2-3 Photograph of profile GS01

Table 2-1 Profile description of representative soils GS 01 (Bago Mountains)

Horizon	Depth (cm)	Descriptions
A_p	0-15	Brown (10YR4/4), moderately dry; silty clay; moderate medium subangular blocky; slightly firm; slightly sticky, plastic; abundant fine roots; distinct smooth boundary to
BA	15-35	Dull yellowish-brown (10YR5/4); moderately dry; silt loam; moderate medium subangular blocky; slightly firm; slightly sticky, plastic; many fine roots; clear smooth boundary to
B_w	35-60	Dull yellowish-brown (10YR5/4), moderately dry; clay; strong medium subangular blocky; slightly firm; sticky, plastic; many fine roots, clear smooth boundary to

BC	60-70+	Bright yellowish-brown (2.5Y6/6); moderately dry; silty clay loam: strong medium subangular blocky structure; slightly firm; sticky, plastic; common fine roots

KC02, located at an upper slope at 366 m above sea level in Bago Mountains (Tables 2-2 and 2-7 and Fig. 2-4), was characterized by clayey soil and clay translocation in the profile was not clear. The soil was slightly acidic with pH values 6.2 to 6.3 and base saturation of 88 to 92% in the B horizons. Since the signature of carbonates were not detected at this profile, the soil had a longer developing history since emergence, even if the parent materials were deposited in a marine environment. The soil was classified as Typic Haplustepts.

Figure 2-4 Photograph of profile KC02

Table 2-2 Profile description of representative soils KC01 (Bago Mountains)

Horizon	Depth (cm)	Descriptions
A1	0-15	Brownish black (10YR3/2); slightly moist; silt loam; moderate medium subangular blocky; friable; slightly sticky, plastic; many fine roots; common strongly weathered gravels; gradual

		smooth boundary to
A2	15-30	Brownish black (10YR3/2); moist; silt loam; moderate medium subangular blocky; friable; slightly sticky, plastic; many fine roots; common strongly weathered gravels; clear smooth boundary to
AB	30-45	Dark brown (10YR3/3); moist; clay loam; moderate medium subangular blocky; friable; sticky, plastic; many fine roots; common strongly weathered gravels; clear smooth boundary to
Bw1	45-60	Brown (10YR4/4); moist; silty clay loam; weak medium subangular blocky; friable; sticky, plastic; common fine and few coarse roots; common strongly weathered gravels; gradual smooth boundary to
Bw2	60-80+	Yellowish-brown (10YR5/6); moist; silty clay loam; weak medium subangular blocky; friable; sticky, plastic; common strongly weathered gravels

LL01 was located on a steep slope in Paunglaung in low elevation areas (627 m above sea level) of southern Shan Highlands (Tables 2-3 and 2-7 and Fig. 2-5). This area was mostly covered by Mesozoic or Paleozoic sedimentary rocks including limestone. In this soil profile, the influence of limestone was observed due to apparently higher exchangeable Ca compared to other soils examined, with pH value of 6.1 and base saturation of 96.5% in the B horizon, respectively. The soil was classified as Udic Haplustepts.

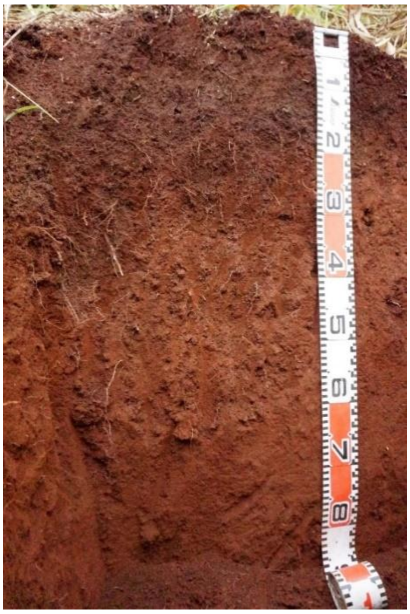

Figure 2-5 Photograph of profile LL01

Table 2-3 Profile description of representative soils LL01 (Paunglaung)

Horizon	Depth (cm)	Descriptions
Ap	0-15	Very dark reddish brown (2.5YR2/2); moist; clay; weak medium subangular blocky; very friable; sticky, plastic; abundant fine roots; abrupt irregular boundary to
AB	15-30	Dark reddish brown (2.5YR3/2); moist; clay; weak medium subangular blocky; very friable; sticky, plastic; many fine roots; clear smooth boundary to
Bw1	30-55	Dull reddish brown (2.5YR4/4); moist; clay; weak medium subangular blocky; friable; sticky, plastic, common fine roots; gradual smooth boundary to
Bw2	55-85+	Dark reddish brown (2.5YR3/6); moist; clay, weak medium subangular blocky; friable; sticky, plastic; common fine roots


Figure 2-6 Photograph of profile LL03

Table 2-4 Profile description of representative soils LL03 (Paunglaung)

Horizon	Depth (cm)	Descriptions
Ap	0-15	Brownish black (7.5YR3/2); moist; clay loam; weak medium subangular blocky; very friable; slightly sticky, plastic; many fine roots; few strongly weathered gravels; clear smooth boundary to
AB	15-25	Brown (7.5YR4/3); moist; clay loam; weak medium subangular blocky; very friable; many fine roots few strongly weathered gravels; clear smooth boundary to
Bw	25-35	Brown (7.5YR4/4); moist; clay loam; weak medium subangular blocky; friable; common fine roots; common strongly weathered gravels; abrupt wavy boundary to
BC	35-75+	Brown (7.5YR4/6); moist; clay loam; no structure; slightly sticky, slightly plastic; abundant strongly weathered gravels and pebbles

LL03 was located along a ridge of a mountain in Paunglaung of southern Shan Highlands, at an elevation of 675 m (Tables 2-4 and 2-7 and Fig. 2-6). Contrasting the characteristics of LL01, the influence of limestone was likely minimum, and the content of exchangeable bases was low, while that of exchangeable Al was as high as approximately 5 $cmol_c$ kg^{-1}. Consequently, the pH value and the base saturation were low, with values of 4.8 and 26.4%, respectively, in the B horizons. The signature of clay translocation was not clear in the profile, and there were a lot of coarse fragments, especially below the B horizons. The soil was, hence, classified as Dystric Haplustepts.

WL03 was located on a steep slope in Pinlaung at a higher elevation (1,811 m above sea level) in southern Shan Highlands (Tables 2-5 and 2-7 and Fig. 2-7). The pH values were low with values of 4.9 to 5.1, the exchangeable bases were less than 2 $cmol_c$ kg^{-1}, and the exchangeable Al was high with values of 5.5 and 9.3 $cmol_c$ kg^{-1} in the B horizons. Consequently, the base saturation was relatively low with a value of 18.9% in the B horizon. The soil below B horizon contained many coarse fragments and clay translocation was not observed. The soil was classified as Dystric Haplustepts.

Figure 2-7 Photograph of profile WL03

Table 2-5 Profile description of representative soils WL03 (Pinlaung)

Horizon	Depth (cm)	Descriptions
A	0-10	Moist, dark brown (10YR3/3), loam; weak red subangular blocky structure, firm; many fine roots; few strongly weathered gravels; clear, smooth boundary to,
AB	10-20	Moist, dark brown (10YR3/4), loam; weak red subangular blocky structure, firm; many fragments, few fine roots; common strongly weathered gravels; clear, abrupt, wavy boundary to,
B_{w1}	20-40	Moist, brown (10YR4/6), clay loam; weak red subangular blocky structure; firm, common fine roots; many strongly weathered pellets, abrupt, smooth boundary to,
B_{w2}	40-60+	Moist, yellowish-brown (7.5YR5/6), clay, weak red subangular blocky structure and firm, few fine roots, few strongly weathered gravels

WL04 was located on a foothill of limestone rock mountains at 1,496 m above sea level in Pinlaung, southern Shan Highlands (Tables 2-6 and 2-7 and Fig. 2-8). Due to its location, the soil contained a relatively high amount of exchangeable Ca and exhibited high pH values of 5.7 to 5.8 in the B horizons. The base saturation was 97.7% in the B horizon. It is likely that the stable landform allowed enough time for the formation of the argillic B horizon. Reflecting the limestone-derived parent materials, the soil color was consistently dark reddish brown in the B horizons. Hence, the soil was classified as Udic Rhodustalfs.

Figure 2-8 Photograph of profile WL04

Table 2-6 Profile description of representative soils WL04 (Pinlaung)

Horizon	Depth (cm)	Descriptions
Ap	0-10	Moist, dark reddish-brown (5YR3/3), silt loam; no gravels, weak red subangular blocky structure, firm; many fine roots; clear, smooth boundary to,
AB	10-25	Moist, dark reddish-brown (2.5YR3/4), silt loam; no gravels, weak red subangular blocky structure, firm; many fine roots; graveled, smooth boundary to,
B_{t1}	25-40	Moist, dark reddish-brown (2.5YR3/4), silty clay; no gravels, weak red subangular blocky structure; firm, common fine roots; graveled, smooth boundary to,
B_{t2}	40-90+	Moist, dark reddish-brown (2.5YR3/6), silty clay; no gravels, weak red subangular blocky structure and firm, common fine roots,

Table 2-7 Physiochemical characteristics of the representative soils

Site Region	Horizon	Particle size distribution (%)			pH		EC (dS/m)	Exchangeable cations ($cmol_c$ /kg)							Cation exchange capacity ($cmol_c$/kg)	Base saturation (%)	Total C (g/kg)	Total N (g/kg)	Available phosphorous	Carbonate CC/kg	Bulk density (g/cm^3)
		Sand	Silt	Clay	H_2O	KCL		K	Na	NH_4	Ca	Mg	Al	H							
GS01	Ap	3.9	32.1	64.0	8.4	7.2	143.7	0.2	1.5	0.0	27.8	5.8	0.0	0.3	16.7	99.2	17.1	1.9	26.2	0.2	1.6
Bago	BA	1.6	36.0	62.4	8.5	7.8	116.9	0.2	0.7	0.0	41.1	8.7	0.4	0.9	15.5	97.6	19.9	1.0	2.3	1.2	1.6
Mountains	Bw	1.5	21.5	77.0	9.0	8.3	111.3	0.3	0.7	0.0	36.4	13.8	0.2	0.2	15.8	99.1	18.2	0.8	1.9	1.3	1.7
	BC	5.7	38.4	55.9	9.2	8.3	118.9	0.3	0.9	0.0	10.3	18.6	0.3	0.2	20.8	98.4	17.3	0.7	0.0	1.2	1.2
KC01	A1	15.9	50.4	33.7	7.5	4.4	13.9	0.4	2.1	0.1	8.1	9.4	1.7	1.0	30.7	88.0	16.2	1.2	1.2	n.d.	1.4
Bago	A2	20.2	44.0	35.8	6.3	4.2	12.0	0.3	1.7	0.1	7.5	9.7	0.9	1.1	31.5	90.8	14.5	1.1	1.7	n.d.	1.4
Mountains	AB	15.7	43.0	41.4	6.3	4.3	11.1	0.3	1.5	0.0	7.3	11.0	1.2	0.8	33.8	90.8	12.5	1.0	2.3	n.d.	1.4
	Bw1	12.8	45.1	42.1	6.2	4.1	8.2	0.2	0.3	0.1	6.2	11.1	2.4	1.1	32.8	83.6	6.2	0.8	0.0	n.d.	1.5
	Bw2	12.9	46.0	41.2	6.3	4.1	10.7	0.3	1.5	0.1	6.9	11.6	1.8	1.3	32.3	86.9	4.9	0.6	0.0	n.d.	1.4
LL01	Ap	15.2	32.0	52.8	6.3	5.2	35.0	0.5	0.4	0.1	14.2	5.1	0.1	0.3	34.8	98.3	26.4	2.1	6.2	n.d.	0.8
Paunglaung	AB	15.3	20.4	64.3	6.4	4.9	21.0	0.3	1.7	0.0	10.7	3.6	0.1	0.3	31.8	97.7	20.6	2.0	2.7	n.d.	1.0
	Bw1	19.5	13.5	67.0	6.1	4.5	20.2	0.2	0.7	0.0	9.5	2.2	0.5	0.4	25.4	93.3	13.6	1.4	2.9	n.d.	1.0
	Bw2	14.0	35.8	50.2	6.1	4.5	13.2	0.1	0.9	0.0	8.5	1.8	0.2	0.4	24.9	95.2	11.2	1.2	4.8	n.d.	1.0
LL03	Ap	22.9	34.0	43.1	5.0	4.2	36.3	0.3	0.5	0.1	2.8	0.7	4.2	1.1	22.6	45.8	25.3	1.8	9.4	n.d.	1.1
Paunglaung	AB	21.1	39.9	39.0	4.8	4.1	28.9	0.3	0.3	0.1	1.4	0.2	4.7	1.0	20.9	28.3	14.1	1.3	4.9	n.d.	1.1
	Bw	29.4	25.0	45.6	4.8	4.0	19.6	0.1	0.3	0..1	1.1	0.1	4.8	1.9	20.4	20.5	10.8	1.0	2.6	n.d.	1.3
	BC	38.8	21.6	39.6	4.8	4.1	14.5	0.1	0.8	0.0	1.0	0.1	5.5	0.7	18.2	24.7	5.7	0.6	4.9	n.d.	0.0
WL03	A	27.3	46.0	26.7	5.1	4.2	15.5	0.2	0.6	0.0	1.5	0.4	4.0	1.0	19.9	36.2	15.2	1.8	8.5	n.d.	1.5

Pinlaung	AB	26.1	44.4	29.5	5.0	4.2	13.7	0.1	0.3	0.0	1.1	0.3	4.9	0.6	18.8	25.1	12.7	1.6	2.4	n.d.	1.6
	Bw1	27.3	37.0	35.8	4.9	4.2	10.9	0.1	0.1	0.0	0.9	0.2	5.5	1.2	19.9	16.1	7.9	1.9	2.0	n.d.	n.d
	Bw2	25.7	37.7	36.6	5.1	4.1	6.9	0.2	0.6	0.1	1.0	0.2	9.3	4.1	25.0	13.4	4.1	1.0	5.8	n.d.	1.6
WL04	A	28.0	37.5	34.4	5.9	5.1	29.8	0.5	0.5	0.1	6.2	2.3	0.1	0.4	26.6	95.4	36.7	3.6	7.6	n.d.	0.9
Pinlaung	AB	28.5	34.0	37.5	6.2	5.2	13.1	0.1	0.4	0.1	4.9	1.7	0.1	0.3	25.6	94.6	27.5	2.8	4.6	n.d.	0.9
	Bt1	31.3	28.0	40.7	5.8	4.8	13.9	0.0	0.2	0.0	2.3	1.7	0.1	0.6	23.8	86.5	18.3	1.8	4.1	n.d.	0.9
	Bt2	34.2	28.5	37.3	5.7	4.9	14.0	0.1	0.3	0.1	3.6	1.6	0.1	0.4	24.3	92.6	15.5	1.6	3.3	n.d.	1.0

Note _n.d., not determined.

2.4. Discussion

2.4.1. Influence of geological conditions on soil development in Bago Mountains and Southern Shan Highlands

The Bago Mountains are located in an area of hilly terrain rising over 400 m in elevation and are bounded in the east by the linear structural segments of the Sagaing Fault. The Bago Mountains, one of the eight tertiary basins between the Indo-Myanmar ranges to the west and Shan plateau to the east, experienced northwest-southeast extension in the Miocene, followed by northeast-southwest transpression in the Pliocene. The Pliocene sedimentation deposited during the post-rift stage is characterized by fluvial-deltaic sequences. The large volume of marine parent materials may be a result of sediment loading, reflecting an Early Cenozoic drainage system more closely linked to the eastern Himalaya (Utitsan *et al.*, 2014).

On the other hand, Southern Shan state is classified as a Lower Jurassic 'Pinnacle Limestone formation' (Utitsan *et al*., 2014). The Shan Plateau was formed during the Mesozoic era, approximately 248 to 65 million years ago (Hadden, 2008). The geology in this area is characterized by the domination of consolidated rocks formed in Mesozoic, and partially Paleozoic, sedimentary rocks. It is a more recent and intensive folding than the western mountains, with north-south longitudinal ranges with the elevation ranges of 1,800 to 2,600 meters (6,000 to 8,600 feet) above the plateau surface. This geology is common in the upper (northern) Indochina peninsula, including northern Vietnam, Lao, and northern Thailand, and southern China.

Reflecting these geological conditions, the soil profiles from the Bago Mountains were slightly acidic to slightly alkaline. The fact that the soils from low elevation area, i.e., GS village, contain considerable amounts of carbonates, suggests that the nature of parent materials, which were deposited under the marine environment, was still maintained. The base saturation of the soil profiles in the Bago Mountains in this study was mostly exceeding 80% (Fig. 2-9), and the soils could be classified as Alfisols if the argillic horizon was detected. However, due to the dominantly steep slopes of this region, the soils were actually classified as Inceptisols. This result seems to be reasonable when considering the savanna climate with annual precipitation of 1,000 mm in the region, but it is considerably different from the past reports by Suzuki (2009), Takeda *et al*. (2005), and Chan *et al.* (2013), in which, soils in Bago Mountains were mostly classified as Ultisols with low base saturation. Therefore, a more extensive soil survey, with detailed climatic data, is still necessary to understand the soils in this area.

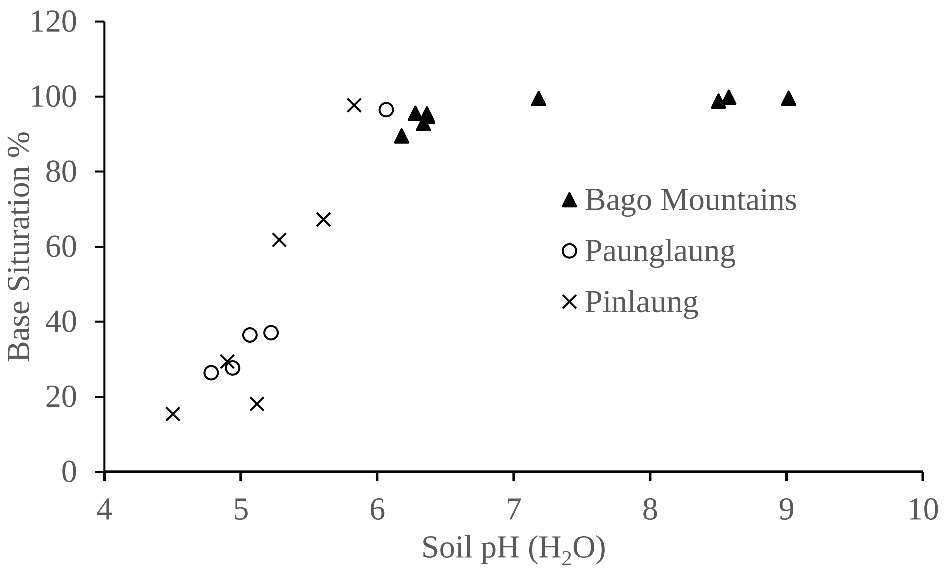

Figure 2-9 Relationship between base saturation and soil pH (H_2O) of the B horizon

On the other hand, two types of soils were found in the Paunglaung and Pinlaung study sites. The soils were usually acidic, if the influence of limestone was not considered, like the cases of LL03 and WL03. The content of exchangeable Al was higher in the soils with a lower pH (Fig. 2-10). Contrasting this, the content of base saturation was higher in the soils with a higher pH (Fig. 2-9). In this case, the amounts of exchangeable bases were low, and those of exchangeable Al were high, resulting in low base saturation and the formation of Ultisols or acidic Inceptisols (Figs. 2-9 and 2-10). Ultisols are the most common soil in Southeast Asia (Sanchez, 1976). Under the strong influence of limestone, however, such soil acidity could be mitigated by carbonates, and soils were generally less acidic, as was the case with LL01 and WL04. This kind of soil was also observed in northern mountainous regions of Thailand, under a monsoon climate (Funakawa *et al.,* 2008). The latter is a favorable condition for agriculture, and Senbayram *et al.* (2015) also suggested that the high content of exchangeable aluminum is harmful for plants in acidic soil, where pH is lower than 5. Soils with a pH of 6.0–7.0 typically have high concentrations of available nutrients (Williston and Lafayette, 1978).

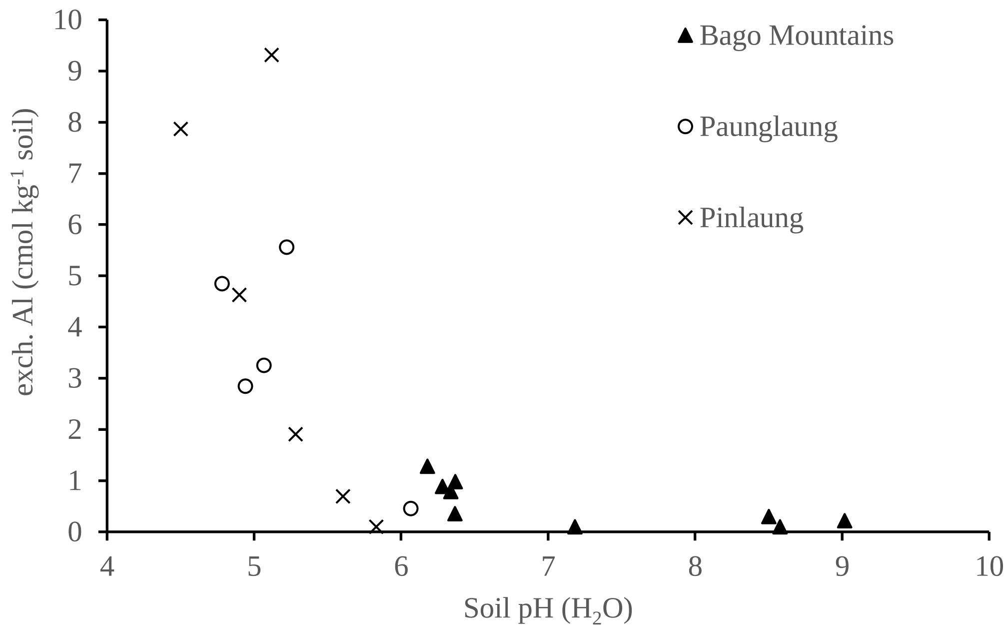

Figure 2-10 Relationship between exchangeable aluminum and soil pH (H_2O) of the B horizon

2.4.2. Soil fertility assessment

In order to assess the soil fertility, soil physicochemical parameters of the surface horizon were analyzed (Figs. 2-11, 2-12 and 2-13). Soil pH greatly influence the agronomical and environmental functions of the soils (Robson, 1989; Funakawa *et al*., 2008). The trend of soil acidity (pH) was negatively correlated with the elevation in this study (Fig. 2-11). Soil from Paunglaung and Pinlaung were more acidic than the soil of Bago Mountains, possibly because of the increase in leaching in higher elevation areas under a high rainfall condition.

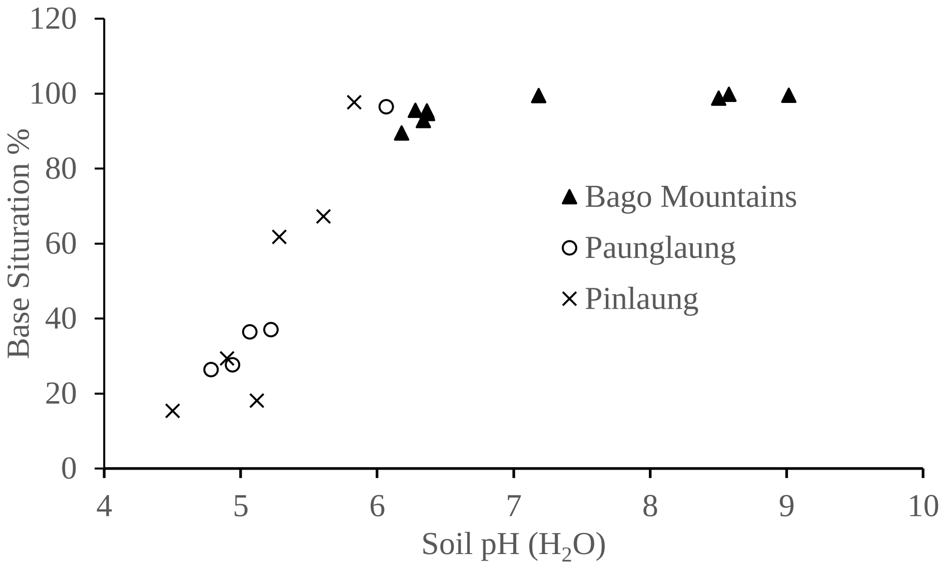

Figure 2-11 Relationship between soil pH (H_2O) and elevation (m) of the surface horizon

Mapa and Kumaragamage (1996) also suggested that soil pH is an important indicator to predict the nutrient availability, because it is strongly related to the amounts and ratios of exchangeable bases and Al. Ca and Mg are essential plant elements because they play vital roles in plant growth, development, and plant defense mechanisms in abiotic stress situations (Senbayram *et al.*, 2015). The results showed that a high content of Ca and Mg were found in the soil of Bago Mountains and followed by a lower content in Paunglaung and Pinlaung (Fig. 2-12). Senbayram *et al.* (2015) and Sumner *et al.* (1978) reported that soil exchangeable Mg dropped more than 50% when the pH of Ultisols increased from 5.5 to 7.5. The annual rainfall amount of Pinlaung and Pinlaung was relatively higher than that of the Bago Mountains. Therefore, a higher rate of leaching of soluble materials of coarse texture Ultisols soil by water moving under high rainfall, could be possible. Limestone-affected soils from Shan Highlands had moderately high content of Ca and Mg, and a pH value higher than six could be suitable for home garden and fruit tree orchards. Ghiberto *et. al.* (2015) and Wong *et al.* (1992) also stated that leaching of basic cations to the subsoil could be beneficial in promoting root growth at great depths in Ca- and Mg-deficient soils. The total carbon and clay content of the three study sites were not significantly different. Available phosphorus content was higher in the soils of the Bago Mountains, than in Paunglaung and Pinlaung region, due to the fertilizer application in GS 01 profile from Bago Mountains (Fig. 2-13).

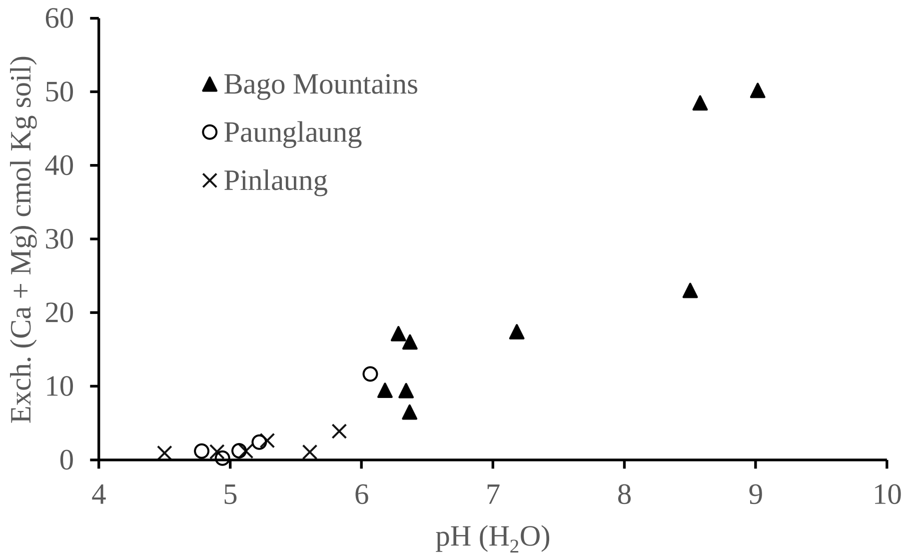

Figure 2-12 Relationship between exchangeable (Calcium and Magnesium) and soil pH (H_2O) of the B horizon

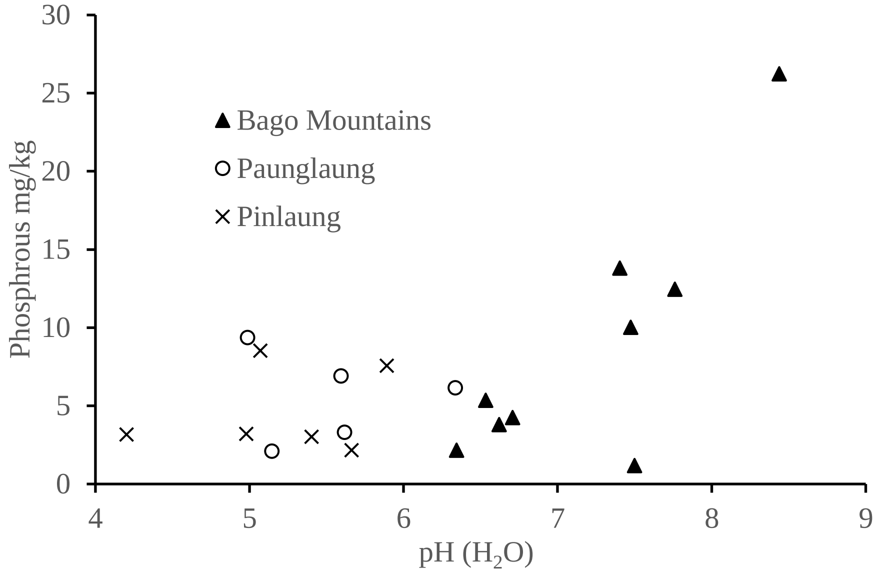

Figure 2-13 Relationship between available Phosphorus and soil pH (H_2O) of the surface soil

As stated previously, according to the auguring survey from 67 plots in the three villages in the Bago Mountains, gravel layers were not found till 110 cm depth of soils at all the plots surveyed. It was concluded that the soil depth in our survey villages was consistently relatively deep, in comparison with other sites, which may potentially contribute to the resistance to soil erosion to a certain extent in steep slopes of the Bago Mountains. On the other hand, in southern Shan Highlands, the average soil depth of 62 points was 79.8 cm ± 37.7 cm (SD). Rocks and limestone were sometimes exposed even at the land surface in some locations. The situation seems to be more common in upland soils in mountainous regions of northern Thailand and Peninsular Malaysia *(Funakawa et al.*, 2006; Fatai *et al*., 2017).

Therefore, I conclude that soil condition of the Shan Highlands is favorable for shallow-rooted tree species. In Paunglaung, for the limestone-affected soil at lower elevation area, home garden, fruit orchards, could be suitable and sedimentary soil could be favorable for crops such as elephant foot yam and turmeric.

CHAPTER 3 DEVELOPING A REMOTE SENSING-BASED MAPPING METHOD FOR SWIDDEN LAND USE DETECTION: CASE STUDIES IN TWO KAREN VILLAGES OF THE BAGO MOUNTAINS, MYANMAR

3.1 Introduction

Swidden agriculture, a dominant land use system in mountainous regions in including SEA (Li *et al.*, 2014; Schmidt-Vogt *et al.*, 2009), is a way of life associated with cultural traditions that provides valuable subsistence products to local farmers, especially poor ethnic minority groups (Noordwijk *et al.*, 2008; Li *et al.*, 2014). In most tropical areas, such agriculture has been regarded as a primitive practice without planning on foresight since colonial times (Padoch *et al.,* 2007; Cramb *et al.*, 2009; Fox *et al.*, 2009; Dressler and Pulhin, 2010; Li *et al.*, 2014). Even though swidden is undergoing a rapid transition to other forms of land use, because of the combined forces of agricultural, forestry, and conservation policies and population growth in many parts of SEA (Padoch *et al.*, 2007; Van Vliet *et al.*, 2013; Heinimann *et al.*, 2017), only a few attempts have been made to assess the accurate estimates of the extent and dynamics of swidden in many previous studies (Schmidt-Vogt *et al.,* 2009) due to its complexity and dynamic nature. Therefore, land use maps and statistical records of swidden areas have been reported upon.

Remote sensing technology, integrated with GIS, can offer continuous land use changes information with better accuracy, and freely available Landsat imageries with a 16-days receptivity are economical and support the extensive use for monitoring the dynamic nature of swidden agriculture (Cihlar, 2000; Venkata Rao *et al.*, 2018). Scholars have started to detect swidden land use changes from satellite imageries recently by extracting burning fire events and burned areas due to its synoptic, multi-temporal, multi-spectral and repetitive coverage capabilities (Li *et al.*, 2014; Liao *et al.*, 2015). (Hansen and Mertz 2006) classified these changes by using maximum likelihood methods in Sarawak, Malaysia. In Lao PDR, (Messerli 2009) proposed analysis of national level swidden land use changes by using meso-level spatial scaled landscape mosaics and introduced a new approach, developed for this area to quantify such changes at the district to national levels in 2009. However, until now, Landsat-related methodologies for detecting swidden areas still have been developed and studies on accurate mapping and the delineation of swidden agriculture at the local scale are still limited because of the difficult work when medium-resolution images are used (Schmidt-vogt *et al*., 2009).

In Myanmar, an estimated 30-40 percent of the total population are swiddeners (Kramer 2013) who are undergoing rapid swidden transformation (Ministry of Forestry, 2005; Ennion, 2015; Chan and Takeda, 2016), but reliable and satisfactory estimates of such changes remain unknown. From this background, based on theories and the nature of swidden agriculture, I aimed at the establishment of a method for analyzing time series swidden land use based on satellite imagery in this study in order to contribute to the understanding of whether there was any continuing rationale of swidden agriculture in the Bago Mountains or not. According to several previous works (Sakai, 2002; Heinimann *et al*., 2017; and Padoch *et al*., 2007), any attempt for developing a method to clarify swidden land use changes for sound evidence can greatly contribute to estimating land use-based greenhouse gas emissions and statistical data, related to slash-and-burn in a particular region, are a basic need for environmental monitoring and conducting various investigation on agricultural development and food security for the swiddeners. In addition, one main challenge of the Myanmar Government after Independence was to reform *de facto* land use policies considering the land use right for ethnic minorities, especially the swiddeners. Developing accurate mapping methods, based on local case studies, is crucial and remain as the best approach in order to implement the adaptation policies in line with local needs, especially for the future sustainability of such people. The main objective of this study is to establish an appropriate method to map existing agricultural land use and detect swidden fields from medium resolution Landsat images, based on ground truth in two Karen villages in the Bago Mountains, Myanmar.

3.2 Materials and Methods

3.2.1 Study area

The Bago Mountains are the homeland of the Karen people, where the Karen swiddeners have been practicing the traditional swidden agriculture for many centuries despite being provided little protection under current land laws on the rights of small landholding farmers in upland areas (Chan *et al*., 2016). The Bago Mountains are located 250–450 m above sea level (ASL) with a mean annual temperature of about 27°C and a mean annual precipitation of approximately 1900 mm (Takeda *et al.* 2005; Chan *et al.*, 2016b). The soil type in the study area was classified as "Ultisols" (Takeda *et al*., 2006; Chan *et al*., 2013). The Alfisols soil types were also found in the Bago Mountains in Chapter 2.

The government established the "Karen area" in the late nineteenth century, permitting swidden agriculture for themselves (Fukushima *et al*., 2007). The Karen areas aggregating 2030.55 km^2, has been set aside for the purpose of the Karen communities since the settlement of the Pegu (Bago) Mountains Reserves in 1869 (Fukushima *et al*., 2007). There are 12 Karen villages in the Bago Mountains. Although the local livelihoods relied on the traditional swidden agriculture, and the designated area has been allocated for swidden agriculture since colonial times (Thein and Minn, 2007), permanent agriculture has been introduced in some villages recently a long time ago. The Karen people have practiced swidden agriculture in the selected sites, cultivated their crops for 1 year, and then shifted to another area in the following year. They started to slash the above-ground biomass after the Christmas season and dried it during the period from January to March. Burning was generally conducted after that, before the first rains in April. According to the ground survey, they grow mainly upland rice in swidden fields and lowland rice in permanent paddy fields for their subsistence needs, and grow cotton, sesame, chili peppers, green and black gram as cash crops in both types of fields. In this study, two Karen villages (anonymously SN and KC) of the Bago Mountains were selected for the case studies. The former village was located beside the main road connected to the nearest city while the latter one was far from the road (Figure 3-1). These villages were selected according to the extent of the introduction of permanent agriculture, conditions of swidden cultivation, and accessibility. Administratively, the two villages belong to the Paukkaung Township, the Bago Region (Figure 3-1), and have been there settled since the colonial times, though not notified as official villages because they were in the reserved forest area. However, in 2015, they were notified as such by the Ministry of Social Welfare, Relief and Resettlement. The village territory was covered by forested land and the major forest type was of mixed deciduous including with teak and other commercial broadleaf tree species (Chan *et al*., 2013). Some of the 1-year fallow land areas and reserved clear-cut land for community forest, designated by the Forest Department, are categorized as settlement areas. Other fallow lands are secondary forests dominated by bamboo, especially *Bambusa polymorpha* (vernacularly *Kyathaung-Wa*) and *Bambusa tulda* (*Thaik-wa*). The slope conditions of the target area ranged from 1 to 45 degree in SN village and from 1 to 46 degree in the KC one. The average fallow peroid of the former village was 11 years and 12 in the latter one, respectively, according to our interview survey described later. SN village has 91 households with a population of 482 and KC has 50 with 214 people. Villagers in the 2 villages grow rice both in swidden and paddy fields for their household consumption, and groundnut and other upland crops, shown above, are mainly commercial crops.

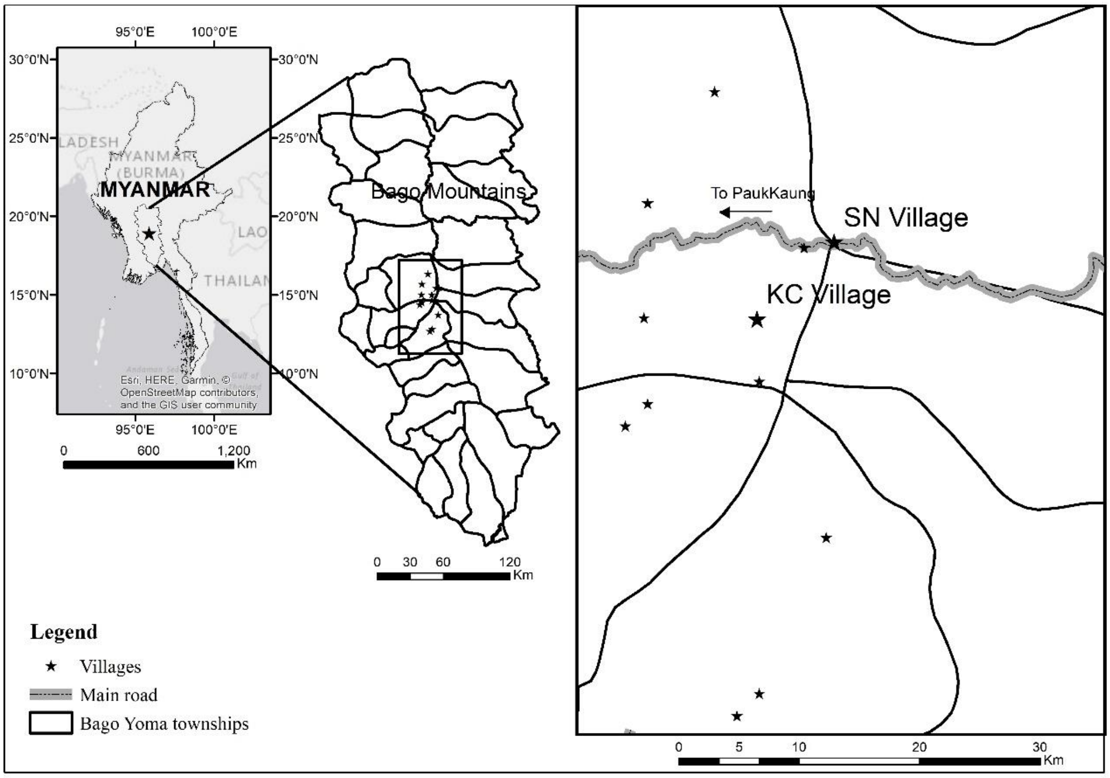

Figure 3-1 Location of twelve Karen villages, including two surveyed villages (large stars) in the Bago Mountains

3.2.2. Mapping agricultural land use

Field observations were carried out during two periods from May to June and November to December 2016, during the burning season and the harvesting season in the villages, explained above. Interview surveys were also carried out to confirm the size of the swidden fields, the swiddeners' agricultural calendar, and fallow period. Two types of permanent agriculture were found in the studied villages: permanent paddy fields (vernacularly, "*le*") and upland fields ("*khone*"). Permanent paddy fields mean paddy fields located alongside streams, and valley and upland fields represent permanently used agricultural land producing upland crops. The boundaries of all the existing swidden fields in 2016 and all the permanent agricultural ones in the two villages were tracked using GPS (GARMIN Darkota 20) in May and June. Mapping for all types of agricultural land use in the villages was done using ArcGIS 10.4 (ESRI ArcGIS). The total area of the shifting cultivation plots and permanent agricultural fields were calculated for each village. Information on other possible land uses such as forest land, bare land (1-year fallow land areas), and clear-cut land area for the establishment of community forests, were also collected as much as possible during the field survey periods.

3.2.3 Developing methods for swidden land use detection

In this study, the classifications with both the NDVI (the normalized difference vegetation index) break value method and the maximum likelihood method were used and specified with the detailed information of ground truth data, after where a final accuracy assessment of the two methods were compared. According to previous studies, the classification with NDVI threshold values was highly recommended to detect the accurate swidden land use at village level (Liao *et al.*, 2015; Takeda *et al.*, 2005; Suzuki, 2009b; Hansen and Mertz, 2006). The maximum likelihood classification is also common in many plot level swidden land use detection (Hansen and Mertz, 2006).

For the NDVI image classification, the range of NDVI break values were determined by the extracted NDVI values from the results of ground truth of all the swidden fields. These values were calculated by using the following equation.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

where NIR and Red mean near-infrared and red band values, respectively. Ground truths played an important role in determining the suitable NDVI values. NDVI images for each village were reclassified with the NDVI break values 0.05 to 0.11 for SN village and 0.05 to 0.15 for the KC one.

In the maximum likelihood supervised classification, swidden fields were separated from the surrounding forest land and village settlement area for both villages by using the ArcGIS (Figure 3-2). Training pixels were selected as much as possible based on the known optical properties for each land use category and field observations. In this study, 430 training pixels for the swidden land use category, 1,510 pixels for forest land and 51 pixels for the settlement area were collected. For the band combination, natural color (432), false color (764), color infrared (vegetation) (543), agriculture (652), vegetation analysis (654), and forest fire burn scars (752) were mainly used for the classification.

A selection of image acquisition dates also played as an important role for swidden land use detection. In order to avoid the lowest existence of similar spectral reflectance of such land to the surrounding forest land, image acquisition dates were selected during the burning season, especially in form March, to May. In this study, therefore, the classifications with the NDVI break values and maximum likelihood method were conducted by satellite imageries taken by Landsat 8 Operational Land Imager (OLI) on April 8, 2016 ("path 133 row 47"). Landsat images are available every 16 days and they can provide data for continuous swidden land use changes. Such images consist of nine spectral bands with a spectral resolution of 30 m from Band 1 to 7 and 9. The resolution of the panchromatic band (Band 8) is 15 m.

3.2.4 Post classification with a suitability model for swidden fields detection

Schmidt-Vogt *et al.* (2009) noted that a better method for accurate swidden land use detection could be obtained by combining demographic data, ethnographic studies, and spatial information databases. After the image classification, the most probable swidden area were specified by using environmental variables in this study. Suitability models, i.e. finding the probable areas for swidden fields integrating the topographic characteristics, sizes and cropping calendar of swidden fields, and interview data, can produce a prospective method for the accurate detection of such fields. Firstly, the elevation values of all these fields were extracted by using a shuttle radar topography mission (SRTM) image and an elevation break value was determined using ground-truth results. The SRTM imagery was also reclassified with the extracted elevation break values of swidden fields in order to discover the specified area for swidden fields. Then, in order to exclude the area beyond the extracted elevation break values in the classified image, the classified raster imageries by both NDVI and maximum likelihood method were specified by a reclassified SRTM image using a weighted overlay tool, an ArcGIS tool that can identify optimal sites for swidden fields. In this study, the land use class, the NDVI break value range and elevation range were used as an input criterion for a weighted overlay analysis. All the criteria, used to find possible areas for swidden, mainly depended on the ground truth. Conditional analysis was carried out to specify the best fit class with actual swidden fields detected by the ground truth among the classes generated by the weighted overlay tool. Then, using the majority filter tool, also one of the ArcGIS tools, the suited sites of swidden fields were extracted and made the classified images smooth. The generated results were confirmed by the size of the swidden fields, with very small polygons (smaller than 0.1 ha) being excluded because swiddeners opened their swidden fields larger than that. The size and shape of their fields were confirmed both by the results of interviews and ground-truth. Areas and shapes are important factors for distinguishing swidden fields in satellite images (Sakai, 2002; Suzuki, 2009b). False detection areas such as permanent agricultural fields in the higher elevation regions were also confirmed with the ground truth and interviews. Moreover, some polygon overlapping with settlement and permanent agricultural areas, were also excluded in this method (Figure 3-2).

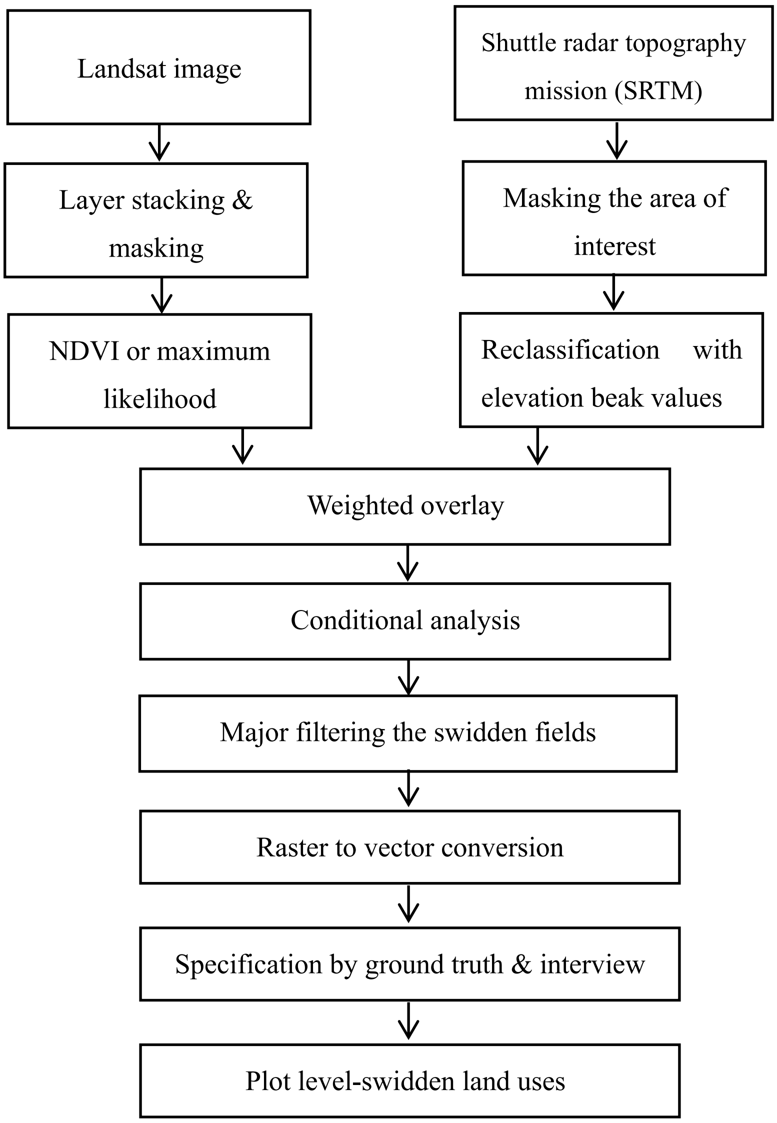

Figure 3-2 Flow chart for the detection of swidden land use for SN and KC villages

3.2.5 Accuracy of the detection of swidden fields from satellite image

In this study, the accuracy of the two developed methods for detecting swidden fields were evaluated based on the ground truth as implemented in that year. The area and the number of swidden plots detected by the developed methods were checked with the ground truth data of swidden fields collected in 2016. Therefore, the actual boundary of swidden fields recorded by GPS, and then were overlaid on the layer of generated swidden plots to confirm the accuracy of the detection method.

Accuracy was assessed by the following equations and the procedures were conducted in each village separately.

$$\text{Accuracy (\%), based on the number of plots} = \frac{100 * \text{total number of accurate detection plots identified by ground truth}}{\text{total detected area (Number of plots)}}$$

$$\text{Area, based on accuracy (\%)} = \frac{100 * \text{total accurate detection area identified by ground truth}}{\text{total detected area (ha)}}$$

False detection (area) = Total detected area – Accurate detection (area)

False detection (Number of plot) = The number of inaccurately detected plots, (in the number of plots, the equation above for the area cannot be applied because sometimes one detected plot included several plots detected by ground-truth.)

Fail to detect (area or the number of plots) = Ground truth swidden fields (area or number of plots) – Accurate detection (area or number of plots)

"False detection" means that the plots or areas were wrongly detected as swidden fields by the developed methods and "fail to detect" means that the developed method failed to detect the actual swidden fields.

3.3 Results and Discussion

3.3.1 Mapping current agricultural land use in 2016

In this study, current agricultural land use maps for two traditional swidden cultivation villages were produced, based on ground truth data. Traditional swidden fields were mainly found around 7 km and 5 km from the center of the village in both villages, respectively, and were in the elevation range between 360 to 440 m ASL in SN village and from 198 to 408 m ASL in KC village. Permanent agricultural fields (including "*khone*" and "*le*") were in both villages (Table 3-1).

All the paddy fields were situated alongside creeks (*chaung*) and valley (*myaung*), and at the bottom of swidden fields. Permanent agricultural fields were mainly found within 4 km from the center of the SN village, and 3 km from KC (Figs. 3-3 and 3-4). They were located at lower elevation than swidden fields, ranging from 340 to 410 m ASL in SN village, and from 195 to 280 m ASL in KC, respectively (Table 3-1).

Table 3-1 Results showing the current agricultural land uses in SN and KC villages

Village name	Swidden fields			Permanent paddy fields			Permanent upland fields		
	Area (ha)	Distance from village (km)	Elevation (m)	Area (ha)	Distance from village (km)	Elevation (m)	Area (ha)	Distance from village (km)	Elevation (m)
SN	94.83	0.1-7	360-440	1.09	ca. 4	340-410	1.35	0.1-5	340-410
KC	46.59	0.5-5	198-408	9.87	ca. 3	195-208	17.27	0.5-3	195-208

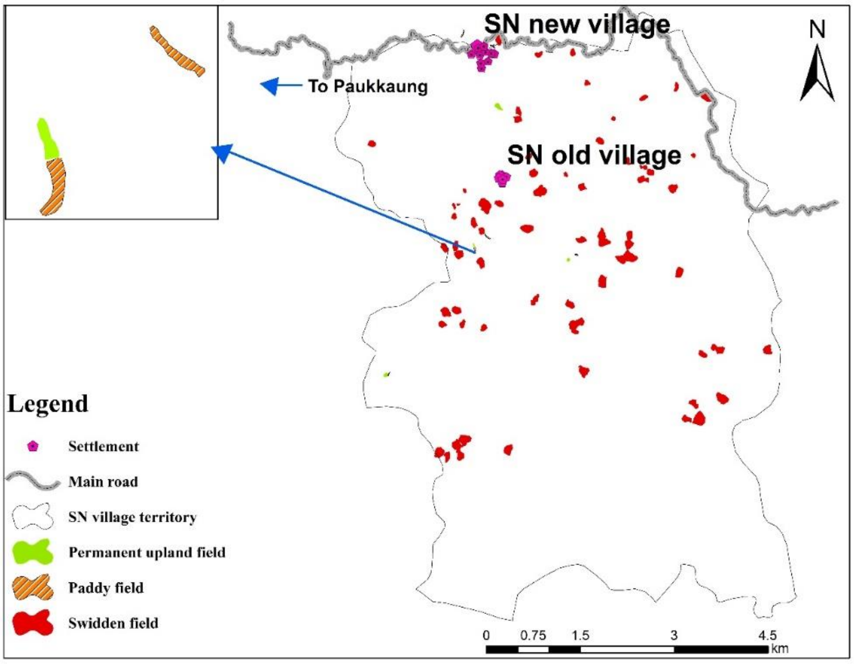

Figure 3-3 Mapping agricultural land uses by ground truth in SN village

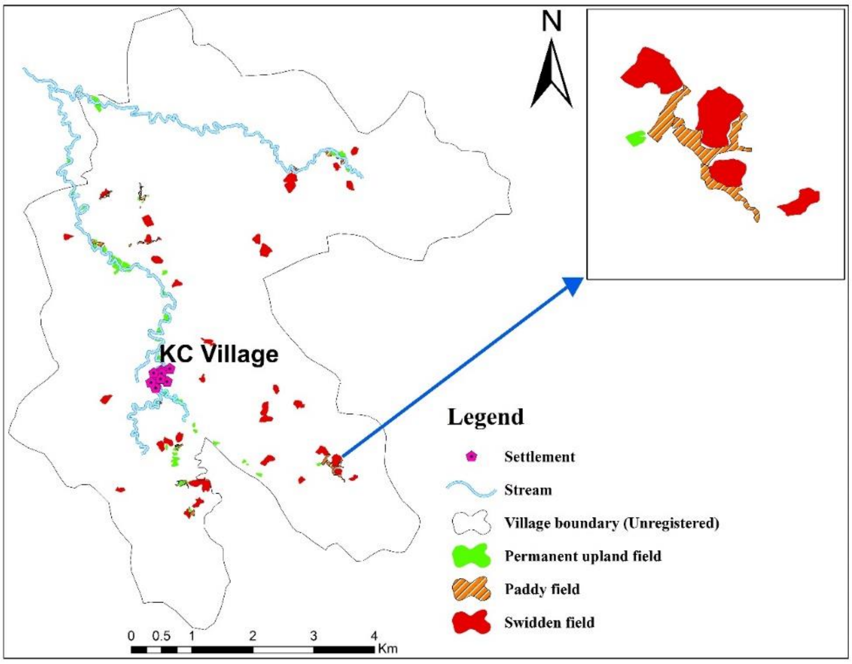

Figure 3-4 Mapping agricultural land uses by ground truth in KC village

3.3.2 NDVI method for swidden land use detection

According to the NDVI classification method, the total swidden area of 94.52 ha (71 plots) was detected in SN village and 47.49 ha (36 plots) in KC (Table 3-2). However, 59.36 (54 plots) ha and 20.04 ha (24 plots) of total generated swidden fields were accurately detected in both SN and KC villages, respectively, by using this method. However, the method could not detect some areas or plots because of the homogeneity of the spatial reflectance of swidden fields with the surrounding forest and bamboo land ("Fail to detect" in Table 3-2 and Table **3-3**). It may be because the swidden fields were not burned completely or had not been burned at all when the images were taken. The result showed that the method could not detect the remaining 24.98 ha (12 plots) and 26.54 ha (11 plots) in either village.

Table 3-2 Results of the NDVI detection method

Village name	Ground truth swidden fields		Area (ha)				Number of plots			
	Area (ha)	Number of plots	Total detected area	Accurate detection	False detection	Fail to detect	Total detected plots	Accurate detection	False detection	Fail to detect
SN	84.34	66	94.52	59.36	35.16	24.98	71	54	5	12
KC	46.58	35	47.49	20.04	27.45	26.54	47	24	12	11

3.3.3 Maximum likelihood method for swidden land use detection

The maximum likelihood method detected swidden fields more accurately than the NDVI one and reduced the false detection in comparison to the later detection method (Table 3-3). The results, of image classification and accuracy assessment in SN village are shown in Table 3-3 and Figs. Figure **3-5**,**Figure 3-6** and Figure **3-7**. This method detected about 86.93 ha (71 plots) and 47.84 ha (36 plots) in the villages, respectively.

Accurately detected swidden areas were 62.5 ha (56 plots) in SN village and 33.79 ha (30 plots) in KC (Table 3-3).

Table 3-3 Results of the maximum likelihood method

Village name	Ground truth		Area (ha)				Number of plots			
	Area (ha)	Number of plots	Total detected	Accurate detection	False detection	Fail to detect	Total detected	Accurate detection	False detection	Fail to detect
SN	84.34	66	86.93	62.5	24.43	8.28	71	58	5	8
KC	46.58	35	47.84	33.79	14.05	1.78	41	30	6	5

3.3.4 Accuracy assessment of the two developed methods

A major challenge for the validation of remote sensing methodology, especially in detecting swidden fields, was a lack of reference data in many previous studies (Heinimann *et al.,* 2017; Li and Feng 2016). In a similar study of swidden land use detection in Northern Laos (Saphangthong and Kono 2009), the UNESCO classification method was conducted from air- and satellite-born images, by using information collected from local people, as well as topographic factors, and a village-level land-cover map was produced but accuracy of image interpretation was not mentioned. The village level swidden land use changes for three decades were also detected from satellite images and a land cover map, and qualitative land use changes were mentioned with no accuracy assessment in Sarawak, Malaysia (Hansen and Mertz 2006). In this study, the final results by the developed method were evaluated with the actual ground truth data collected in 2016. Plots based accuracy and area-based accuracy were calculated for both methods by the equations mentioned previously. The accuracies were calculated using data shown in Tables 3-2 and 3-3.

The accuracy assessment of the NDVI method showed the plot-based accuracy of

76.1 % and the area-based accuracy of 62.8 % in SN village, and 51.1 % and 42.2% in KC village respectively (Tables 3-2 and 3-3). (Liao *et al.*, 2015)) also monitored the spatio-temporal dynamics of swidden land use and swidden intensity, using Landsat TM/ETM+ imageries by the NDVI threshold values with no accuracy assessment. In this study, the accuracy assessment of the NDVI method showed relatively low values when compared to previous results. The reason for this is discussed later.

The results of the accuracy assessment for the maximum likelihood method were better than those of the NDVI method. The main land cover map, including swidden land, forest land, and settlement areas produced by the maximum likelihood supervised classification in SN village is shown in Figure 3-5 and the swidden field map generated by the developed method in SN village was shown in Figure 3-6. The result showed the plot-based accuracy of 81.7 % and area-based accuracy of 71.9 % for SN village and 73.1 % and 70.6% for KC village respectively in 2016 (Table 3-3 and Figure 3-6, Figure **3-7**, Figure **3-8** and Figure **3-9**). In this study, the results of the maximum likelihood method were approved as a proper method for swidden land use detection with the satisfactory accuracy for further time series swidden land use changes in the Bago mountainous area of Myanmar.

Both methods, therefore, could not fully identify ground-truth results, probably because of similar spectral reflectance between swidden fields and abandoned fallow land from previous years. According to the field observation, it is also clear that the vegetation in swidden cultivation fields was not burned very well during the burning phase. Some of the swidden farmers who were busy during that time, did not slash and burn their fields completely. Therefore, the NDVI values of some incomplete burned swidden fields were almost similar to the surrounding forests. Moreover, the spectral reflectance of swidden fields that the methods could not detect, were very similar to the forest land, and the maximum likelihood method did not identify that they were swidden fields. However, this method represented nearly 90% of the actual plots confirmed by the ground truth of 2016, even though the freely available Landsat images with relatively low resolutions were used in this study. Also in the previous study, the complex nature of swidden made it difficult to achieve the accuracy higher than 70% by using these images and the accuracy calculation was rarely carried out for swidden land use detection (Liao *et al.*, 2015; Müller *et al.*, 2013; Padoch *et al.*, 1998; Castella *et al.*, 2013; Saphangthong and Kono, 2009; Hansen and Mertz, 2006).

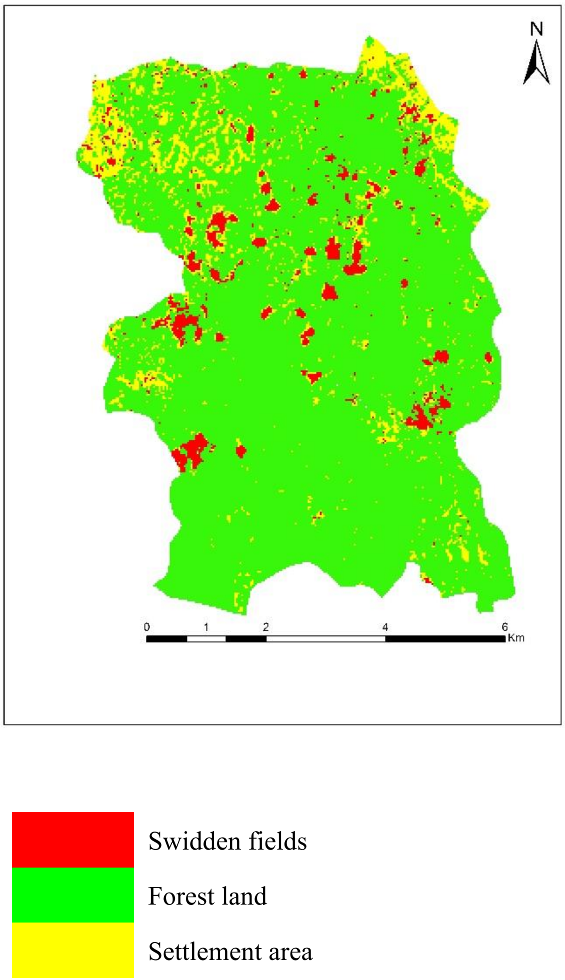

Figure 3-5 General land cover map classified by the maximum likelihood method for SN village

The accuracy of the maximum likelihood method and post-classification with the environmental factors was satisfactory for relatively accurate detection of swidden fields. However, there are some limitations for its applicability. The developed methods could successfully detect these fields if they were well burned during the burning phase. In addition, very small swidden fields were also difficult to detect by the developed method, mainly due to the resolution of the images or those fields were not burned completely when the images were taken. Other possible factors that could have reduced the accuracy of the methods were a tilt of the sensor while taking the images, and an error of GPS. Therefore, the developed methods could not fully detect the whole extent of the swidden fields located on steep lands. However, the nature of the swidden systems originally was that they were practiced in undulating regions and the cultivation fields shifted every year in the Bago Mountains. Therefore, the topographical factors are still challenging for accurate detection of swidden land use. Sakai (2002) also mentioned that the burning and cultivation date of swidden are not uniform for all the fields realistically. Therefore, differences among irregular burning dates of swidden plots and applied image acquisition dates can also reduce the accuracy of detection results. Single image classification cannot detect some of the swidden fields that are not burned on the applied image acquisition date. Such in missing fields, during the burning season, can be replaced by checking them during the harvest season. Therefore, multiple image classifications in one year can increase the accuracy of swidden detection methods in order to check for any missing fields on a particular image acquisition date.

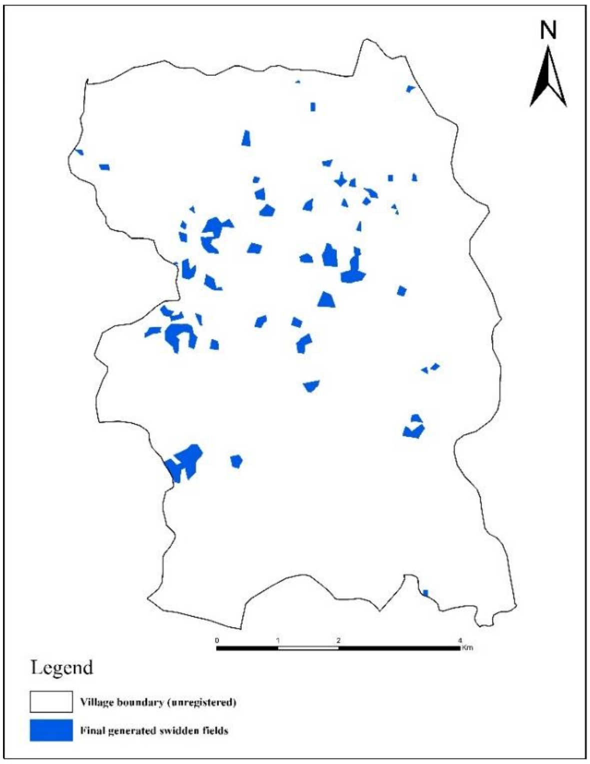

Figure 3-6 Swidden fields generated by the maximum likelihood method in SN village

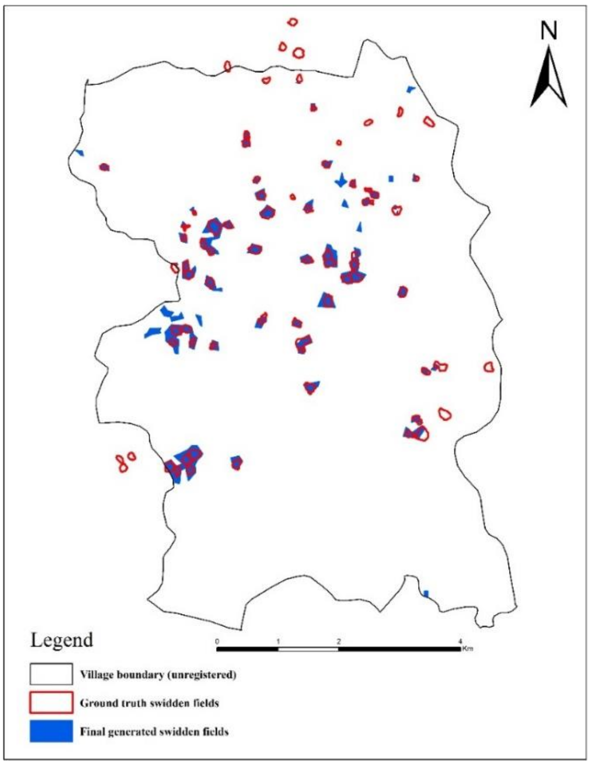

Figure 3-7 Mapping for checking accuracy for SN village

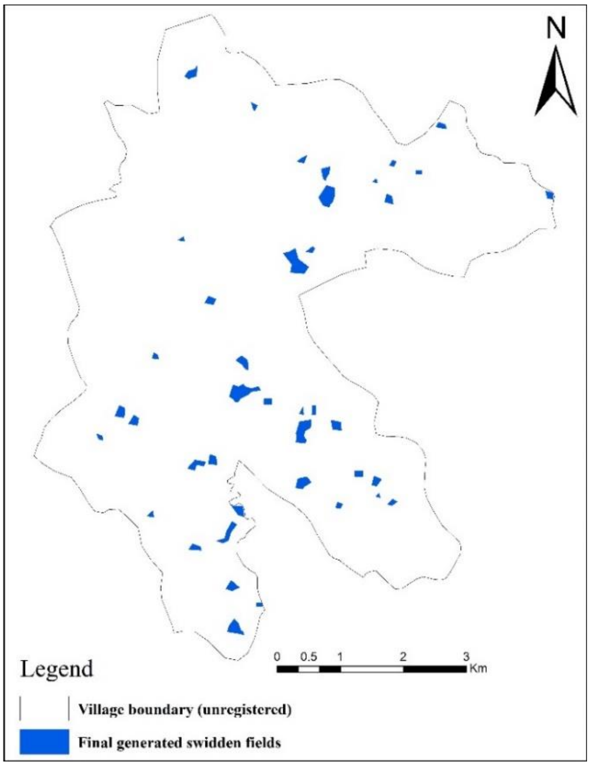

Figure 3-8 Swidden fields generated by the maximum likelihood method in KC village

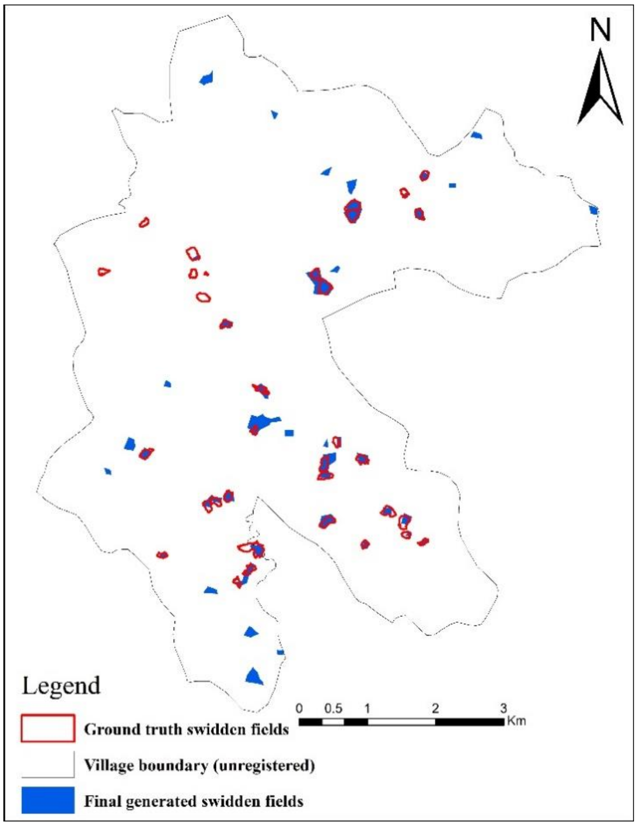

Figure 3-9 Mapping for checking accuracy for KC village

3.4 Conclusions

In this study, a relatively accurate mapping method for swidden land-use detection was established by using freely available satellite images with relatively low resolutions. The method developed in this study detected more than 80 % of the actual swidden plots, enabling them to show changing trends of such fields on sloping land at the local level in tropical countries. Owing to the complexity and dynamic nature of swidden, it is difficult to detect the spectral signature of such plots in steep areas, especially, when swidden fields were not burned completely during the burning phase, it is difficult to clearly identify such plots. Compared to previous remote sensing-based studies for such detection using low-resolution images, this method revealed the better accuracy to identify these swidden fields for the further time-series swidden land use detection in sloping areas.

CHAPTER 4 CHANGING PRACTICES FROM SWIDDEN TO PERMANENT AGRICULTURE IN TRADITIONAL SWIDDEN CULTIVATION AREAS-CASE STUDIES IN THREE KAREN VILLAGES OF THE BAGO MOUNTAINS, MYANMAR

4.1 Introduction

Swidden is an old agricultural system, and the common features of swidden agricultural systems are clearing a patch of vegetation by a slash and burn method, growing different varieties of crops in the cleared land for one or two seasons and then moving to a new plot of land on a rotational basis (Rasul and Thapa, 2003). Nowadays, a number of drivers of the changes in swidden agriculture in SEA, have been mentioned in many previous researches, including political and economic pressures as well as economic opportunities and incentives (Cramb *et al.*, 2009; Fox *et al.*, 2009; Castella *et al.*, 2013; Chan and Takeda, 2016).

Swiddening was regarded as a smallholder practice, and national policies in all the countries of SEA have tried to mitigate the swidden agriculture and encourage the swiddeners to adopt the permanent agriculture (Padoch *et al.*, 2007; Castella *et al.*, 2013). The persistence or demise of swidden agriculture are being debated among the governments and academia. Padoch *et al.* (2007) assessed the demise of swidden agriculture and confirmed the disappearance of swidden in many parts of mainland SEA. Government policies in northeast India have attempted to replace the swidden with other land uses (Teegalapalli and Datta, 2016) and has still been trying to change into forest plantation in the fallow land area. Rapid decrease of swidden land and replacement of swidden with permanent cropping have occurred in the mountainous mainland of SEA (Rerkasem *et al.*, 2009).

In addition, all those swidden transformations are clearly related in complex ways to many aspects of changing local livelihoods such as the in-and out-migration, political factors, social factors and the introduction of innovative technologies engaged with markets. Cramb *et al.* (2009) categorized the political driving factors for swidden transformation into four groups; 1. outright prohibition, 2. prohibition without permit, 3. prohibition in certain classes of land especially in reserved forest and protected areas, and 4. tenure-related disincentives such as the non-recognition of customary land use right of swiddens combined with securing land ownership to permanent commercial agriculture. Boserup (1965) theorized that demographic trends (population growth, population decline, and in- and out-migration) also induced the agrarian transition in the upland areas. Similar studies were conducted in the central Highlands of Vietnam, where lowlander's immigration to the upland areas induced the intensification and commercialization of swidden into permanent agriculture (Cramb *et al.*, 2009). Cramb *et al.* (2009) and Mertz *et al.* (2009) also discussed the swidden land use changes and those changes have led to both the decline of swidden farming and the changes in livelihoods security and environmental sustainability. Cramb *et al.* (2009) also explored the major interactions in the swidden land use changes and recognized the farmer's adaptation to these changes. Swiddeners were adopting new practices, but in many situations swidden is still an important safety net to their livelihood strategies (Cramb *et al.*, 2009).

Swidden in the Bago Mountians is also going into extinction, and has been replaced with permanent agriculutre under increasing political, social and dempgraphic pressures accoring to the field survey conducted by the authors. Swidden agriculture was regarded as the constraints of the forest policy imperatives by the Ministry of Forestry (1996), as shown in the Forest Policy 1995, "discourage shifting cultivation practices, which are causing extensive damages to the forests ...". Thus, the Ministry of Natural Resources and Environmental Conservation has tried to mitigate the swidden cultivation and transformed the fallow land of Karen swiddeners into community forests according to the guidance of the Community Forest Instruction 1995.

In addition, Myanmar has experienced a period of political and economic transition since 2011 and, meanwhile, the Farmland Law 2012 and the Vacant Fallow and Virgin Lands Management Law 2012 were enacted to transform the old laws into modernized ones governing agricultural lands. However, customary land use rights over swiddeners were not addressed in the rules of these two laws (Ennion, 2015). But the permanent farmland is officially recognized as a land use category in the Farmland Law 2012 in contrast to swidden. Therefore, swiddeners started to introduce the permanent agriculture on the available flat land area in order to secure their future food consumption. However, due to the topographic conditions in the Bago Mountains, flat land availability is very limited in some Karen villages. Therefore, food security, and land use sustainability for the Karen swiddeners are urgently needed to be considered.

Based on these situations, this study was conducted to explore how newly introduced intensified agriculutre influence the existing swidden system and its contribution to the local livelihoods need. The specific objectives of this study were to determine the influences of permanent agriculture on the extent of swidden agriculture, to clarify the influential factors for the introduction of permanent agriculture and to assess how is the contributions of permanent agriculture to local livelihoods.

4.2 Materials and Methods

4.2.1 Study area

This study was conducted in the Bago Mountains, located at the elevation of 250–450 m above sea level with the mean annual temperature of about 27°C, and the mean annual precipitation of approximately 1,900 mm (Takeda *et al.*, 2006; Chan *et al.*, 2016). The soil type in the study area is classified as Ultisols (Takeda *et al.*, 2006; Chan *et al.*, 2013). The Bago Mountains are the home to Karen people, where the Karen swiddeners have been practicing the traditional swidden agriculture since many centuries ago (Chan *et al.*, 2016). They slash and burn the vegetation and typically relies on a large number of crops, planted both simultaneously and successively with the long cropping cycle.

There are 12 Karen villages in the Bago Mountains. In this study, three Karen villages (anonymously recorded as SN, KC and GS) of the Bago Mountains were selected as sample villages according to the extent of the introduction of permanent agriculture, conditions of swidden agriculture and accessibility (Figure 4-1). The main livelihood in SN and KC villages was traditional swidden agriculture even though permanent agriculture was introduced. In GS village, permanent agriculture became their main livelihood since long time ago. The villagers from all three villages mainly grow the upland rice in swidden fields. They grow lowland rice in the permanent paddy fields only one time in a year for their subsistence needs, and cotton, sesame, chili pepper, groundnut, cowpea and green gram in both swidden and permanent upland fields as cash crops in all three villages.

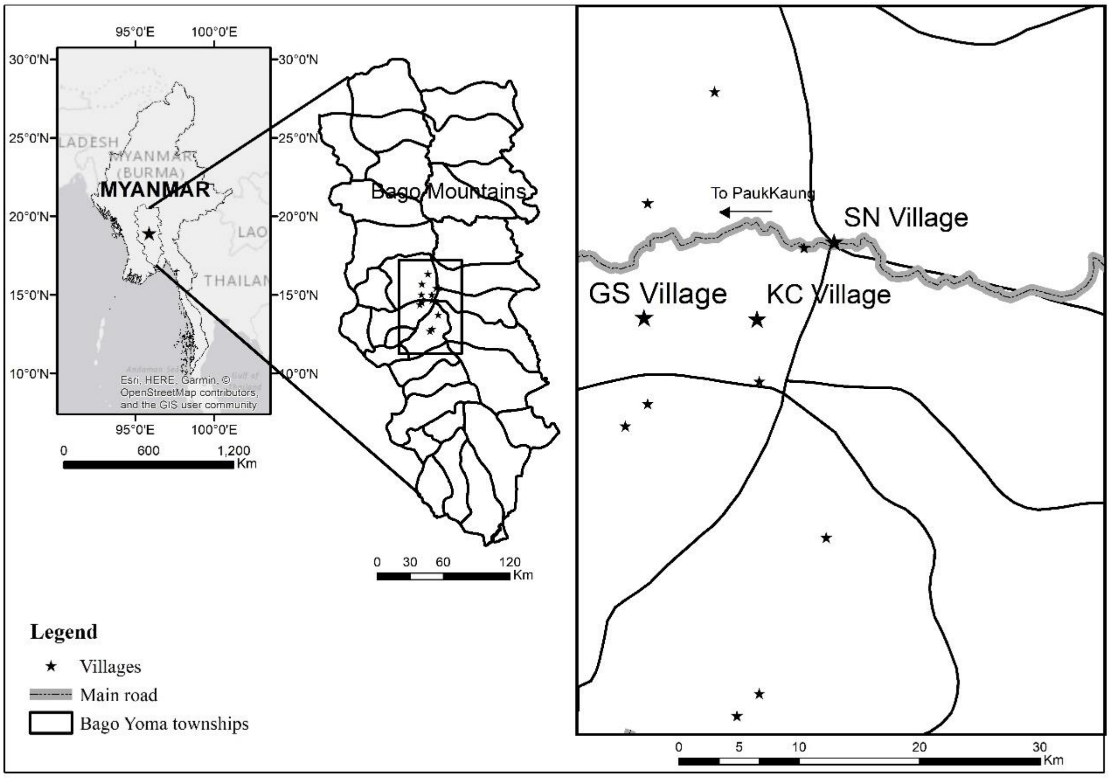

Figure 4-1 Location of Karen villages including 3 surveyed (large stars) and 9 other neighboring Karen villages (small stars) in the Bago Mountains.

4.2.2 Data collection and analysis

Based on the accurate ground truth data, a method for swidden land use detection from the satellite images was developed in our previous work (Swe and Nawata, 2019) and accuracy was confirmed by the actual data. The validity and applicability of the applied method were mentioned in our previous work (Swe and Nawata, 2019). Village boundary for the SN and KC village were determined depending on the number of compartments that are allowed for practicing swidden by the forest department. Compartment means the management unit for timber extraction in the Bago Mountains reserved forest. In the case of the GS village, the actual boundary was traced with the GPS with the help of villagers. Subsequently, time series swidden land uses were detected using satellite images by the developed method to determine the influence of introduced permanent agriculture on the extent of existing traditional swidden agriculture. The validity and applicability of the applied methods were mentioned in our previous work. Ground truth data and socioeconomic data collection was carried out twice in three villages. In the preliminary survey, complete household interviews were conducted during the period from May to June 2016, and in the second time, interview surveys focusing only on the households engaged in the permanent agriculture were carried out during the period from November to December 2016. The questionnaire was designed for four main areas, namely general information about the households, agricultural land use history, income and rice contribution from each land category, and the underlying causes of changing practices from swidden to permaent agiriculture. Although the detailed surveys were conducted, only the directly related data to this study were shown in the results and discussion. A binary logistic regression analysis was also carried out to clarify the social influential factors that may cause the introduction of permanent agriculture. In addition to political factors, changes of swidden land use into more intensive permanent agriculture may also be associated with social factors. A complex set of socio-economic, demographic, institutional and biophysical factors influence farmers' decision to adopt or reject innovative technologies at any time (Boundeth *et al.*, 2012). Practicing permanent agiculture was considered as a dependent varible (dummy variable) influenced by the seven independent variables including : family Size (X1), number of male labors available for agricultural activities (X2), household's head education level (X3), household's head age (X4), rice sufficiency (X5), number of cattles/household (HH) (X6), and the participation in community forestry programme (X7) (Table 4-1). The logistic regression model has more advantages than probit models, and can overcome the problem of violating the assumption of linearity (Boundeth *et al.*, 2012; Asrat *et al.*, 2004). The Wald statistics (values) indicated the relative importance of the contribution of each explanatory variable in the model. The higher the value, the more important it is (Mon *et al.*, 2012; Chan, 2004). The odd ratio (Exp B) explains increased or decreased likelihood of the occurrence of the event (Mon *et al.*, 2012). Therefore, a unit increase of the odd ratio of each explanatory variable may result in more higher tendency in the increse of practicing permanent paddy fields in this study.

Table 4-1 Characteristics of independent variables selected for the logistic regression model

Independent Variables	Unit	Variable Type
Family Size (X1)	Number of person	Continuous
Number of male labors(X2)	Number of person	Continuous
Household's head education (X3)	Education level	Categorial 0 = Illiteracy 1 = Primary School 2 = Secondary School 3 = High School
Household`s head age (X4)	Year	Continuous
Rice sufficiency (X5)	Dummy	"1" for the rice sufficient households, "0" for the insufficient households
Number of buffalo / HH (X6)	Number of buffalo	Continuous
Practicipating in community forestry programme (X7)	Hectare	Continuous

4.3 Results and Discussion

4.3.1 Past land use detection

4.3.1.1 Swidden transition in SN village

Past agricultural land uses were detected from the satellite images acquired during the period between 2000 and 2016 in SN village. In SN village, the total swidden area in 2000 was detected as 153.46 ha and an abrupt decrease of 76.90 ha was observed in 2010 (Table 4-2). However, the population of the village showed an increasing trend from 2000 to 2016 (Table 4-2). On the other hand, the number of swidden plots decreased, and total area and average size of swidden plots also gradually decreased from 2000 to 2016 (Table 4-2).

Increase in the popultaion in SN village from 2009 to 2016 could be a possible factor for swidden transformation (Table 4-2). There is a similar phenomenon for this sort in SEA: in Indonesia and Northern Laos, where the demogrophic pressure forced the swiddeners to make new investnment in wet rice cultivation and this may lead to the demise of siwddening (Boserup, 1965; Cramb *et al.*, 2009; van Noordwijk *et al.*, 2008; Mertz *et al.*, 2009 and Rekarsem *et al.*, 2009).

Table 4-2 Swidden fields, its extents and swidden demography over 2000 to 2016 in SN village

Year	Population	No. of HH	No. of swidden plots	Total area of swidden plots (ha)	Average plot size (ha) ± SD	Minimum Size (ha)	Maximum Size (ha)
2000	350+	64	66	153.46	2.32 ± 1.92	0.13	8.03
2009	408	75	60	134.42	2.24 ± 1.46	0.36	5.44
2010	414	82	58	76.90	1.33 ± 1.21	0.05	6.48
2013	447	86	77	90.99	1.18 ± 1.20	0.14	5.45
2014	459	88	81	89.20	1.10 ± 0.74	0.37	5.68
2015	470	86	69	90.98	1.32 ± 1.25	0.14	7.94
2016	482	91	76	94.80	1.25 ± 0.65	0.11	3.37

Source: Time series satellite image analysis from 2000 to 2016 in SN village.

According to the interview survey, the average fallow peroid of SN village in 2016 is 11.2 year. According to the Takeda *et al.* (2006), the fallow periods in SN village were about 17.9 years in 2002, 15.1 years in 2003, and 12.8 years in 2004. Therefore, it is shown that the average fallow peroiod of SN village after the introduction of permanent agriculture in 2009 were slightly decreased when compared to the period before the introduciton of the permanent agriculture. It can be assumed that the fallow period has already been shortened before the introduction of the permanent agriculture, probably because of the limited land availability for swidden agriculture. Another possible reason is that SN village still have enough land available to maintain such a long fallow period. However, as the Forest Department converted the fallow land into the community forest recently, there may be a possibility of the demise of swidden because one of the main targets of 30-year Forestry Master Plan of 2001-02 to 2030-31 was to achieve 919,000 ha of the community forest by 2030; it was 1.36% of the country area (Tint *et al.*, 2011). Thus, swiddeners in the Bago Mountains were eager to introduce permanent agriculture in order to secure their future food production, when the Government fully prohibits the swiddening. Therefore, the main cause of swidden transformation may be the policy pressure by the Forest Departnment to reduce swidden agiruclutre and to establish the community forest plantations in the fallow land area. It induced the less land availability for the swiddeners to practice their traditional swidden agriculture. Rekarsem *et al.* (2009) also mentioned that the pressure on the land has resulted in shorter fallow periods and lead to the permanent cropping and paddy developnment for wetland rice cultivation in Indonesia and the Philippines. The expansion of forest areas such as reserved forests, the rise of conservation zones for the timber production and biodiversity conservation zones by the Forest Department have also affected swidden agriculture in SEA (Fox *et al.*, 2009).

Another possible factor for a decreasing trend of swidden fields from 2000 to 2016 was probably flowering of *Bambusa tulda* in the Bago Mountains. The fallow lands in the Bago Mountains forests are the bamboo-dominated secondary forests, especially by the

B. polymorpha and *B. tulda*. According to the interview survey, Bamboo flowering occurred in 2006 and 2010 in the Bago Mountains reserved forest and the abundant food resource of bamboo seeds made the rodent population increase consequently. Rodent outbreaks generally cause chronic losses to the production in the traditional upland rice farms. Similar claims of annual pre-harvest losses in rice production by rodents' outbreaks were also found ranging from 5 to 10% yield reduction per annum in Asian countries: Bangladesh, Cambodia, People's Republic of China, India, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Thailand, and Vietnam in 1996 (Singleton *et al.*, 2004).

According to the interviews, the swidden cultivators in SN village started to open paddy fields in 2009 and upland fields in 2012 (Figure 4-2). Though the small extent of permanent agricultural area (nearly 3 ha) was found after 2009 in SN village (Figure 4-2), the number of households who engaged in permanent agriculture have been gradually increased from 1 HH in 2009 to 13 HHs in 2016 (Figure 4-3). According to the Farmland law 2012, the advantage of permanent agiruclture for securing the land use right and land ownership certificate approved by the Government, some of the swiddeners in SN village were trying to open the permanent agricultural fields, such as the paddy field "*le*" and upland field "*khone" or "dah-yan-khin*". The neglection of the customary land use right of the siwddeners by the Government is a major cause of the decline of swidden fields and has been commonly found in the mainland SEA (Ennion, 2015; Cramb *et al.*, 2009; Fox *et al.*, 2009).

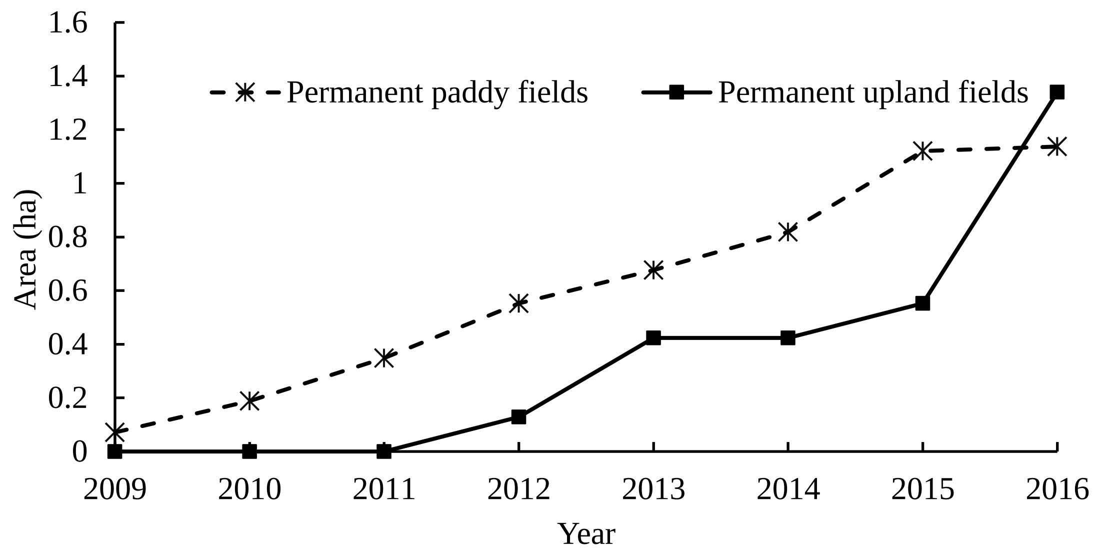

Figure 4-2 An increasing trend of permanent agriculture in SN village (2009-2016).

Source: Data from interview survey in 2016

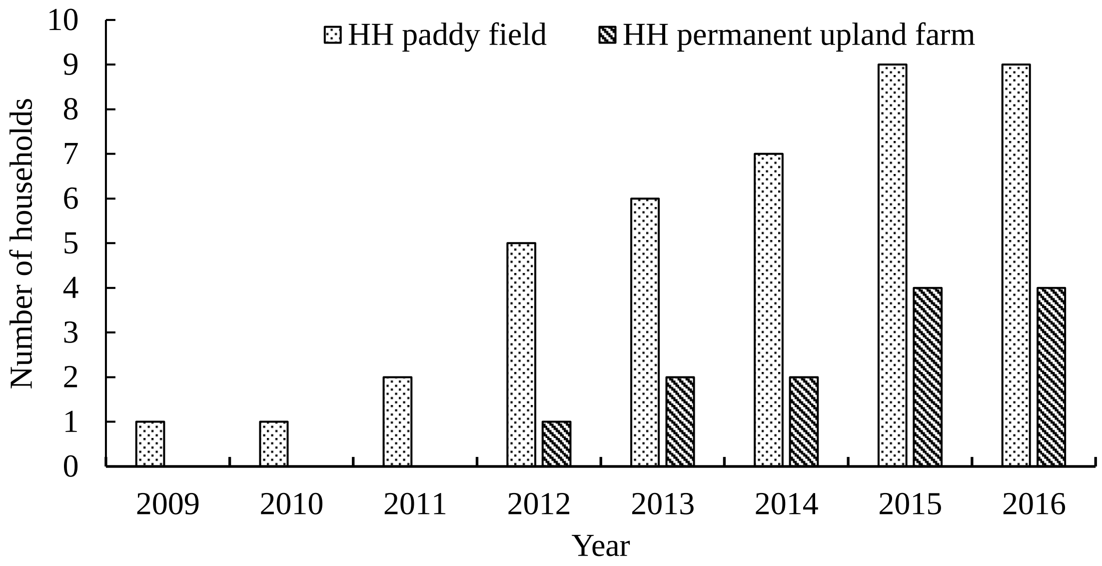

Figure 4-3 Changes in permanent agriculture-engaged households in SN village during the period from 2009 to 2016

Source: Data from interview survey in 2016

4.3.1.2 Swidden Transition in KC Village

In KC village, swidden plots were detected during the period from 1990 to 2016 to assess the influence of the introduction of permanent agriculture on the extent of swidden agriculture (Table 4-3). The detected swidden area reached nearly 100 ha in 2006 and 2009, probably because of the significant increase of population in 2006, compared to the population in 1990. Although 30 HHs with the population of 140 opened 41 swidden fields of 51.29 ha in 1990, 50 HHs with the population of 214 opened 35 swidden fields of 46.59 ha in 2016 (Table 4-3). Even though the village population increased from 1990 to 2016, the total area of swidden fields and the average size of swidden fields gradually decreased (Table 4-3. According to the satellite image analysis and interview results, the total area of paddy fields gradually increased until 2008, and sharply increased from the year 2010 (Figure 4-4). In case of upland field, an increasing trend was also found in KC village (Figure 4-4). According to the interviews to villagers, there was only one HH engaged in paddy field, and two HHs practiced permanent upland fields in 1992, but in 2016, over half of the total HHs in KC village were practicing permanent agriculture (Figure 4-5).

Table 4-3 Swidden fields, its extents and swidden demography over 1990 to 2016 in KC village

Year	No. of HH	Population	Number of Swidden Plots	Total Area of Swidden Plots in ha	Average Plot Size ± SD	Minimum Size (ha)	Maximum Size (ha)
1990	30	140	41	51.29	1.29 ± 0.59	0.34	3.02
1991	32	152	32	70.05	2.19 ± 0.99	0.51	4.12
2000	33	142	37	77.72	2.10 ± 1.68	0.69	7.93
2006	38	176	36	94.08	2.62 ± 1.97	0.74	7.39
2009	38	176	31	98.51	3.18 ± 1.88	1.06	7.74
2010	37	178	39	76.52	2.02 ± 0.87	0.77	3.90
2013	42	198	37	64.67	1.75 ± 0.88	0.63	3.94
2014	46	204	44	47.73	0.43 ± 0.65	0.27	2.41
2015	48	211	33	47.33	1.44 ± 1.56	0.71	2.73
2016	50	214	35	46.59	1.33 ± 0.73	0.11	4.04

Source: Time series satellite image analysis from 1990 to 2016 in KC village

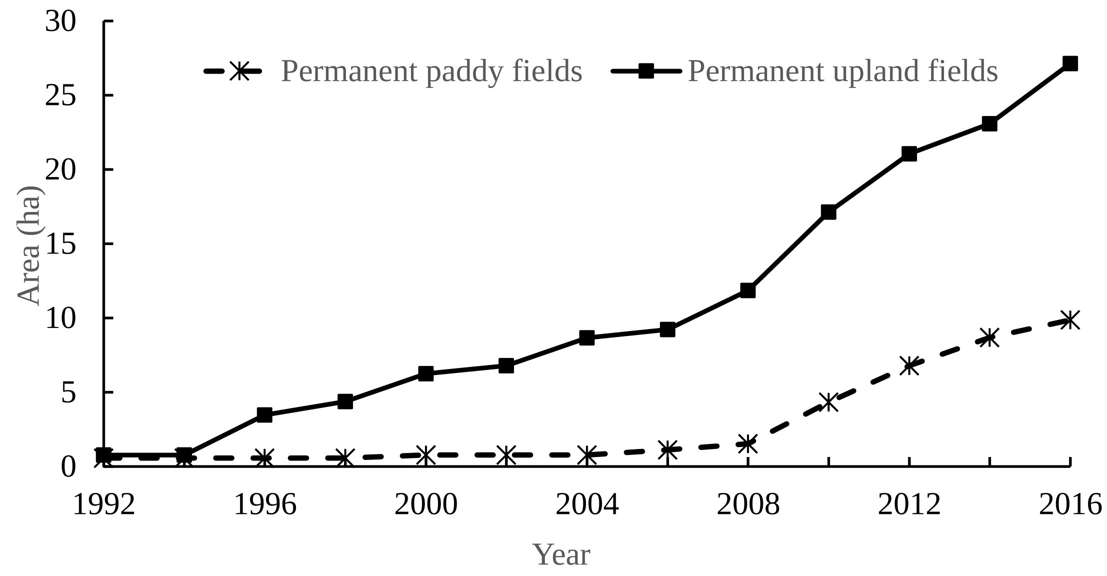

Figure 4-4 An increasing trend of permanent agriculture (ha) in KC village (1992-2016)

Source: Data from interview survey in 2016

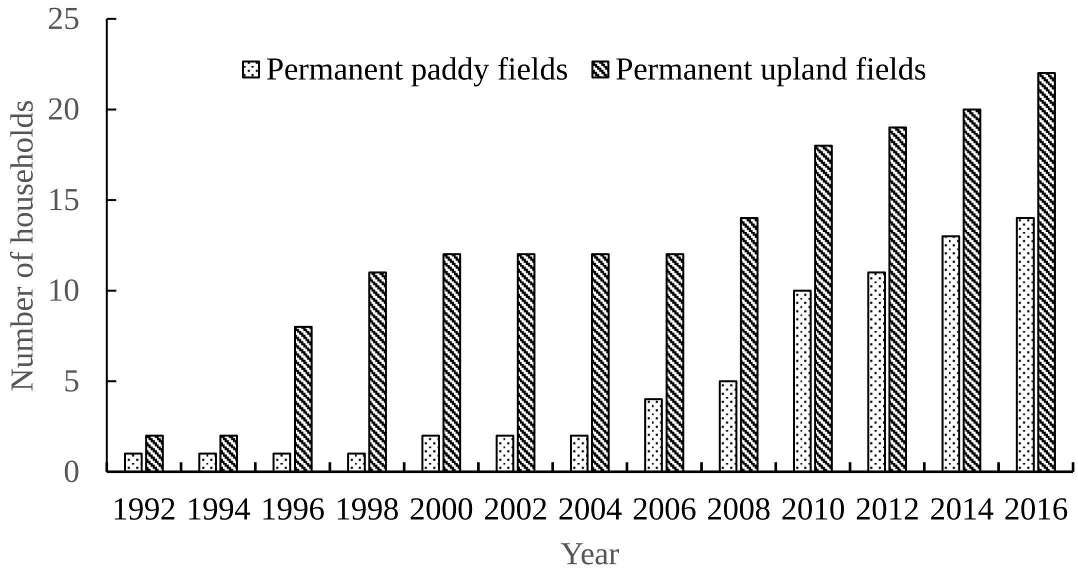

Figure 4-5 Changes in permanent agriculture-engaged households during the period from 1990 to 2016 in KC village

Source: Data from interview survey in 2016

The driving forces of swidden transformation in KC village seem to be similar to those occurred in SN village, but another significant factor is that some women in KC village got married with men from lowlands, where permanent agriculture dominated. According to the Karen tradition, men must stay together with their housewives' family after they got married with Karen women. Therefore, getting married with lowlanders is also likely to disseminate lowland farming technologies (especially for paddy production) in traditional swidden cultivation areas.

Cramb *et al.* (2009) mentioned that the immigration of lowlanders into upland area reduced the area available to each HH for swiddening and ultimately changed into permanent cropping in Cabayugan, Philippine. Local highlanders adopted the lowland farming technologies, especially the use of plough, brought by these immigrants (Cramb *et al.*, 2009). Also, in this study, it was revealed that swiddeners gradually exchanged the lowland farming technologies with the lowlanders, who came to the forest plantation sites near their villages as plantation workers hired by the Forest Department, and also sometimes by travelling to lowland areas and getting married with the lowlanders. However, the HHs without any relationships with lowlanders needed to work together with the lowlanders for some years, so that they could learn the technologies for practicing permanent agriculture.

4.3.1.3 Demise of Swidden in GS Village

Demise of swidden was found in GS village. According to the interview survey, most of the villagers completely relied on the traditional swidden cultivation during the post-colonial time till around mid-1970s. After the country had gained the independence, governmental actions started to increase more rice production by giving incentives to the farmers such as the remission of debts, the introduction of low-interest loan, and security of land tenure (Win, 1991). The Government provided the low-interest loans to the farmers depending on the paddy field areas they practiced and approved land use rights only for the paddy fields. Therefore, by getting the low-interest loan from the Government, the swidden cultivators in GS village were trying to open the paddy fields near the creek, valley and streams, where water is available. Consequently, villagers form GS village opened the permanent paddy fields around 17 ha in 1980 and stable increasing trend was found from 1980 to 2016 (Figure 4-6). On the other hand, GS village was located outside the reserved forest area and villagers got the customary right to cultivate the paddy rice around their village. Later in 2015, villagers got the official land use certificate approved by the Government.

In the case of upland field (locally called *dah-yan-khin*), a sudden increase of permanent upland fields was found during the period from 1980 to 1985 (Figure 4-6), because a Chinese sugar factory was established near the GS village in 1984, and the swidden cultivators were starting to open the upland fields in relatively flat land areas to grow sugarcane. Meanwhile, the South Nawin Water Reservoir, the second largest water reservoir in Myanmar, was constructed around 1983, and the local people had to give up their farmland in the planned inundated area of the Reservoir. Consequently, the lowlanders, who lost their agricultural land for the construction of water reservoir, grabbed the land originally belonged to GS villagers and triggered the land grabbing problem among the lowlanders and swiddeners. Therefore, GS villagers tried to change all swidden fields into permanent upland fields to protect their lands against the land grabbing by lowlanders. They used the same land for the next year to maintain their land around the vicinity of the village and tried to get their private land title. Since that time, all the swidden fields have been changed into permanently used upland fields without fallow periods (Figure 4-6). In 2003, earthen road from GS village to Paukkaung city, where the nearest market was located, was completed, and the villagers were trying to intensively grow the cash crops after that. It could also be one of the possible reasons for upland fields to be maintained at rather large area from 2005 to 2016 (Figure 4-6). Therefore, the main factors of swidden transformation in GS village were agricultural land use policies at different times, land grabbing by lowlanders in the South Nawin Water Reservoir construction site, and accessibility to the crop market.

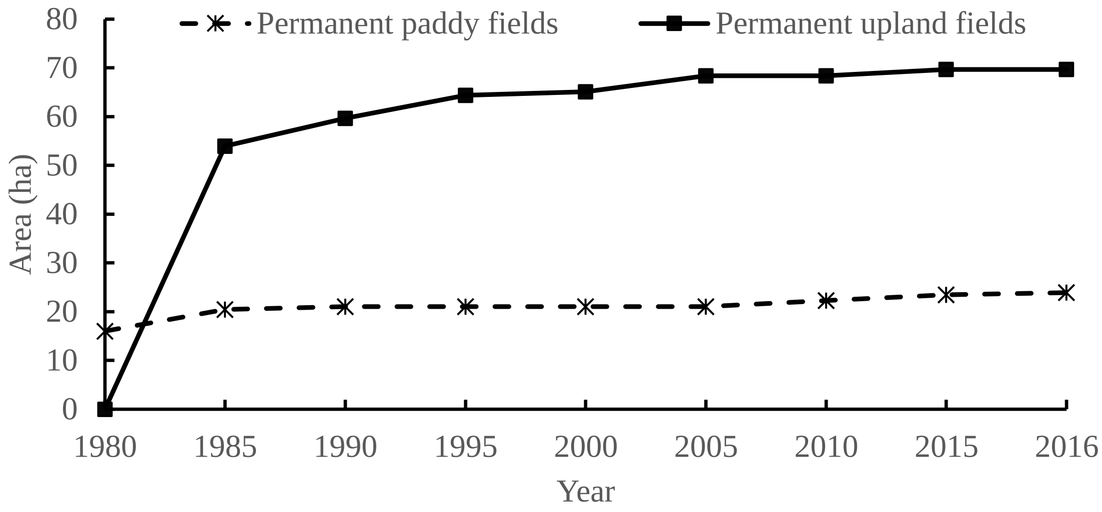

Figure 4-6 An increasing trend of permanent agriculture in GS village (1980 – 2016)
Source: Data from interview survey in 2016

4.3.2 Social drivers for practicing permanent agricultre

According to the result of a binary logistic regression analysis, three of the seven variables showed a significant relationship with the swidden changes into permanent agriculture. The model showed that a unit increse of the number of male labour may have resulted in the increse of practicing permanent agriculture by a factor of 2.122 (Exp (B), Table 4-4), because it is so laborious to open the permanent agricultural fields by digging soils near the valleys, and swiddeners have to prepare paddy fields by blocking the natural water ways. The Boserup (1965) also described that preparation for permanent agricultural fields is rather time consuming and laborious in contrast to the nature of swiddening practice. In the Philippines uplands, farmers' decisions to adopt the innovative farming technology were also associated with an increased workload for men (Cramb and Culasero, 2003; Cramb *et al.*, 2009; Grigg, 1979; Nielsen *et al.*, 2006). However, many comparative studies between the long-fallow swidden and permanent agriculture concluded that the labor input per unit area of crop harvested is higher than that of permanent agriculture (Hunt, 2000; Padoch, 1985).

Table 4-4 Socioeconomic factors for practicing permanent agriculture in the logistic regression model in the three villages

Independent Variables	B	S.E.	Wald	df	P.	Exp (B)
Family Size (X1)	-0.202	0.117	2.991	1	0.084	0.817
Number of male labors for agricultual activites (X2)	0.752	0.274	7.533	1	0.006*	2.122
Household's head education (X3)			1.191	3	0.755	
Primary School (1)	-0.858	1.084	0.626	1	0.429	0.424
Secondary School (2)	-0.784	1.101	0.462	1	0.497	0.473
High School (3)	-1.166	1.154	1.021	1	0.312	0.312
Household's head age (X4)	-0.006	0.016	0.132	1	0.716	0.944
Rice sufficiency 1 (X5)	-0.896	0.404	4.908	1	0.027*	2.449
Number of cattles/ HH (X6)	0.287	0.09	10.14	1	0.001*	1.332
Participating in community forest programme (X8)	0.048	0.324	0.022	1	0.883	1.049
Constant	-0.615	1.298	0.225	1	0.636	0.540

Source: Data form interview survey in 2016

Moreover, rice sufficiency index (X5) showed that the negative relationship with the independent variable. The model showed that HHs with enough rice production have a lower tendency for practicing permanent agriculture by the factor of 2.449 (Table 4-4). In fact, households with less rice sufficiency had a higher possibility to produce more rice from the permanent agriculture in addition to the production in swidden fields for their self-consumption. It also can be said that swidden could not secure the rice production for the swiddeners. According to Mon *et al.* (2012), the highest Wald value indicated the strong and important variable for the likelihood of intensity of dependent variables in logistic regression. Hence, the number of cattle per HH also showed the strong positive relationship with the dependent variable by the factor of 1.332 with the Wald value of 10.14 in the present model, because cattle are very crucial agricultural inputs for practicing permanent agriculture.

4.3.3 Contribution of the permanent agriculture to the local livelihoods

Income contribution percentage of the permanent agriculture to the households' total income of swiddeners in each village were calculated in order to determine the contribution of permanent agriculture in the livelihoods of the villagers. Even though the interview survey was carried out in 2016, rice production and consumption data were available only for 2015. The detailed information of cash income souces and its contribution percentages were shown in Table 4-5. Contribution percentages of each income source were calculated as follows:

$$\text{Contibution of income category (\%)} = \frac{100\ *\ \text{Individual income category}}{\text{Total household's income}}$$

Swiddeners in the SN and KC villages have a larger extent of swidden areas and highly depend on the siwdden agricultre. However, SN village is located just beside the road connected to the nearest cities and the accessibility of this village is better than that of KC village, so that villagers have more opportunities to get the alternative incomes such as selling bamboo and other off-farm income sources. In the case of KC village, swiddeners have two agricultural income sources from both swidden and permanent agiruclutre because larger permnent agirucltural fields were found than those in SN village. In GS village, demise of siwdden was found and their main livelihoods totally rely on the permanent agriculture.

Table 4-5 Household annual cash income in Kyats in 2016 in SN, KC and GS villages

Village	Income Categories	No. of HH	Average Income (±SE) (Kyats)	Income Range (Kyats)	Contribution % to total income
SN Village	Swidden Income[1]	65	319,265 ± 27,395	7,000 - 900,000	43.7
	Upland Farm Income[2]	0	0	0	0
	Bamboo Income[3]	25	139,920 ± 20,822	8,000 - 400,000	7.37
	Animal Husbandry[4]	64	93,070 ± 12,770	5,000 - 600,000	12.6
	Other Income[5]	23	749,869 ± 132,727	60,000 - 2,400,000	36.3
KC village	Swidden Income[1]	35	242,014 ± 33,815	36,000 - 930,000	36.0
	Upland Farm Income[2]	11	242,700 ± 45,713	72,000 -500,000	10.3
	Bamboo Income[3]	0	0	0	0
	Animal Husbandry[4]	34	98,058 ± 11,037	5,000 - 310,000	14.2
	Other Income[5]	12	776,667 ± 160,110	180,000 - 2,400,000	39.6
GS Village	Swidden Income[1]	0	0	0	0
	Upland Farm Income[2]	22	866,659 ± 115,711	207,000 - 2,360,000	84.6
	Bamboo Income[3]	0	0	0	0
	Animal Husbandry[4]	21	63,929 ± 14,088	5,000 - 210,000	6.00
	Other Income[5]	4	535,000 ± 99,343	200,000 - 720,000	9.49

Income are measured in Kyats (1,300 Kyats ≈ 1 USD).

[1]income from selling crops cultivated in swidden fields (cotton, chilli pepper, sesame, and banana)

[2]income from selling crops cultivated in permanent upland farm (groundnut, sesamne, green gram, blackgram, and pigeon pea)

[3]income from selling bamboo

[4]income from selling pig, piglet, and chicken

[5]income from non-farm job (grovernment staff, resturant worker, carpenter, car spare, etc.)

Source: Data form interview survey in 2016

Contribution of permanent upland fields to the agricultural income is also calculated in the three villages. Table 4-6 showed that the agricultural income mainly comes from the swidden agriculture in SN village, about 20% of agricultural income from the permanent agriculture in KC village, and all agricultural income from the permanent agriculture in GS village.

The total amount of rice harvested from each field was also measured by counting the number of baskets and converted into kilogram (kg) in three villages in order to compare the rice sufficiency for each village. The largest number of rice sufficient HHs were found in GS village, followed by KC and SN village (Table 4-6), probably because the largest area of permanent agriculture fields, especially paddy fields, was found in GS and it significantly contributed to the local rice production.

Table 4-6 Contribution percentage of swidden and permanent upland fields to total agricultural income and rice sufficiency in SN, KC and GS villages in 2015

Contribution Percentage to total Agricultural Income and Rice Sufficiency	Village		
	SN	KC	GS
Contribution percentage of swidden to agricultural income	100	78	0
Contribution percentage of permanent upland fields to agricultural income	0	22	100
Percentage of households with rice sufficiency	42	59	84

Source: Data form interview survey in 2016

4.3.4 Conclusions and policy implications

The satellite image analysis and mapping results showed that increasing trends of the permanent agriculture in all the three villages led to a decreasing trend of swidden agricultural area in SN and KC villages and demise of swidden was found in GS village. Those agrarian transition were mainly related with topographic conditions, land use policy, population changes, and labour availability. In SN village, small extent of the permanent agricultural land was found and almost all the households still have to rely on the swidden. In KC village, even if large areas of permanent agricultural lands were found, their contribution to local livelihoods was relatively small. Consequently, the rice production from the swidden fields were not sufficient for the swiddeners in those villages. However, the introduced permanent agriculture significantly contributed to the total households' income and rice sufficiency in GS village.

Based on the results of this study, policy implications will be provided as follows. In this study, most of paddy fields were found along the streams, and some are opened by blocking the natural waterways. Therefore, rather than opening the new permanent paddy field inside the natural water way, agricultural intensification including the introduction of the technologies with environmentally friendly farming techniques is urgently needed not only for the rural development but for the protection of the natural ecosystems. For this, further research will be conducted especially identifying soil conditions, topography and climate of the Bago Mountains. Infrastructure development for the market accessibility is also prerequisite in remote areas like KC village, because the contribution of permanent agriculture is still limited even though their permanent agricultural fields are increased recently. Additionally, territorial boundaries for swidden practice and land use ownership for permanent agriculture are supposed to be assured for the swiddeners. Finally, to implement above-mentioned recommendations, the collaboration and cooperation among the aligned departmental institutions are also important for the establishment of the sustainable development of swiddeners.

CHAPTER 5 AGRICULTURAL TRANSITIONS AND LIVELIHOOD DIVERSIFICATION IN PAUNGLAUNG TOWNSHIP, SOUTHERN SHAN HIGHLANDS, MYANMAR

5.1 Introduction

Globally, different scenarios of agrarian transitions, the rapid evolution of agricultural systems, farmland abandonment have been reported in several previous studies (Labao and Meyer, 2001, Kanazawa *et al.,* 2006, Vanwambeke *et al.,* 2006, and Arvor *et al.,* 2012). Drastic changes in agricultural land use and agrarian transition increasingly growing in mountainous areas in mainland Southeast Asia (Cramb *et al.*,2009, Castella *et al.*, 2013, Swe and Nawata, 2019). Agrarian transition and rural livelihoods of farmers in the forest diversified into off-farm activities mainly concerned with the local government`s policy, forest conservation activities, and complex land tenure systems in Myanmar. In Mato Grosso, Brazil, agrarian transitions such as the crop expansion with the commercial crops and the ecological intensification with non-commercial crops were also reported by (Arvor *et al.,* 2012). Mostly, agrarian transitions in rural sectors were leading to cash cropping in accordance with the market demand (Vanwambeke *et al.,* 2006). The Boserup agrarian change theory (1956), theorized the agrarian transition in terms of demographic trend (in-out migration) in upland areas. Agrarian transition in this study will highlight the structural changes in both upland and lowland farm and livelihood changes after the village relocation because of hydropower dam construction.

Since the 1950s, dams have been considered as key to a country's development by contributing to water supply, irrigation, and energy generation (Galipeau *et al.,* 2013). Presently, about 16% of the global energy requirements are met by hydropower dams

(Morimoto, 2013). Around two-thirds of the world's large rivers have been impounded with dams (Finer and Jenkins, 2012). Asia, also, is a major region of hydropower development (Morimoto, 2013). Several studies have found that dams induce significant environmental and socioeconomic impacts on the local communities (Galipeau *et al.*, 2013; Beck *et al*., 2012; Kirchherr and Charles, 2016; Rousseau *et al.,* 2017, and Yankson *et al.,* 2017). Manyari and de Carvalho (2007) and Chen *et al.* (2015) reported the environmental impacts of large-scale hydroelectric projects in the Amazon region, which include interruption of the natural streamflow, deforestation, and forest degradation. Besides, land use and land cover changes caused by dam construction, especially in primarily agricultural landscapes, have impacted farmers living near construction sites. This was documented in the case of the Manwan hydropower dam in China; the dam caused a significant reduction in forest cover and farmlands being submerged under reservoirs (Zhao *et al.,* 2010). Moreover, forced displacement and farmland loss were major problems induced by hydropower dam constructions in Sri Lanka and west Java in Indonesia (Manatunge *et al.,* 2009). Relocation and farmland loss due to hydropower dam construction have been frequently observed in China, Sri Lanka, and Vietnam, as reported by Galipeau *et al.,* (2013); Rousseau *et al.,* (2017); Zhao *et al.,* (2010); & Jackson and Sleigh, (2000).

For instance, economic development projects of Myanmar focused only on national development severely impacted local communities. These impacts include human rights violations and adverse effects on livelihoods, food security, and health (Physicians for Human Rights, 2015). Rampant economic growth has led to the establishment of hydropower dams to meet the increasing demand for electricity required by industries and factories.

Paunglaung hydropower dam was built in 2013 to supply electricity to the capital of Myanmar with the aid of Chinese, Swiss and British firms (Physicians for Human Rights, 2015). Villages adjacent to the dam site were relocated to the surrounding mountainous areas, resulting in loss of land possession and displacement of local communities. The World Commission also recognized dam construction as an important issue in sustainable development and developed a strategic assessment to mitigate socio-environmental impacts caused by dams (Finer and Jenkins, 2012). However, assessing the spatial changes and socioeconomic conditions of relocated villages after dam construction is not well-documented in Myanmar. For the Paunglaung dam, too, there is no proper strategic assessment of the spatial and socioeconomic changes in circumstances after its construction. In this context, examining the considerable impacts, changes in livelihood and faming system, and investigating the linked factors for new adoption strategies are essential for future rural development and sustainability.

I examined the agrarian transitions after the Paunglaung dam construction. I also investigated the socioeconomic conditions before and after dam construction and clarified the livelihood strategies of local farmers subsequent to dam construction to aid implementation of sustainable agricultural land use planning and ensure their food security.

5.2 Materials and Methods

5.2.1 Study sites

Paunglaung reserved forest, occupying 163,551 ha, is situated in Pinlaung Township of Taunggyi District, in the Southern Shan State of Myanmar (Fig. 5-1). The area is undulating and hilly with an elevation of 900–2,000 m above sea level; it is covered by evergreen and upper-mixed deciduous forests. The mean annual temperature is 27°C and the mean annual precipitation is ~1,000 mm that occurs mostly between May and October.

The Paunglaung multi-purpose dam is located on the Paunglaung approximately midway between Myanmar's capital, Naypyitaw, and Pinlaung town. Its construction, which commenced in 2003, was completed in 2013 and led to submergence of 9,708 acres, including 23 villages that were relocated to a designated site nearby. The affected villages were collectively renamed as Paunglaung Myo Thit. The main ethnic group of this area is Burma, but other ethnic minorities (such as Karen, Chin, and Kayah) are also present. The majority of local people in this area mainly grow turmeric in swidden fields and some people are doing rubber, beetle nut plantation and fruit tree orchards.

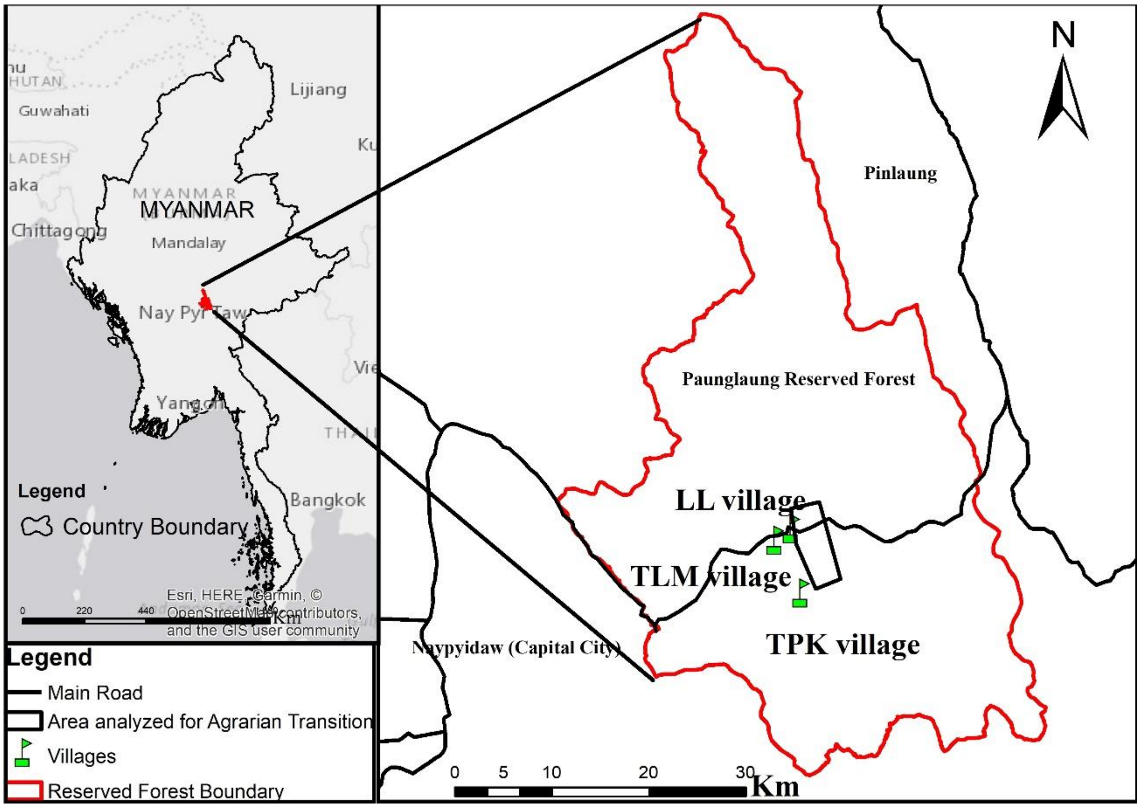

Figure 5-1 Paunglaung Reserved forest in the Southern Shan State (160,500 ha)

5.2.2 Mapping agrarian transition due to hydropower dam construction

I collected ground data to map swidden, fruit tree orchards, plantations, and lowland paddy fields using GPS (GARMIN Darkota 20). Field data collection was carried out four times viz. November-December in 2018; January and February; May and June 2019; September and October in 2019). First, I carried out manual delineation of lowland paddy fields and settlements area was carried out with the help of Google Earth image archives and ground-truthing. Subsequently, these delineated areas were masked out to avoid confusion with the young aged orchards, plantations and swidden fields.

I applied maximum likelihood methods to classify the agrarian transitions and land cover change of the entire reserved forest. Freely available Landsat images (30 m resolution) taken in January 2011 and February 2018 were used for mapping the spatial changes of reserved forest. To detect agrarian transition, especially the changes in upland swidden fields and lowland permanent lowland paddy fields, I utilized high-resolution Geo-eye images (1.6 m resolution) acquired in January 2011 and February 2018. For the latter I particularly focused on the 25 km^2 area covering the agricultural lands of three villages selected as samples. Imagery dates were selected considering the time of dam construction, image availability, cloud cover, and harvest season to avoid possible confusion in the spectral reflectance between swidden fields and permanent farmland with the surrounding orchards and forests. Land use mapping was done using ENVI 5 and ArcGIS 10.6 (ESRI) software.

I overlaid the classified images with the farmland (masked areas) and categorized six land cover classes viz. open forest, closed forest, farmland, roads and settlement, water body, and bare land. For the agrarian transition, the GeoEye images for the 25 km^2 focal area were classified into five land cover classes for 2011, while for 2018, the newly introduced orchards and plantations were taken as an additional category. I subsequently conducted post-classification, e.g., refinement with topographic factors. The final classified images were smoothed with a 3x3 majority filter tool, "boundary clean" tool, and "nibble tool" in ArcGIS software (Fig. 5-2).

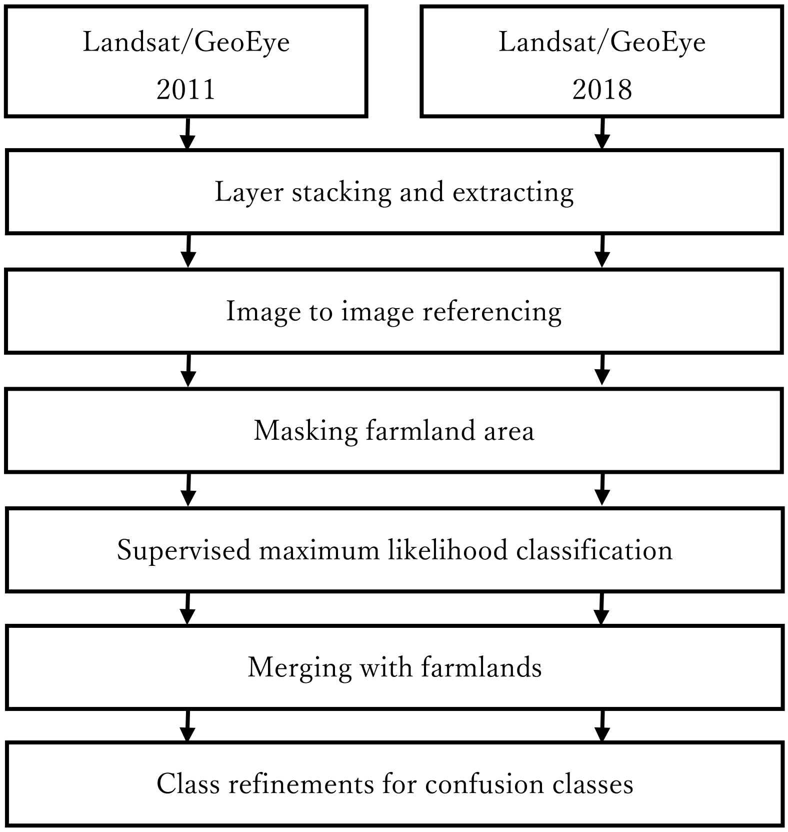

Figure 5-2 Workflow of image classification

5.2.3 Accuracy assessment for image analysis

I carried accuracy assessment of land cover classification using the confusion matrix, and comparison between the reference data and the corresponding results of the classification. Here, I used ground truth data for the 2018 images as reference data. Accuracy checks for the 2011 images were computed with Google Earth and topographic map obtained from the Forest Department. I computed overall accuracy, producer and user accuracies, and kappa coefficient of each classified map (Table 5-1) and conducted detailed accuracy assessment agrarian transition maps (Appendix-1).

Table 5-1 Accuracy assessment for the land cover change map of Paunglaung reserved forest and agrarian transition map of 25 km^2 area from 2011 and 2018

Classified Images	User Accuracy%	Producer Accuracy%	Overall Accuracy%	Kappa Coefficient%
2018 Agrarian transition map	88	85	92	0.89
2011 Agrarian transition map	91	91	92	0.90

5.2.4 Socioeconomic survey and data analysis

Out of the 23 relocated villages, I selected a sample of three, anonymously recorded as TLM, LL, and TPK, for socioeconomic assessment according to the research objective and accessibility (Fig. 5-1). In-depth interview surveys were conducted and interviewed 52, 38 and 32 respondent households of LL, TPK, and TLM, respectively, which corresponded to 30% of the total households. LL and TLM were located on the main road connecting Naypyidaw and Pinlaung town, while TPK was ~ 5 km away from the main road (Fig. 5-1). These villages were located inside the reserved forest and were listed as illegal encroached villages before dam construction. Therefore, those villages were under the administration of the Forest Department before dam construction. The Ministry of Natural Resources and Environmental Conservation had tried to mitigate the swidden cultivation area of those villages and transformed into community forests. After the dam construction, those 23 villages were collectively renamed as "Paunglaung Myo Thit" and notified as official villages by the Ministry of Social Welfare, Relief and Resettlement.

I carried out interview surveys, including focused group discussions and key informant interviews four times (November–December in 2018, and January–February, May–June, and September–October in 2019). The questionnaire covered five main topics:

agrarian transition after dam construction, general information about the household's profile, agricultural land use history, household income, and rice yield from each land category, including costs and benefits of each agricultural land use.

Data on 18 socioeconomic variables was collected (Table 5-2) and descriptive statistics were calculated (N=122 households). I assessed the relationship between contributed income sources and annual household income as Spearman's rank-order correlation.

Average total household income was compared from the three relocated villages from this study and that of five villages in the previous study (Cho, 2018) by using the one sample t-test. Those villages were assumed to be existed before dam construction as a control.

I also conducted principal component analysis (PCA) on ten selected variables to explore their inter-relationships and summarize the multiple variables to understand the underlying pattern of socioeconomic conditions in the three villages. PCA is considered useful for summarizing multiple variables based on particular characteristics (Maung and Yamamoto, 2008). I extracted the prominent factors for each component by using the Varimax rotation option in SPSS software. PC scores derived from the principal components were analyzed to calculate Fisher's Least Significant Differences (LSD) to determine the differences in farmers' adapted income strategies among the three villages. Households were stratified into three wealth status groups based on total income, and income share were compared among groups. Finally, the quantity of rice purchased annually by each household from the market was converted into monetary value and compared with the total annual income. I then estimated the ability of each household to buy rice (hereafter termed as 'rice sufficiency') by comparing household-wise rice production and consumption.

Table 5-2 Characteristics of socioeconomic variables

Variables	Unit	Variable Type
Household member (V1)	Number of persons	Continuous
HH head's age (V2)	Number of persons	Continuous
Number of children (V3)	Number of persons	Continuous
Rubber plantation ha in the year of 2018 (V4)	hectare	Continuous
Income from rubber plantation† (V5)	Kyats	Continuous
Income from fruit tree orchard‡(V6)	Kyats	Continuous
Income from swidden§(V7)	Kyats	Continuous
Income from NTFPs¶(V8)	Kyats	Continuous
Non-farm income††(V9)	Kyats	Continuous
Income from animal husbandry‡‡(V10)	Kyats	Continuous
Swidden field area in the year of 2018 (V11)	hectare	Continuous
Fruit tree orchard area in the year of 2018 (V12)	hectare	Continuous
Rice consumption (V13)	kilogram	Continuous
Total income (V14)	Kyats	Continuous
Paddy field area in the year of 2018 (V15)	hectare	Continuous
Fuelwood consumption (V16)	Cubic meter (m^3)	Continuous
Number of male labors (V17)	Number of persons	Continuous
Household's head education (V18)	Education level	Category 0 = Illiteracy 1 = Primary School 2 = Secondary School 3 = High School

†income from selling rubber; ‡income from selling the fruit harvested from fruit tree orchards; §income from selling crops cultivated in swidden fields (turmeric); ¶income from selling NTFPs (elephant-foot yam, Bamboo shoots, orchids, broom grass); ††income from non-farm job (hired labor, governmental staff, restaurant, carpenter, bus car conductor, merchant, shopkeeper, timber trading, and hiring motorboat, and hotel); and ‡‡income selling from pig, piglet, and chicken

5.3 Results

5.3.1 Agrarian transitions

Notably, the area of farmland showed a sharp reduction within seven years because farmlands were submerged under the expanded water bodies according to the results of satellite image analysis of the dam area. Farmland extent of 788 ha, 1,361 ha of settlements, and 304 ha of bare land was changed into water bodies. Analyzing the increase in water bodies vis-a-vis other land use categories after dam construction showed that 1,602 ha of closed forest area and 641 ha of open forest area was converted into water bodies (Fig. 5-3).

Agrarian transition detected with GeoEye for the 25 km^2 focal area revealed that the area of farmland showed a sharp reduction of from 11% to 1% within seven years because farmlands were submerged under the expanded water bodies. (Fig. 5-4, Table 5-3). Notably, the area of swidden showed the remarkable decrease from 13% to 7% within 7 years, and most of the swidden fields were found near settlement areas, along the reservoir and near the newly established rubber plantations and fruit tree orchards in 2018. Area under permanent agriculture decreased sharply due to submergence under the increasing water bodies after dam construction. Conversely, newly introduced orchards and plantations were detected in 2018 images, and these were mainly established by swiddeners near their turmeric swidden fields (Fig. 5-4, Table 5-3). Finally, transition analysis showed that the settlement area increased from 2011 to 2018.

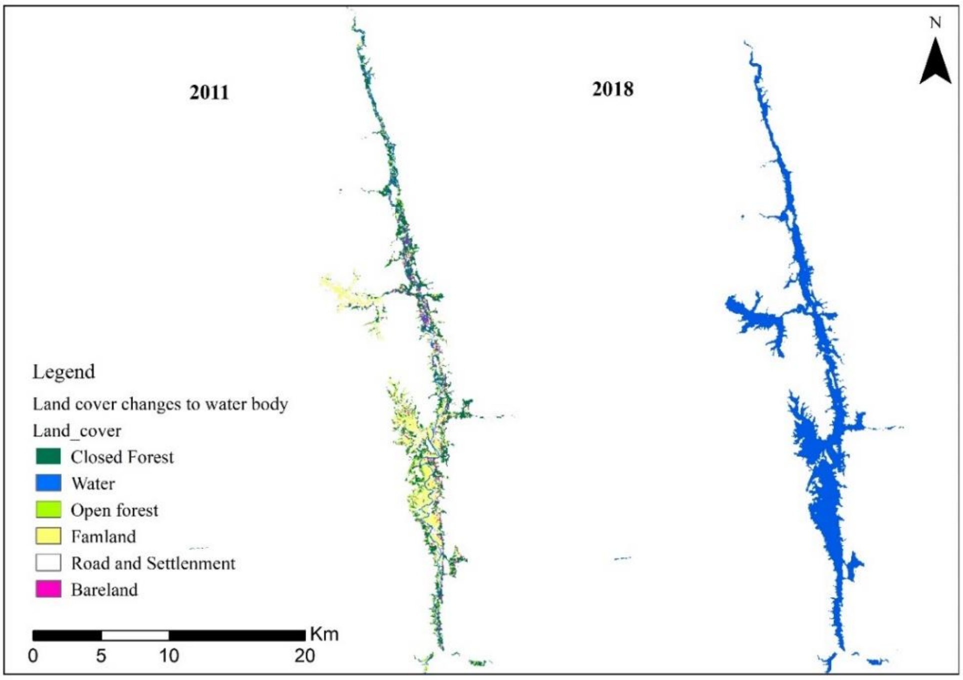

Figure 5-3 Land cover changes to water body from 2011 to 2018

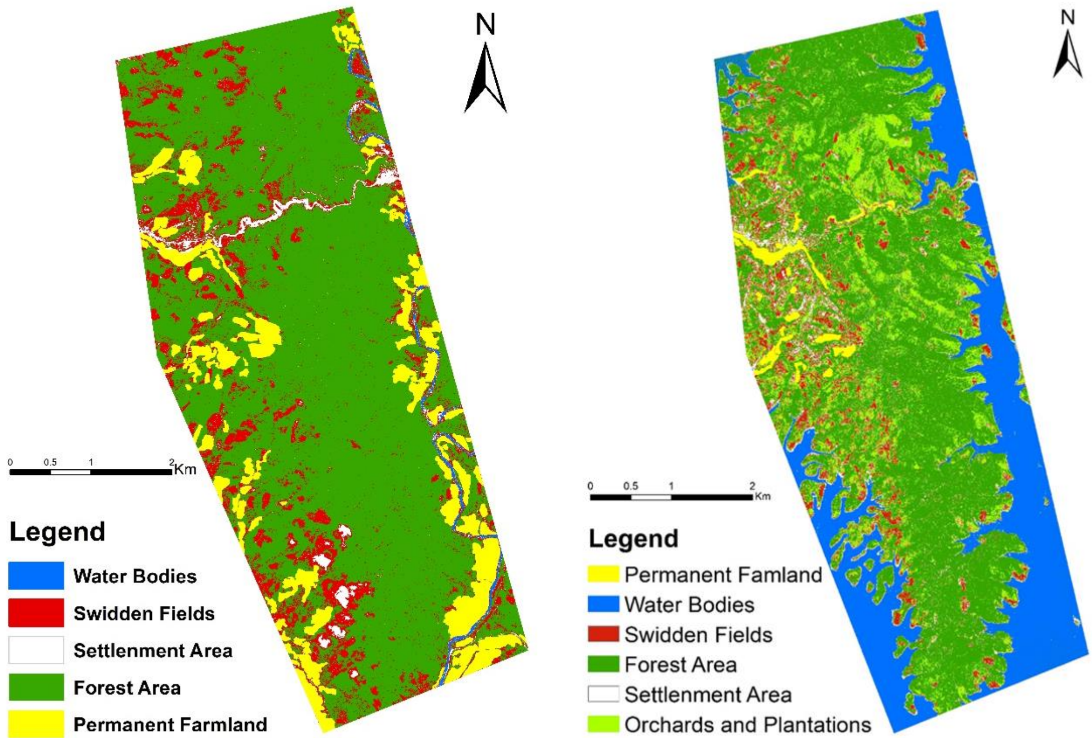

Figure 5-4 Map showing the agrarian transition from 2011 to 2018

Table 5-3 Results of agrarian transitions from 2011 to 2018

Land use/cover categories	2011		2018		Change in 2011–2018	
	ha	%	ha	%	ha	%
Swidden fields	330	13.12	185	7.35	(–)145	(–)5.77
Permanent farmlands	278	11.05	35	1.41	(–)242	(–)9.64
Forest areas	1,842	73.19	1,208	47.99	(–)634	(–)25.18
Settlement areas	48	1.92	136	5.39	(+)87	(+)3.47
Water body	18	0.72	588	23.39	(+)570	(+)22.67
Orchard & Plantations	0	0	364	14.47	(+)364	(+)14.47
Total	2,517	100	2,517	100		

Source: Data obtained by Satellite Image analysis

5.3.2 Socioeconomic conditions after dam construction

According to the interview responses from 122 households in 2018, the average area of paddy field was 0.15 ha, and the average rice consumption per household per annum was 704.65 kg (Table 5-4). The average total income in 2018 was 2,688,613 Kyats (Ks) per household (1 USD = 1,400.3 Ks, according to the Central Bank of Myanmar on 17.4.2020). Rubber plantations and fruit tree orchards (FTO) that were introduced after the dam construction, on an average contributed 15,082 Ks and 68,391 Ks, respectively. The average area of the swidden extent per household was 1.57 ha, with an average contribution of 842,295 Ks per household. Average income from the collection of non-timber forest products (NTFPs) and animal husbandry was 206,893 Ks and 55,214 Ks, respectively (Table 5-4). The income contribution from non-farm activities was relatively high, i.e., 837,811 Ks in 2018. The average family size per household was 4.35, while the average number of laborers and children was, respectively, 4.34 and 1.13 per household. The average consumption of fuelwood was 10.25 m^3 per household in the year of 2018 (Table 5-4).

Table 5-4 Descriptive statistics of socioeconomic variables in three relocated villages in 2018 (n = 122)

Descriptive statistics of socioeconomic variables in three relocated villages in 2018 (n = 122)

Variables	Average Income (Kyats)	Standard Deviation	Range
Household member (V1)	4.35	1.41	2–9.00
HH head's age (V2)	45.84	12.57	24–75.00
Number of children (V3)	1.13	1.05	0–5.00
Rubber plantation hectare in the year of 2018 (V4)	0.61	2.79	0–25.00
Income from rubber plantation[1](V5)	1.5×10^4	8.4×10^4	$0–6.00\times10^5$
Income from fruit tree orchard[2] (V6)	6.8×10^4	1.5×10^5	$0–8.00\times10^5$
Income from Swidden[3] (V7)	8.4×10^4	7.8×10^5	$0 – 5.00\times10^6$
Income from NTFPs[4] (V8)	2.0×10^5	4.9×10^5	$0 – 4.00\times10^6$
Non-farm income[5] (V9)	8.3×10^5	1.0×10^6	$0 – 6.30\times10^6$
Income from animal husbandry[6](V10)	5.5×10^4	1.3×10^5	$0 – 1.00\times10^6$
Swidden field area in the year of 2018 (V11)	1.57	1.28	0 – 10.00
Fruit tree orchard area in the year of 2018 (V12)	1.46	2.46	0 – 16.00
Rice consumption (V13)	704.65	324.31	193.97 – 1,745.81
Total income (V14)	2.6×10^6	1.7×10^6	$2.10\times10^5 – 7.80\times10^6$
Paddy field area in the year of 2018 (V15)	0.15	0.58	0 – 4.00
Fuelwood consumption (V16)	10.25	6.27	0 –36.18
Number of male labors(V17)	4.34	1.41	2.00 – 9.00
Household's head education (V18)	1.52	0.78	0 – 4.00

Source: Data from interview survey in 2019

There was a significant positive correlation between the total income and non-farm income (r_s= 0.73, p< 0.01; Fig. 5-5). A similar relationship was also observed between total income and animal husbandry income (r_s= 0.74, p< 0.01; Fig. 5-6). Conversely, a weak but significant correlation was seen between total income and the rubber plantation income (r_s= 0.20, p=<0.05; Fig. 5-7). NTFPs income was not significantly correlated with the total income (Fig. 5-8), while income from swidden was significantly correlated with the total annual income (r_s= 0.32, p< 0.01; Fig. 5-9).

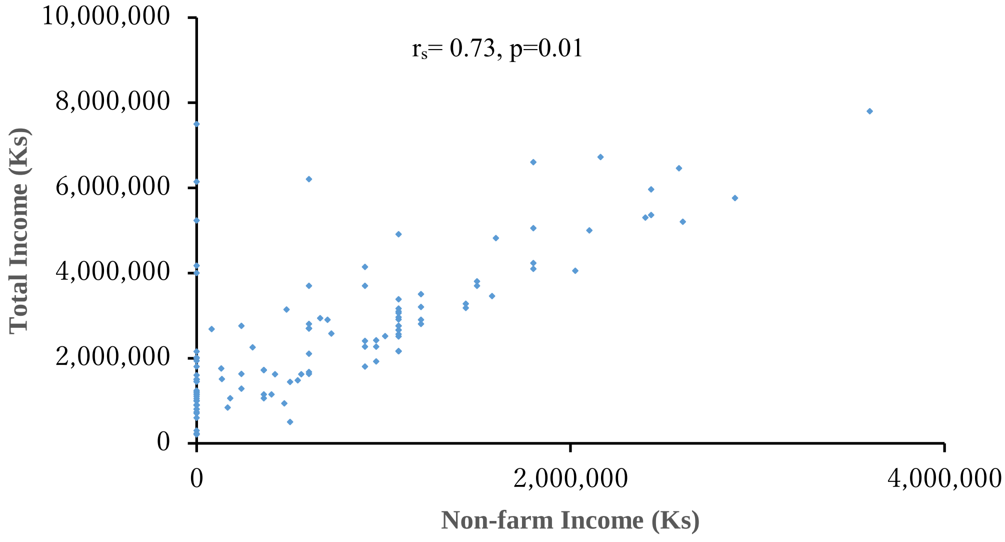

Figure 5-5 Correlation between non-farm income and total income

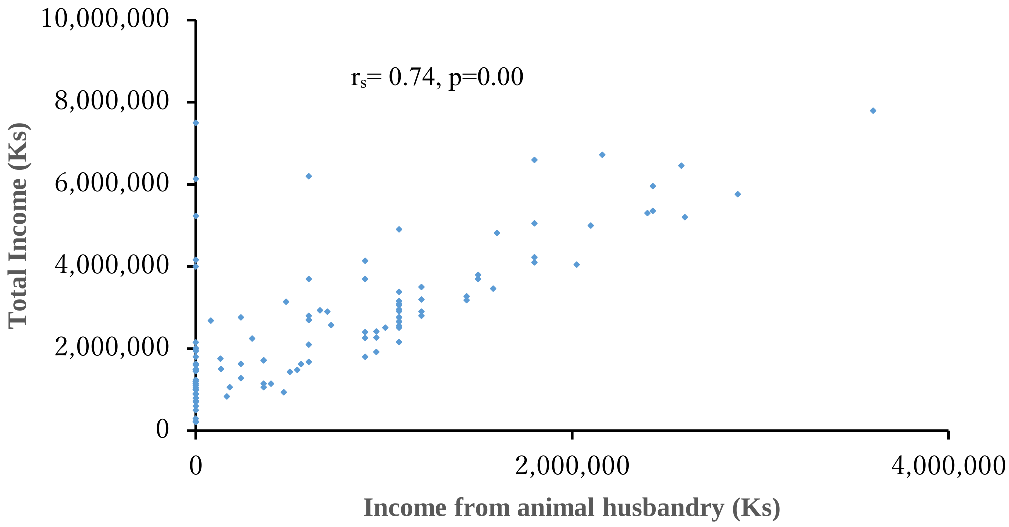

Figure 5-6 Correlation between animal husbandry income and total income

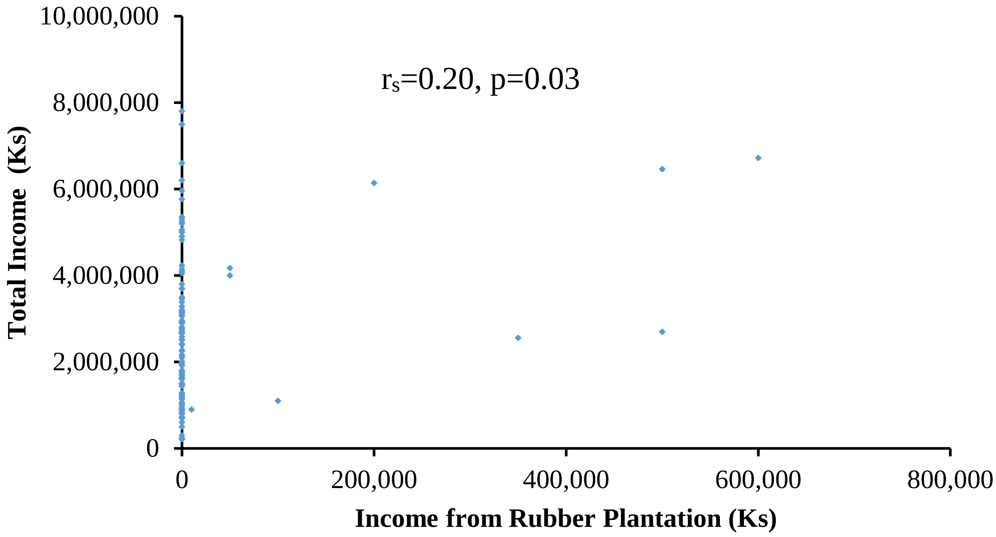

Figure 5-7 Correlation between income form rubber plantation and total income

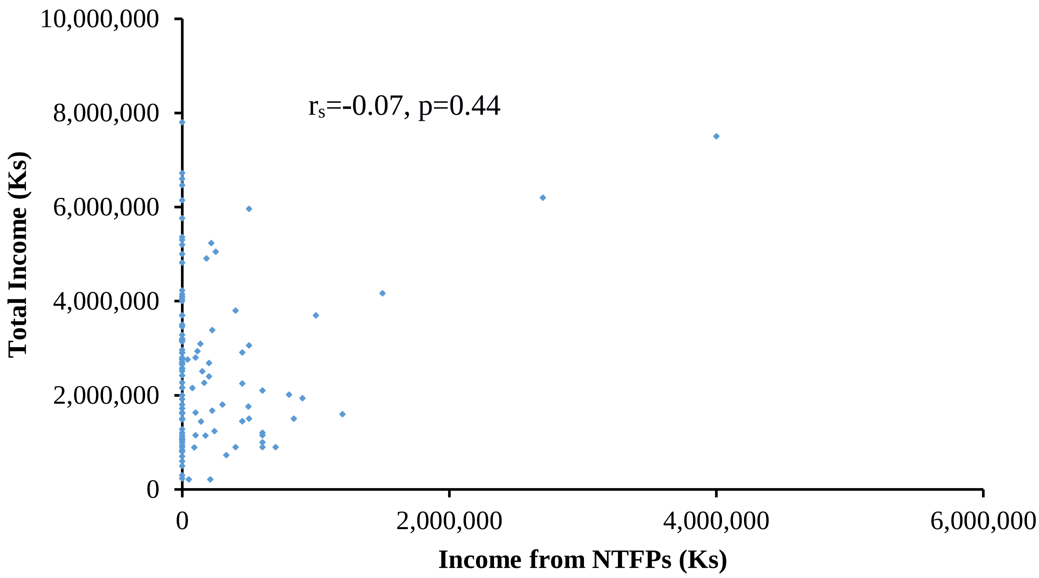

Figure 5-8 Correlation between income from NTFPs and total income

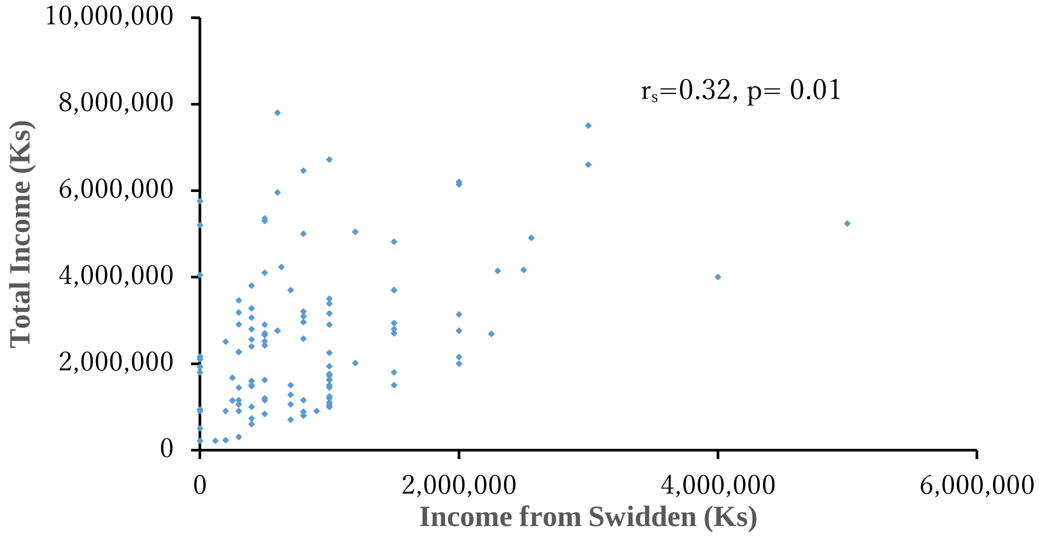

Figure 5-9 Correlation between income from swidden and total income

5.3.3 Distribution of income share among the three wealth status groups

The sampled 122 households were stratified according to wealth status into low-income group (LIG), medium-income group (MIG), and high-income group (HIG) based on total household income (Table 5-5). LIG received the highest income from swidden (57.97%), followed by NTFPs collection (17.69%). MIG earned from swidden income (35.51%), followed by non-farm income (27.71%) and income from animal husbandry (26.57%). HIG received most earnings from non-farm employment (31%) such as private shops and salaried jobs, followed by animal husbandry (30.89%) and swidden (27.10%). Hence, it was observed that the dependency on swidden decreased with an increase in total income.

Table 5-5 Result of income share in percentage (%) among three different types of income groups (n = 122)

Wealth groups	Income from rubber plantation	Income from fruit tree orchard	Income from swidden	Income from NTFPs collections	Non-farm income	Income from animal husbandry
LIG (*n* = 40)	0.28	6.06	57.97	17.69	9.63	8.38
MIG (*n*=40)	0.56	3.23	35.51	6.72	27.71	26.57
HIG (*n* = 42)	0.94	3.56	27.10	6.52	31.00	30.89

5.3.4 Comparison of socioeconomic conditions before and after dam construction

The average total income of the villages was significantly different before and after dam construction (Table 5-6). Local people could make more income after the dam construction. Significance in average total income was observed in LIG, and the income of LIG decreased after the dam construction. The strong significant differences existed among the MIG and HIG, and the income of those groups were getting increased after the dam construction. The number of populations also increased in LL and TLM and decreased in TPK village after the dam construction. The former two villages were located beside the road, and it had the better changes non-farm job opportunities. In-migration into sample villages from other area were also found in this study. According to the interview survey, some of the households from TPK village moved to the LL and TLM villages (Table 5-6).

Table 5-6 Comparison of socioeconomic conditions before and after dam construction (One sample t test, n=122)

	Average total income (MMKs)		P-value
	This study	Previous study (Cho, 2018)	
Total Household Income	2589432	1593651	0.00
LIG	998981	1051731	0.37
MIG	2231750	1606452	0.00
HIG	4444797	2713591	0.00

Source: Data from field survey and previous study

5.3.5 Rice Sufficiency

I assessed whether households produced adequate rice for their self-consumption, and whether they can earn sufficient money to purchase the rice needed for their sustenance. Therefore, the amount of cash needed to buy the rice was deducted from annual absolute income. Some farmers were unable to earn enough to buy rice in LL and TLM villages (Table 5-7). Some households from LL and TLM villages could produce enough rice for their self-consumption, but most purchased rice form the market. Even though the farmers from TPK village purchased rice for consumption, all households could afford to buy rice.

Table 5-7 Rice sufficiency assessments for three villages

Rice Sufficiency	Village Name		
	LL	TLM	TPK
Percentage of HH that can produce sufficient rice for self-consumption	10	26	0
Percentage of HH that cannot produce sufficient rice for self-consumption	90	74	100
Percentage of HH that can make enough money to buy rice for annual rice consumption	96	94	100
Percentage of HH that cannot make enough money to buy rice for annual rice consumption	4	6	0

Source: Interview survey in 2019

5.3.6 Farmers' adaptation to dam-induced land use changes and household strategies

According to PCA analysis scores, the first component accounted for the highest variance, explained 25%, while the second, third, and fourth component explained 22%, 18%, and 14%, respectively (Table 5-8). PC1 highlighted the dependency of non-farm job activities, PC2 was related to engagement in newly introduced agricultural practices, PC3 depended on swiddening while PC4 was related to the household profile and consumption. These scores were also used to determine the differences in income strategies among the three villages (Table 5-9).

ANOVA results showed that engagement in non-farm strategies was significantly different among the three villages (Table 5-9). High dependency on the non-farm strategies was observed in TPK village, followed by TLM and LL villages. LSD post hoc test showed that dependency on the non-farm income strategies between LL and TPK was significantly different at the 95% confidence level, but there was no significant difference between LL and TLM, or between TLM and TPK. Besides, villagers from TLM engaged mainly in practicing the newly introduced agriculture, followed by TPK and LL villages. Villagers from LL highly relied on the swidden, followed by TLM and TPK villages. In the case of swidden dependency, there was no significant difference among the three villages (Table 5-9).

Table 5-8 Results from principal component analysis based on the correlations of 10 social variables

Variables	PC Components			
	PC1	PC2	PC3	PC4
Household member (V1)	0.04	0.07	0.02	**0.88**
Number of children (V3)	-0.01	-0.10	-0.05	**0.67**
Rubber hectare in the year 2018 (V4)	-0.04	**0.89**	0.19	-0.09
Income from rubber plantation (V5)	0.25	**0.68**	-0.08	0.02
Income from fruit tree orchard (V6)	-0.10	**0.86**	0.11	-0.01
Income from swidden (V7)	-0.07	0.12	**0.93**	0.02
Non-farm income (V9)	**0.98**	-0.03	-0.15	-0.01
Income from animal husbandry (V10)	**0.98**	-0.03	-0.14	0.00
Swidden field area in the year of 2018 (V11)	0.00	0.05	**0.91**	0.01
Daily rice consumption (V13)	-0.01	-0.01	0.08	**0.82**
Total income (V14)	**0.83**	0.26	0.43	0.03
Variances explain	**25%**	22%	18%	14%

Table 5-9 Comparison of income strategies among the three villages

Income Strategies	Village Name	N	Mean	SD	One-way ANOVA
Non-farm	LL	52	-0.22	0.83	a
	TLM	32	0.05	1.20	ab
	TPK	38	0.26	0.99	b
Newly introduced plantation	LL	52	-0.22	0.16	a
	TLM	32	0.50	1.81	b
	TPK	38	-0.11	0.45	a
Swidden	LL	52	0.10	1.01	a
	TLM	32	-0.07	1.19	a
	TPK	38	-0.08	0.81	a

Note: Values with the same letters are not significant using a LSD post hoc test ($p< 0.05$).

Comparing the income share among the three wealth status groups, swidden was the main contributor for LIG and MIG (Table 6). Income from NTFPs also contributed more income to the LIG when compared to other groups. HIG was mainly contributed from non-farm job income (Table 8).

5.4 Discussion

5.4.1 Agrarian transition and socioeconomic conditions before and after dam construction

The most severe impact of dam construction on the local community was the loss of permanent farmlands. Notably, within the focal 25 km^2 area, 242 ha permanent farmland was submerged under the dam (Fig. 5-4, Table 5-3). Most of the farmers lost their lowland paddy fields and permanent farmlands that were along the river when the areas were submerged in 2018. Jackson and Sleigh (2000) also reported a similar finding wherein 34,000 ha of agricultural land were inundated due to the construction of the Three Gorges dam in China. In Vietnam, too, 15,738 people lost their land and houses due to the construction of the Ban Chat dam in 2014 (Rousseau *et al.,* 2017). Affected community members relied on the market more for their daily consumption. These results were in agreement with the findings of Rubin *et al.* (1999). Farmers could not produce sufficient amounts of rice for their self-consumption, and consequently needed to earn cash to offset this deficiency. It highlighted that the construction of the Paunglaung dam caused a dramatic reduction in rice production by local communities, and some households could not even afford to buy rice. All the farmers from TPK could earn the cash income needed to buy the rice from the market because they were engaged in diverse household income strategies, and their economic condition was better compared to other villages. Therefore, dam construction resulted in improved food security in TPK village. Similar findings were found in a study from the Volta Estuary, Ghana (Rubin *et al.,* 1999).

Swidden extent conspicuously decreased probably because of limited land availability and accessibility after the dam construction. Most of the fallow land transformed into the Community Forest (CF) under the management of the Forest Department. The swidden transformation into a more permanent form of agriculture were observed in this study. A similar phenomenon of swidden transformation was also observed in Bago Mountains, Myanmar (Swe and Nawata, 2019). According to the interview survey, the average fallow period of swidden was shorter because of limited land availability in order to move on a rotational basis after the dam construction. The longest fallow age was 3 years, and most of the respondent swiddeners mentioned the lower quality of turmeric because of consecutive growing. This fallow age was relatively short when compared to the other studies (Swe and Nawata, 2019) in traditional swidden cultivations areas in Myanmar. Another possible factor of shorter fallow age could be population growth and in-migration from other areas (Fig. 5-10). This finding concurs with Boserup's Agrarian Change Theory (1965). According to the interview, swiddeners stated that the price of turmeric had declined and therefore swiddening alone could not secure their subsistence livelihoods. Prior to the dam construction the main occupation of the local people was lowland paddy and upland swidden farming according to interview survey. However, currently, most of them do odd jobs. Due to dam construction, access to farmlands and natural resources was cut off for the swiddeners. Consequently, the motorboat became an essential vehicle for swiddeners to commute between their swidden fields along the reservoir and their homes. Those who could not afford motorboats were forced to abandon their swidden farms and find employment as hired laborers for existing swidden farmers or take up odd jobs. In Vietnam the Handai farmers started to engage in swiddening in the sloping land adjacent to the floodplain after losing their farmland (Rousseau *et al.,* 2017).

The agrarian transition map of 2018 showed an increase in orchards and plantations where market-oriented crops such as rubber, betel nut, coffee, pineapple, and banana were also recently introduced in these villages after dam construction. According to the interview survey, the major driving forces for the introduction of new agricultural practice were the farmland loss after dam construction, marginalization of swidden by the Forest Department, changes in market demand, and contract farming introduced by some non-government organizations (NGOs). Coffee plantation were mainly introduced by some NGOs in this study site. A similar phenomenon was observed in Laos and the Laos government-supported land use segregation with agricultural intensification through the regeneration of forest cover and promoted the swiddeners into farm enterprise by allocating the land zoning, agribusiness, contract farming, and plantation concessions (Castella *et al.,* 2013). TLM and LL villages were located beside the main road, and they have better changes to disseminate the new farming technologies. Even though some farmers adopted newly introduced agricultural practices such as rubber plantation and fruit tree orchards, the majority could do so due to their inability to finance the initial investment required for these. However, income contributions from these were yet limited because those plantations or orchards were still young (Fig.5-7). Conversely, the correlation between the income from rubber plantation and total annual income showed that the maximum income from rubber could contribute approximately 10% to the total income; this could be assumed to be a feasible economic adaptation to dam-induced impacts (Fig. 5-7).

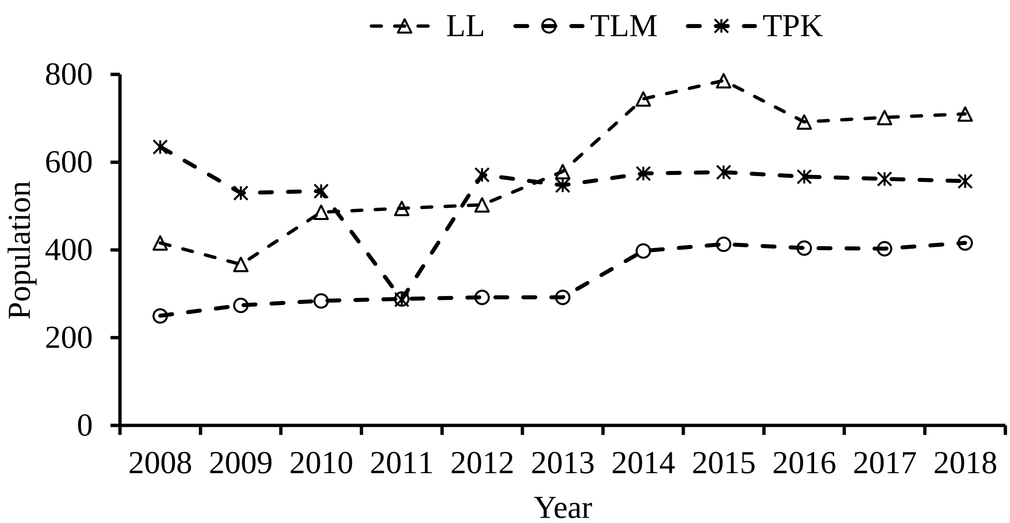

Figure 5-10 Population changes in LL, TLM and TPK villages from 2008 to 2018

Considering livelihood, other income sources such as non-farm income and animal husbandry were highly correlated with the total household income (Fig. 5-5 and 5-6); these livelihood activities became their main economically viable income strategies after dam construction. The number of households engaged in such activities was limited, possibly because displaced and landless farmers did not have technical and financial capacities for such newly introduced agricultural practices. Swidden income continued to contribute significantly to the total income, suggesting that it functions as a safe livelihood option for swiddeners (Fig. 5-9). When I compared the income share among the three wealth status groups of after dam construction, LIG and MIG were mainly contributed by swidden income (Table 5-5). It confirmed the previous finding that swidden still remains as a safety net for the local people in the study sites. Income from NTFPs also contributed more income to the LIG when compared to other groups. Moe and Liu, (2016) and Aye *et al.,* (2017) also reported a similar finding. Shackleton and Sheona (2006) also added that the forest resource income significantly contributed to the LIG. Villagers from this study site collected the orchids, bamboo, elephants-yams, cane, as well as broom grass, and sold them to local merchants. In contrast, HIG obtained more earnings from non-farm job activities. The turmeric harvested from the swidden field and NTFPs were sold to the local merchants belonging to HIG or MIG (Table 5-5).

Annual household income significantly increased especially in the MIG and HIG after the dam construction (Table 5-6). Dam construction provided alternative livelihoods such as the seasonal boating to the tourism site for the LIG, restaurants, motels, and home shop for the MIG and HIG. After the dam construction, the government provided electricity, official land title of the relocated village areas, public hospitals, and schools to the relocated local communities. Even after they had access to electricity, the relocated villagers continued collecting fuelwood from surrounding forests. The average consumption of fuelwood was relatively high in this study (10.25 m^3 per household in 2018). In Katha District of Myanmar, the average fuelwood consumption was 3.4 m^3 in the results of Hlaing *et al.* (2017). This implies that most of the villagers could not afford electricity and, therefore still relied on the adjacent forests. Increased dependencies in casual jobs, especially displaced farmers and landless farmers, might lead to increased dependence on the surrounding forests for collecting more NTFPs and engaging in illegal timber extraction.

5.4.2 Farmers' adaptation strategies to agrarian transitions

Our interpretation of PCA results showed that farmers typically adopted three types of income strategies of the local people after the dam construction. These were: dependency on non-farm job activities, engagement in newly introduced agricultural practices and dependency on swiddening (Table 5-8).

The adaptation strategies of the local people were different depending on the village. I found that non-farm strategies were significantly different across the three villages (Table 5-9). Farmers from TPK village had motorboats and engaged in season-based tourism by renting motorboats to transport tourists to the waterfall located in the northern part during summer. TLM villagers engaged mainly in newly introduced agriculture. As TLM was located on the main road, farmers from that village had more opportunities to introduce permanent agriculture. Villagers from LL village highly relied on swidden, which highlights that swidden still remained as a safety net (Table 5-9). After dam construction, local communities were engaged in diverse livelihood strategies. Besides agriculture, local communities also engaged in non-farm activities such as animal husbandry, casual jobs, and NTFP collection, and these livelihood options significantly contributed to household earnings. Some households engaged in newly introduced agricultural practices, which markedly contributed to their household income. Currently, most of the households engaged in non-farm jobs after dam construction. However, all three villages lacked stable household strategies after the dam construction.

Globally, major underlying causes of agrarian transition are clearly related in complex ways to social, economic, and environmental factors. In this study, agrarian transition in the case if lowland paddy was linked to the drastic land use changes because of dam construction.

Agrarian transition in upland farm, such as swidden transformation into a more permanent form of agriculture and intensification with commercial crops, were related to the forest conservation activities, contract farming, and changes in demographic tend. Dam construction mainly impacted the livelihood system of low-income household groups, who subsequently had to take up casual jobs. Our study also showed that non-farm jobs were the prominent income strategies that contributed to household earnings. However, engagement in newly introduced agricultural practices can also be one of the feasible alternatives to supplement the household income. The latter could be challenging because of limitations in land availability, initial investment, and road access to farmland areas. Infrastructure development for accessibility to their farmlands, resolution of land use conflicts between the Forest Department and local communities, as well as incentive policy for integrated agro-based business is required in these areas. In addition, further research needs to be conducted to identify suitable cultivars that can be grown in the area; positive adaptation strategies for changing livelihoods need to be promoted in the relocated villages.

CHAPTER 6 DEVELOPMENT OF PADDY FIELDS IN TRADITIONAL SWIDDEN CULTIVATION AREAS

6.1 Introduction

Swidden was going under different stress in different countries (Li *et al.,* 2014; Mertz, Padoch, *et al.,* 2009). Contemporary land use changes at the traditional swidden were common in the mainland of SEA countries (Padoch *et al.,* 2009; Chan and Takeda, 2016). Even though swidden still remains as the safety net of mountain dwellers and swidden was transforming into a more permanent form of agriculture under pressure (Swe and Nawata, 2019, Li and Feng, 2016; Van Vliet *et al.* 2013). In Sam Sob Bon village of northern Thailand, government established the national park in the fallow land areas, and then the fallow period became shorter. Consequently, the slopping land were converted into permanent cultivation fields and forested areas (Kanazawa, 2006).

In Myanmar, forest conservation activities and land use conflicts among the forest department and swiddeners were the main driving forces for swidden transformation. Forest department have been introduced the monoculture teak plantations and community forest in the swidden cultivations areas in order to mitigate the swidden. Most the fallow land has been replaced with the teak plantations and community forests in those mountainous areas. Moreover, the forest department still proceeding to establish the community forest acreages yearly until they meet their long-term master plan. Therefore, land availability was limited for shifting the fallow period was getting shorter in those areas. Consequently, swiddeners introduced the permanent paddy fields to secure their future consumption alongside the small streams, and valleys and mountains foothills with the labor forces. This was the wise utilization of surface soil nutrients carried by the surface runoff from the upper part of the slope. The number of households engaged in practicing the permanent agriculture incased yearly in all three villages (Swe and Nawata, 2019). Therefore, an attempt is necessary to map how much extent of paddy fields have been introduced and how much extent was still available and where was the best area to open the paddy fields in the future. This study was conducted to analyze the suitability land use map for the paddy field development to contribute towards the effective selectin for paddy fields development two traditional swidden cultivation areas in Myanmar.

6.2 Materials and Methods

6.2.1 Study area

This study was conducted in the Bago Mountains, located at the elevation of 250–450 m above sea level. The typical soil type in the study area was Alfisols, as discussed in Chapter 2. The Bago Mountains are the home to Karen people, where the Karen swiddeners have been practicing the traditional swidden agriculture since many centuries ago (Chan *et al.,* 2016). They slash and burn the vegetation and typically relies on a large number of crops, planted both simultaneously and successively with the long cropping cycle. Three Karen villages (anonymously recorded as SN, KC, and GS) of the Bago Mountains were selected as sample villages according to the extent of the introduction of permanent agriculture, conditions of swidden agriculture, and accessibility (Figure 6-1). The main livelihood in SN and KC villages were traditional swidden agriculture, even though permanent agriculture was introduced. In GS village, permanent agriculture became their main livelihood since a long time ago. They mainly grow the upland rice in swidden fields and lowland rice in the permanent paddy fields for their subsistence needs, and cotton, sesame, chili pepper, groundnut, cowpea, and green gram in both swidden and permanent upland farms as cash crops. The detailed introduction of Chapter 2.

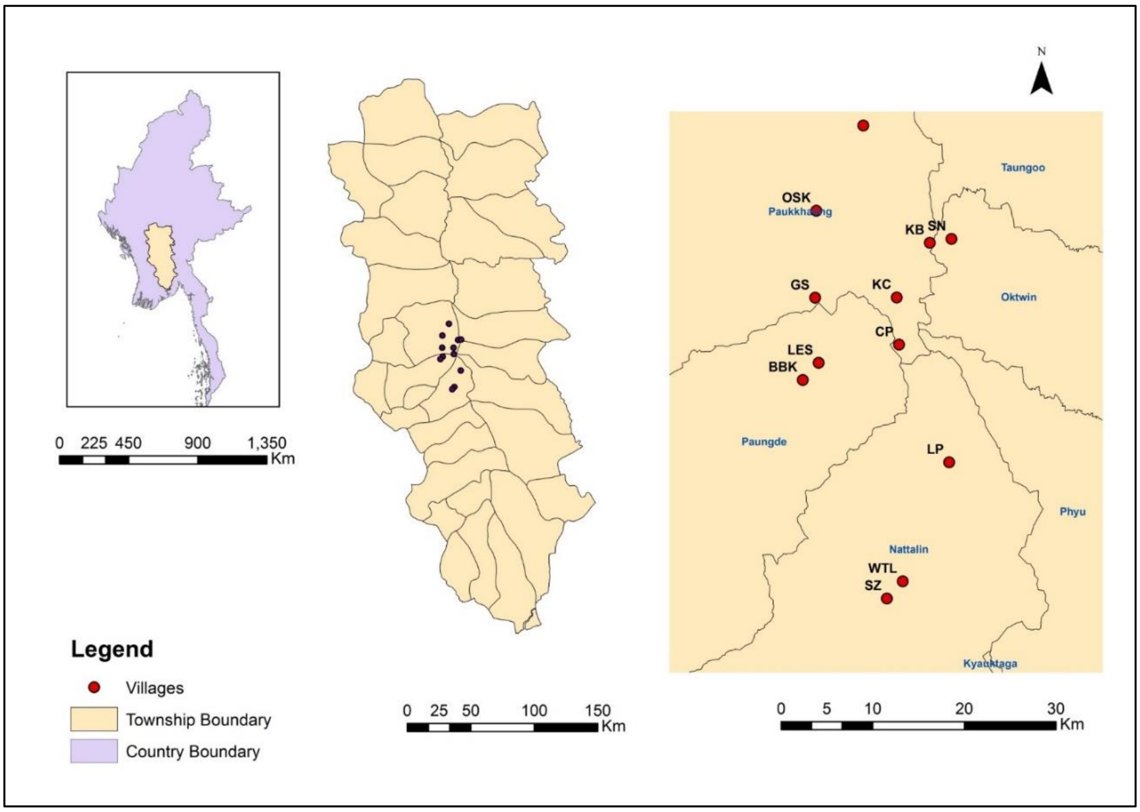

Figure 6-1 Location of the study sites and Karen villages of the Bago Mountains

6.2.2 Land use suitability analysis

Field observations were carried out during the period from May to December 2016, and two types of permanent agriculture were found in the studied villages: permanent paddy fields (vernacularly, "*Le*") and upland farms ("*Khone*") (Swe and Nawata, 2019). Boundaries of all the existing swidden fields in 2016 and all the permanent agricultural fields in all three villages were tracked using GPS (GARMIN Darkota 20) in May and June. Based on the accurate ground truth, slope value, the elevation value of paddy fields was extracted from the DEM images, and four suitability classes were set up, as shown in Table 6-1. There is no water reservoir in this study sites, and water availability needs to be considered as an important criterion for the rainfed paddy field. Hydrological analysis was conducted based on the steam network located within the boundary of three selected sample villages. The final drainage density map was classified into four suitability classes for paddy fields based on the stream network in order to exclude the high drainage area. Subsequently, the final land use suitability map was created based on the elevation, slope, and water availability. One more criterion of soil depth was considered as land use productivity in this method. Surprisingly, the soil depth of the Bago Mountains was relatively deep, and the rock layer was not found until 120 cm depth in all points. Therefore, the parameter of soil depth will not be applied in the land use suitability analysis for the paddy field. The flow chart of the methods was shown in Figure 6-2.

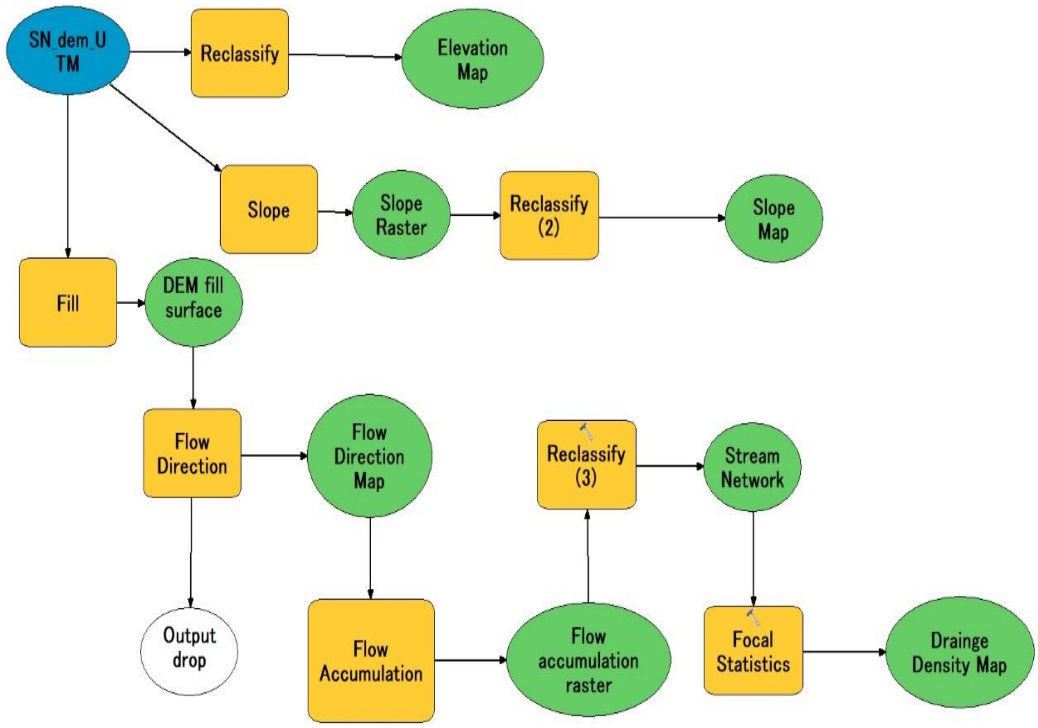

Figure 6-2 Flow chart of data analysis for elevation map, slope map, and drainage density map

Table 6-1 Suitability criteria of elevation, slope, and drainage density for the development of paddy fields

Suitability class	Elevation	Slope	Drainage density
Ideal Condition	125-200m(GS) 166-200m (KC) 304-320m (SN)	0-2 Degree (Flat to Gentle Slope)	High
Moderately Suitable	201-210m (GS) 201-250m (KC) 321-350m (GS)	2-4 Degree (Gentle Sloping)	Moderately
Difficult for paddy field	211-220m (GS) 251-380m (KC) 351-380m (SN)	Over 4 Degree (Sloping)	Low
Useless	221-231m(GS) 381-456m (KC) 381-496m (SN)	Steep and very steep	Very low

Source: Ground data collected in 2016

6.3 Results and Discussion

6.3.1 Land use suitability Analysis for paddy field in Bago Mountains

The first two suitability classes were considered as the available area for paddy field development, and the results showed that the available area of KC village was much larger than the other remaining villages. However, the currently opened area was only 27.14 ha in the year 2016 (Figure 6-3 and Table 6-2). It means that KC village still has much available flat land for opening permanent paddy fields in the future. The available area of SN village is relatively small when compared to other villages. The slope of the SN village was relatively steep, and the number of streams was very limited when compared to KC and GS village. In GS village, the currently opened area is larger than the available area determined by our methods. It is highlighting that the development of paddy fields in GS village had already reached to the maximum stage (Figure 6-3 and Table 6-2).

Table 6-2 Results of suitability analysis for the development of paddy fields

Village Name	Ideal Condition area (ha) Class 1	Moderately Suitable (ha) Class 2	Total Available Area (ha)	Currently Opened Area (ha)	Total village boundary
SN	30.93	51.54	82.47	2.44	5052.78
KC	45.54	178.41	223.95	27.14	3949.54
GS	42.6	46.79	85.39	91.25	388.706

Source: Results from land use suitability analysis

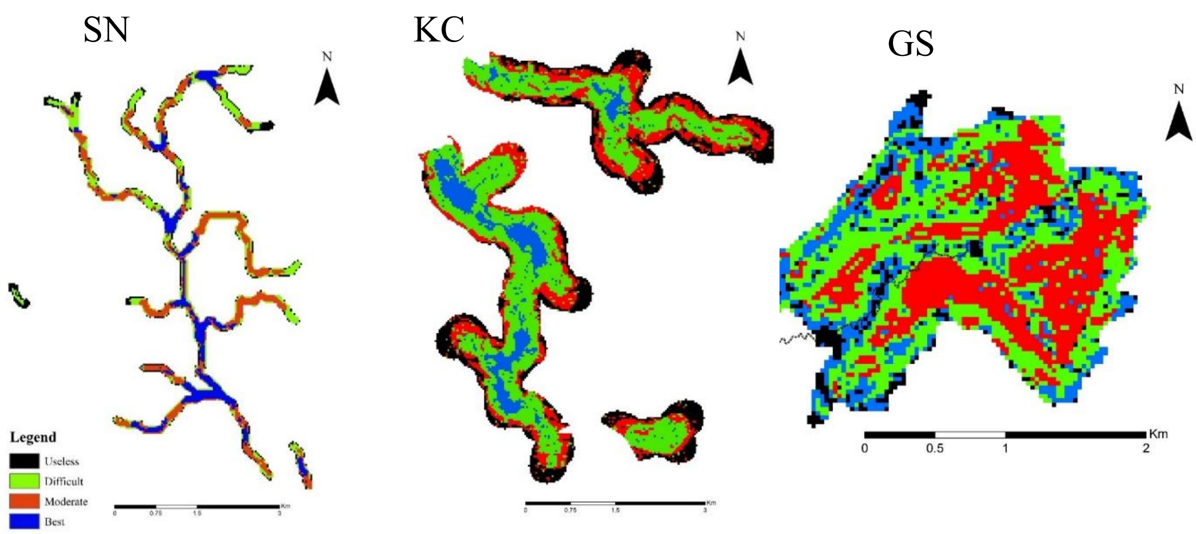

Figure 6-3 Land use suitability map for SN, KC, and GS villages

6.3.2 Accuracy assessment for suitability model

Accuracy of the suitability model was confirmed by using the ground truth data of GS village because I have the ground truth data of all permanent agricultural fields. Over 90% of the permanent agricultural fields that were collected as ground truth data fitted with the best and moderate suitability classes generated by the suitability model. Therefore, land use suitability maps for three villages were done with the proper accuracy (Figure 6-4).

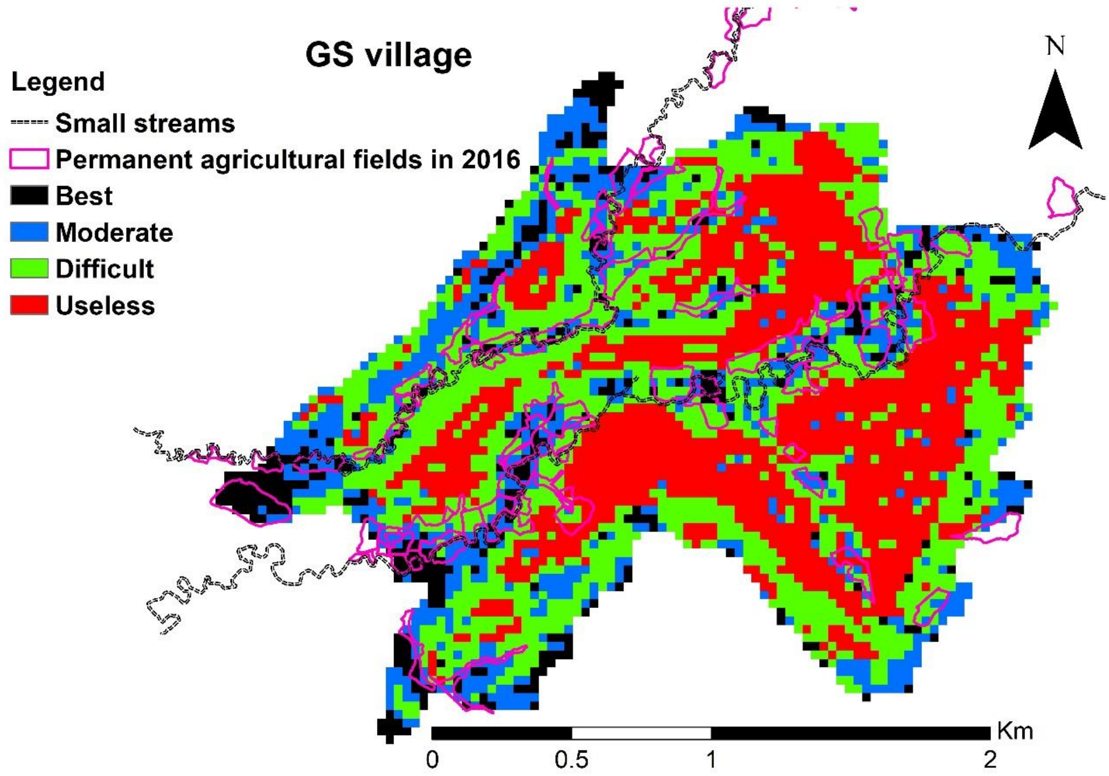

Figure 6-4 Result of accuracy checking for suitability model

6.4 Conclusions

Development paddy fields was one of the feasible alternatives to secure the future consumption of the swiddeners. It was the effective utilization of nutrients carried down by the surface runoff from the upper portion of the sloping land and mountains. In this study, a relatively accurate mapping for the development of paddy fields in three villages of the Bago Mountains with proper accuracy. The best and moderate land use suitability class could be utilized for the development of paddy fields in the Bago Mountains. In GS village, the introduction of permanent agriculture reached the maximum stages, and villagers opened some of the permanent agricultural fields, even the difficult suitability class. Forest tree species, perennial and annual plants should be maintained in the difficult and useless suitability classes to reduce the soil erosion in sloping land.

CHAPTER 7 GENERAL DISCUSSION AND CONCLUSION

7.1 Detection Methods for swidden land use changes

This study aimed to understand the swidden conditions in two mountainous areas to contribute to sustainable land use planning in Myanmar. Thus, remote sensing methodology was developed to detect the swidden land use changes from two types of images with the suitable accuracies. Currently, the statistical data for the extent of the swidden in Myanmar were very variable, and the development of detection methods was urgently needed to know the changing trend of swidden. Attempt for developing the detection methods for swidden could contribute to estimating the land use-based greenhouse gas emissions and a basic need for environmental monitoring as well as conducting various investigation on agricultural development and food security for the swiddeners (Sakai, 2002; Heinimann *et al*., 2017; Padoch *et al*., 2007).

Freely available medium-resolution images (Landsat imageries) were used to develop the mapping methods for detecting the swidden land use changes. Landsat images are available every 16 days, and they can provide data for continuous swidden land use changes in detecting the times series swidden land uses. The accuracy of the developed methods can increase if the area of interest has the less complicated land use categories so that it can reduce the confusion with the surrounding land use categories. Besides, the selection of the image acquisition date is also crucial to apply the developed method. A perfect timing of burning time and image acquisition date should be at the same time. However, Higher resolution images (GeoEye images) are preferable for those areas with the higher complicated land use categories rather than freely available Landsat imageries were used to detect the swidden fields.

Therefore, the method I developed in the Bago Mountains is suitable where ground truth data for the swidden fields can be collected, and land use categories are less complicated. Higher resolution images were more efficient or those areas, like Paunglaung, where accessibility was challenging to collect the ground truths. Moreover, the Paunglaung site had more complex land use categories that make it confused to detect the swidden fields. Therefore, these developed methods were separately applied to detect the swidden land use changes in two study sites.

All these developed methods can be applied in detecting the changing trend of time series swidden land uses. The accurate mapping methods, based on local case studies, were crucial and remained the best approach in order to implement the adaptation policies in line with local needs, especially for the future sustainability of such people.

7.2 Swidden Transition and its underlying causes

This study also provided a clear understanding of agrarian transitions and an insight into how swiddeners were adapting to those agrarian transitions in both mountainous areas of Myanmar. Agrarian transitions into a more permanent form of agriculture occurred in two study sites. The major driving forces for agrarian transition in both study sites were the political intervention, land use conflicts among the forest departments and swiddeners. The country`s development, such as hydropower dam development, also induced the agrarian transition in upland areas. The results from this study were useful in improving the National Land Use Planning, especially the section of communal land use management of upland areas.

7.2.1 Cases in the Bago Mountains

Since many centuries ago, Karen peoples have been practicing the swiddening in the reserved forest, and they have relied solely on the swidden in some parts of the Bago Mountains. Land use conflicts among the forest departments and National Land Use Policy were the main underlying cause for the swidden transformation in Bago Mountains.

The current trends of the swiddening extent in two study villages (KC and SN villages) of the Bago Mountains were gradually leading to a decrease in the number of plots and area extent while the demise of swidden were observed in GS village. The fallow period and average sizes of swidden also gradually decreased in the two cases of the Bago Mountains, as presented in Chapter 3. However, the rotational fallow period of the swidden in those cases in the Bago Mountains was relatively longer than that of Pinlaung. The major controlling factor of decreasing the fallow period was the limitation of land availability in the area because the Forest Department has still been implementing to replace the swidden with the Community Forest (CF) yearly until the target of the CF master plan is met. Swiddening with the shorter fallow period might not be appropriate in a sustainable perspective in such steep slope areas. In view of the forestry sector, previous studies (Russell, 1988; Takeda *et al.,* 2006) have been reported that swidden with short cropping period and long fallow period is ideally suited to the environment.

Although swidden was put under stress and intensified into a more permanent form of agriculture in the two case studies, villagers have still relied on their traditional swidden practice only for their subsistence livelihoods, but also for earning cash. In those cases, an absolute total of income was significantly contributed by the swidden; and it highlighted that swidden still remains as a safety net for the local people in those villages of the Bago Mountains, except GS village.

In the SN and KC village, swidden was found as the main income source and still remains as a safety net of upland farmers. The extent of permanent agricultural extent depends mainly on the topography such as slope, elevation, and water availability. Meanwhile, the introduction of permanent agriculture occurred as an additional livelihood activity to ensure their food security. The introduced permanent agriculture significantly contributed to the rice sufficiency, especially in the GS village. However, opening the permanent agricultural fields by blocking the natural waterways should be avoided not too harmful to the mountain ecosystem. Karen swiddeners in the Bago Mountains mainly grow the upland rice, and most of the households could produce an adequate amount of rice for their household consumption. Some households of rice insufficiency need to buy, and the annual average amount of rice bought during the study period was 388.2 kg per household.

7.2.2 Cases in Paunglaung

Swiddeners from Paunglaung have been practicing the traditional agricultural practice in the Paunglaung reserved forest, and therefore similar land use conflicts between the Forest Department and swiddeners in the Bago Mountains was also observed in Paunglaung. The fallow age was relatively short, and it was ranging from 1 to 3 years in Paunglaung.

The swiddener's adaptation strategies in Paunglaung were different compared to Bago Mountains. Farmland loss was the most severe problem for the local farmers because of dam construction. Besides, the dam construction cut out the access to the farmlands, and only a few farmers introduced the cash crops such as rubber, orchards, and home garden. The market accessibility in Paunglaung led the swiddeners to grow the market crops such as turmeric and rubber and changed their traditional practice into semi-commercial farming such as rubber plantations, fruit tree orchards, and home gardens. However, that newly introduced agriculture could not contribute to the local livelihoods yet. Only a few wealthy households could invest in plantation, but most of the ordinary households engaged more in random jobs and still relied on the nearby forest. Land-lost farmers due to dam construction and those who do not have stable jobs could have a higher tendency of forest dependency.

In this case study, most of the households could not produce sufficient rice for their subsistence consumption. Even though they have still relied on the swidden, they grew only turmeric as a cash crop in the swidden fields. Market dependency of Paunglaung swiddeners was relatively higher than those in the Bago Mountains, and they had to buy the rice of 721.78 kg on average per household per year. Unable to produce the rice for household consumptions and lack of stable jobs may induce a higher tendency of increased forest dependency, such as the increased collection of NTFPs and illegal time extraction in the future.

7.2.3 Communal land use rights and land tenure security in Bago Mountains and Southern Shan Highlands

Issues related to the swidden came up together with land use conflicts among the swiddeners and the local government, especially in the mainland of SEA. Local farmers have been practicing their swidden under their customary land use system, whereas the Forest Department has also been trying to replace the swidden fields with the forest plantations or community forests. Land use policies, the rapid expansion of forest plantations and community forests, and insufficient rice production led the swiddeners to introduce the permanent agricultural plots, especially for paddy alongside the creek, valley, and streams by blocking the natural waterways. They are trying to apply for the land use certificate because paddy fields were classified as farmland under the Farmland Law 2012 in subs 3 (b) (The Republic of the Union of Myanmar, 2012). However, the land ownership of those permanent agricultural fields has not been certified by the local government. It was more challenging to get the ownership certificate, especially for those land that is administered by the Forest Department. Land use planning, including the provision of protecting cultural heritage, the promotion of public open space, and reduction of land use conflicts, will provide the basis of proper land use planning for the swiddeners. Therefore, it is also important to recognize and protect individual property rights and usages and restore indigenous land use practice to integrate all these rights into existing farmland laws, in which indigenous rights were not considered.

Local farmers prefer to practice the swiddening rather than the permanent agriculture. Therefore, territorial boundary for swidden practice and land ownership for permanent agriculture needed to be assured for the swiddeners because previous studies (Russell 1988; Takeda *et al.* 2005) have also been reported that swidden with short cropping period and long fallow period is ideally suited to the environment. Resolving the land use conflicts and ensuring clear processes for making decision about competing land use options are of utmost importance among the forest sector and swiddeners in both study sites.

7.3 Feasible alternatives based on the climatic, topographic and edaphic factors in Bago Mountains

Based on the climatic, topographic, and soil condition, the feasible alternatives were reported as follows if the village territories of the Bago Mountains were occupied with the community forest and forest department fully stop practicing the swiddening.

7.3.1 SN & KC village in Bago Mountains

In SN and KC village, the soil was not so acidic, and the monthly rainfall amount was relatively low. The land was usually steep, but soil was deep. Land use intensification such as monoculture plantation and community forest with teak introduced by the Forest Department may lead to soil erosion. Therefore, the agrosilvopastoral system and agroforestry system can be one of the feasible alternatives. Integration with perennial trees to maintain the forest cover, fruit tree species, and cash crops for household income should be encouraged in steep slope area. The Bago Mountains provide a favorable condition for the elephant foot yam, and it naturally grows there. Therefore, domestication of elephant foot yam can be introduced as cash crops if the proper market condition can be created. Besides, most of the farmers form the Bago Mountains were not using the chemical fertilizer, and it would be more effective if the government created the specified niche market for organic foods with a better price to promote the additional income. Organic farming for high-value vegetables, naturally dominated species of spice, and herbs and quality seed production with the help of the horticulture department can be another feasible alternative in Bago Mountains. In KC village, even though the more considerable extent of permanent agricultural fields was introduced, income and rice contribution from permanent agriculture were still limited. Therefore, technical support and infrastructure development for the market accessibility also needed to be promoted in KC village. In SN and KC villages, income contribution from bamboo selling was also high. Rather than selling the bamboo as a whole to the merchants, value-added products with the much higher prices made from bamboo should be promoted in those villages.

7.3.2 GS village in Bago Mountains

GS village was located at the lower elevation area and the slope condition was not as steep as that of the former villages. Permanent agricultural field have been largely introduced and already reached to the maximum limit. Therefore, in this village, agricultural intensification should be promoted for the lowland farming technologies. Other suitable commercial crops that can endure the market changes should be introduced.

7.4. Feasible alternatives based on the climatic, topographic and edaphic factors in Shan Highlands

In LL and TLM villages, soils derived from sedimentary rocks were moderately acidic with moderate to high exchangeable Al content, but the influence of limestone often mitigated such soil acidity. The average soil depth was 79.8 cm. The monthly rainfall was higher than the Bago Mountains, and leaching could be higher than the Bago Mountains. In Paunglaung, for the liming soil at lower elevation area, home garden and fruit orchards might be suitable while the areas with sedimentary soil are favorable for growing crops such as elephant foot yam and turmeric. Perennial pastures are also feasible in that area.

7.4.1 LL and TLM villages in Paunglaung, Shan State

Local people from LL and TLM village largely introduced the rubber plantation, because of the better accessibility than the TPK village. Most importantly, the introduction of diversified cash crops to avoid the risk of market price changes of grown crops. Rather than the monoculture rubber plantation, mixed plantation of perennial species such as coffee, pineapple, and beetles but should be introduced in liming soil.

Intensive cultivation with the use of fertilizer may lead to soil acidification.

7.4.2 TPK village, in Paunglaung, Shan State

Most of the villagers form the TPK village were the swiddeners. However, dam construction cut off the access to the agricultural fields, and therefore motorboat played an essential role in daily works. Therefore, infrastructure development for road access to their farmlands is also a prerequisite in those areas. Most of the swiddeners from Paunglaung reported that the market price of turmeric fluctuated yearly, and the price was falling compared to former times. In order to overcome that, technical and monetary support from the government is necessary to establish the small business and small industry to produce finished products such as turmeric powder and medicine by using locally owned raw materials. Collaboration and cooperation among the aligned departmental institutions are essential to implement the recommendations mentioned above.

REFERENCES

Adams, C., Munari, L. C., Vliet, N. V., Murrieta, R. S. S., Piperata, B. A., Pedroso jr., N. N., Taqueda, C. S., Crevelaro, M. A., and Prado, V. L. S. P. 2013. Diversifying Incomes and Losing Landscape Complexity in Quilombola Shifting Cultivation Communities of the Atlantic Rainforest Brazil. Human Ecology, **41**: 119–137.

Asrat, P., Belay. K, and Hamito. D. 2004. Determinants of Farmers' Willingness to Pay for Soil Conservation Practices in the Southeastern Highlands of Ethiopia. Land Degradation and Development, **15**: 423–38.

Arvor, D., Meirelles, M., Dubreuil, V., Begure, A., & Shimabykuro, Y. E. 2012. Analyzing the Agricultural Transition in Mato Grosso, Brazil Using Satellite-Derived Indices. Applied Geography, **32**: 702–713.

Beck, M. W., Claassen, A. H., and Hundt, P. J. 2012. Environmental and Livelihood Impacts of Dams: Common Lessons Across Development Gradients That Challenge Sustainability. International Journal of River Basin Management, **10**, 73–92.

Boserup, E. 1965. The conditions of agricultural growth: The economics of agrarian change under population pressure. George Allen and Unwin Ltd (London) pp. 28-31.

Boundeth, S., Nanseki, T., Takeuchi, S., and Satho, T. 2012. Land use change and its determinant factors in northern Laos: Spatial and socio-economic analysis. Journal of Agricultural Science. **4**: 191-204.

Bruun, T. B., Mertz, O., and Elberling, B. 2006. Linking Yields of Upland Rice in Shifting Cultivation to Fallow Length and Soil Properties. Agriculture, Ecosystems & Environment. **113**: 139–49.

Burgers, P., Ketterings, Q. M., and Garrity, D. P. 2005. Fallow Management Strategies and Issues in Southeast Asia. Agriculture, Ecosystems & Environment. **110**:1–13.

Chan, N., Takeda, S., Suzuki, R., and Yamamoto, S. 2013. Establishment of allometric models and estimation of biomass recovery of swidden cultivation fallows in mixed deciduous forests of the Bago Mountains, Myanmar. Forest Ecology and

Management. **304**: 427–436.

Chan, N. and Takeda, S. 2016. The transition away from swidden agriculture and trends in biomass accumulation in fallow forests: Case studies in the southern Chin hills of Myanmar. Mountain Research Development. **36**: 320–31.

Chan, N., Takeda, S., Suzuki, R., and Yamamoto, S. 2016. Assessment of biomass recovery and soil carbon storage of fallow forests after swidden cultivation in the Bago mountains, Myanmar. New Forest. **47**: 565–85.

Chan, Y. H. 2004. Biostatistics 202: Logistic Regression Analysis, Singapore Med. J. **45**: 149–153.

Chen, G., Powers, R. P., Carvalho, L. M. T. D, and Mora, B. 2015. Spatiotemporal Patterns of Tropical Deforestation and Forest Degradation in Response to the Operation of the Tucuruí Hydroelectric Dam in the Amazon Basin. Applied Geography, **43**:1–8.

Castella, J. C., Lestrelin, G., L., Hett, C., Fitriana, Y. R., Heinamann, A., and Pfund, J. L. 2013. Effects of Landscape Segregation on Livelihood Vulnerability: Moving from Extensive Shifting Cultivation to Rotational Agriculture and Natural Forests in Northern Laos. Human Ecology. **41**: 63–76.

Cho, K.L. (2018). Household wealth status and utilization of non-timber forest products (NTFPs) in Pinlaung township, Shan State. (Master Thesis), University of Forestry and Environmental Science, Yezin.

Cihlar, J. 2000. Land cover mapping of large areas from satellites: Status and research priorities. International Journal of Remote Sensing. **22**: 1093–1114.

Cramb, R. A., and Culasero, Z. 2003. Landcare and livelihoods: The promotion and adoption of conservation farming systems in the Philippine uplands. International Journal of Agricultural Sustainability. **1**: 141–154.

Cramb, R. A., Colfer, C. J. P., Dressler, W., Laungaramsri, P., Le, Q. T., Mulyoutami, E., Peluso, N. L., and Wadley, R. L. 2009. Swidden transformations and rural livelihoods in Southeast Asia. Human Ecology. **37**: 323–46.

Dressler, W. and Pulhin, J. 2010. The shifting ground of swidden agriculture on Palawan Island, the Philippines. Agriculture and Human Value. **27**: 445–59.

Dressler, W. H., Wilson, D., Cramb, R., Keenan, R., Manhanty, S., Bruun, Brunn, T. B., Mertz, O., and Lasco, R. D. 2017. The Impact of Swidden Decline on Livelihoods and Ecosystem Services in Southeast Asia: A Review of the Evidence from 1990 to 2015. Ambio. **46** (3): 291–310.

Ennion, J. D. 2015. From conflicting to complementing: The formalisation of customary land management systems governing swidden cultivation in Myanmar. University of Wellington. p. 1–129. (A thesis submitted to the Victoria University of Wellington in fulfilment of the requirements for the degree of Master of Laws).

Fatai, A. A., Shamshuddin, J., Fauziah, C. I., Radziah, O. and Bohluli, M. 2017. Formation and Characteristics of an Ultisols in Pennisular Malaysia Utilized for Oil Palm Plantation. Solid Earth Discussions. **60**:1-21.

Finer, M., & Jenkins, C. N. 2012. Proliferation of Hydroelectric Dams in the Andean Amazon and Implications for Andes-Amazon Connectivity. PLoS ONE, **7**.e35126.

Fox, J., Fujita, Y., Ngidang, D., Peluso, N., Potter, L., Sakuntaladewi, N., Sturgeon, J., and Thomas, D. 2009. Policies, political-economy, and swidden in Southeast Asia. Human Ecology. **37**: 305–22.

Fukushima, M., Kanzaki, M., Thein, H. M., Minn, Y. 2007. Recovery process of fallow vegetation in the traditional Karen swidden cultivation system in the Bago Mountain Range, Myanmar. Japanese Journal of Southeast Asian Studies. **45**: 317–333.

Funakawa, S., Hayashi, Y., Tazaki, I., Sawasa, K., and Kosaki, T. 2006. The main functions of the fallow phase in shifting cultivation by Karen People in northern Thailand- a quantitative analysis of soil organic matter analysis. Tropics. **15**:11–27.

Funakawa, S., Watanabe, T. and Kosaki, T. 2008. Regional trends in the chemical and mineralogical properties of upland soils in humid Asia: with special reference to the WRB classification scheme. Soil Science and Plant Nutrition. **54**: 751-760.

Galipeau, B. A., Ingman, M., and Tilt, B. 2013. Dam-Induced Displacement and Agricultural Livelihoods in China's Mekong Basin. Human Ecology. **41**: 437-446.

Ghiberto, P.J., Libardi, P.L. and Trivelin, P.C.O. 2015. Nutrient Leaching in an Ultisol

Cultivated with Sugarcane. Agricultural Water Management.**148**: 141–49.

Grigg, D. 1979. Ester Boserup’s theory of agrarian change: A critical review. Sage Journals. **3**: 64–84.

Hadden, R. L. 2008. The geology of Burma (Myanmar): An annotated bibliography of Burma`s geology, geography and earth science. Topographic Engineering Center US Army Corps of Engineers. Geospatial library.

Hansen, T. S., and Mertz, O. 2006. Extinction or adaptation? Three decades of change in shifting cultivation in Sarawak, Malaysia. Land Degradation and Development. **17**: 135–48.

Heinimann, A., Mertz, O., Frolking, S., Christensen, A. E., Hurni, K., Sedano, F., Chini, L. P., Sahajpal, R., Hansen, M. and Hurtt. G. 2017. A global view of shifting cultivation: Recent, current, and future extent. PloS One. **12**: e0184479.

Hlaing, Z. Chi., Kamiyama, C., and Saito, O. 2017. Interaction between Rural People's Basic Needs and Forest Products: A Case Study of the Katha District of Myanmar. Journal of Forest Research, 1–18.

Hunt, R. C. 2000. Labor productivity and agricultural development: Boserup revisited. Human Ecology. **28**: 251–277.

Jackson, S., & Sleigh, A. 2000. Resettlement for China's Three Gorges Dam: Socio-Economic Impact and Institutional Tensions. Communist Post-Communist Studies. **33**: 223–241.

Kanazawa, Hisami., Hoshikawa, K, and Nawata, E. 2006. The Changes in Land Use and Agricultural Systems of Karen People in North Thailand - A Case Study of Sam Sop Bon Village. Japanese. Journal of Tropical Agriculture Development. **50**: 131–141

Kramer, T. 2013. Access denied: Land use right and ethnic conflict in Burma. Burma Policy Briefing Series **11**: pp. 1–16. (A short report of Transition Institute and Burma Centrum Nederland).

Kirchherr, J., and Charles, K. J. C. 2016. The Social Impacts of Dams: A New Framework for Scholarly Analysis. Environmental Impact Assessment Review. **60**: 99–114.

Lobao, L., & Meyer, K. 2001. The Great Agricultural Transition: Crisis, Change and

Social Consequences of Twentieth Century US farming. Annual Review of Sociology. **27**: 103–24.

Li, P. and Feng, Z. 2016. Extent and area of swidden in montane mainland Southeast Asia: Estimation by multi-Step thresholds with landsat-8 OLI data. Remote Sensing. **8**: 1 –17.

Li, P., Feng, Z., Jiang, L., Liao, C., and Zhang, J. 2014. A review of swidden agriculture in Southeast Asia. Remote Sensing. **6**: 1654–83.

Liao, C., Zhiming, F.,Peng, L., and Jinhau, Z. 2015. Monitoring the spatio-temporal dynamics of swidden agriculture and fallow vegetation recovery using landsat imagery in northern Laos. Journal of Geographical Science. **25:** 1218–34.

Manatunge, J., Zakesada, N., Miyata, S., and Herath, L. 2009. Livelihood Rebuilding of Dam-Affected Communities: Case Studies from Sri Lanka and Indonesia. International Journal of Water Resources Development. **25**: 479–89.

Mapa, R. B., and Kumaragamage. D. 1996. Variability of Soil Properties in a Tropical Alfisol Used for Shifting Cultivation. Soil Technology. **9**: 187–97.

Manyari, W. V., and Carvalho, O. A. D. 2007. Environmental Considerations in Energy Planning for the Amazon Region: Downstream Effects of Dams. Energy Policy. **35**: 6526–34.

Maung, T. M., and Y.amamoto, M. 2008. Exploring the Socioeconomic Situation of Plantation Villagers: A Case Study in Myanmar Bago Yoma. Small-Scale Forestry. **7**: 29–48.

Mertz, O., Padoch, C., Fox, J., Cramb, R. A., Leisz, S. J., Lam, N. T., and Vien, T. D. 2009. Swidden change in Southeast Asia: Understanding causes and consequences. Human Ecology. **37**: 259–64.

Messerli, P. 2009. Finding homogeneity in heterogeneity: A new approach to quantifying landscape mosaics developed for the Lao PDR. Human Ecology. **37**: 291–304.

Ministry of Forestry, 1996. Myanmar forest policy, 1995 policy statement. Press in Yangon (Yangon) pp. 1–7.

Ministry of Forestry. 2005. National action programme of Myanmar to combat desertification in the context of the United Nations Convention to Combat Desertification (UNCCD). The Union of Myanmar Press (Yangon) pp. 1–98.

Moe, K. T., and Liu, J. (2016). Economic Contribution of Non-Timber Forest Products (NTFPs) to Rural Livelihoods in the Tharawady District of Myanmar. International Journal of Sciences. **5**: 12–21.

Mon, M. S., Mizoue, N., Htun, N. Z., Kajisa, T. and Yoshida, S. 2012. Factors affecting deforestation and forest degradation in selectively logged production forest: A case study in Myanmar. Forest Ecology and Management. **267**: 190–98.

Morimoto, R. (2013). Incorporating Socio-Environmental Considerations into Project Assessment Models Using Multi-Criteria Analysis: A Case Study of Sri Lankan Hydropower Projects. Energy Policy. **59**: 643–53.

Müller, D., Suess, S., and Hoffmann, A. A. and Buchholz, G. 2013. The value of satellite-based active fire data for monitoring, reporting and verification of REDD+ in the Lao PDR. Human Ecology. **41**: 7–20.

Nath, T. K., Jashimuddin, M., Hasan, M. K., Shahjahan, M. and Pretty, J. 2016. The Sustainable Intensification of Agroforestry in Shifting Cultivation Areas of Bangladesh. Agroforestry Systems. 90: 405–16.

Nielsen, U., Mertz, O., and Noweg, G. T. 2006. The rationality of shifting cultivation systems: Labor productivity revisited. Human Ecology. **34**: 201–18.

Noordwijk, M. V., Mulyoutami, E., Sakuntaladewi, N., and Agus, F. 2008. Swiddens in transition: Shifted perceptions on shifting cultivators in Indonesia. World Agroforestry Center Occasional Paper **9**: 1–48.

Padoch, C. 1985. Labor efficiency and intensity of land use in rice production: An example from Kalimantan. Human Ecology. **13**: 271–289.

Padoch, C., Coffey, K., Mertz, O., Leisz, S. J., Fox, J., and Wadley, R. L. 2007. The demise of swidden in Southeast Asia? Local realities and regional ambiguities. Journal of Geography. **107**: 29–41.

Petropoulos, George P., Kontoes, C., and Keramitsoglou, I. 2011. Burnt Area Delineation from a Uni-Temporal Perspective Based on Landsat TM Imagery Classification Using Support Vector Machines. International Journal of Applied Earth Observation and Geoinformation.**13**: 70–80.

Rasul, G., and Thapa, G. B. 2003. Shifting cultivation in the mountains of South and Southeast Asia: Regional patterns and factors influencing the change. Land Degrad.

Dev. **14**: 495–508.

Rerkasem, K., Lawrence, D., Padoch, C., Schmidt-Vogt, D., Ziegler, A. D. and Bruun, T. B. 2009. Consequences of widen transitions for crop and fallow biodiversity in Southeast Asia. Human Ecology. **37**: 347–60.

Rubin, J.A, Gordon, C., and Amatekpor, J. K. 1999. Causes and Consequences of Mangrove Deforestation in the Volta Estuary, Ghana: Some Recommendations for Ecosystem Rehabilitation. Marine Pollution Bulletin. **37**: 441–49.

Prueksapong, A., Watanabe, T., and Funakawa, S. 2015. Profile Description, Properties, and Classification of Paddy Soils at Different Topographical Positions in Surin Province, Thailand. Japanese Society of Pedology. **59**: 63–73.

Sakai, S., 2002. GIS analysis on slash and burn cultivation in Indonesia. In: Guideline of technical transfer on geographic information system. Ministry of Land, Infrastructure and Transport of Japan, Infrastructure Development Institute of Japan (Japan) pp. 28–54.

Saphangthong, T., and Kono, Y. 2009. Continuity and Discontinuity in Land Use Changes: A Case Study in Northern Lao Villages. Southeast Asian Studies. **47**: 263–286.

Senbayram, M., Gransee, A., Whale, V., and Thiel, H. 2015. Role of Magnesium Fertilisers in Agriculture: Plant–Soil Continuum. Crop and Pasture Science, **66**: 1219–1229.

Singleton, G. R., Brown, P. R. and Jacob, J. 2004. Ecologically based rodent management part 1. Australian center for international agricultural research. NJAS - Wageningen Journal of Life Science. **52**: 163–171.

Sumner, M. E., Farina, P. M. W., Hurst, V. J. 1978. Magnesium fixation—a possible cause of negative yield responses to lime applications. Communications in Soil Science and Plant Analysis. **9**: 995–1007.

Suzuki, R., Shinya, T., Hla, M.T. 2009. Effect of Slash-and-Burn on Nutrient Dynamics during the Intercropping Period of Taungya Teak Reforestation in the Bago Mountains, Myanmar. Tropical Agriculture and Development. **53**: 82-89.

Swe, K. N., and Nawata, E. 2019. Developing a remote sensing-based mapping method for swidden land use detection - Case studies in two Karen villages of the Bago

Mountains, Myanmar. Tropical Agriculture and Development. **64**: 13-22.

Takeda, S., Suzuki, R. and Hla, M.T. 2006. Three-year monitoring of shifting cultivation fields in a Karen area of the Bago Mountains, Myanmar. In: Crossing disciplinary boundaries and re-visioning area studies. (Maruyama, J., L. Wang, T. Fujikura and M. Ito eds.), Kyoto University Press (Kyoto) pp. 49-54.

Teegalapalli, K., and Datta, A. 2016. Shifting to settled cultivation: Changing practices among the Adis in central Arunachal Pradesh, north-east India. Ambio **45**: 602–12.

Tint, K., Baginski, O. S. and Gyi, M. K. K. 2011. Community forestry in Myanmar: Progress & potentials. Ecosystem conservation and community development initiative, Press in Yangon (Yangon) p. 93.

Tovar, C., Seijmonsbergen, A. C. and Duivenvoorden, J. F. 2013. Monitoring Land Use and Land Cover Change in Mountain Regions: An Example in the Jalca Grasslands of the Peruvian Andes. Landscape and Urban Planning. **112**: 40–49.

Uhlig, J., Hall, C. A. S. and Nyo, T. 1994. Changing Patterns of Shifting Cultivation in Selected Countries in Southeast Asia and Their Effect on the Global Carbon Cycle. In Effects of Land-Use Change on Atmospheric CO2 Concentrations, edited by Virginia H. Dale, New York, NY: Springer New York. **101**:145–200.

Van Vliet, N., Mertz, O., Thomsen, T. B., and Schmook, B. 2013. Is there a continuing rationale for swidden cultivation in the 21st century? Human Ecology. **41**: 1–5.

Venkata Rao, G., Kumar, A., Kumar, A. S., and Shashi, M. 2018. Spatio-temporal monitoring of shifting cultivation using landsat images: soft classification approach. J. Ind. Soc. Remote Sensing. **46**: 1047–52.

Win, U. K. 1991. A century of rice improvement in Burma. International Rice Research Institute (Los Baños) p. 162.

Yankson, P. W.K., Asiedu, A. B., Owusu, K., O., Urban, F. and Siciliano, G. 2016. The Livelihood Challenges of Resettled Communities of the Bui Dam Project in Ghana and the Role of Chinese Dam-B- Uilders. Develoment Policy Review. **36**: 476-494.

Zhao, Qinghe, Liu, S. and Dong, S. 2010. Effect of Dam Construction on Spatial-Temporal Change of Land Use: A Case Study of Manwan, Lancang River, Yunnan, China. Procedia Environmental Sciences. **2**: 852–58.

Internet Documents

Aye, T. H, Maung, T.M. and Chan, N. (2017, December). The Contribution of Non-Timber Forest Products Income to the Local Communities Living in and around the Kyaikhtiyoe Wildlife Sanctuary in Mon State, Myanmar. Ministry of Natural Resources and Environmental Conservation Forest Department. Retrieved from http://www.forestdepartnmnet.gov.mm/sites//default/files/Research%20Books20 file/Leafflet%20No.15Tin%20Hnaung%20Aye.pdf

Aye, T. M. (2001). Developing Sustainable Soil Fertility in Southern Shan State of Myanmar. Massey University, New Zealand. 352. Retrieved from https://doi.org/2001.

Fan, S. 1998. 'A Large Terrestrial Carbon Sink in North America Implied by Atmospheric and Ocanic Carbon Dioxide Data and Models'. Science.

FAO, 2015. The State of Food Insecurity in the World. The State of Food Insecurity in the World. Rome: FAO.

Jackson, L.Ann. 1995. 'Non degrading Land Use Strategies for Tropical Hillsides. 2020 Brief No. 27.pdf. International Food Policy Research Institute. Retrieved from https://www.google.com/search?q=Non+degrading+Land+Use+Strategies+for+Tropical+Hillsides.+2020+Brief+No.+27.Pdf%E2%80%99.+International+Food+Policy+Research+Institute.&oq=Non+degrading+Land+Use+Strategies+for+Tropical+Hillsides.+2020+Brief+No.+27.Pdf%E2%80%99.+International+Food+Policy+Research+Institute.&aqs=chrome..69i57.352j0j7&sourceid=chrome&ie=UTF-8

Physicians for Human Rights. (2015, October). Forced Displacements and Destroyed Lives around Upper Paunglaung Dam in Shan State, Myanmar. New York, NY. Retrieved from http://www.google.com/search?q=Forces+Dosplacements+and+Destroyed+LIves+around+Upper+Paunglaung+Dam+in+Shan%2C+Myanmar&oq=Forced+Displacenments+and+Destroyed+Lives+around+Upper+Paunglaung+Dam+in+Shan+State%2C+Myanmar&aqs=chrome..69i57.513joj7&sourceid=chrome&ie=UTF-8

Springate-Baginski, Oliver. 2013. Rethinking Swidden Cultivation in Myanmar'. University of East Anglia/Pyoe Pin.

Utitsan, Seehapol., Benjawan, T., Tanatit, S., Wetmongwetgorn, W., Than, U. S., Myint,

K. H. and Wah, L. B. 2014. Geological Evolution of Bago-Yoma Basin, Onshore Myanmar. Search and Discovery article. http://www.searchanddiscovery.com/pdfz/documents/2014/10659utitsan/ndxutitsan.pdf.html.

APPENDICES

Appendix 1 Classification accuracy assessment of land cover change of Paunglaung reserved forest in 2018 (Landsat image)

Class types determined from classified map	Class types determined from reference data							
Land Cover	Permanent Upland Farm	Water Body	Swidden fields	Forest area	Settlement ar	Orchard and Plantation	Grand Total	User Accuracy
Permanent Upland Farm	3	0	0	0	0	0	3	100
Water Bodies	0	36	0	1	0	0	37	97
Swidden fields	0	0	5	2	0	0	7	71
Forest area	0	0	0	12	0	1	13	92
Settlement area	2	0	0	0	21	0	23	91
Orchards and Plantation	0	0	0	0	1	3	4	75
Grand Total	5	36	5	15	22	4	87	
Producer Accuracy	60	100	100	80	95	75		

Overall Accuracy = 92 %

Kappa Coefficient = 0.89

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