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Changes of traditional farming systems and their effects on land degradation and socio-economic conditions in the Inle Lake region, Myanmar

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Summary

At many locations in Myanmar, ongoing changes in land use have negative environmental impacts and threaten natural ecosystems at local, regional and national scales. In particular, the watershed area of Inle Lake in eastern Myanmar is strongly affected by the environmental effects of deforestation and soil erosion caused by agricultural intensification and expansion of agricultural land, which are exacerbated by the increasing population pressure and the growing number of tourists. This thesis, therefore, focuses on land use changes in traditional farming systems and their effects on socio-economic and biophysical factors to improve our understanding of sustainable natural resource management of this wetland ecosystem. The main objectives of this research were to: (1) assess the noticeable land transformations in space and time, (2) identify the typical farming systems as well as the divergent livelihood strategies, and finally, (3) estimate soil erosion risk in the different agro-ecological zones surrounding the Inle Lake watershed area.

GIS and remote sensing techniques allowed to identify the dynamic land use and land cover changes (LUCC) during the past 40 years based on historical Corona images (1968) and Landsat images (1989, 2000 and 2009). In this study, 12 land cover classes were identified and a supervised classification was used for the Landsat datasets, whereas a visual interpretation approach was conducted for the Corona images. Within the past 40 years, the main landscape transformation processes were deforestation (- 49%), urbanization (+ 203%), agricultural expansion (+ 34%) with a notably increase of floating gardens (+ 390%), land abandonment (+ 167%), and marshlands losses in wetland area (- 83%) and water bodies (- 16%). The main driving forces of LUCC appeared to be high population growth, urbanization and settlements, a lack of sustainable land use and environmental management policies, wide-spread rural poverty, an open market economy and changes in market prices and access.

To identify the diverse livelihood strategies in the Inle Lake watershed area and the diversity of income generating activities, household surveys were conducted (total: 301 households) using a stratified random sampling design in three different agro-ecological zones: floating gardens (FG), lowland cultivation (LL) and upland cultivation (UP). A cluster and discriminant analysis revealed that livelihood strategies and socio-economic situations of local communities differed significantly in the different zones. For all three zones, different livelihood strategies were identified which differed mainly in the amount of on-farm and off-farm income, and the level of income diversification. The gross margin for each household from agricultural production in the floating garden, lowland and upland cultivation was US$ 2108, 892 and 619 ha^{-1} respectively. Among the typical farming systems in these

zones, tomato (*Lycopersicon esculentum* L.) plantation in the floating gardens yielded the highest net benefits, but caused negative environmental impacts given the overuse of inorganic fertilizers and pesticides.

The Revised Universal Soil Loss Equation (RUSLE) and spatial analysis within GIS were applied to estimate soil erosion risk in the different agricultural zones and for the main cropping systems of the study region. The results revealed that the average soil losses in year 1989, 2000 and 2009 amounted to 20, 10 and 26 t ha^{-1}, respectively and barren land along the steep slopes had the highest soil erosion risk with 85% of the total soil losses in the study area. Yearly fluctuations were mainly caused by changes in the amount of annual precipitation and the dynamics of LUCC such as deforestation and agriculture extension with inappropriate land use and unsustainable cropping systems. Among the typical cropping systems, upland rainfed rice (*Oryza sativa* L.) cultivation had the highest rate of soil erosion (20 t $ha^{-1}yr^{-1}$) followed by sebesten (*Cordia dichotoma*) and turmeric (*Curcuma longa*) plantation in the UP zone. This study indicated that the hotspot region of soil erosion risk were upland mountain areas, especially in the western part of the Inle lake. Soil conservation practices are thus urgently needed to control soil erosion and lake sedimentation and to conserve the wetland ecosystem. Most farmers have not yet implemented soil conservation measures to reduce soil erosion impacts such as land degradation, sedimentation and water pollution in Inle Lake, which is partly due to the low economic development and poverty in the region.

Key challenges of agriculture in the hilly landscapes can be summarized as follows: fostering the sustainable land use of farming systems for the maintenance of ecosystem services and functions while improving the social and economic well-being of the population, integrated natural resources management policies and increasing the diversification of income opportunities to reduce pressure on forest and natural resources.

Deutsche Zusammenfassung

Die derzeitigen Landnutzungsveränderungen in Myanmar führen zu negativen Umweltauswirkungen und bedrohen die natürlichen Ökosysteme auf lokaler und nationaler Ebene. Insbesondere das Wassereinzugsgebiet des Inle Sees im Osten Myanmars ist stark von den Auswirkungen der Entwaldung, der landwirtschaftlichen Intensivierung und Ausweitung landwirtschaftlicher Flächen betroffen, welche durch den steigenden Bevölkerungsdruck und die wachsenden Zahl an Touristen noch verstärkt werden.

Die vorliegende Arbeit beschäftigte sich deshalb mit den Änderungen in der Landnutzung durch traditioneller Anbausysteme und deren Auswirkungen auf die sozio-ökonomischen und bio-physikalischen Faktoren, um das allgemeine Verständnis hinsichtlich der nachhaltigen Bewirtschaftung der natürlichen Ressourcen in dieser Region zu verbessern.

Dabei war das Ziel, die Transformationsprozesse der Landschaft in Raum und Zeit abzubilden, die traditionellen Anbausysteme sowie die unterschiedlichen Überlebens- und Erwerbstrategien der lokalen Bevölkerung zu untersuchen und die Bodenerosionsgefahr in den verschiedenen agrarökologischen Zonen rund um den Inle See abzuschätzen.

Mit Hilfe von GIS und Fernerkundungstechniken wurde die Dynamik der Änderungen von Landnutzung und Landbedeckung (LUCC) während der letzten 40 Jahre auf der Basis von historischen Corona (1968) und Landsat Satellitenbildern (1989, 2000 und 2009) untersucht. Hierbei wurden 12 Landbedeckungsklassen indentifiziert und eine automatische, überwachte Klassifizierung für die Landsat -Datensätze verwendet, während die Landbedeckung für die historischen Corona Bilder visuell interpretiert wurde.

Die stärksten Transformationsprozesse der Landschaft innerhalb der letzten 40 Jahre waren Entwaldung (- 49%), Verstädterung (+ 203%), Ausdehnung landwirtschaftlicher Flächen (+ 34%) insbesondere von schwimmenden Gärten (+ 390%), Landaufgabe (+ 167%), und Flächenrückgang für Feuchtgebiete (- 83%) und Gewässer (- 16%).

Zu den Haupttreibern der LUCC zählen der steigende Bevölkerungsdruck, die Urbanisierung und Ausdehnung der Siedlungen, ein Mangel an nachhaltigen Landnutzungs- und Umweltmanagementstrategien, die weit verbreitete Armut in ländlichen Gebieten, Preisveränderungen für landwirtschaftliche Produkte und der Zugang zu Märkten.

Um die unterschiedlichen Überlebens- und Erwerbsstrategien der lokalen Bevölkerung im Wassereinzugsgebiet des Inle-See und die Diversifizierung des Einkommens zu untersuchen, wurden Haushaltsbefragungen durchgeführt (insgesamt 301 Haushalte), auf

der Basis eines stratifizierten zufälligen Stichprobendesigns in drei verschiedenen agrarökologischen Zonen: schwimmende Gärten (FG), Anbau im Flachland (LL) und Hochlandanbau (UP). Cluster- und Diskriminanzanalysen zeigten auf, dass es in den verschiedenen Zonen signifikante Unterschiede in der sozio-ökonomischen Situation und den Erwerbsstrategien der Bevölkerung gibt. Für alle drei Zonen wurden verschiedene Überlebens- und Erwerbsstrategien identifiziert, die sich insbesondere in der Höhe des landwirtschaftlichen- und nicht-landwirtschaftlichen Einkommens und im Grad der Einkommensdiversifizierung voneinander unterscheiden. Der Deckungsbeitrag für jeder Haushalt aus der landwirtschaftlichen Produktion ergab für schwimmende Gärten (FG) 2108 US$ pro ha, für den Anbau im Flachland (LL) 892 US$ pro ha und den Hochlandanbau 619 US$ pro ha. Zu den typischen Anbaukulturen in den schwimmenden Gärten zählen Tomaten, welche den höchsten Nettonutzen erzielten, gleichzeitig aber aufgrund des hohen Einsatzes von Mineraldünger und Pestiziden negative Umweltauswirkungen verursachten.

Um das Bodenerosionsrisiko in den unterschiedlichen agrarökologischen Zonen und für die Hauptanbausysteme im Untersuchungsgebiet zu schätzen, wurde ein überarbeitetes Modell der Bodenabtragsgleichung (Revised Universal Soil Loss Equation, RUSLE) zusammen mit räumlichen Analysen im GIS verwendet. Die Ergebnisse zeigen, dass die durchschnittlichen Bodenverluste durch Wassererosion im Jahr 1989, 2000 und 2009 20, 10 und 26 t je Hektar betrugen. Auf Brachflächen bzw. bei karger Vegetation und entlang der Steilhänge wurden die höchsten Bodenerosionsraten ermittelt, welche insgesamt 85% der gesamten Bodenverluste im Untersuchungsgebiet ausmachten. Die jährlichen Schwankungen beruhten vor allem auf Veränderungen in der Menge des jährlichen Niederschlags und der Dynamik der LUCC wie Abholzung und Erweiterung landwirtschaftlicher Flächen mit unangepasster Landnutzung und nicht nachhaltigen Anbautechniken. Im Hochland führte vor allem der Reisanbau zu den höchsten Bodenerosionsraten (20 t je ha und Jahr), gefolgt von Sebesten und Kurkuma Plantagen. Dies zeigt, dass die Anbaugebiete in den Hochlagen mit einem besonders hohen Bodenerosionsrisiko konfrontiert sind, vor allem in der westlichen Region des Inle Sees. Die Durchführung von Bodenschutzmassnahmen zur Verminderung von Bodenerosion und Sedimentationsprozessen im See ist nötig, um das Ökosystem zu erhalten und Bodendegradierung und Wasserverschmutzung vorzubeugen. Bislang werden von den meisten Bauern noch keine aktiven Bodenschutzmaßnahmen durchgeführt, was zum Teil auch an der geringen wirtschaftlichen Entwicklung und Armut in dieser Region liegt.

Die größten Herausforderungen für die Landwirtschaft in Bergregionen Zentral-Myanmars können folgendermaßen zusammengfasst werden: Implementierung nachhaltiger

Landnutzungsstrategien für den Erhalt der Ökosystemfunktionen und –dienstleistungen bei gleichzeitiger Steigerung des sozialen und wirtschaftlichen Wohlergehens der Bevölkerung, stärkere Diversifizierung des Einkommens und Schaffung neuer Einkommensmöglichkeiten, um die derzeitige starke Nutzung von natürlichen Ressourcen zu verringern.

Chapter 1

1 General introduction

1.1 Introduction

Rapid landscape transformation processes occurred in Asia with the highest deforestation rates detected for Southeast Asia, which amounted to annual forest losses of approximately 23,000 km^2 between 1990 and 2000 (Zhao et al., 2006). Deforestation, cropland expansion and other human-induced land use changes seriously affected terrestrial ecosystems and biodiversity across regional and global scales and induced environmental pollution, especially of water resources such as rivers and lakes (Syphard et al., 2005; Zhao et al., 2006).

About 27% of the total land area in South and Southeast Asia are seriously degraded because of agricultural activities (Hillstrom & Hillstrom, 2003) and the increasing use of inorganic chemical inputs to agricultural production leads to water pollution and eutrophication of groundwater, rivers and lakes (Bouman et al., 2002). Population growth and the macro-scale economic processes induced ecological degradation (Geist & Lambin, 2002; McNeely & Scherr, 2003) and resulted in agriculture expansion and the intensification of production, which also caused deforestation with the loss of biodiversity and natural habitats (Shiva, 1993; Fang et al., 2005; Zhao et al., 2006).

The natural environments, especially in the mountain regions, support a wide range of valuable ecosystem services and the local population depend, to a high degree, on primary goods and services (Snel, 2004) and resource extraction (Scherr, 2003) to sustain their livelihoods. In view of the ongoing rapid transformation processes, the maintenance of these natural resources remains a challenge for sustainable land use management.

The ongoing urbanization processes increased social welfare and economy but created a serious impact on the local and global natural environment (Zhao et al., 2006; Wu, 2010). Deforestation, land degradation, loss of biodiversity, poor waste management, natural disasters and urbanization problems have been aggravated by poor economic policies and natural resource management that increased the dependence of local people on the environment for food and energy (Calkins & Thant, 2011). This is particularly true for Myanmar, which is a resource rich country and the ninth of the global 200 Eco-regions (Olson & Dinerstein, 2002) as well as one of the eight hottest biodiversity hotspots included in Indo-Burma (Myers et al., 2000), but has many environmental threats such as deforestation, illegal wildlife trade, construction of large dams and large scale gas and oil extraction (Wang et al., 2013).

The Inle Lake in Southern Shan Plateau of eastern Myanmar is the country's second largest terrestrial lake and one of its most prominent hotspots for national and international tourism (Goombridge & Jenkins, 1998) because of its beautiful sceneries and its importance for agriculture and fishery. Given its distinct bio-physical features and biodiversity, Inle Lake was not only designated as the 190th World's Eco-region in 1998 (Olson & Dinerstein, 2002), but also nominated as one of ASEAN Heritage Sites in 2004 (The Burma Environmental Working Group [BEWG], 2011) and nominated as one of the freshwater biodiversity hotspots by the World Conservation Monitoring Center (WCMC, 1998).

The Inle Lake watershed region comprises 11 townships, but our study only included Nyaung Shwe, Taunggyi, Kalaw and Pin Laung Townships covering an area of 2115 km^2 (Figure 1-1). The area has a tropical to sub-tropical climate favourable for cereal crops and horticultural crops. The average annual temperature is 23℃ with the maximum temperature over 35℃ during the summer season and mean annual rainfall is about 930 mm. Local inhabitants are employed in agriculture and in hydroponics, fishing, craft works, textile industry, and in small scale duck farming. The most recent statistics indicate that the population concentration is 89 people km^{-2} around the Lake and 386 people km^{-2} on the water (The Myanmar Times, 2005). The *Intha* ethnic group dominates around the lake (70%), but there are also Shan (15%), Pa-O (10%), Myanmar (3%), Dhanu and Taungyoe people (together 2%) inhabiting the surrounding hills (UNDP, 2005). The people around the lake largely live of lowland paddy fields, floating gardens and fishing while inhabitants of the mountain ranges practice rotational upland farming along steep slopes on both sides of the lake (*Taung yar*). There are therefore three types of farming systems found in and around Inle Lake.

1.2 Floating gardens

Inthas are practicing to hydroponics farming using floating islands of decayed grasses, reeds and marsh plants. Floating islands are organic blocks that have organic-rich soils of low bulk density and floatability of 10-20 cm above the water (Sidle et al., 2007). The islands (locally known as *Ye-chan*) are typically about 2 m wide and 40 m long, but may reach a size of up to 800 m^2. Silt and clay alluvium from the bottom of the lake and weeds such as water hyacinth are used to augment the structure and fertility of these islands. By trimming these islands annually, *Inthas* grow vegetables year-round. Floating islands (Figure 1-2) can be used for gardening about 15 years and more, depending on floatability of the submerged mattress and farmers' practices (Than, 2007).

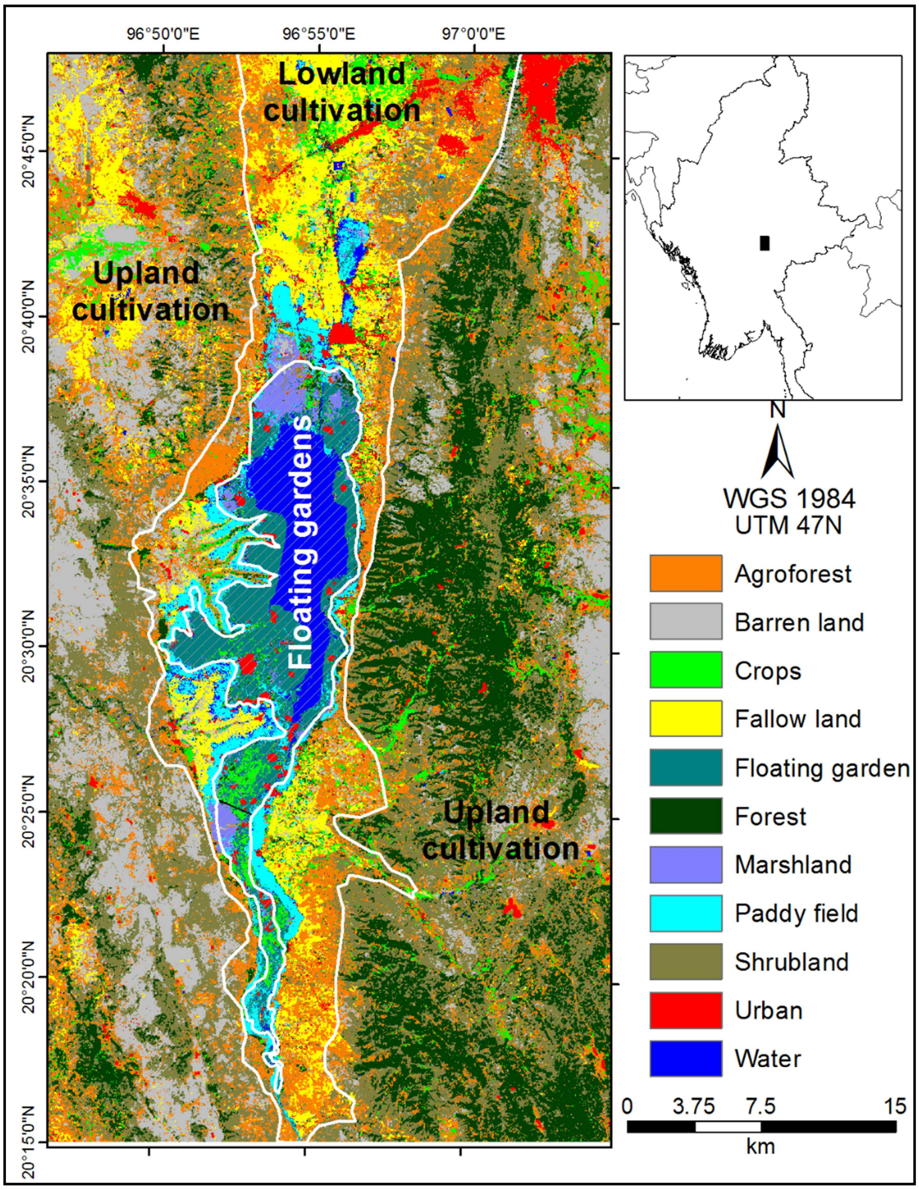

Figure 1-1. Location of study area showing detailed land use and the different agricultural zones of the Inle Lake region.

Lwin (2006) reported that the floating agriculture area has increased from 180 ha between 1955 and 1960 to 581 ha between 1960 and 1992. By 2007-2008, it reached 2,926 ha (Myanma Agriculture Service [MAS], 2009). Tomato (*Lycopersicon esculentum* L.*)*, the main cash crop, is grown on the man-made floating islands. In recent years, a high-yielding variety of tomatoes has been introduced from Thailand that is now widely grown on the floating islands leading to an overuse of agrochemicals and eutrophication in the lake. Thus Inle Lake has become a major tomato production area in the country. Such overuse of agricultural land and floating gardens are creating an additional challenge to the wetland ecosystem in Inle Lake.

Figure 1-2. Tomato plantation on floating gardens at Inle Lake, Myanmar.

1.3 Lowland cultivation

Lowland cultivation comprises paddy (*Oryza sativa* L.; Figure 1-3*a*) and other crops, which are planted on flat areas between the lake and the mountains. Further lowland cultivation techniques are dryland cultivation (*yar*), wetland agriculture (*le*), and horticulture. In 2005-2006, the area of dry land, wet land, and horticultural crop production was 5,887 ha, 5,254 ha, and 586 ha, respectively (Lwin, 2006). Paddy fields cover over 48% of the total cultivated area (UNDP, 2006). Beside paddy, other crops are sugar cane (*Saccharum officinarum* L.; Figure 1-3*b*.), niger (*Hyoscyamus niger* L.), wheat (*Triticum aestivum* L.), groundnut (*Arachis hypogaea* L.) and maize (*Zea mays* L.), vegetables such as potatoes (*Solanum tuberosum* L.), chili (*Capsicum annuum* L.) and flowers such as chrysanthemum (*Chrysanthemum* ssp.), near the streams entering the lake. This leads to an even higher risk of eutrophication.

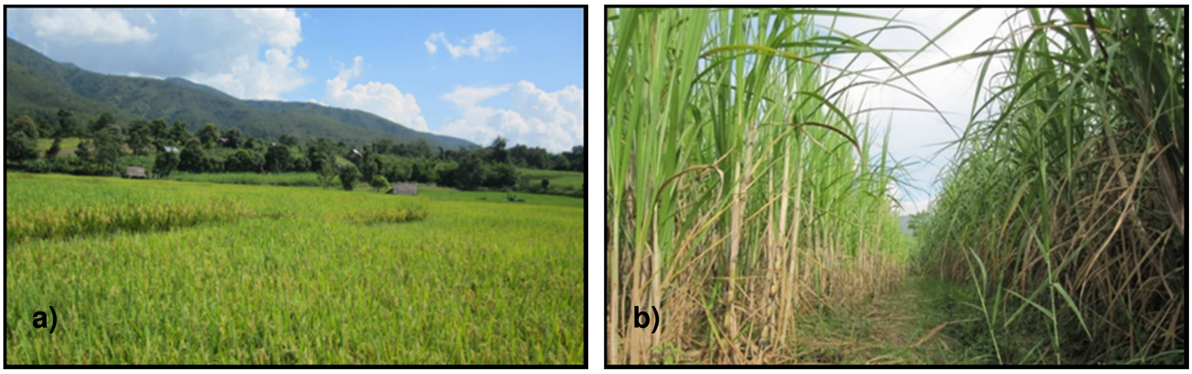

Figure 1-3. Lowland cultivation; a) paddy field and b) sugar cane plantation at Inle Lake, Myanmar.

1.4 Upland cultivation

In upland cultivation systems, cultivation practices are mostly based on monocultivation, shifting cultivation, terraces and agro-forestry systems. Most farmers cultivate sebesten tree (*Cordia dichotoma* G. Forst; Figure 1-4*a*) locally known as thanatphet on sloping land without soil conservation practices under intensive cultivation and commercial cropping strategies with high inputs of pesticides and mineral fertilizers. In 2001, the sebesten farming area in the upland cultivation zone was 1,397 ha (San, 2007).

To slow down the ongoing land degradation, some local farmers already started to terrace their fields for rice cultivation and/or agro-forestry systems composed of perennial crops such as mango (*Mangifera indica* L.) and annuals such as soybean (*Glycine max* L. Merr.), ricebean (*Vigna umbellate* Thunb. Ohwi & Ohashi), groundnut (*Arachis hypogaea* L.), maize and rainfed rice (*Oryza sativa* L., Figure 1-4b).

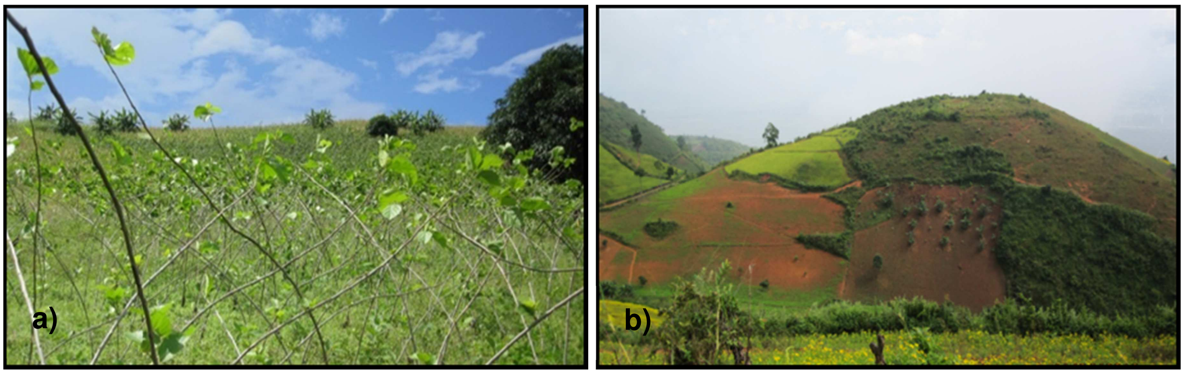

Figure 1-4. Upland cultivation; a) sebesten plantation and b) rainfed rice near Inle Lake, Myanmar.

1.5 Problem statement

The prevalent deforestation and inappropriate land use practices threatens the natural ecosystems in Myanmar (Johannesburg, 2002), especially in the Inle Lake watershed area of the Southern Shan Plateau. The pressure on natural resources is extreme and income opportunities are few, whereby inappropriate agricultural farming systems in the surrounding areas of Inle Lake lead to land degradation. Within the last 20 years, the landscape surrounding Inle Lake has undergone dramatic changes mainly caused by deforestation, agricultural expansion, and urbanization combined with a rapid growth in the tourist sector and industrialization. Shifting cultivation and deforestation processes affect about 80% of the total catchment surface area leading to widespread erosion and subsequent lake sedimentation. Excessive non-timber forest cutting, unsuitable cultivation practices including shortened fallow periods for shifting cultivation and uncontrolled livestock grazing have led to severe loss of soil organic matter and poor water retention, erosion, landslides, sedimentation and flooding. The freshwater ecosystem of Inle Lake is therefore threatened by sedimentation and water pollution due to inappropriate agricultural practices on the surrounding hills, intensive vegetable production on floating gardens, and increasing population as well as urbanization (Johannesburg, 2002).

Many surrounding forests are degraded due to intensive logging, fuel wood usage for the numerous sugar cane factories located around Inle Lake as well as home consumption (MAS, 2009). This is one of the major causes for the sedimentation and the resulting decrease in size of the Inle Lake. In addition to the sediments, industrial residues are being disposed into Inle Lake from sugarcane factories and breweries located at the eastern and western sides of the lake. These are aggravated by the uncontrolled disposal of household waste and effluents from weaving industries, tomato cultivation and intensive livestock units. The watershed degradation of Inle Lake seems rather widespread and is likely caused by (1) socio-economic problems, (2) technical / institutional problems and (3) man-made and natural erosion. Population growth, economic development and infrastructural construction increase the pressure on natural resources as well (ADB, 2006).

Several previous studies (Su & Jassby, 2000; Thiha, 2001; Akaishi et al., 2006; Lwin, 2006; Sidle et al., 2007; Lwin & Sharma, 2012) semi-quantitatively described environmental degradation in the Inle Lake area, however, little is known about how reliable these reports are and quantitative data on land use and land cover change (LUCC), as well as information on livelihood strategies and soil erosion risk in the study region is still lacking. However, such data - verified in space and time - is necessary to take informed policy decisions in order to enhance the resilience of the Inle Lake land use systems. To this end, Nyaung Shwe Township of the Inle watershed area was selected for a study of a reportedly degraded watershed. Its inhabitants are predominantly subsistence farmers living in villages dotted around the lake and on the hillsides, and work either on the land or on the floating islands. They thus are typical examples for the complex livelihood strategies that farmers practice and the effects that these livelihood strategies have on agroecosystem services and functions. This study aimed at analyzing these land users – agroecosystem interactions and their consequences for the Inle Lake system. Therefore, the assessment of land use change, the socio-economic and livelihood strategies of the local communities, and of soil erosion risk within the watershed area of Inle Lake is imperative for sustainable land use management and biodiversity preservation in this region.

1.6 Research objectives and hypotheses

The objective of this study was to analyse the effects of changes in traditional farming systems on land degradation in the Inle Lake region and to assess their sustainability based on socio-economic and biophysical factors.

The specific objectives of the study were:

(i) To analyse the current distribution of different farming systems in space and time (based on oral history and remote sensing data) and to unravel the drivers for the changes in land use and land cover over the last 40 years;

(ii) To evaluate the socio-economic conditions of the traditional farming systems and their importance for people’s livelihood; and

(iii) To determine the effects of different farming systems on soil degradation (soil erosion risk) in space and time.

The following hypotheses were tested in the study:

(i) LUCC during the last 40 years is predominantly characterized by deforestation processes, a decrease in the size of water bodies and an expansion of cropland, and is mainly driven by an increase in population density and changes in market prices for agricultural products.

(ii) The dynamics and different types of farming systems depend on the bio-physical conditions of land as well as socio-economic and demographic factors especially farm, household size, farmers’ educational level and market orientation.

(iii) The soil erosion risk increased during the last 40 years, with the current upland cultivation system (rainfed rice and sebesten plantation) mainly triggering soil degradation processes.

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Chapter 2

2 Transformation processes in farming systems and surrounding areas of Inle Lake region, Myanmar during the last 40 years

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2.1 Abstract

Inle Lake in Eastern Myanmar is strongly affected by environmental effects of rapid population growth and an increase in the agricultural and tourist sector. To identify land use and land cover changes (LUCC), a post-classification comparison method was employed using historical Corona images (1968) and Landsat data (1989, 2000 and 2009). A supervised classification was performed for the Landsat datasets, whereas a visual interpretation was used for the Corona images.

During the last 40 years, the dominant landscape transformation processes were urbanization (+ 203%), crop expansion (+ 34%) with a particular increase of floating gardens (+ 390%), land abandonment (+ 167%), deforestation (- 49%) and wetland losses in marshlands (- 83%) and water bodies (- 16%). The main driving forces of LUCC appeared to be population increase, industrial activities, government policies, widespread rural poverty and changes in market prices and access.

Keywords: Crop expansion; deforestation; LUCC; urbanization; wetland losses; Sequential Maximum A Posteriori Classifer (SMAPC)

2.2 Introduction

Human-induced land use and land cover modifications are among the most significant agents of environmental change at local to global scales (Friedl et al., 2011) and they have significant implications for both the sustainability of the Earth's ecological systems and the socio-economic stability of current and future generations (Lubchenco, 1998; Foley et al., 2005). In Southeast Asia, the rates of land use and land cover changes (LUCC), including cropland expansion and deforestation, increased rapidly over the last 40 years due to social, political, environmental and economic developments (Richards, 1990; Ramankutty & Foley, 1998; Rao & Pant, 2000). In this context, the agricultural sector changed from traditional subsistence production to an increasing globalized commercial production. Since 1990 production rates increased, whereby up to 40% of land area is affected by land degradation (Johnston et al., 2009).

In the Southeastern Asian country of Myanmar (formerly Burma), widespread deforestation and unplanned land use changes threaten the natural ecosystems (United Nations, 2002), especially in the Inle Lake region in southern Shan Plateau. Inle Lake is the country's second largest terrestrial lake after Indawgyi Lake and plays an important role in people's livelihood and as a biodiversity hotspot (Goombridge & Jenkins, 1998). In the year 1996, tourism started to be promoted by the government (Su & Butkus, 2001), resulting in the establishment of new infrastructure such as hotels and roads, whereby tourist numbers rapidly increased in the following years. During the past 40 years the landscape surrounding Inle Lake has undergone dramatic changes mainly caused by an intensification of agriculture, deforestation and urbanization. Shifting cultivation and deforestation processes affect about 80% of the total catchment surface area. The freshwater ecosystem is threatened by water pollution and sedimentation due to slash and burn farming techniques on the surrounding hills, intensive vegetable production on floating gardens, which were introduced in in the early 1960s (Sidle et al., 2007), and increasing population (United Nations, 2002).

The pressure on natural resources is intense and extra-farm income opportunities are few, whereby unsustainable agricultural technologies in the surrounding areas lead to land and soil degradation processes. Excessive fuel wood cutting, shortened fallow periods for shifting cultivation, inefficient cultivation practices and uncontrolled livestock grazing have led to severe loss of soil organic matter and poor water retention, uncontrolled runoff, landslides, flooding and sedimentation of dams (Than, 2006).

Estimating the impacts of land use changes on land degradation and the interaction between land-use changes, livelihood strategies and the environment is required for more effective and sustainable land use planning and regional development (Lambin et al., 2006). In this context, the analysis of remote sensing data from different decades provides a powerful tool to assess landscape alterations, to estimate the rates and temporal dynamics of tropical deforestation and to monitor land cover change in different ecosystems (Dunn et al., 1991; Wilkie & Finn, 1996).

In Myanmar, the use of aerial photographs and satellite images for land use planning and reconnaissance started three decades ago (Aggrawal, 1980), but until now remote sensing studies have not systematically investigate the history of land use changes and their environmental effects such as soil erosion around Inle Lake, where major deforestation likely started in the 1960s.

Only a few LUCC studies exists for Myanmar, most of them with a special focus on deforestation, such as forest cover changes based on automated classification algorithms (Leimgruber et al., 2005; Win et al., 2009) and the analysis of the spatial and temporal deforestation dynamics (Songer et al., 2009). Other remote sensing studies in Myanmar were conducted to assess urban environmental changes (Aung & Yamazaki, 2003). For the Inle Lake region, remote sensing and GIS studies have been conducted to analyze contemporary changes in open water surface area of Inle Lake alone (Sidle et al., 2007) and to establish land management strategies based on a watershed classification from 1995 to 2000 (Thiha, 2001).

In contrast to the above mentioned studies, our work focuses on the temporal and spatial LUCC of the Inle Lake region, including different agricultural farming systems from wetland, lowland to upland cultivation areas. The main objectives of our study were to (i) analyze the current distribution of different farming systems in space and time, (ii) compare two classification approaches to detect land use and land cover changes and (iii) identify possible drivers for LUCC over the last 40 years. To do so, the supervised classification approach “Maximum Likelihood Classifer” (MLC) and the “Sequential Maximum A Posteriori Classifer” approach (SMAPC, Bouman & Shapiro, 1994) were compared.

2.3 Materials and Methods

2.3.1 Study area

The research area is located in the Southern Shan Plateau in Eastern Myanmar around the Inle Lake region, covering an area of 2115 km² (Figure 2-1), including Taunggyi and Nyaung Shwe Township. Inle Lake is Maynmar’s second largest terrestrial lake with a total watershed area of 5612 km² and is located between 20°18' to 20°53' N latitudes and 96°50' to 96°57' E longitudes at an altitude of 890 m a.s.l. (Su & Jassby, 2000). This area is characterized by a water body adjoining the vegetative shore line of marsh land in the nearby valley plain and at the foothills. Given its distinct biophysical features and species endemism, Inle was not only designated as the World’s 190th eco-region, but also nominated as one of the freshwater biodiversity hotspots by the World Conservation Monitoring Center (Groombridge & Jenkins, 1998).

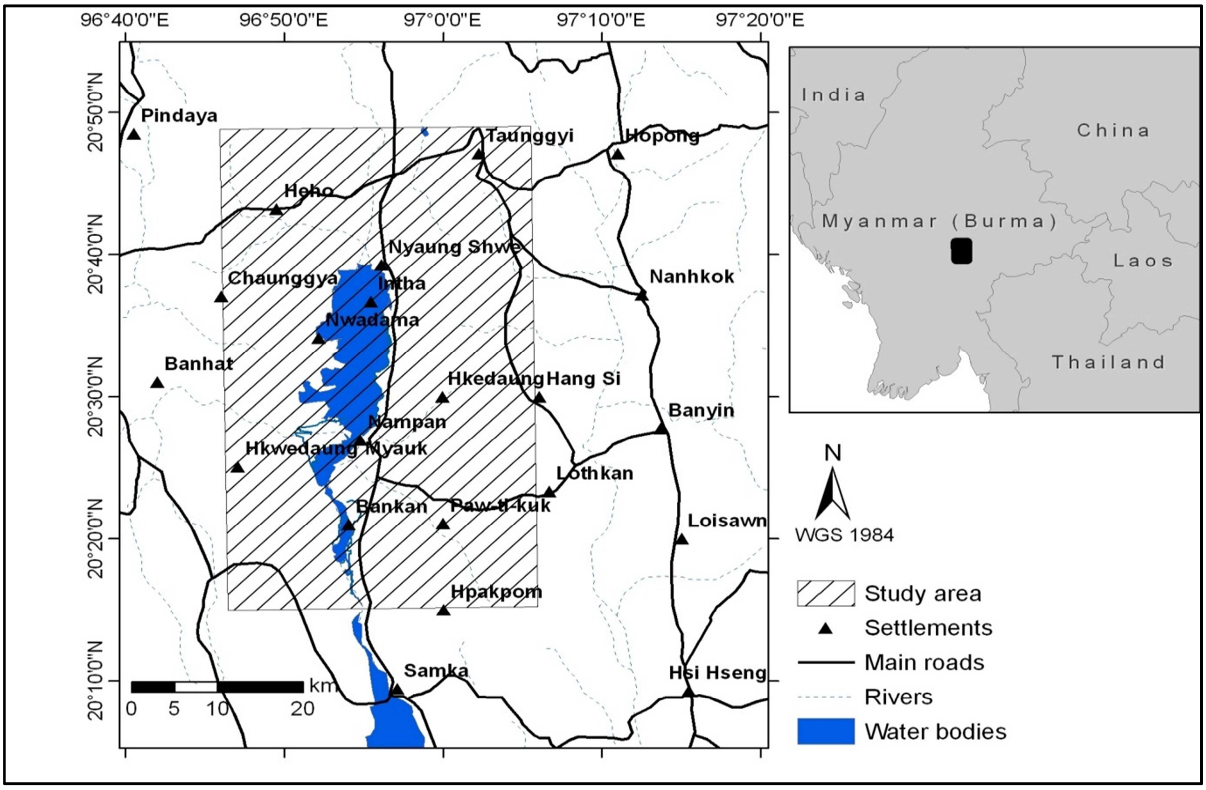

Figure 2-1. Location of the study area, Inle Lake in the southern Shan Plateau in Eastern Myanmar.

The Nyaung Shwe township (899 m a.s.l.) comprises a total area of 1454 km^2, which includes 451 villages, out of which 196 are in the Inle Lake area (UNDP, 2006). Taunggyi is the capital city of Shan State at an altitude of 1436 m a.s.l. The Taunggyi township comprises 233 villages with a total area of 1090 km^2.

In Nyaung Shwe and Taunggyi, the respective daytime temperature ranges from 9℃ to 32℃ and 9℃ to 27℃ in December, reaching a maximum of 25℃ to 35℃ and 14℃ to 32℃ in April with a 10-year average annual rainfall of 988 mm and 1509 mm, respectively (MAS, 2012).

This study area has a tropical to sub-tropical climate favourable for horticultural crops, especially mango (*Mangifera indica* L.), orange (*Citrus sinensis* L.) and grape (*Vitis vinifera* L.). While people around Inle Lake live from lowland paddy fields, floating gardens and fishing, the inhabitants of the mountain ranges practice rotational upland farming along steep slopes on both sides of the lake. There are therefore three types of farming systems adopted in and around Inle Lake.

Floating gardens are based on floating, man-made islands composed of decayed grasses, reeds and marsh plants. The islands (locally known as *Ye-chan*) are typically about 2 m wide and 40 m long, but may reach up to 800 m². Silt and clay alluvium from the lake bottom and weeds such as water hyacinth are used to augment the structure and fertility of these islands. By trimming these islands annually, Inle Lake farmers (*Inthas)* grow vegetables year-round. Tomato (*Lycopersicon esculentum* L.) is the main cash crop on these islands. In recent years, a very productive tomato variety has been introduced from Thailand and Inle Lake has become a major production area of the country. Floating islands are cultivated approximately 15 years dependent on the floatability of the submerged mattress of vegetation and farmers' practices (Than, 2007).

On-land cultivation comprises paddy fields (*Oryza sativa* L.) which are planted on flat areas between the lake and the mountains. Further on-land cultivation techniques are dryland cultivation (*yar*), wetland agriculture (*le*), and horticulture. Besides paddy, the main crops are sugarcane (*Saccharum* ssp.), potato (*Solanum tuberosum* L.), chili (*Capsicum* ssp), groundnut (*Arachis hypogaea* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) and some ornamental plants such as Chrysanthemum spp. and niger (*Guizotia abyssinica* L.) are produced near the streams entering the lake.

In upland cultivation systems (*taung yar*), management strategies are mostly based on shifting cultivation, field terraces and agro-forestry gardens. Farmers cultivate the sebesten tree (*Cordia dichotoma* G. Forst.) locally known as thanatphet, on sloping land without soil conservation practices, using intensive cultivation and commercial cropping strategies with high inputs of insecticides, pesticides, and mineral fertilizers. In 2001, the sebesten farming area in the upland cultivation zone was 1,400 ha (San, 2007).

2.3.2 **Data acquisition and pre-processing**

Different satellite image sources were used to classify LUCC from 1968 to 2009 in the study area (Table 2-1). For the year 1968, several panchromatic Corona (KH-4B) images from the U.S. Geological Survey’s Earth Resources Observation and Science (USGS/EROS) were used with 1.8 m resolution at nadir. All panchromatic Corona images were georeferenced based on topographic maps, Google Earth scenes and recent Landsat satellite images using readily recognizable, stable features such as pagodas, roads, urban structures and geomorphologic features (number of ground control points per image: 10-28; total root mean square error < 0.06; transformation: second-order polynomial; resampling method: nearest neighbour). To classify LUCC in 1989, 2000 and 2009 Landsat 5 and 7

Level 1 terrain corrected data sets with less than 5% cloud cover were acquired from USGS/EROS. To detect changes in land use based on a map comparison, all satellite images depict the main cropping season during winter before crop harvest (Table 2-1).

All images except the 2009 ones underwent radiometric, geographic and topographic corrections with 30 m resolution. For the SLC-off 2009 images, we conducted a gap filling procedure with NASA's gap filling tool "Frame and Fill" (NASA's Goddard Space Flight Center, Greenbelt, MD, USA) using co-registered cloud-free images as fill scenes that have been acquired close to the main scene to reduce the effects of changing ground cover.

Table 2-1. Satellite sensor, provider, date of acquisition, path and row (Landsat scene), spatial (m) and spectral resolution of the satellite dataset used for LUCC analysis in Inle Lake region, Myanmar.

Satellite (Sensor)	Provider	Date of acquisition	Path/ row	Spatial resolution	Spectral resolution
Corona KH-4B	U.S. Geological Survey's Earth Resources Observation an Science	05.02.1968	n.a.	2	Panchromatic
Landsat-4 (TM)	U.S. Geological Survey's Earth Resources Observation an Science	10.02.1989	132/46	30	Bands 1, 2, 3, 4, 5, 7
Landsat-7 (ETM)	U.S. Geological Survey's Earth Resources Observation an Science	24.01.2000	132/46	30	Bands 1, 2, 3, 4, 5, 7
Landsat-7 (ETM)	U.S. Geological Survey's Earth Resources Observation an Science	17.02.2009	132/46	30	Bands 1, 2, 3, 4, 5, 7

2.3.3 **Classification methods and accuracy assessment**

For the supervised classification of the Landsat 2009 image, several classification approaches were used to compare the results and identify the most appropriate automated procedures to determine land use and land cover changes at a broader scale. MLC and SMAPC were compared using the open source software Quantum GIS 1.7.4 'Wroclaw' with the GRASS plug-in (Quantum GIS Development Team, 2012). MLC is a supervised statistical approach based on a simple pixel which is assigned to the class for the highest probability (Tso & Mather, 2009).

SMAPC is used to classify multispectral images or single-band images based on image segments. At each scale, the best segmentation is calculated given the previous coarser segmentation and the observed data using a spectral class model known as a Gaussian mixture distribution (Bouman & Shapiro, 1994). The model improves by using a larger neighbourhood for each pixel and calculates the sequence of random fields from coarse to fine scale and the observed data using a spectral class model (Bouman & Shapiro, 1994; McCauley & Engel, 1995). After segmentation, a MLC was applied for final image classification. Various land use classes were detected in the study area (Table 2-2) according to field observations and visual inspections of Google Earth® images. Landsat standard false color composites were used to define the training data set for the year 2009.

Table 2-2. Predefined land use classes, number and size (ha) of training samples (TS) and number of validation plots (VP) for the classification of LUCC in Inle Lake, Myanmar.

.Class	Class name	Ground objects	Number and size of TS	Number of VP
1	Agroforest	Trees & crops on cultivated land	94 (210.4)	34
2	Barren land	Non-vegetated areas and sparsely vegetated areas on dry soils	105 (171.6)	27
3	Crops	Intensively cultivated field crops	84 (89.1)	18
4	Fallow land	Fallow fields on cultivated land (wet soil)	92 (156.5)	55
5	Floating garden	Hydroponics farming using floating islands of decayed grasses. reeds and marsh plants	98 (462.1)	8
6	Forest	Dense hill forest, High vegetation cover	109 (258.8)	30
7	Marshland	Marshy grassland and swamp near rivers and lakes	109 (133.3)	4
8	Paddy field	Upland rice production	95 (73.1)	16
9	Shrubland	Rangeland and grasslands with shrubs and isolated trees	80 (318.3)	51
10	Urban	Settlements, cities, single houses, industrial facilities	89 (170.9)	6
11	Water	Open waterbody, lake, reservoirs, Streams, branches	202(1637.7)	10
12	Open woodland	Low-density and degraded forest in transition to shrubland, affected by shifting cultivation	86 (212.4)	41

An accuracy assessment was conducted by using 300 independent validation plots (pixel size: 30 m, Table 2-2) to identify the most appropriate classification method for the study area. The location of the validation plots was randomly selected for the study region. The observed land cover of the validation plots was visually classified using recent (2009/2010) Google Earth® high resolution satellite images and own field observations. Error matrices based on cross-tabulation of the classified data *versus* the validation plots were used to conduct an accuracy assessment (Congalton & Green, 1999). Thereby, user's, producer's and overall accuracies, and kappa coefficients were calculated based on error matrices. Overall accuracy evaluates the percentage of cases correctly classified, and the kappa coefficient is the most widely used statistic measure for the estimation of the effect of change agreement (Gómez & Montero, 2001).

2.3.4 **Analysis of LUCC over the last 40 years**

For the analysis of LUCC along the time series, the post classification comparison method was used based on independently classified images from different times on a pixel-by-pixel comparison (Cetin, 2009). Since no geographical information on past land cover and land use was available, the training samples used for the classification of the 2009 image were also employed to classify older images. They were visually redefined for each classification of the 1989 and 2000 Landsat scenes based on the spectral information of the colour composites, respectively. Thereby the visual interpretation was calibrated for already known spectral and shape characteristics (colour, structure, and size) of 2009.

In order to improve the overall classification accuracy, the already classified Landsat data (1989, 2000 and 2009) were post-processed. Some classes had similar spectral characteristics, resulting in a relatively high error of confusion, mainly for urban areas and barren land, as well as for water areas, floating gardens and marshland. The Google Earth® and historical Corona satellite images allowed visual identification and digitization of all urban areas and water bodies for 1968 and 2009/2010. Based on this information, all areas misclassified as urban, water and barren land outside the digitized zones were reclassified.

Since panchromatic Corona images have only one spectral band, and because of the high heterogeneity in size, shape and colour of the ground objects within the classes and similar characteristics of ground objects belonging to different classes (fallow land or crop land, barren land, open woodland, urban area or water and wetland), visual interpretation was applied for the Corona data set using the predefined classification scheme (Table 2-2). Visual interpretation is one of the most widely used methods for detecting, identifying and characterizing the spatial features on an image since the human brain is a solid, integrating interpreter of images (Lillesand & Kiefer, 1994; Cetin, 2009). An accurate differentiation between fallow land and crop land was difficult for the panchromatic Corona images. This is why a combined class (fallow land and crops) for visual classification was used.

To highlight the LUCC during the last 40 years, classes that refer to agricultural production such as ‘Crops’, ‘Fallow land’ and ‘Agroforest’ were summarized for map comparison and change detection (‘Agricultural land’). The spatial distribution of the land use classes was extracted from each of the classified images in the time series.

To locate, quantify and compare the land use dynamics of the three main farming systems in and around Inle Lake, the study region was divided into three agricultural zones. The floating garden zone was defined by a visual identification using recent Google Earth® high resolution satellite images and GIS features of the water body, marshland and floating gardens. The upland cultivation zone on hilly slopes above 900 m a.s.l. was identified with a Digital Elevation Model (ASTER DEM, 15 m). The areas below 900 m adjoined to floating gardens belong to the lowland cultivated zones.

Within these zones, the extent of the main landscape transformation processes such as deforestation, crop expansion and urbanisation were identified. Map changes between the 1968 and 2009 classified land cover images were calculated for each agricultural zone within the study region to provide landscape transformation images that depict the pixel gains for the categories urban areas (= urbanisation), agricultural land including crops, agro-forestry zones, paddy fields, floating gardens and fallow land (= crop expansion) and barren land (= abandonment), as well as pixel losses for the category forest (= deforestation) and the category water and marshland (= wetland losses).

2.4 Results

2.4.1 **Accuracy assessment**

The validation of the produced maps of the classified Landsat image for 2009 revealed that classifications were most reliable using the SMAPC method (Table 2-3). The subsequent post processing, which was applied to improve the accuracy of the different land cover classes, increased the kappa coefficient from 0.79 to 0.83. Thus, the error matrices obtained pointed to a major reduction of errors due to post-processing (Appendix A). The overall accuracy of 85% met the specified general target threshold for land cover products, as defined by Thomlinson et al. (1999). This method was therefore also used for the classification of the 1989 and 2000 Landsat data.

The categories revealed different accuracy levels, which were lowest for fallow land (0.74) and marshland (0.71). Due to confusion with open woodland and due to misclassifications in ‘Crops’, ‘Marshland’ and ‘Paddy field’, omission errors were high for ‘Shrubland’. Post-processing decreased the former misclassification error by improving the producer’s accuracy from 66.7 to 90.2%. Some urban, water and marshland areas were misclassified as ‘Crops’, ‘Fallow land’ and ‘Shrubland’. Here, post-processing permitted to reduce the confusion, especially for urban areas (Appendix A).

Table 2-3. Accuracy assessment (kappa-coefficient and overall accuracy) of the different classifiers for the 2009 Landsat data used to examine LUCC in and around Inle Lake region: Maximum Likelihood Classifier" (MLC), sequential Maximum A Posteriori Classifier" (SMAPC) and post-processing of SMAPC.

Class name	Post-SMAPC	SMAPC	MLC
Agroforest	0.87	0.97	0.53
Barren land	0.92	0.88	0.50
Crops	0.89	0.61	0.50
Fallow land	0.74	0.80	0.65
Floating garden	0.89	0.77	0.77
Forest	0.79	0.70	0.42
Marshland	0.71	0.66	0.49
Paddy field	0.78	0.70	0.70
Shrubland	0.83	0.86	0.50
Urban	1.00	0.66	0.33
Water	0.81	0.81	0.53
Open woodland	*	0.69	0.46
Average	0.83	0.79	0.53
Overall accuracy (%)	**85**	**81.33**	**58.86**

* In post-processing the class ‘Open woodland’ was combined with the class ‘Forest’ to reduce the error of confusion.

2.4.2 Analysis of LUCC during the last 40 years

Urban areas expanded constantly during the last 40 years and increased threefold from 20 km^2 in 1968 to 60 km^2 in the year 2009 (Figure 2-2). Agricultural land including agroforestry areas, crops and fallow land expanded by 20% in 1989, 23% in 2000 and 34% in 2009, resulting in an area increase of 164 km^2 during the last 40 years.

The urbanization trend from 1968 (20 km^2) to 2009 (60 km^2) reflect a strong increase in population. Over the last 40 years the population density doubled its size from 194,190 in 1970 to 479,735 people in Nyaung Shwe and Taunggyi township (Figure 2-2).

Forest area declined sharply from 659 km^2 in 1968 to 414 km^2 in 1989. However, the forest area in the year 2000 increased slightly to 456 km^2, but by 2009 it declined again to 337 km^2. A similar trend in the opposite direction was detected for barren land, which increased from 1968 to 1989 up to 300 km^2 (+148%) and subsequently decreased to 288 km^2 until 2000 and increased again from 2000 to 2009 to a total area of 323 km^2. Shrubland decreased slightly from 586 km^2 in the year 1968 to 583 and 536 km^2 in 1989 and 2000, respectively. In the year 2009, shrubland rose to 550 km^2 compared with the year 2000 (Figure 2-3a).

The paddy field area remained nearly constant (60 km²) during the past 40 years with a slight decrease in 2009 (Figure 2-3b). In contrast, the total area of floating gardens increased notably from 14 km^2 in the year 1968 to 49, 60 and 69 km^2 in the years 1989, 2000 and 2009. The marshland area was highly dynamic during the past four decades and decreased significantly from 100 km^2 in 1968 to 55, 28 and 17 km^2 in the years 1989, 2000 and 2009. The area of water bodies shrunk significantly from 70 km^2 in 1968 to 45 km^2 in 1989, but increased in the following years, reaching a size of 50 km^2 in 2000 and 59 km^2 in 2009 (Figure 2-3b).

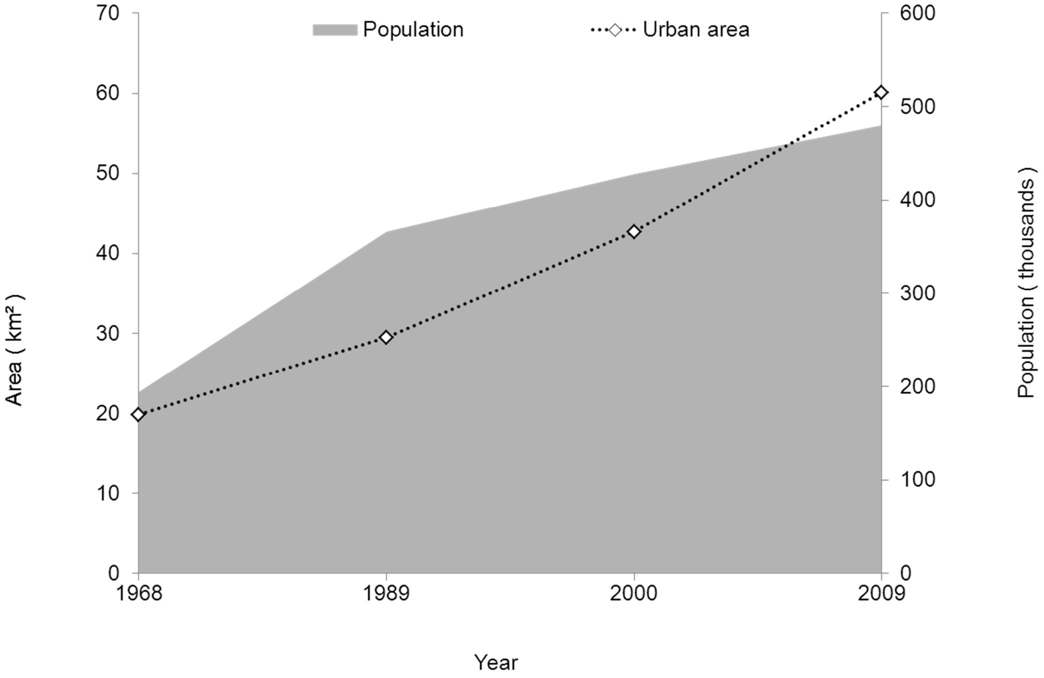

Figure 2-2. Changes in urban area and population density. Source for population trend from 1968 to 2009: ADB, 2006 and Department of Immigration and National Registration, Ministry of Immigration and Population, 2009.

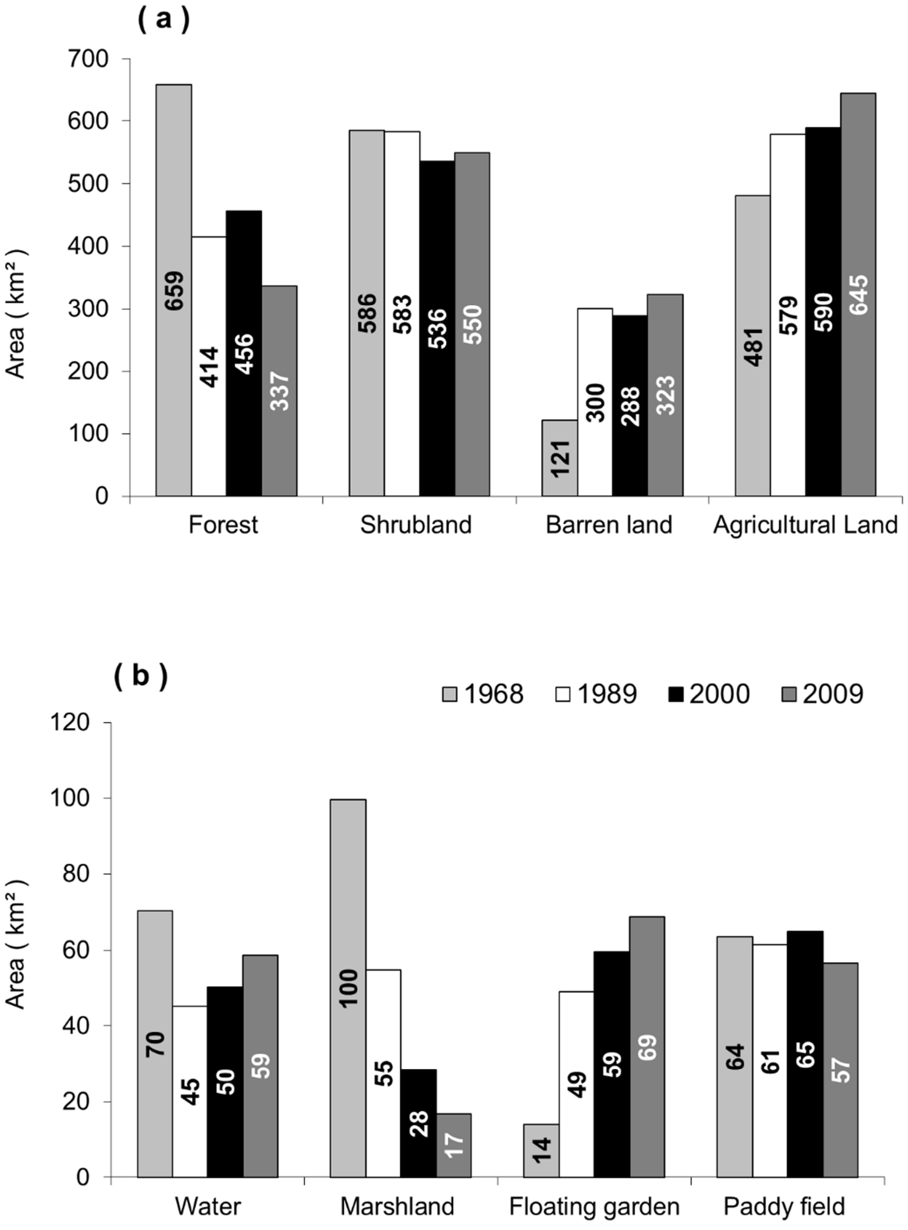

Figure 2-3. Changes in Forest, Shrubland, Barren land and Agricultural land (a); Changes in Water, Marshland, Floating garden and Paddy field (b).

2.4.3 **Landscape transformation processes for the three agricultural zones**

The areas of the three different agricultural zones in the study region were 154 km^2 for floating gardens (zone 1), 406 km^2 for lowland cultivation (zone 2) and 1565 km^2 for upland cultivation (zone 3). The extent and characteristics of transformation processes differed in each zone, whereby the changes were highest for the floating garden zone (Table 2-4). Many former water and marshland areas (71 km^2) were transformed to agricultural areas (66 km^2), and floating gardens increased from 14 to 69 km^2. Most of these changes occurred in the western and southern part of Inle Lake (Figure 2-4, Appendix B).

The urbanization, deforestation and abandonment trends were highest for the upland cultivation zone. New settlements have been established, mainly in the northern part of zone 3, and existing urban areas such as Heho and Taungyi were extended resulting in an urbanization zone of altogether 20 km². Deforestation mainly took place in the hilly forest areas, especially along the western mountain ridge. In zone 2, the main changes of LUCC were crop expansion (118 km²) in the northern region of Nyaung Shwe and deforestation (99 km²).

Table 2-4. Area changes (km²) from 1968 to 2009 in the three different agricultural zones of the Inle Lake region, Myanmar.

Transformation processes	**Floating garden (zone 1)**	**Lowland cultivation (zone 2)**	**Upland cultivation (zone 3)**
Crop expansion	66.43	118.07	251.41
Abandonment	0.48	27.37	230.97
Urbanization	1.78	17.84	20.33
Deforestation	0.25	98.77	398.42
Wetland losses	71.10	34.25	0.42
Total area	154	406	1565

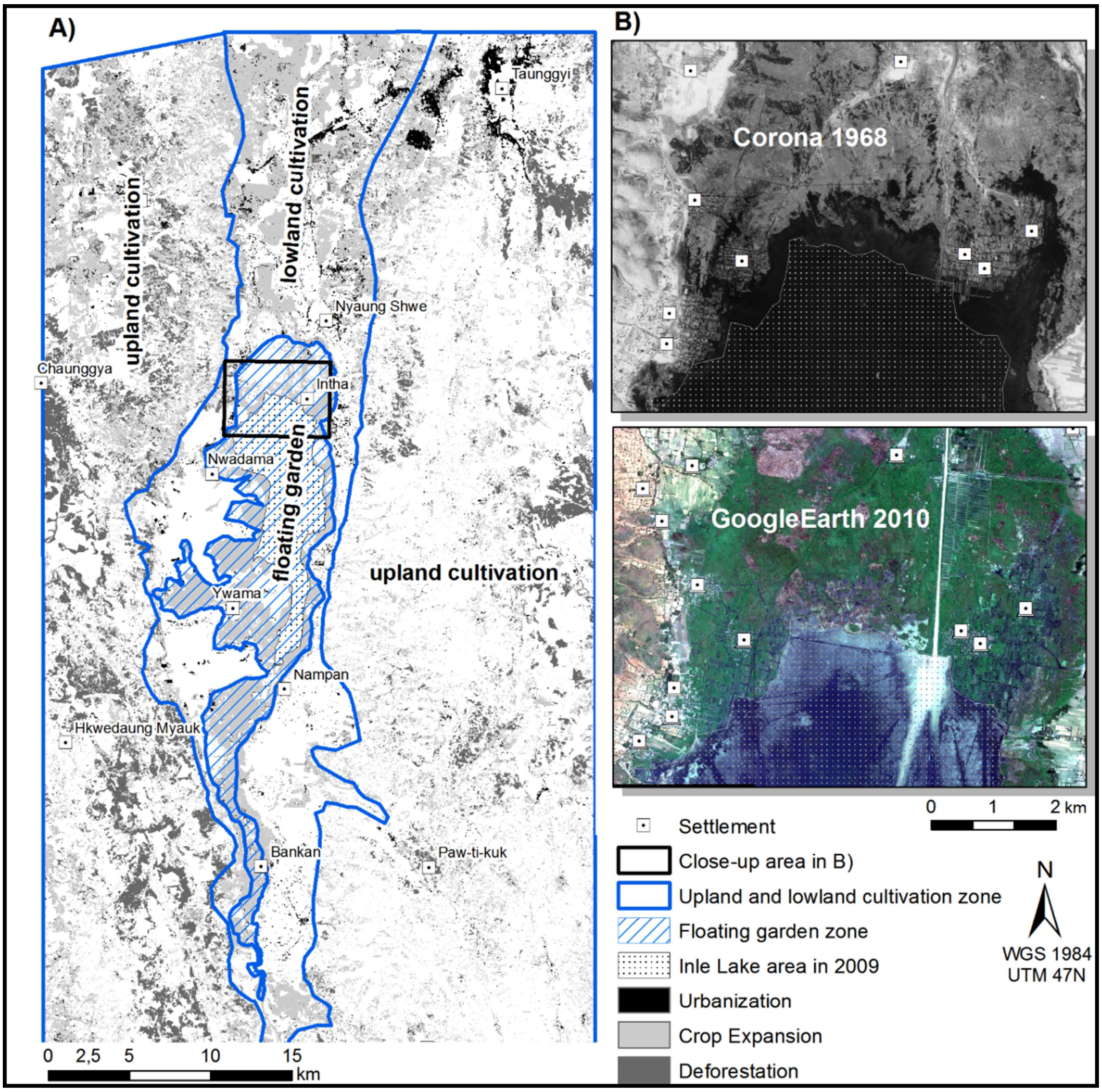

Figure 2-4. Urbanization, deforestation and crop expansion trends from 1968 to 2009 in the Inle Lake region, Myanmar. (A); Close-up of the northern Inle Lake region in 1968 (Corona image) and 2010 (Google Earth image).

2.5 Discussion

2.5.1 LUCC during the last 40 years

The observed general trends of LUCC including deforestation and the expansion of cropland are confirmed by other remote sensing studies and field observations in the Inle Lake region (Leimgruber, 2005; Akaishi et al., 2006; Lwin, 2006; Furuichi, 2007; May, 2007; Sidle et al., 2007; Su & Jassby, 2000).

The forest area declined to 49% from 1968 to 2009, while May (2007) reported a deforestation rate of 10% with the transformation of closed forest to open forest, shrublands and agricultural land between 1990 and 2005 in the Inle Lake watershed area. In contrast hereto, Leimgruber et al. (2004) investigated the forest-cover changes in Myanmar between 1990 and 2000 and detected a countrywide net annual rate of forest loss of only 0.2 to 0.3%. However, deforestation varies considerably among regions and one of the deforestation hotspots is indeed the northern Shan plateau (Leimgruber et al., 2005).

In the western area of the lake in the upland cultivation zone, deforestation is mostly due to the slash and burn practices on adjacent hills, which contribute to soil erosion and lake sedimentation. Most sediments come from the western mountains by the Thandaung and Inndein streams (Lwin, 2006). Deforestation, land cover change and shifting cultivation caused the shrinkage of the water body of Inle Lake (Sidle et al., 2007). Some reports indicate that the lake's surface of 23 km x 11 km in 1967 shrunk to 11 km x 5 km in 1996 (Su & Jassby, 2000). The loss of lake surface area was about 34% of open water body during the 65 years between 1935 and 2000 (Sidle et al., 2007; UNDP, 2012). Compared with the year 1968, the urban areas increased threefold with an extension of already existing cities of Taungyi, Nyaung Shwe and Heho and the establishment of new settlements.

About 12.5 km^2 of the original marshland area was modified in combination with changing water bodies, floating gardens and other agricultural land from 1990 to 2005 (May, 2007), whereby 4.2% of the total wetland area of Inle Lake disappeared (ADB, 2006). In our study area, marshland declined continuously during the last 40 years mainly because of expansion of floating gardens, paddy fields and sedimentation from the upland area.

The crop expansion was highest in the upland and lowland cultivation zone. The former reflects the high dynamic of the shifting cultivation system, whereby abandoned areas and extended cultivated areas occurred scattered in the landscape. The lowland cultivation zone is mainly characterized by paddy fields, sugar cane plantations and agroforestry (especially mango production). Local people grow rice on their land for food security and marketing. Paddy fields cover over 48% of the total cultivated area of Nyaung Shwe township (UNDP, 2006). In Taunggyi township, 311 km^2 were under cultivation in 2007 and 2008 and further areas were classified as fallow land (0.52 km^2) and cultivable wasteland (11 km^2; MAS, 2007). In 2005/2006, the area of dryland or upland cultivation (rain-fed area), wetland (paddy field), and horticultural crop production was 59 km^2, 53 km^2, and 6 km^2, respectively, in the Nyaung Shwe township (Lwin, 2006). Even though the population numbers in Nyaung Shwe township increased from 1968 to 2009, the paddy field area remained roughly constant during the past 40 years without endangering local food supply. This is mainly because of the introduction of high yielding rice varieties and hybrid rice in the Inle Lake region. Local food security of Nyaung Shwe township was between 98% and 99% in the years 1989, 2000 and 2010 (MAS, 2012). However, the location of paddy fields changed as a consequence of increasing sedimentation processes on paddy land, whereby some paddy land was converted to other cropland such as sugar cane, groundnut, potato, tomato and garlic. In marshland areas, new paddy fields extended at the expense of marshland area.

Tomato is the main crop in floating gardens and occupies two-thirds of the land (Butkus & Su, 2001). Large scale floating agriculture started in the 1970s and increased constantly in the 1980s and 1990s (Oo et al., 2010). Lwin (2006) reported that the area dedicated to floating agriculture rose from 1.8 km² in 1955 to 5.81 km² in 1960-1992. By 2007-08, it reached 29.26 km² (MAS, 2009). Many abandoned floating gardens decomposed and sunk to the lake bottom, thereby accelerating the sedimentation process.

2.5.2 **Driving forces of LUCC**

Population growth, changes in land management and agricultural expansion, processes of industrialization and urbanization, government policies and socio-economic factors such as economic development and infrastructural constructions typically greatly impact LUCC (Rao & Pant, 2000; Quan et al., 2006; Wu & Zhang, 2012) and increase the pressure on natural resources (ADB, 2006). National land tenure policies, market pressures and resource availability are the major driving forces contributing to LUCC (Fox & Vogler, 2005; Wannasai, & Shrestha, 2008).

In Myanmar, all land resources belong to the State and local people need to register for land use rights. As a consequence of the military regime in the past decades, Myanmar has deficits in appropriate land management and is weak in political commitment, inadequate law enforcement, limited environmental safeguards and lack of sustainable financial mechanisms as well (UNDP, 2012). Up until now, there are no secure tenure rights for the country’s individual farmers. Moreover, there exist no regulations to recognize traditional upland land use (e.g. shifting cultivation or slash and burn cultivation) and to protect these traditional land management practices legally (Burma Environmental Working Group [BEWG], 2011). The same authors also reported that land tenure insecurity affected about one quarter of all households, and that landlessness in upland ethnic areas of Southern Shan State ranged between 8-50%. Upland cultivation is becoming increasingly vulnerable because of land use grants by agribusiness with military-state support to accelerate national economic activities (Hudson-Rodd & Nyunt, 2001).

In the study region, the population density increased more than twofold over the past 40 years, which was one of the main factors for LUCC. In 2005, the population density per km^2 of Nyaung Shwe and Taunggyi was 114 and 55, respectively (May, 2007). The most recent statistics indicate that the population concentration is 89 people km^{-2} around the lake and 386 people km^{-2} on the water (The Myanmar Times, 2005). Some rural people migrated to urban areas in search for new opportunities and better livelihood conditions. Moreover, industrial areas were constructed at Aye Thar Yar place within Taunggyi city in 2000 and 2001 as a result of changes in government policy. In the Nyaung Shwe township, the government announced the year 1996 as the 'Visit Myanmar Year' which led to the construction of tourist infrastructure comprising about a total of 41 hotels and resorts around and even in the Inle Lake area (MAS, 2012).

The observed deforestation processes are attributable to population density and the expansion of shifting cultivation practises (Thiha, 2001). The establishment of new settlements on forest land, wasteland or open woodland caused encroachment of the forest area. Agricultural land gradually extended on former forest, shrubland and grass land in Inle watershed area (May, 2007). However, a small increase of forest areas was detected in the year 2000, possibly reflecting the effects of a new forest policy introduced in 1995 when the Myanmar Forest Policy (1995) and the Protection of Wildlife and Wild Plant and Conservation of Natural Areas Law and Rule (1994 and 2002) was formulated, which emphasized a balance between conservation and development (Oo, 2009). As a consequence, community forestry measures promoted the participation of the local population in forest management (United Nations, 2002). However, by 2009, forest area declined again as a result of tree cutting for construction, fuel wood collection and charcoal production as well as the expanded use of non-timber forest products such as bamboo shoots, medicinal plants, wild vegetables and fruits, honey and mushrooms. Nowadays, these activities are the main additional income sources for local poor farmers in the upland cultivation zone. On the mountain ridges around Inle Lake, the degree of soil erosion and deforestation is becoming even more problematic given the widespread use of slash and burn farming leading to lake sedimentation.

The expansion of human settlements such as houses, the increase of agriculture areas including paddy fields on lake shore areas, and of floating gardens in the lake in combination with sedimentation are reflected in a major loss of open water bodies (ADB, 2006; May, 2007). Climatic factors might be an additional cause for the long term decline in the water body area of Inle Lake (Su & Jassby 2000). Sidle et al. (2007) mentioned that annual rainfall in the year 1988 was 610 mm and thus well below the average annual rainfall of 920 mm (Figure 2-5). This lack of rainfall was reflected by the low surface of water areas (45 km^2) in the year 1989. However, the water bodies increased in the following years because of higher annual rainfall, government policies and changing agricultural activities. The sediments were dredged by the Irrigation Department every year, especially in the main waterways. In addition, local farmers dredged the sediments from the jetties and minor water ways for their transportation, whereby fertile sediments were spread on agricultural land (Furuichi, 2007).

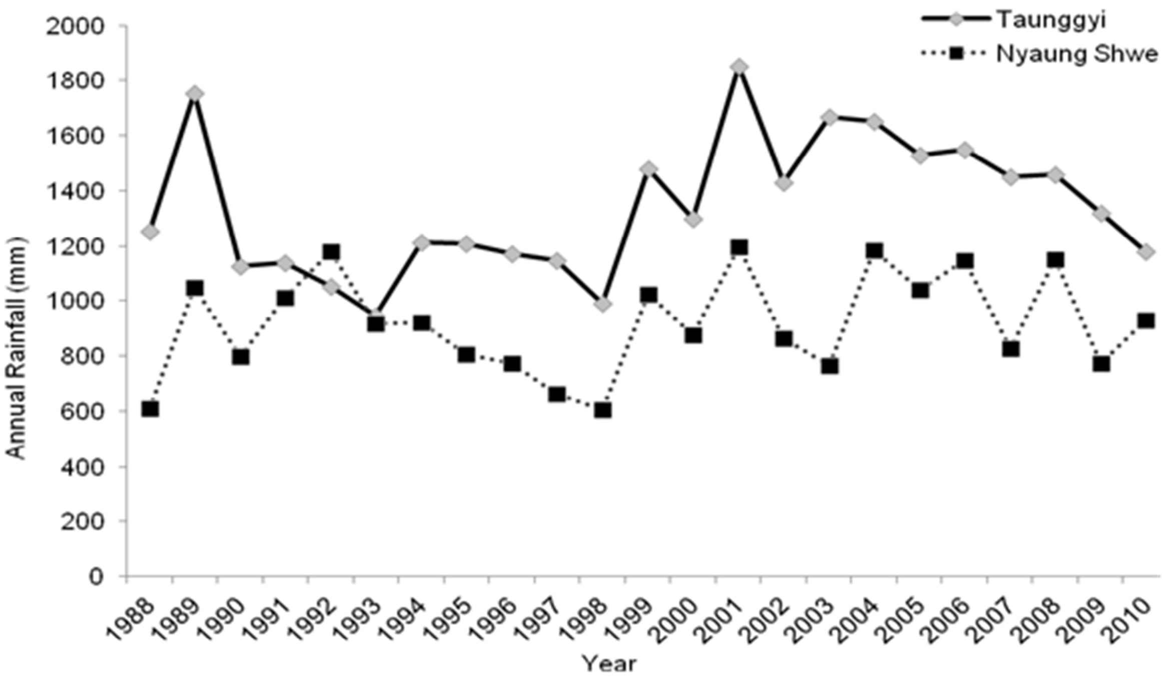

Figure 2-5. Annual rainfall data from 1988 to 2010 for Taunggyi and Nyaung Shwe township. Data from Myanmar Agriculture Service and Irrigation Department of Nyaung Shwe township, Ministry of Irrigation and Agriculture, and Meteorology and Hydrology Department, Taunggyi.

2.5.3 **Methods of satellite image classification**

The classification accuracies of the SMAPC and the MLC approaches were significantly different and the SMAPC classifier produced higher accuracies than the MLC. The SMAPC proved more suitable for classification of various types of crops cultivated on homogenous fields (McCauley & Engel, 1995). Additionally, Dittrich, Buerkert, and Brinkmann. (2010) indicated that SMAPC with subsequent post-processing method may lead to large improvements of accuracy. A post processing of SMAPC of the classified Landsat datasets for this study area reduced the misclassification of urban, water and marsh land areas and improved the PA values of the classes ‘water’ by 10%, and of ‘urban’ and ‘marshland’ by 20% each. Moreover, post-processing significantly decreased the error of confusion among the classes ‘crops’, ‘forest’ and ‘floating garden’.

The low classification accuracies and misclassifications for fallow land, marshland interspersed with barren land, agroforestry areas and forest land may be explained by their similar reflectance characteristics, since all classes describe highly productive landscape features. Another reason is the erratic structure of the lake shore areas with small scale changes of different land use types. To classify such areas contained in ‘mixed pixels’ with spectral information of different ground features, soft classification techniques such as a fuzzy classification approach (Tso & Mather, 2009) or a spectral mixture analysis (Hostert et al., 2003) may reduce the classification errors.

The training sites were in land cover areas of the same class throughout the entire observation period to allow a maximized correspondence between the classification of the panchromatic Corona images and the multispectral Landsat images (Ruelland et al., 2011). Similar training sites were used in historical images of the study area to minimize the classification errors for the Landsat image classification. Although visual image interpretations are time consuming, these methods are essential for the panchromatic Corona images and offer a quite accurate and realistic way of interpretation (Ruelland et al., 2010). However, for a post-classification comparison resulting from different classification approaches (visual interpretation of Corona images *versus* automatic classification of Landsat images) some observed land cover changes may be overestimated.

2.6 Conclusions

Remote sensing of landscape transformation processes allows to monitor dynamic land use and land cover changes such as observed in Myanmar over the past 40 years. Of the supervised classification methods used in this study, SMAPC was the most suitable to examine LUCC in and around Inle Lake region using a post-classification comparison approach. An expansion of paddy fields and floating gardens led to high deforestation and a significant decline in lake area and marshland. The study also indicates the need for multiple data sources such as high resolution satellite images combined with environmental and socio-economic base data to properly identify the causes of the observed LUCC and to derive effective recommendations for land management policies that help to reconcile the needs of a rapidly growing population and resource conservation.

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2.8 Appendix

Appendix A

Error matrices (CA=Consumer's Accuracy; PA=Producer's Accuracy; EC=Error of Commission; EO=Error of Omission) of the land use classes identified by the validation plots within the study area in Inle Lake. Data are based on the SMAPC classification results of the 2009 Landsat data before (a) and after (b) post-processing. For class abbreviations see Table 2 in the article.

(a)		Ground Truth Data														
	Class	1	2	3	4	5	6	7	8	9	10	11	12	Total	CA (%)	EC (%)
Classified map	1	34	0	0	0	0	0	0	0	0	0	0	1	35	97.1	2.9
	2	2	25	0	1	0	0	0	0	0	0	0	0	28	89.3	10.7
	3	0	0	12	3	0	1	0	0	0	1	0	2	19	63.2	36.8
	4	4	1	0	46	0	0	0	0	2	0	1	1	55	83.6	16.4
	5	0	0	1	0	7	0	0	0	0	0	0	1	9	77.8	22.2
	6	0	0	1	0	0	22	0	0	0	0	0	7	30	73.3	26.7
	7	1	0	0	0	0	1	4	0	0	0	0	0	6	66.7	33.3
	8	0	0	0	2	1	1	0	10	0	0	0	0	14	71.4	28.6
	9	1	0	1	0	0	0	1	0	44	0	0	3	50	88.0	12.0
	10	1	0	0	1	0	0	0	0	0	4	0	0	6	66.7	33.3
	11	0	0	0	0	1	0	0	1	0	0	9	0	11	81.8	18.2
	12	0	0	0	0	0	8	0	0	2	0	0	27	37	73.0	27.0
	Total	43	26	15	53	9	33	5	11	48	5	10	42	244		
	PA (%)	79.1	96.2	80.0	86.8	77.8	66.7	80.0	90.9	91.7	80.0	90.0	64.3			
	EO (%)	20.9	3.8	20.0	13.2	22.2	33.3	20.0	9.1	8.3	20.0	10.0	35.7			

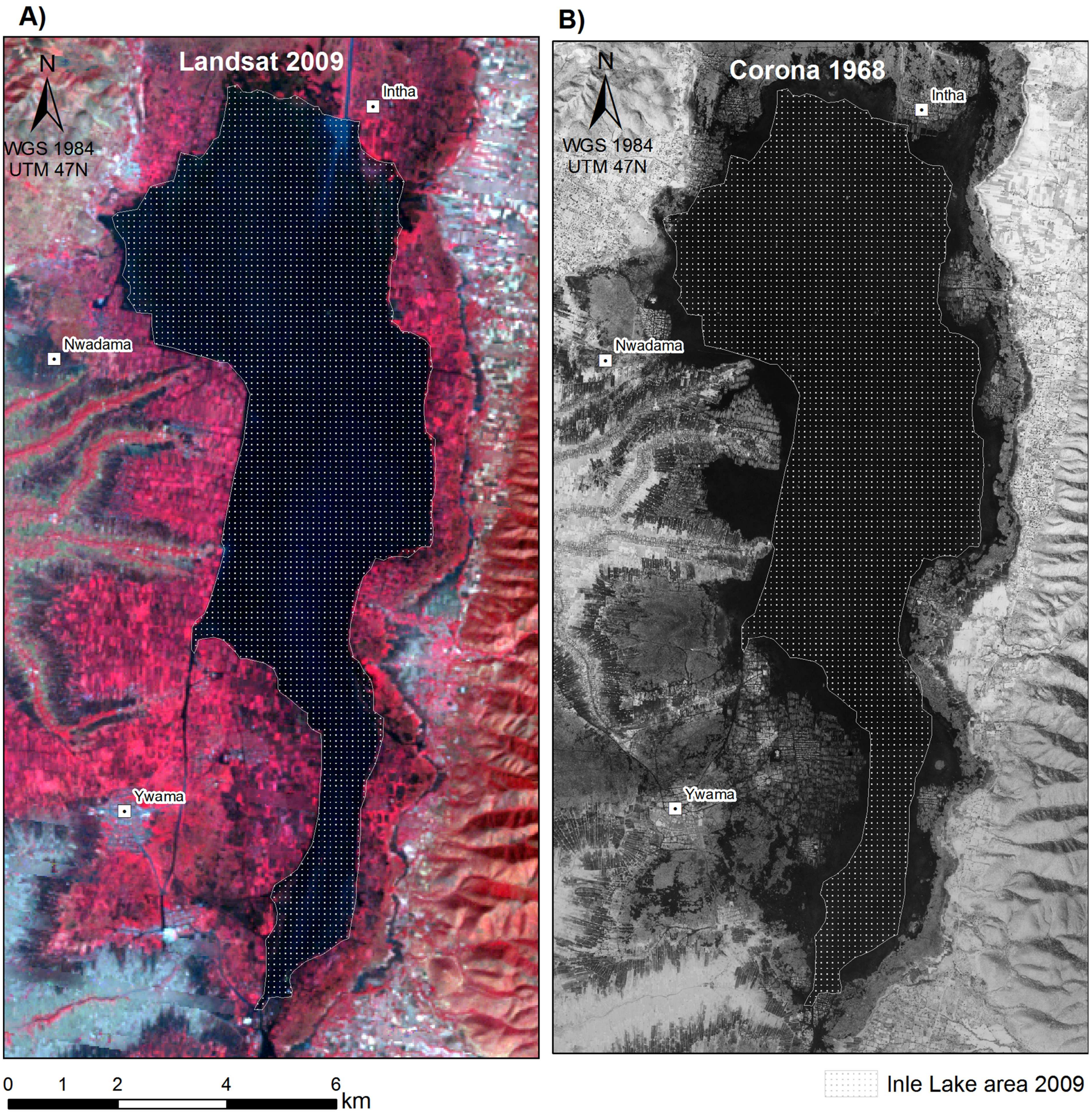
(b)		Ground Truth Data													
	Class	1	2	3	4	5	6	7	8	9	10	11	Total	CA (%)	EC (%)
Classified map	1	31	1	0	1	0	1	0	0	1	0	0	35	88.6	11.4
	2	1	26	0	0	0	0	0	0	1	0	0	28	92.9	7.1
	3	1	1	17	0	0	0	0	0	0	0	0	19	89.5	10.5
	4	2	8	0	43	0	0	0	0	2	0	0	55	78.2	21.8
	5	0	0	1	0	8	0	0	0	0	0	0	9	88.9	11.1
	6	1	1	2	0	0	37	0	0	4	0	0	45	82.2	17.8
	7	1	0	0	0	0	1	5	0	0	0	0	7	71.4	28.6
	8	0	0	0	1	1	1	0	11	0	0	0	14	78.6	21.4
	9	4	3	1	0	0	1	0	0	62	0	0	71	87.3	12.7
	10	0	0	0	0	0	0	0	0	0	6	0	6	100.0	0.0
	11	0	0	0	0	1	0	0	1	0	0	9	11	81.8	18.2
Total		41	40	21	45	10	41	5	12	70	6	9	255		
PA (%)		75.6	65.0	81.0	95.6	80.0	90.2	100.0	91.7	88.6	100.0	100.0			
EO (%)		24.4	35.0	19.0	4.4	20.0	9.8	0.0	8.3	11.4	0.0	0.0			

CA=Consumer’s Accuracy; PA=Producer’s Accuracy; EC=Error of Commission; EO=Error of Omission)

The PA is a measure to assess how correctly classes were classified, whereas the CA reflects how reliable a classified map is. The EO indicates which areas were wrongly excluded from a class and the EC is a measure of which areas were wrongly included in a class (Congalton & Green, 1999).

Appendix B

Satellite image of the Inle Lake region in 2009 (Landsat image) and 1968 (Corona image).



Chapter 3

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3 Diversification of livelihood strategies along an agro-ecological gradient in Inle Lake region, Myanmar

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3.1 Abstract

In the Inle Lake region of Myanmar, local people primarily rely on the exploitation of natural resources for their livelihood and little is known about the diversity of income generating activities, which strongly vary between sites. The aim of this study therefore was to record the socio-economic conditions of the traditional farming systems and their importance for people's livelihoods along an agro-ecological gradient around Inle Lake. To this end household and field survey data collected in three different agricultural zones was subjected to cluster and discriminant analysis to develop livelihood typologies. The annual gross margin for each household in the floating garden, lowland and upland cultivation was US$ 2108, 892 and 619 ha^{-1}, respectively. Tomato plantation in floating gardens yielded the highest profit, but has also negative environmental effects given the intensive application of mineral fertilizers and pesticides.

The data show that the socio-economic household characteristics and livelihood strategies in the floating garden, lowland and upland cultivation zone differ significantly. In each zone, the identified livelihood strategies depend on farm size and the diversification strategy of the household. The different agricultural zones are closely linked and future research and management plans should integrate all three zones to effectively mitigate the ongoing degradation processes.

Keywords: Floating gardens; Income diversification; Smallholder farmers, Wetland agriculture

3.2 Introduction

The pattern of agricultural, forest and other land uses across the surrounding landscape has cumulative effects on watershed functions and maintenance of wetland ecosystems. It is well known that wetlands are harboring untapped land and water resources for the cultivation of many different crops (Adams, 1993) which makes them very vulnerable to transformation, but they also provide important ecosystem services for income generation and food security of local communities in their surrounding (Wood, 1996; Rebelo et al., 2010; Barbier, 2011; Sakane et al., 2013; Kipkemboi et al., 2014). Globally, millions of poor households (HHs) dependon the use of wetland resources for their livelihood, especially in developing countries (Silvius et al., 2000) where diverse livelihood activities are a critical buffer against many devastating calamities (Ellies, 2000; Barrett et al., 2001).

The livelihood activities in wetlands and their surroundings strongly vary with site conditions, the socio-economic situation of the HHs and the national, historical and political conditions (Morardet & Tchamba, 2005). As a result of the intensive and often inappropriate resource use, land degradation and environmental degradation and pollution of wetlands, on whose ecosystem functions direct and indirect users depend, have become a major concern worldwide (Millennium Ecosystem Assessment, [MEA] 2005; Nabahungu & Visser, 2011; Stratford et al., 2011; Sakane et al., 2014). In Asian wetland areas, water pollution, salinization, and the overuse of resources have all been reported to threaten biodiversity and ecosystem services and functions (Dudgeon, 2000; Shuqing et al., 2013).

In the Inle Lake region of Myanmar for many centuries local minorities primarily rely on the exploitation of natural resources such as timber and other forest products, game, land, water, and fish for their livelihood and are increasingly confronted with the consequences of increasing competition for wetland resources (Soe, 2012; Ministry of Environmental Conservation and Forestry [MOECAF], 2013). Around Inle Lake over 60% of the total area is dedicated to permanent agriculture (UNDP, 2013). Since decades opening new land frontiers caused extensive pressure on existing forest areas and swamp lands, which threatened the environmental and ecological conditions of the uplands and the lowlands (Kyi, 2006). As a consequence the landscape surrounding Inle Lake has undergone dramatic transformation during the past 40 years, whereby shifting cultivation and deforestation processes affected about 80% of the total catchment surface area (Htwe et al., 2014). The main officially recognized socio-economic constraints to agriculture in this area are insufficient credits, regional zoning of specific crops based on agro-ecological suitability without considering profitability, rice-based policies, inadequate mechanization, limited research and extension for technology transfer and poor input supply (Kyi, 2006). MOECAF

(2013) proposed to enlist the Inle Lake region as a biosphere reserve for conservation of biodiversity, sustainable development and maintenance of the cultural values of the traditional communities living in the area. Like in other regions in Southeast Asia, watershed management requires balancing the diverse interests of all stakeholders, but to achieve this goal empirical information on existing farming systems and their livelihood strategies is required to define effective adaptation strategies and to meet the challenges of a sustainable watershed management on which local livelihoods depend (Ratner, 2000).

To contribute to this goal the aims of the current study therefore, were (i) to record and evaluate the socio-economic conditions of the traditional farming systems and their importance for people's livelihood in the Inle Lake watershed of the southern Shan State in Myanmar, and (ii) to compare different livelihood strategies of residents from each cultivation zone and their effects on ecosystem services.

3.3 Materials and Methods

3.3.1 Study area

The research area is located in Nyaung Shwe township, the Southern Shan highlands of Myanmar around the Inle Lake, covering a total area of 2,115 km^2 (Figure 3-1). Inle Lake is the second largest inland water body of the country and stretches out between 20°18' to 20°53' N latitudes and 96°50' to 96°57' E longitudes at an altitude of 890 m a.s.l. (Su & Jassby, 2000). It is one of the country's most prominent hotspots for national and international tourism because of its beautiful sceneries as well as its importance for agriculture and fishery. Given its distinct bio-physical features and biodiversity, Inle was not only designated as the 190th World's Eco-region in 1998 (Olson & Dinerstein, 2002), but also nominated as one of ASEAN Heritage Sites in 2004 (The Burma Environmental Working Group [BEWG], 2011).

Nyaung Shwe township has an average monsoon-dependent annual rainfall of 1045 mm (observation period from 2002-2011; Source: Agriculture Department, Ministry of Agriculture and Irrigation, Nyaung Shwe) and is characterized by three main seasons: dry summer (mid-February to mid-May), rainy season (mid-May to mid-October) and dry winter (mid-October to mid-February). The population of Nyaung Shwe township is 168,900 (Department of Immigration and National Registration, Ministry of Immigration and Population 2012) and population density amounts to 385 people km^{-2} in lake water areas and 90 people km^{-2} around the lake (Than, 2007).

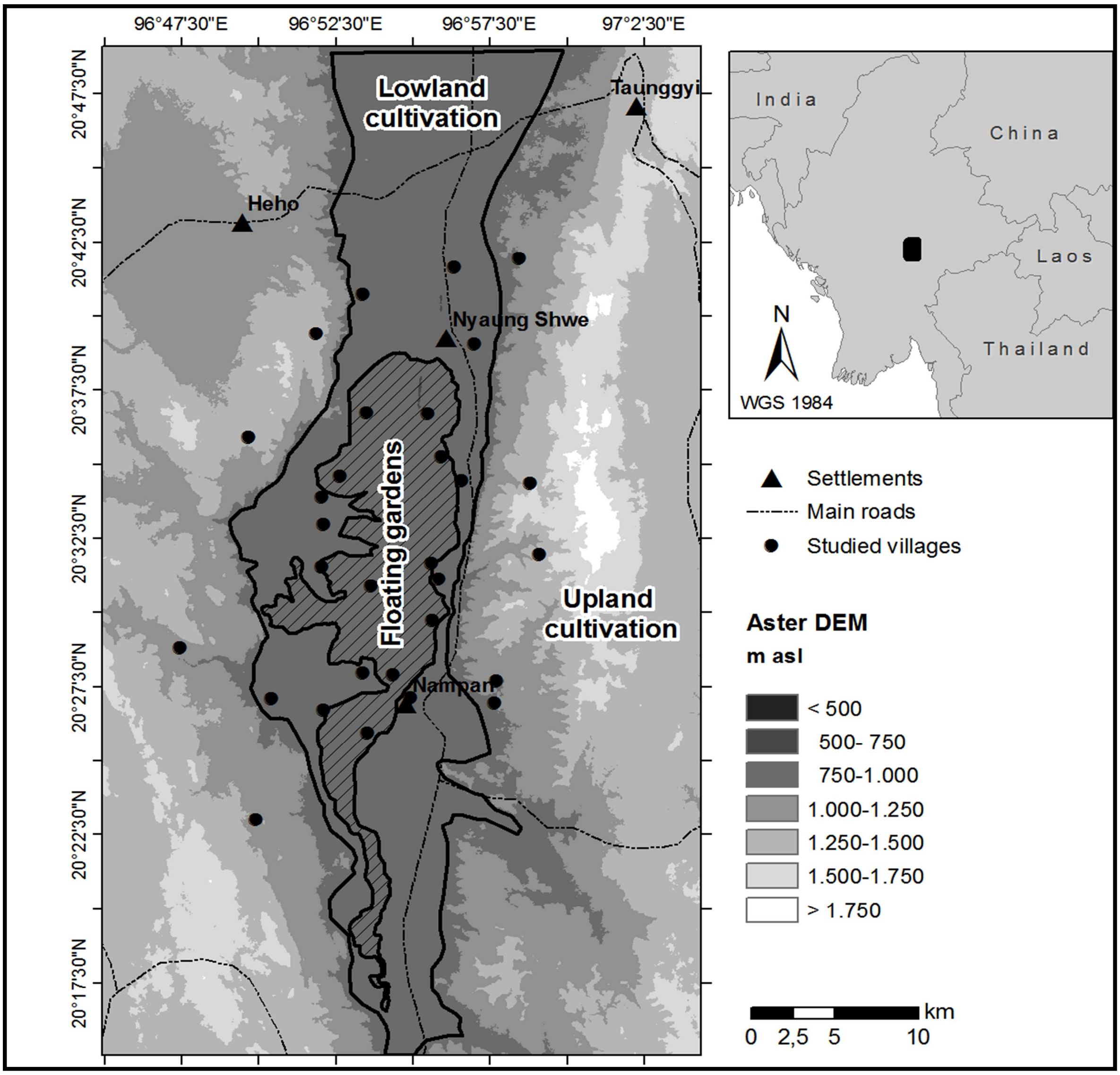


Figure 3-1. Location of the study area showing the different agricultural zones of the Inle Lake region, Myanmar.

Livelihood strategies in the Nyaung Shwe township were dominated by agriculture (57%), casual employment (27%), self-employment (5%), fishery (3%), trade/commerce (3%) and livestock (0.27%; UNDP, 2001).

The Inle Lake region can be divided in three different agricultural zones based on the topographic location and the prevailing cropping system (Htwe et al., 2014; Figure 3-1): (1) Floating gardens (FG) are man-made islands composed of decayed grasses, reeds and marsh plants of the Inle Lake and are located directly in the lake area. The islands are typically about 2 m wide and 40 m long. Tomato (*Lycopersicon esculentum* L.) is the main cash crop on these islands; (2) Lowland cultivation (LL) comprises paddy fields (*Oryza sativa* L.) along the lake's shoreline and rain-fed crop cultivation on the adjacent flat areas comprising sugar cane (*Saccharum* ssp.), potato (*Solanum tuberosum* L.), chili (*Capsicum* ssp.), groundnut (*Arachis hypogaea* L.), wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.); (3) Upland cultivation (UP) systems are located on hilly slopes and characterized by shifting cultivation, field terraces and agro-forestry gardens comprised by mango (*Mangifera indica* L.) as perennial crop and annuals, such as upland rice (*Oryza sativa* L.), turmeric (*Curcuma longa* L.), groundnut (*Arachis hypogaea* L.), maize and soybean (*Glycine max* L.). Most farmers cultivate sebesten trees (*Cordia dichotoma* G. Forst.) locally known as ‘thanatphet’ on sloping land without soil conservation practices, using intensive cultivation and commercial cropping strategies with high inputs of insecticides, pesticides, and mineral fertilizers. In 2001, the sebesten farming area in the UP zone was 1,397 ha (San, 2007).

3.3.2 **Data collection**

In 2012 and 2013, semi-structured household interviews and focus group discussions were conducted to collect socio-economic data on farming activities in 30 selected villages of the Inle Lake region. For the selection of 10 villages within each of the three agricultural zones that were geographically defined by Htwe et al. (2014) (Figure 3-1) a stratified random sampling design was applied within a Geographic Information System (GIS). Within each of these villages 10-11 HHs were randomly selected (n total = 301 HHs).

The questionnaire for semi-structured interviews addressed the current socio-economic situation of the farmers in terms of HH composition, education, assets, agricultural yields, crop management strategies, sales, livestock keeping and activities for income generation.

Field observations on the bio-physical, environmental conditions and farm management practices and overall living standard of the farmers were conducted to verify the information provided during the interviews. The geographic location and the total area of the HHs’ crop fields were determined using a handheld Trimble GeoXT GPS device (Trimble Navigation Ltd., Sunnyvale, CA, USA).

3.3.3 **Statistical analysis**

To identify relatively uniform groups of households with similar livelihood strategies a cluster analysis was performed (Brown et al., 2006; Jansen et al., 2006; Iiyama et al., 2008; Hair et al., 2010). Since the dataset included both categorical and numeric data on socio-economic household characteristics, a two-step cluster analysis was applied (Dossa et al., 2011; Abdulkadir et al., 2012; Abas et al., 2013). Within two step cluster analysis a 'pre-clustering' into many sub-clusters is performed using a sequential clustering approach and during the final clustering these sub-clusters are merged to produce an appropriate number of clusters (Okazaki, 2006; Michailidou et al., 2008).

Before cluster analysis, multi-collinearity was removed from the data set resulting in the following subset of variables: Altitude and distance to nearest market places from homestead, age and education of HH head, farming experience (years), cultivated area (ha), Tropical Livestock Units (TLU), total HH assets, crop diversity, cash crop production, number of months without income from agricultural activities, manure and pesticide application for crop production and non-agricultural HH activities (employment, handicraft, fishery, tourism and use of forest resources) (Appendix 1). Using an automatic selection of cluster numbers based on the Akaike's information criterion (AIC), three clusters were identified discriminating between households in the FG, LL and UP zones (Figure 3-1). To reveal a more detailed identification of livelihood strategies, we thus conducted a separate cluster analysis for each agricultural zone. Subsequently, a discriminant analysis was conducted to interpret cluster differences and compare selected variables at the 0.05 probability level and 95 percent confidence interval (Hair et al., 2010).

For the main cultivated crops the gross margin was calculated based on the gross income of crop production (yield multiplied by unit price for each crop) minus total variable costs. The latter included costs of land preparation, seed or grain and seedling, manure and mineral fertilizers, pesticides, labour costs for weeding and harvesting for crop production. All statistical analysis were performed with SPSS version 17.0 (SPSS, 2008).

3.4 Results

3.4.1 Socio-economic characteristics of the agricultural zones

The ethnic group of *Intha* predominates around the lake (70%), but there are also *Shan* (15%), *Pa-O* (10%), *Bamar* (3%), *Dhanu* and *Taung Yo* people (together 2%) inhabiting the surrounding hills (UNDP, 2005; Ingelmo, 2013). In the FG zone, all households were *Intha*, whereas in the LL zone 6% belonged to other ethnic groups. In the UP zone, *Pa-O* dominated (59%), followed by *Taung Yo* (21%) and *Dhanu* (19%), whereas only 1% of the people were *Intha*, which migrated from the FG zone. Irrespective of its ethnic affiliation, a HH on average comprised five members. Most of the HH heads in the UP were male (97%), whereas in the FG and LL zone 15% were female.

The distance to the nearest market place was on average 3 km for the villages in the FG and LL zones, whereas UP villages were often far away from market places. The average age of HH heads was highest in the LL zone (51 years) and lowest in the UP zone (43 years). The farming experience of HH heads was 24 years in the FG and UP zone, but 28 years in the LL zone.

The farming system in the three agricultural zones differed significantly in most parameters analysed (Table 3-1). The average total HH assets, total HH income and off-farm income as well as cash crop production decreased from the FG zone to the UP zone, whereas the number of cultivated crops, livestock property and the use of forest resources increased and was highest for HHs of UP. Average farm size (0.65 ha) and number of livestock (0.11 TLU) of peasants in the FG zone were relatively small compared to the UP and LL zone, whereas the number of HH assets (5.34) was relatively high. Manure and pesticides were applied by almost every household in the FG zone, where cash crop production dominated. However, farmers had to sustain on average 6 months per year without agricultural income and the cultivated cash crops were insufficient to meet the family food demand. Therefore, farmers in the FG zone often practiced other income generating activities such as fishery, employment, handicraft and tourism for maintaining their livelihoods.

Table 3-1. Socio-economic characteristics of the households (n = 301) in the three different agricultural zones of the Inle Lake region, Myanmar. Numbers in bracket show ± one standard deviation of the mean.

Variable	Unit	Cluster FG n = 90 HH	Cluster LL n = 118 HH	Cluster UP n = 93 HH	Prob.
Altitude	m a.s.l.	889 (5)	917 (99)	1187 (192)	***
Distance to nearest market	Km	3.3 (1.38)	3.1 (1.91)	5.3 (1.91)	***
Age of HHH	Years	47.98 (9.57)	50.95 (10.88)	43.29 (11.75)	***
High education level	Yes/No	0.00 (0.00)	0.28 (0.45)	0.00 (0.00)	***
Farming experience	Years	24.37 (10.86)	27.75 (12.80)	24.12 (10.74)	*
Cropland area	Ha	0.65 (0.53)	1.67 (1.43)	1.11 (0.73)	***
Livestock	TLU	0.11 (0.27)	0.33 (0.63)	1.15 (1.60)	***
Crop diversity	Number	1.34 (0.79)	2.14 (1.09)	2.96 (1.17)	***
Total physical HH assets	Number	5.40 (2.56)	3.19 (2.03)	1.54 (1.27)	***
Months without agricultural income	Number	5.90 (1.81)	4.68 (1.94)	3.20 (1.31)	***
Pesticide application	Yes / No	0.96 (0.21)	0.68 (0.47)	0.66 (0.48)	***
Manure application	Yes / No	0.81 (0.39)	0.64 (0.48)	0.62 (0.49)	**
Cash crop production	Yes / No	0.96 (0.21)	0.52 (0.50)	0.53 (0.50)	***
Sufficient food supply	Yes / No	0.49 (0.50)	0.56 (0.50)	0.31 (0.47)	***
Total income	US$	4559 (2735)	3395 (2464)	1863 (1211)	***
Off farm income	US$	686 (748)	549 (742)	422 (695)	Ns
Employment	Yes / No	0.21 (0.41)	0.28 (0.45)	0.28 (0.45)	Ns
Handicraft	Yes / No	0.12 (0.33)	0.09 (0.29)	0.15 (0.36)	Ns
Fishery	Yes / No	0.37 (0.48)	0.03 (0.16)	0.01 (0.10)	***
Tourism	Yes / No	0.17 (0.37)	0.07 (0.25)	0.00 (0.00)	***
Use of forest resources	Yes / No	0.01 (0.10)	0.00 (0.00)	0.16 (0.37)	***

*** Significant at 0.001; ** Significant at 0.01; * Significant at 0.05; ns = not significant

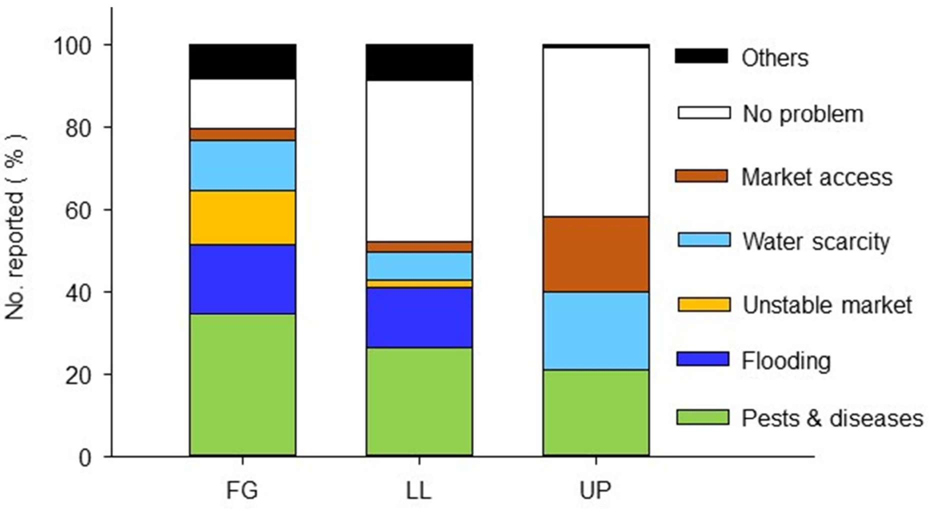


Figure 3-2. Proportion of agricultural problems related to crop production mentioned by the farmers in each agricultural zone of the study area in Inle Lake region, Myanmar (FG = floating garden, LL = lowland, UP = upland).

The highest education level (more than 10 years of schooling) and cropland area (1.7 ha) were detected in the LL zone, where 65% of the farmers apply manure and pesticides, and 50% cultivate sugarcane as cash crop. The food supply from agricultural production was sufficient for 56% of farmers, but many farmers depended on off-farm employment to earn their living and buy additional food.

Peasants in the mountain area of the UP zone were characterized by the lowest number of physical household assets (1.54) and the highest number of livestock (1.15 TLU). They kept a few non-dairy cattle and small ruminants that grazed the surrounding communal grasslands. Altogether, 50% of these farmers cultivated sebesten as cash crop and 60% used manure, fertilizer and pesticides. The food supply from crop production was insufficient for the majority of farmers (69%) and farmers practiced additional household activities, mainly off-farm employment and making of handicrafts for income generation (Table 3-1).

The major problem of crop production in the three cultivation zones was pests and diseases (30%, Figure 3-2), which decreased from the FG zone to the UP zone. Flooding or other extreme weather events (15%) were often reported in the FG and LL zones. The FG zone is also confronted with unstable market prices, which is problematic for the marketing of the cash crops. In the UP zone, water scarcity is a limiting factor for agriculture (mentioned by 14% of HH) because of variable rainfall distribution. Moreover, the limited access to market places (8%) was the third major problem of crop production in the UP zone. Other problems mentioned by the farmers of the three zones were lack of financial sources, of purified seeds/grains and adequate fertilizer supply in the FG zone.

3.4.2 **Gross margin of crop production**

The average annual GM for each HH was US$ 2110, 890 and 620 in the FG, LL and UP zones, respectively. In the three different zones, total gross margin (GM) was significantly ($p<0.01$), but weakly ($r^2 = 0.10 – 0.19$), correlated with farm size (hectares, Figure 3-3).

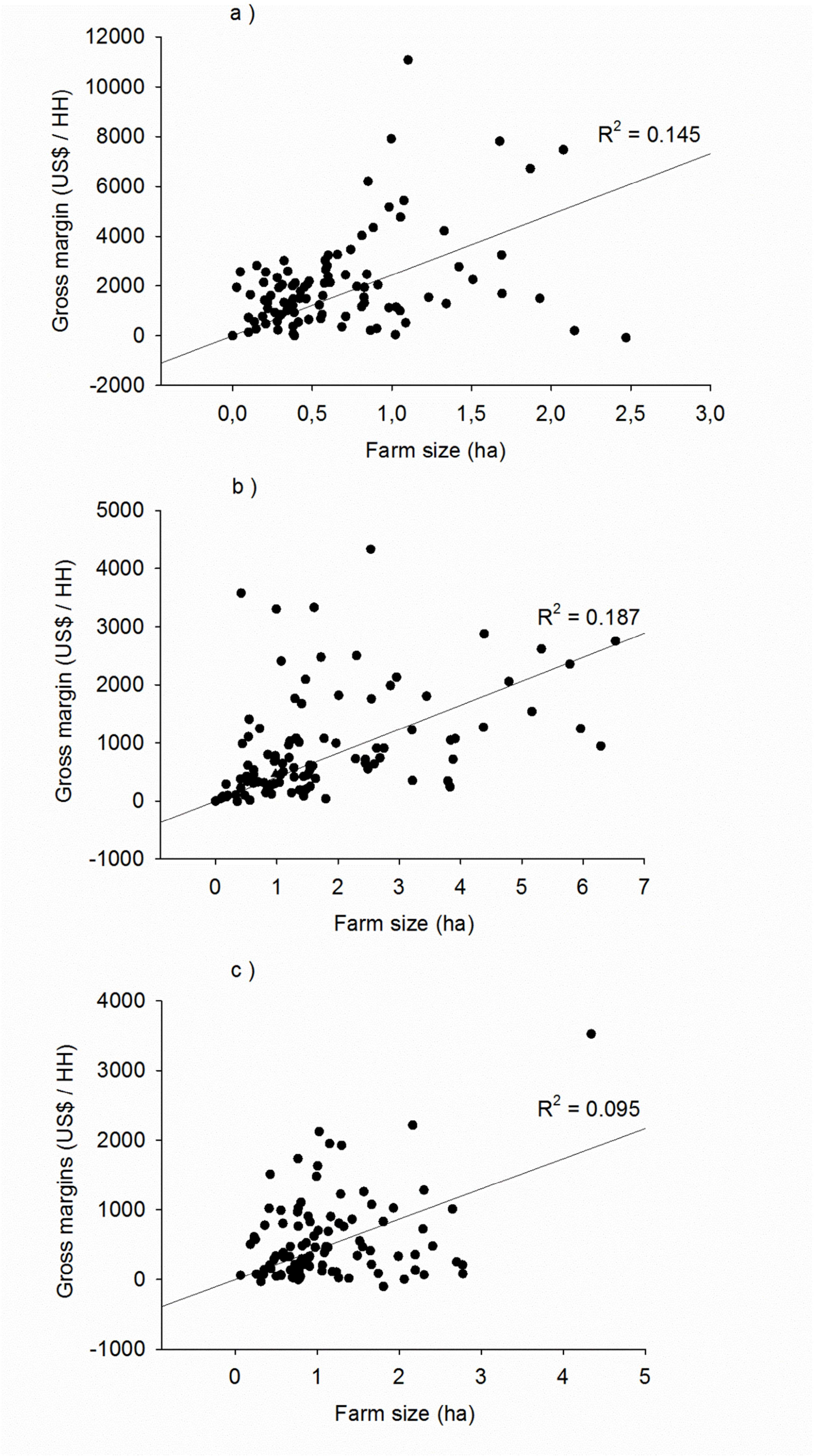


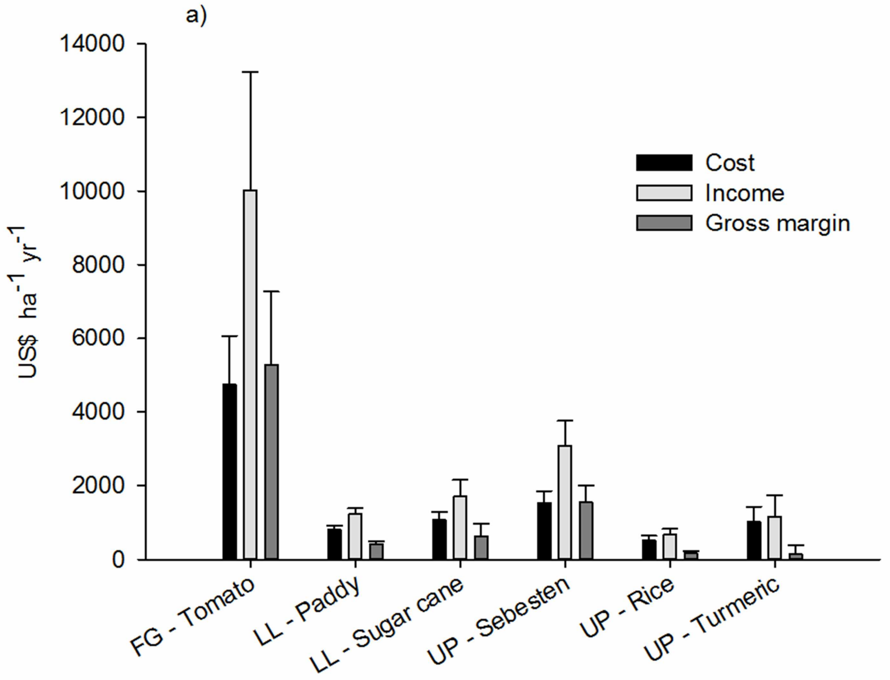
Figure 3-3. Correlation between farm size and household gross margin yr^{-1} in the FG zone (a), LL zone (b) and UP zone (c) of the study area in the Inle Lake region, Myanmar.

There was no clear linear relationship between farm size and the total gross margin, which may reflect the high variability of the farming systems. The most important cash crop of the FG zone was tomato. In the LL zone, farmers practiced both rain-fed agriculture and irrigation of rice, sugar cane and maize. Groundnut, pea (*Pisum sativum* L.), garlic (*Allium sativum* L.) and vegetables were cultivated mainly for subsistence production. In the UP zone, the main cropping systems were sebesten plantations and rainfed crops in the mountainous areas. Along the environmentally more favourable valleys, farmers cultivated rice as a staple and secondary crops such as garlic or soybean.

The crop-specific GM was highest for tomato in the FG zone, followed by sebesten in the UP zone and sugarcane in the LL zone (Figure 3-3a). The results clearly showed the importance of tomato cultivation for household income, which was on average US$ 10,029 ha^{-1} yr^{-1}. Rice and sugarcane production contributed to household income in the LL zone with US$ 418 and 629 ha^{-1} yr^{-1}.

The costs consisted of land preparation costs, seedling and transplanting costs, fertilizer costs, pesticide costs, labour costs for land preparation, weeding and harvest (Figure 3-3b). Farmers in the FG zone used many agricultural inputs resulting in very high costs of US$ 4,753 ha^{-1} yr^{-1}, especially for fertilizer and pesticides.

For the harvest, highest costs were found for sebesten plantations because of daily harvesting times and the labour intensive drying of sebesten leaves. Similar high harvest costs were found for tomato fields. For both cropping systems farmers often hired external workers during harvesting time.



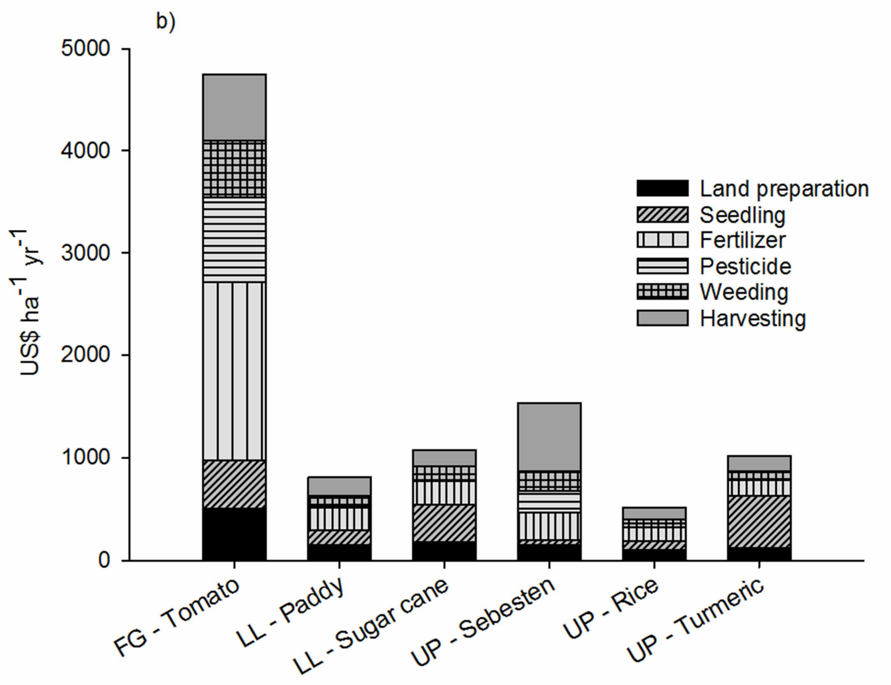


Figure 3-4. Costs, income and gross margin (a) and individual cost factors (b) for the main crops in the three agricultural zones of the Inle Lake region, Myanmar. FG = floating gardens zone, LL = lowland cultivation zone, UP = upland cultivation zone.

3.4.3 Livelihood strategies and well-being

Based on first main three cluster groups according to agricultural zone, there had got each three cluster groups in each agricultural zone using two-step cluster analysis. In the FG zone, cluster 1 had the most diverse income structure with mixed HH activities including crop production, fishery, animal husbandry (ducks and pigs), employment, handicraft and tourism. Cluster 2 of the FG zone represented less diversified farms without livestock production and handicraft activities. Highly specialised agricultural farms are grouped in cluster 3, which totally depended on cash crop production and thus managed a large area of floating gardens and had a high agricultural income.

The results for the LL zone showed a clear gradient in farm size from cluster 4 (small farms) to cluster 6 (large farms). Clusters 4 and 5 were characterized by high income diversification (Figure 3-4) without distinct specialisation. Off-farm activities included employment and handicraft for cluster 4, as well as tourism and animal husbandry for cluster 5. Other off-farm activities were small shop keeping, vegetable marketing, hotel and carpentry work. Cluster 6 comprised HHs specialized in agricultural activities, including cash crop production such as sugar cane and maize as well as work in sugarcane and rice milling plants for processing. For the UP zone, clusters 7 and 8 represent farms with mixed livelihood strategies and a high number of livestock. For subsistence production, farmers kept few non-dairy cattle and small ruminants as well as some pigs and poultry for sale. Young HH heads tended to focus on employment as off-farm activity (cluster 7), whereas old ones were more specialized in handicraft and the collection of forest resources (cluster 8). Cluster 8 was characterized by the highest livestock number (cows and buffaloes) and the lowest agricultural income. In contrast, cluster 9 was composed of HHs mainly focussing on cash crop production such as sebesten plantations, including paddy and garlic in a double cropping system on small terraced fields.

Table 3-2. Livelihood strategies, total cropland area and Tropical Livestock Units (TLU) for each agricultural zone of the study area in the Inle Lake region, Myanmar. Numbers in bracket represent one standard deviation (for details see Appendix 2).

	Description	**N**	**Cropland (ha)**	**TLU**
FG zone:				
Cluster 1	Highly diversified (agriculture, employment, fishery, livestock, handicraft), small to medium farms	30	0.60 (0.53)	0.30 (0.40)
Cluster 2	Less diversified (fishery, tourism, employment), small to medium farms	39	0.52 (0.33)	0.01 (0.06)
Cluster 3	Specialized in agriculture (cash crop: tomato), large farms, high income	21	0.98 (0.68)	0.00 (0.00)
LL zone:				
Cluster 4	Small farms, diversified (agriculture, employment and handicraft), low income	29	0.89 (0.59)	0.14 (0.19)
Cluster 5	Medium farms, diversified (agriculture, employment, livestock and tourism)	27	1.23 (0.98)	0.71 (0.91)
Cluster 6	Large farms, mostly specialized in agriculture (cash crop: sugar cane), high income	62	2.22 (1.63)	0.25 (0.56)
UP zone:				
Cluster 7	Diversified strategy (agriculture, livestock and employment), young farmers, high income	46	1.13 (0.63)	0.87 (0.93)
Cluster 8	Diversified strategy (agriculture, livestock, handicraft, use of forest resources, employment), old farmers	22	1.40 (1.02)	2.59 (2.39)
Cluster 9	Specialized in agriculture (cash crop: sebesten)	25	0.82 (0.47)	0.39 (0.67)

The total income decreased from the FG to the UP zone with lowest income for cluster 8. For all clusters, income was highest from crop production (53 to 100% of total income) followed by off-farm activities (Figure 3-5), especially in the FG zone, where the agricultural income amounted to 74 - 100% of total income. However, for the more diversified strategies in the LL and UP zone (clusters 4, 5, 7 and 8), off-farm activities played an important role (29 - 43% of total income). The income generated by livestock production was relatively low, indicating the low level of livestock farmers in the study region. Total income was highest for HHs in the specialized clusters in the FG zone (US$ 5,008 yr^{-1}, cluster 3) and the LL zone

(US$ 3,938 yr^{-1}, cluster 6). In the UP zone farmers with a more diversified strategy (cluster 7 and 8) generated nearly the same total income as specialized farms (cluster 9).

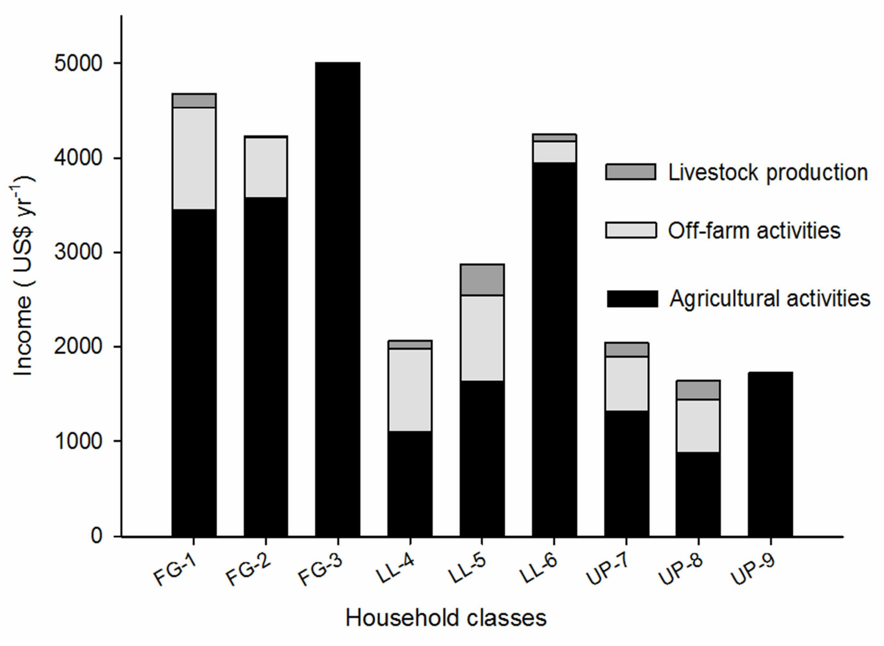


Figure 3-5. Contribution of different income sources to total household income of nine livelihood clusters (see Table 2) in the Inle Lake region, Myanmar (all units are expressed in US$, 1 US$ = 850 Kyat on average in 2012).

3.5 Discussion

3.5.1 Socio-economic aspects of traditional farming systems in the Inle Lake region

The three agricultural zones in the Inle Lake region differed strongly in environmental conditions and land use dynamics (Htwe et al., 2014), but also in income generating activities and general socio-economic conditions of the farm households. The agro-ecological conditions have a strong influence on land use diversity, farming types, livelihood strategies, agricultural production and activities in wetland environments (Sakane et al., 2013), which are known to directly affect decision making for land use (Valbuena et al., 2008).

In the FG zone, cash crop production dominated and agricultural production mainly contributed to farmers' livelihood. Altogether, 85% of the work force is used for agricultural activities on the floating islands (Than, 2007). Tomato is the main cash crop in the FG zone and subsistence production played only a minor role. Thus, farmers have to purchase their staple food, such as rice, and other requirements. Due to the prevailing cropping system and low crop diversity, agricultural income is restricted to four to eight months per year, which may be one reason for the high number of off-farm income activities, such as temporary or permanent engagement in fishery, tourism, employment and handicraft production.

The traditional floating garden cultivation was economically beneficial for local people, raised the cultural attractiveness for tourism, but was also reported to severely affect wetland ecosystems (Ingelmo, 2013). During the past 40 years the surface of floating gardens increased by 390% (Htwe et al., 2014), triggered by population increase and the expansion of human settlements. The increases in cropland area and soil erosion were reflected in a major loss of open water surface (ADB, 2006). The lake's water quality deteriorated due to sedimentation, accumulation of human waste and pollutants from untreated sewage and the frequent use of agrochemical inputs from floating garden cultivation (Than, 2007; Lwin & Sharma, 2012; MOECAF, 2013).

Average annual HH income in the study region was low, but considerable higher than the household income estimated by the Ecology and Economic Development Company (US$ 470-1,176, ECODEV, 2012) for the Inle Lake.

Livestock production was not a major livelihood strategy, often restricted to subsistence production at small scales; a decade ago only 0.3% of the households in the whole township of Nyaung Shwe were livestock keepers (UNDP, 2001).

The cropland area per HH is largest in the LL zone, where livelihoods are less diversified and the most important off-farm activity was employment. Farmers in the UP zone depended to a higher degree on the use of forest resources, which was not observed in the FG and LL zone. Inadequate access to markets was often reported as problematic in the UP zone, because of lacking infrastructure in the mountainous area. Food from agricultural production is often insufficient and total income is relatively low in the UP zone compared with the two other zones. One limiting factor of the rain-fed agriculture is water availability. The soils dry out quickly after the rainy season and a second cropping season is mostly impossible (Kangalawe & Liwenga, 2005). The diversity of cultivated crops is very high to reduce the general production risk.

In former decades, upland shifting cultivation practices were environmentally sustainable comprising a long fallow period (3-5 years), but with the recent population increase, very short or even no fallow periods are prevailing (MOECAF, 2013). In addition, land tenure insecurity became increasingly problematic and affected about one-quarter of all HHs. Landlessness in upland ethnic areas of southern Shan State ranges between 8% and 50% (BEWG, 2011). Rammohan & Pritchard (2014) reported that 26% of HHs in hilly areas were landless and unable to meet their food and nutrition security needs.

3.5.2 **Cropping systems and gross margin of main crops**

For the different agricultural zones, the total gross margin (GM) and the farm size of households were positively correlated, but correlation coefficients were low compared with other studies (Nabahungu & Visser, 2011). The total GM in the three agricultural zones of the Inle Lake region depends on many variable factors, such as market access and prices, agro-climatic and site conditions and on adaptive management strategies which vary among farmers, especially in the upland cultivation zone.

Different crop species dominated in the three agricultural zones. The highest GM was obtained by tomato plantations in the FG zone. Its annual production volume, attaining several thousand metric tons, was previously described as being distributed across the country by Soe (2012). However, tomato was also the crop species with the highest production costs for imported hybrid seed and external inputs are applied several times throughout the cropping season (Swe, 2008; Soe, 2012).

The most limiting factors of tomato production are pest and diseases, flooding and changing market prices (Soe, 2012). Across Myanmar, prices of the major crops such as pigeon pea, sesame and cotton were relatively stable from 2002 to 2008, but market prices for tomatoes may vary within one year from US$1.25 to 14 per 50 kg bag (Matsuda, 2013). During low price periods, farmers were not able to recover the total input costs. To reduce production risks, some farmers therefore practiced a double cropping system intercropping tomato with other crops such as cucumber (*Cucumis sativus* L.) or chilli or sweet pepper (Soe, 2012), or increased income diversification from non-agricultural sources.

A mixed cropping system prevails in the LL zone with rice as a staple and sugar cane as a cash crop. In fields near streams, where irrigation water is available throughout the year, double and triple cropping systems based on rice cultivation exist. Sugar cane is cultivated in a mono-cropping system for at least 3 years. The gross margin of sugar cane was higher than of rice, but because of the high input costs for sugar cane. Farmers often prefer to cultivate rice for their livelihood, as its production risks are lower. However, as a result of the increasing soil erosion and sedimentation, the lake’s water level decreases and many paddy fields are now left fallow because of water scarcity (Soe, 2012; MOECAF, 2013). Farmers are increasingly forced to cultivate crops such as sugarcane or to move to other marshland areas in order to establish new paddy fields (Htwe et al., 2014).

The upland cultivation zone was characterized by a mixed cropping system with a large crop diversity including sebesten as cash crop, upland rice and turmeric. Sebesten is planted as a perennial mono-cropping system (more than 100 years) and farmers collect the leaves for selling to make cheroots every year and occasionally cut the stem. Sebesten was not only the most profitable crop, but also required the highest input costs due to mineral fertilizers, pesticides and firewood needs for drying of leaves. Therefore, some farmers grew the drought resistant pigeon pea (*Cajanus cajan* L.), of which the dry stems are a valuable fuel wood (Kyi, 2006; Matsuda, 2013).

3.5.3 **Livelihood strategies and well-being**

The main driving forces of land use in many wetland areas are their underexploited resources such as land for crop production and grazing, access to water and the availability of labour and produce markets to open up new livelihood strategies (Erenstein et al., 2006; Sakane et al., 2013). For the Inle Lake region the resources availability and livelihood opportunities were different in the FG, LL and UP zones. Many studies reported that farm size (Rebelo et al., 2010; Sakane et al., 2013), soil conditions and input use for crop production (Nabahungu & Visser, 2011) are important determinants for the contribution of wetland agriculture to farmers' livelihoods, which was also confirmed by our study.

Altogether, three livelihood types were identified for each agricultural zone (9 clusters) representing a gradient from small to large farms and from highly diversified strategies to specialization in agriculture. The highest income and most diversified livelihood types were located in the FG zone. Market access is known to determine opportunities and HH income levels of farmers (Escobal, 2001) and the opportunity for off-farm activities (Soltani et al., 2012). In the FG zone, there is a rotating market every five days to exchange products between the *Intha* and upland dwellers such as the *Pa-O* and *Taung Yo* (Okamoto, 2012). Because of the region's cultural attractiveness for tourism, the opportunities for off-farm activities are high in the FG zone and include selling of handicrafts, antiques, motorboat riding, hotel services, cheroot rolling and lotus flowers (Than, 2007). Fishing is another off-farm alternative in the FG-zone, but mostly restricted to subsistence production, since the fish population is already degraded (Silvius, 2000). *Intha* fishermen were forced to change their livelihood strategy because of the declining water quality and expansion of croplands, resulting in a massive reduction of fish (Okamoto, 2012; Soe, 2012).

Despite numerous job opportunities, the contribution of the off-farm activities to total HH income is relatively low in the FG zone compared to the LL and UP zone. In both zones the more specialized farms with cash crop production yielded the highest total income compared with farms of mixed livelihood strategies (agriculture, livestock and off-farm activities) and the level of income increased with increasing farm size. Income of large farms was nearly twice as high as the income of small farms under the same environmental and market conditions. According to a recent food security study in Myanmar a farm size of 4 ha is needed to secure sufficient agricultural income and food availability (Rammohan & Pritchard, 2014). However, the majority of households in the country (63%) own less than 2 ha and only 13% own more than 4 ha of land (Kyi, 2006), indicating the importance of off-farm income sources for peoples' livelihoods.

In the UP zone of the Inle Lake region, HH income and off-farm income opportunities were lowest, largely due to the lack of infrastructure (Kyi, 2006). Nevertheless, off-farm income was more important and contributed more (25%) to the total income. Young farmers were often involved in small business and employment, whereas older farmers still practiced more traditional off-farm activities including the making of handicrafts and the collection of forest resources. Some farmers regularly collected fire wood from surrounding forests. Most of the rural households have no electricity and still depend on fuel wood for cooking, heating and construction purposes (Than, 2007; Sovacool, 2013). Given legal restrictions to forest use a few upland villages adopted a community forest system to control fuel wood collection, resulting in a reduction of income from forest resources (Soltani et al., 2012). Several farmers collected additional non-timber forest products such as vegetables, mushroom and honey. In contrast to the FG and LL zone, income among UP households was highest for the more diversified livelihood types compared with specialized farms. In this zone, the main objective of agricultural production is to satisfy household food requirements and to sell surplus produce, whereas cash crop production is less relevant. This is a common phenomenon in many hilly regions of Southeast Asia were local populations are confronted with the consequences of unsustainable land use practices and insecure property rights (Ratner, 2000).

3.6 Conclusions

Our study revealed that socio-economic HH characteristics and livelihood strategies in the floating gardens, lowlands and uplands of the Inle Lake region differ strongly. In each zone, the identified livelihood types represented a gradient from small to large farms and from highly diversified strategies to specialization in agriculture with highest agricultural income for the floating gardens. Currently, the rapid intensification of land use threatens the remaining wetland ecosystem: fertilizer and pesticide residues in floating gardens and that cause lake eutrophication and soil erosion processes in upland areas lead to lake sedimentation. Since the three agricultural zones are economically and environmentally closely linked to each other, future research and management plans should integrate these zones as only understanding their interrelationships allows to design appropriate strategies that prevent further environmental degradation and local livelihood strategies.

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3.9 Appendix

Appendix 1. Characteristics of farming systems: category, description, unit and data type.

Category	Description	Unit	Data type
Altitude	Altitude of farmers' house	above sea level (m)	Scale
Distance to nearest market places	Distance from house to the nearest market place	Km	Scale
Crop diversity	The number of crops cultivated by a household	Number	Scale
Age	Age of the head of the HH	Years	Scale
Gender	Sex of the head of the HH	Male = 0, Female = 1	Nominal
Family size	Family members in the HH	Number	Scale
Labor	Persons working on the farm	Family labor = number of family member Hired labor = days worked	Scale
Experience	Farming experience of HH head	Years	Scale
Education	Number of years of schooling completed by HH head	0 = ≤ 10 years 1 = ≥ 10 years	Nominal
Farm size	Area of HH's own land resources	Hectares	Scale
Farming system	Farming practice based on location	1 = floating garden 2 = lowland cultivation 3 = upland cultivation	Nominal
Cash crops production	Farmers' cultivated crops in their land for only cash crop or not	Cash crops = tomato, sugarcane, sebesten	Nominal
Food sufficient	Food sufficiency from farm product	food sufficient = 1, food insufficient = 0	Nominal
Months without agri: income	Months per year without income from crop production	Months	Scale
Tropical livestock unit	Number of livestock units owned by a HH	Buffalo = 1.4 Cow = 0.7 Horse = 0.8 Pig = 0.2 Poultry = 0.01 Duck = 0.01	Nominal
Household assets	Farmers' own housing structure, furniture, all other facilities	Number of assets	Scale
Input use to crops	Use of manure / compost and pesticides	Manure / Compost application (Yes=1,No=0) Pesticide application (Yes=1, No=0)	Nominal
Income	HH income from different sources per year	Farm income from only agricultural activities Livestock income from livestock production Off-farm income from off-farm activities included	Scale

		fishery and so on	
Costs of crop production	Total costs of crop production in US$ per hectare per year	Land preparation cost Seedling cost Mineral fertilizer and manure cost Pesticide cost Weeding cost Harvesting cost	Scale
Ethnic group	Ethnic group of the respondents	1 = Inthar 2 = Pa-O 3 = Dhanu 4 = Taung Yoe	Nominal
Employment	Engaged in employment	Yes = 1, No = 0	Nominal
Fishery	Engaged in fishery	Yes = 1, No = 0	Nominal
Handicraft	Engaged in handicraft	Yes = 1, No = 0	Nominal
Tourism	Engaged in tourism	Yes = 1, No = 0	Nominal
Use of forest resources	Farmers who are selling forest products or not	Yes = 1, No = 0	Nominal

Appendix 2-a. Floating garden zone.

Variable	Unit	Cluster_1 n = 30	Cluster_2 n = 39	Cluster_3 n = 21	Sig.
Age of HH	Years	44.53 (7.76)	48.26 (9.75)	52.38 (10.09)	*
Education	Years	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	ns
Farming experience	Years	21.10 (9.25)	24.38 (11.55)	29.00 (10.40)	*
Cultivated area	Hectares	0.60 (0.53)	0.52 (0.33)	0.98 (0.68)	**
Tropical livestock units	Number	0.30 (0.40)	0.01 (0.06)	0.00 (0.00)	***
Total household assets	Number	5.60 (2.56)	5.13 (2.49)	5.62 (2.74)	ns
Months with no agricultural income	Number	6.63 (2.39)	5.74 (1.27)	5.14 (1.31)	**
Pesticide application	Yes / No	0.87 (0.35)	1.00 (0.00)	1.00 (0.00)	*
Manure application	Yes / No	0.73 (0.45)	0.82 (0.39)	0.90 (0.30)	ns
Cash crops production	Yes / No	0.97 (0.18)	0.92 (0.27)	1.00 (0.00)	ns
Food sufficiency	Yes / No	0.37 (0.49)	0.46 (0.50)	0.71 (0.46)	*
Employment	Yes / No	0.33 (0.48)	0.23 (0.43)	0.00 (0.00)	*
Handicraft	Yes / No	0.37 (0.49)	0.00 (0.00)	0.00 (0.00)	***
Fishery	Yes / No	0.53 (0.51)	0.44 (0.50)	0.00(0.00)	***
Tourism	Yes / No	0.23 (0.43)	0.21 (0.41)	0.00 (0.00)	ns
Forest products	Yes / No	0.03 (0.18)	0.00 (0.00)	0.00 (0.00)	ns
Total income$^{1)}$	US$	4610 (3247)	4222 (2043)	5008 (3133)	ns

$^{1)}$ US$ per year, 1 US$ = Kyats 850 (mean of 2012)

*** Significant at 0.001; ** Significant at 0.01; * Significant at 0.05; ns = not significant

Appendix 2-b. Lowland Cultivation zone.

Variable	Unit	Cluster_1 n = 29	Cluster_2 n = 27	Cluster_3 n = 62	Sig.
Age of HH	Years	49.72 (10.75)	51.07 (9.95)	51.47 (11.43)	ns
Education	Years	0.10 (0.30)	0.22 (0.42)	0.37 (0.49)	ns
Farming experience	Years	27.69 (14.03)	26.56 (11.11)	28.29 (13.05)	ns
Cultivated area	Hectares	0.89 (0.59)	1.23 (0.98)	2.22 (1.63)	***
Tropical Livestock Units	Number	0.14 (0.19)	0.71 (0.91)	0.25 (0.56)	**
Total household assets	Number	2.86 (2.60)	2.85 (0.99)	3.48 (2.05)	ns
Months with no agricultural income	Number	5.41 (1.40)	6.04 (2.24)	3.74 (1.48)	***
Pesticide application	Yes / No	0.59 (0.50)	0.44 (0.51)	0.82 (0.38)	**
Manure application	Yes / No	0.45 (0.51)	0.85 (0.36)	0.65 (0.48)	**
Cash crops production	Yes / No	0.10 (0.31)	0.63 (0.49)	0.66 (0.48)	***
Food sufficiency	Yes / No	0.34 (0.48)	0.30 (0.46)	0.77 (0.42)	***
Employment	Yes / No	0.55 (0.51)	0.59 (0.50)	0.02 (0.13)	***
Handicraft	Yes / No	0.38 (0.49)	0.00 (0.00)	0.00 (0.00)	***
Fishery	Yes / No	0.00 (0.00)	0.11 (0.32)	0.00(0.00)	**
Tourism	Yes / No	0.00 (0.00)	0.30 (0.46)	0.00 (0.00)	***
Forest products	Yes / No	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	ns
Total income[1)]	US$	2062 (1233)	2872 (1592)	4247 (2856)	***

[1)] US$ per year, 1 US$ = Kyats 850 (mean of 2012)

*** Significant at 0.001; ** Significant at 0.01; * Significant at 0.05; ns = not significant

Appendix 2-c. Upland Cultivation zone.

Variable	Unit	Cluster_1 n = 46	Cluster_2 n = 22	Cluster_3 n = 25	Sig.
Age of HH	Years	37.96 (8.14)	51.59 (13.17)	45.80 (11.36)	***
Education	Years	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	ns
Farming experience	Years	20.74 (9.26)	29.14 (12.27)	25.92 (10.06)	**
Cultivated area	Hectares	1.13 (0.63)	1.40 (1.02)	0.82 (0.47)	*
Tropical livestock units	Number	0.87 (0.93)	2.59 (2.39)	0.39 (0.67)	***
Total household assets	Number	1.67 (1.28)	1.10 (1.11)	1.68 (1.35)	ns
Months with no agricultural income	Number	4.83 (1.06)	6.45 (0.80)	4.80 (1.44)	***
Pesticide application	Yes / No	0.85 (0.36)	0.14 (0.35)	0.76 (0.44)	***
Manure application	Yes / No	0.67 (0.47)	0.77 (0.43)	0.40 (0.50)	*
Cash crops production	Yes / No	0.52 (0.50)	0.36 (0.49)	0.68 (0.48)	ns
Food sufficiency	Yes / No	0.28 (0.45)	0.00 (0.00)	0.64 (0.49)	***
Employment	Yes / No	0.50 (0.51)	0.14 (0.35)	0.00 (0.00)	***
Handicraft	Yes / No	0.07 (0.25)	0.50 (0.51)	0.00 (0.00)	***
Fishery	Yes / No	0.00 (0.00)	0.06 (0.21)	0.00(0.00)	ns
Tourism	Yes / No	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	ns
Forest products	Yes / No	0.17 (0.38)	0.32 (0.48)	0.00 (0.00)	*
Total income[1)]	US$	2040 (1104)	1649 (1330)	1726 (1292)	ns

[1)] US$ per year, 1 US$ = Kyats 850 (mean of 2012)

*** Significant at 0.001; ** Significant at 0.01; * Significant at 0.05; ns = not significant

Chapter 4

4 Spatio-temporal assessment of soil erosion risk in different agricultural zones of the Inle Lake region, Southern Shan State, Myanmar

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4.1 Abstract

Many parts of Southeast Asia are severely affected by soil erosion. Myanmar is one of the region's climatically diverse countries, where sheet, rill and gully erosion affect crop yields and subsequently income levels of the people. In the unique wetland ecosystem of Inle Lake, soil erosion in surrounding uplands strongly cause sedimentation and pollution of the lake. The current study used the Revised Universal Soil Loss Equation (RUSLE) to identify soil erosion risks of the Inle Lake region in space and time and to assess the relationship between soil erosion and degradation for different agricultural zones and cropping systems. Altogether, 85% of soil losses occurred on barren land along the steep slopes. The hotspot of soil erosion risk is situated in the western uplands characterized by unsustainable land use practices combined with a steep topography. The estimated average soil losses amounted to 19.9, 10.1 and 26.2 t $ha^{-1}yr^{-1}$ in 1989, 2000 and 2009, respectively. These fluctuations were mainly the results of changes in precipitation and land cover (deforestation and cropland expansion). Most farmers in the study area have not yet adopted effective soil protection measures to mitigate the effects of soil erosion such as land degradation and water pollution of the lake reservoir. This urgently needs to be addressed by policy makers and extension services.

Keywords: Floating gardens; Land degradation; RUSLE; Soil loss

4.2 Introduction

In rapidly developing countries of Southeast Asia, the overuse of renewable natural resources (forests, soils and fresh water) is an important environmental challenge (Ian, 2002). The economic growth during the last two decades caused severe environmental degradation such as soil erosion, land degradation, deforestation, water pollution, loss of biodiversity, and degradation of marine and coastal zones (Radka, 2000; Bahadur, 2009).

Soil erosion is a major consequence of human-induced soil degradation that affects 56% of the world's terrestrial surface (Gabriels and Cornelis 2009). In Southeast Asia soil erosion risk causes annual average soil losses of 138 t ha^{-1} with major on-site and off-site damages whose severity depends on the resilience of the natural resource base, the institutional and economic conditions, the rate of population growth and the policy environment (Ananda and Herath 2003; Yang et al. 2003). Myanmar has the highest erosion hazard of Southeast Asia (over 80% of sloping lands) and combined with soil nutrient depletion this severely hampers agricultural development (FAO 2000; Amsalu and Graff 2006), particularly in mountainous regions where steep slopes with shifting cultivation prevail (Swe 2003).

In the southern Shan State of Myanmar erosion occurs as sheet, rill and gully erosion, causing declines of crop yields and income levels (GAF 1996) and triggering the eutrophication of the Inle Lake water body (Than 2007; Soe 2012). Under these circumstances, quantitative assessments of soil erosion risk at farmers' level are urgently needed to monitor the potential risk in space and time.

For this purpose, models have been developed, such as the Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978; Renard et al. 1997), the Water Erosion Predict Project model (WEPP; Nearing et al. 1989), the Chemical, Runoff, and Erosion for Agricultural Management system (CREAMS; Knisel 1980), the European Soil Erosion Model (EuroSEM; Morgan et al. 1990), the Pan-European Soil Erosion Risk Assessment (PESERA; Kirkby et al. 2000, 2003) and the Soil Erosion Model for Mediterranean regions (SEMMED; De Jong 1994).

The Revised Universal Soil Loss Equation (RUSLE; Renard et al. 1997) has been successfully used in many studies for both agricultural and forest watersheds to identify erosion risks and predict average annual soil losses under different environmental conditions (Angima et al. 2003; Lu et al. 2004; Cohen et al. 2005; Fu et al., 2005; Yue-Qing et al. 2008; Sharma et al. 2011; Prasannakumar et al. 2012; Kumar et al. 2014). The model allows to depict the spatial heterogeneity of soil erosion risks using information about the watershed characteristics and local hydro-climatic conditions (Angima et al. 2003).

This approach was used in the current study to identify soil erosion risks of the Inle Lake region in space and time and to analyse the relationship between soil erosion and degradation for different agricultural zones and cropping systems.

4.3 Materials and methods

4.3.1 Study area

The Inle Lake watershed is situated in southern Shan State, Myanmar (Figure 4.1a). Inle Lake is the second largest inland lake of the country, located at 20°18' to 20°53' N latitudes and 96°50' to 96°57' E longitudes and an altitude of 890 m asl (Su and Jassby 2000). It occupies the central part of a trough between two mountain ranges limiting the lake to the East and West. The area is one of the primary tourist locations of Myanmar because of the rich biodiversity; it was designated as the 190th World’s Eco-region in 1998 (Olson and Dinerstein 2002) and nominated as a fresh water biodiversity hotspot (Lwin and Sharma 2012).

Due to the limited availability of spatial data (soil, land use) for the whole watershed area, the center of the Inle Lake watershed was selected as study area (Figure 4.1b) for the assessment of soil erosion risk. The study area comprises 2115 km^2 and includes the townships of Taunggyi (20°47' N, 97°02' E, 1400 m a sl) Nyaung Shwe (20°45' N, 96°56' E, 885 m asl), Kalaw (20°38' N, 96°34' E, 1320 m asl) and Pinlaung (20°5' N, 96°47' E, 1463 m asl) with a population density of 180, 119, 108 and 49 people km^{-2}, respectively (Ministry of Health 2011). The climate is characterized by monsoon-dependent annual rainfall of approximately 1370, 931, 1036 and 2113 mm at the four respective locations (observation period from 1988-2012; Meteorology and Hydrology Department, Taunggyi and Agriculture Department, Ministry of Agriculture and Irrigation, Nyaung Shwe) with three main seasons: dry summer (mid-February to mid-May), rainy season (mid-May to mid-October) and dry winter (mid-October to mid-February).

The dominant soils in the Inle Lake region are Acrisols, mainly in the uplands (Su and Jassby 2000, Hai et al. 2006) and Histosols including paddy soils (Hydragric Anthrosols) in the bottom valley near the lake.

Given its topography and the prevailing cropping systems, the study area can be divided into three agricultural zones (Htwe et al. 2014; Figure 4.1b): (1) Floating gardens (FG), (2) Lowland (LL) and (3) Upland (UP) cultivation zone. The floating garden zone, where tomato cultivation on floating islands prevails, was identified by a visual identification of floating gardens in the water body using recent high resolution Google Earth® images (Htwe et al. 2014). The areas below 1150 m a.s.l. adjoined to floating gardens belong to the lowland cultivated zone, which is characterized by paddy fields, sugarcane (*Saccharum* ssp.) and other crops. We defined the upland cultivation zone on hilly slopes at altitudes above 1150 m a.s.l, where shifting cultivation and agroforestry systems are dominant. Farmers' livelihood strategies are divers in the three different agricultural zones and depend on farm size. The diversification strategies range from cash-crop producing large farms to highly diversified small farms (Htwe 2015).

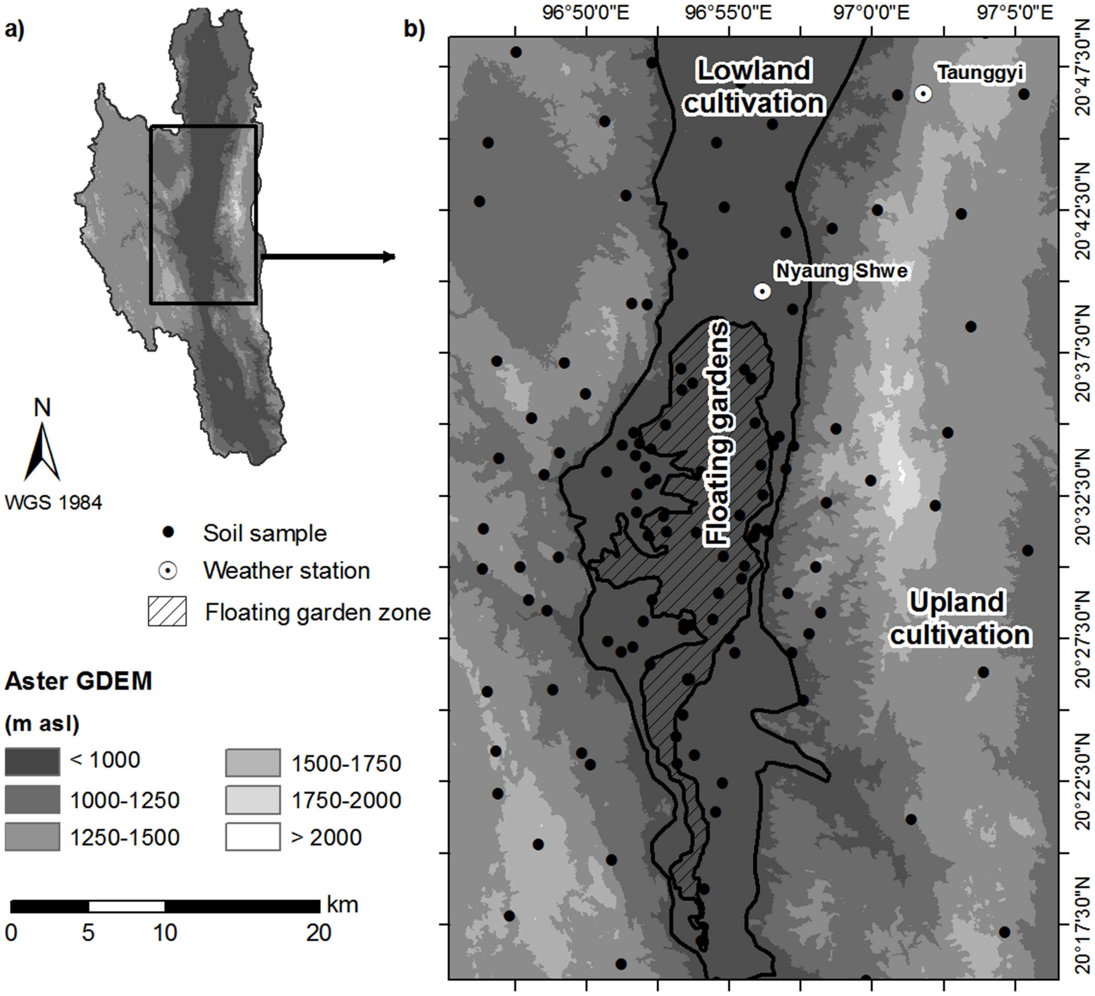

Figure 4.1. Location of the study area and weather stations in the Inle Lake watershed in southern Shan State, Myanmar (a) and location of the different agricultural zones and soil samples in the study area (b).

4.3.2 **Household interviews on soil erosion risk**

In 2012, semi-structured household interviews were conducted to collect socio-economic data and information on land degradation and soil erosion risk in thirty villages of the three agricultural zones in the Inle Lake region. Village selection was based on a stratified random sampling design for each agricultural zone using a Geographic Information System (GIS). The interviews were part of a larger survey of 301 households (Htwe et al. 2014) and included questions about farmers' perception of land productivity, soil fertility, soil erosion, soil deterioration, depletion of topsoil and nutrients, and effects of soil erosion and degradation over the past 5 years. For each household, the cultivated crops were inventoried and the limits of the crop fields were determined using a handheld GPS device (Trimble GeoXT, Trimble, Navigation Ltd., Sunnyvale, CA, USA). GPS measurements were subsequently imported into a GIS and used for mapping of crop fields. The resulting land use maps of households were used for the randomized selection of soil samples.

4.3.3 **Analysis of soil physical and chemical properties**

Soil samples were collected for the different agricultural zones and topographic locations to analyze differences in soil properties between the three agricultural zones and estimate the soil erodibility factor, an important input variable for the RUSLE model. Altogether, 128 farmers' fields (22 in floating gardens, 51 in the lowland and 55 in the upland zone) from the household survey were selected for analysis of soil properties. For each field, five soil samples were taken at 0-20 cm depth and pooled together resulting in 128 samples. Samples were air-dried, sieved and kept for subsequent soil analysis. The soils were analyzed for physical (soil texture) and chemical properties: soil organic matter (SOM), available phosphorus (P), available potassium (K), total nitrogen (N_{tot}), total carbon (C_{tot}), electrical conductivity (EC) and pH using standard laboratory methods. The pipette method was used for soil texture analysis (Gee and Or, 2002) after dispersion with 0.4 N sodium metaphosphate ($NaPO_3$). SOM was roughly measured by heating the dry soil for 5 hours at 550˚C. A CHN analyzer was used to determine N_{tot} and total C_{tot}, available P was determined according to the method of Olsen et al. (1954) for alkaline soils and Bray and Kurtz (1945) for acid soils. Available K was measured using a flame photometer and ammonium acetate as the reagent. EC was measured at a ratio of 1:10 in an aqueous suspension of soil using a portable EC meter. Soil pH was measured in water at a ratio of 1:2.5.

4.3.4 **Estimation of soil erosion risk using RUSLE model**

The RUSLE empirical model was used to predict annual average soil loss (A) as follows (Renard et al. 1997; Equation (1):

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A (t ha^{-1} yr^{-1}) is the average soil loss of the study area, R (MJ mm $ha^{-1}h^{-1}yr^{-1}$) is the rainfall-runoff erosivity factor, K (t ha h $ha^{-1}MJ^{-1}mm^{-1}$) is the soil erodibility factor, LS (dimensionless) is the slope length and slope steepness factor, C (dimensionless) is the cover and management practice factor, and P (dimensionless) is the support practice factor. Each factor in the RUSLE equation was calculated based on existing geospatial data (30m resolution) such as a digital elevation model, soil/geology map, land cover and land use maps from satellite image classification (Htwe et al. 2014), climatic data (rainfall) and field measurements (soil samples) and converted into a raster file format. The spatial distribution of soil erosion risk of the selected Inle Lake region (2115 km^2) was calculated for different years (1989, 2000 and 2009) by multiplying the corresponding raster files of each factor within ArcGIS 10.0 (ESRI, Redlands, CA, USA). Estimated soil loss was summarized for land cover classes (Htwe et al, 2014), agricultural zones and main cropping systems by using zonal statistics of the Spatial Analysis tool in ArcGIS 10. To calculate the potential soil erosion risk of household's main cropping systems in the lowland and upland cultivation zone (lowland and upland rice, maize, sugarcane, turmeric) soil losses were summarized for the mapped crop fields.

4.3.5 **Calculation of RUSLE factors**

Rainfall data (monthly and daily amount of precipitation) of a 21 year observation period (1988 to 2009) was received from four meteorological stations (Taunggyi: 20°46'35"N and 97°1'49"E, 1430m asl; Nyaung Shwe: 20°39'39"N and 96°56'10"E, 885m asl; Kalaw: 20°37'58"N and 96°33'58"E, 1317 m asl; Pinlaung: 2 0°5'26"N and 96°47'16"E, 1484 m asl) within the study area (Figure 1) in order to estimate the rainfall erosivity factor R. Since data on rainfall intensity was lacking for our study area, we derived the R factor for each station using Wischmeier's empirical equation (2) adapted by Wu et al. (2012) and Pan and Wen (2014):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5\log_{10}\left(\frac{P_i^2}{P}\right)-0.08188\right)} \tag{2}$$

where R is rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}), P is the average annual precipitation (mm) and P_i is the average monthly rainfall (mm). Due to the limited number of data points a deterministic interpolation method based on Thiessen Polygons was used within ArcGIS to depict the R-factor in space. To improve the resulting R-factor map by considering the altitude, areas of the floating garden and lowland cultivation zone (< 1100 m asl) were extracted and reclassified to the R-factor value of the station at 885 m asl (Nyaung Shwe).

Since field measurements of the K-factor (t ha h ha^{-1} MJ^{-1} mm^{-1}) are often too expensive to conduct, the soil erodibility nomograph (Wischmeier et al. 1971) is commonly used for soil erodibility calculations (Chen et al. 2011; Panagos et al., 2014). An algebratic approximation of the nomograph that includes five soil parameters (texture, organic matter, coarse fragments, structure and permeability) was proposed by Wischmeier and Smith (1978) and Renard et al. (1997) and used in the current study (Equation 3, adapted by Panagos et al. 2014):

$$K = [(2.1 \times 10^{-4} M^{1.14} (12 - OM) + 3.25(s - 2) + 2.5(p - 3))] / 100] * 0.1317 \qquad (3)$$

where:

M	the textural factor with $M = (m_{silt} + m_{vfs}) * (100 - m_c)$;
m_c (%)	clay fraction content (<0.002 mm);
m_{silt} (%)	silt fraction content (0.002 – 0.05 mm);
m_{vfs} (%)	very fine sand fraction content (0.05 – 0.1 mm);
OM (%)	organic matter content;
s	soil structure class (s = 1: very fine granular, s = 2: fine granular, s = 3: medium or coarse granular, s = 4: blocky, platy or massive);
p	permeability class (p = 1: very rapid, p = 2: moderate rapid, p = 3: moderate, p = 4: slow to moderate, p = 5: slow, p = 6: very slow)

This equation is only recommended if the silt content is below 70% and the organic matter content is known (Panagos et al. 2014). For calculations we used the results of our soil analysis (soil texture and soil organic matter content). The soil structure class was estimated based on the corresponding FAO soil type and own field observations in 2012 and 2013. The permeability class was estimated using the soil texture classes of collected samples according to the US Department of Agriculture's National Soils (USDA 1983). Since the K-factor was only estimated for the soil-sample point locations, the results were interpolated using ordinary kriging in ArcGIS. Kriging is a geo-statistical interpolation method to predict the values of unknown locations using a weighted average of neighbouring measured values (Wu et al. 2012; Elbasiouny et al. 2014). The weight depends on the distance of the measured points to the prediction location, and the spatial relationships among the measured values around the prediction location (Yaserebi et al. 2009; Phachomphon et al. 2010). Ordinary Kriging is the simplest, most commonly used stochastic interpolation technique (Mishra 2009) and the most effective for the computation of a soil erosivity map (Alexakis et al. 2013). The resulting map was converted to a raster format.

A Digital Elevation Model (ASTER GDEM, version 2, product of METI and NASA, acquisition date: 17.08.2011) was used in basic terrain analysis and as input variable for the calculation of the topographic LS-factor for each raster cell of the Inle watershed area using the standard method of the Hydrology tool in SAGA GIS, which is based on the algorithm of Moore et al. (1991).

Plant crown coverage, ground cover, crop sequence, length of the growing season and tillage practice are commonly used to determine the C-factor for crop management. Land use and land cover maps were classified for the Inle Lake region based on Landsat images from 1989, 2000 and 2009 in a previous study (Htwe et al. 2014) and were used to estimate the C values. These land cover maps comprised 11 classes, which were reclassified to C-factor values according to Bhandari et al. (2014) and own field data (Table 4.1).

P is the ratio of soil loss with a support practice such as contouring, strip cropping, or terracing to soil loss. According to Renard et al. (1997), the P-factor is considered the most difficult factor to determine and the least reliable factor of the RUSLE input factors. By interviewing the farmers during the field visit, it was found that nearly no soil erosion protection measures exist in the studied area. Therefore, the RUSLE model was run with a P-factor of 1.0 to predict erosion potential under current conditions of no soil conservation support practices (Renard et al. 1997).

Table 4.1. Land cover classes according to Htwe et al. (2014) and the corresponding C- factor (crop and management practice) in the Inle Lake region, Myanmar.

Class	Class description	C value[1)]
Agroforest	Trees and crops on cultivated land	0.15
Paddy field	Rice cultivation in the lowlands	0.35
Floating garden	Fields on floating islands in the lake area	0.01
Other cropland	Other field crops (e.g. sugarcane, maize, upland rice, turmeric)	0.45
Fallow land	Fallow fields on cultivated land covered with grass	0.02
Forest	Dense hill forest	0.001
Marshland	Marshy grassland and swamp near lake	0.01
Shrubland	Rangeland or grassland with shrubs and isolated trees	0.01
Barren land	Sparsely vegetated areas and wasteland	1.00
Urban	Settlements, cities, single houses, industrial facilities	0.05
Water body	Open waterbody	0.00

1) Source: adopted from Bhandari et al. (2014), Roose (1977), Hurni (1987), Morgan (1986), Hashim and Wong (1988) and own field data.

4.4 Results

4.4.1 Farmers' perception of soil erosion and land degradation

Altogether, 36% of the surveyed farmers reported a decline in soil productivity. In the FG zone, only 10% of farmers noticed a decrease in crop productivity, which reduced the operating life of floating islands, whereas about half of surveyed farmers in LL and UP zones noticed a decline.

About 25% of farmers reported that their lands had degraded within last 5 years and the issue of soil erosion is prominent (Table 4.2). In the LL and UP zones, 31-33 % of the farmers observed land degradation effects on their farms such as deterioration and depletion of top soil and 25 % reported a decline in crop yields, whereas only a few farmers had noticed erosion-induced nutrient depletion and water pollution. Further erosion effects such as biodiversity losses and changes in livelihood strategies were only mentioned by two farmers.

Table 4.2. Soils erosion risk and its effects as observed and perceived (%) by farmers in the Inle Lake region, Myanmar, according to HH interviews.

	FG (n = 90)	**LL (n = 118)**	**UP (n = 93)**	**Total (n = 301)**
Observation (%)				
Soil erosion	0.0	6.8	19.4	8.6
Soil deterioration	5.6	11.0	4.3	7.3
Topsoil depletion (of field)	0.0	8.5	9.7	6.3
Other	2.2	5.1	0.0	2.7
Unaware	92.2	68.7	66.7	75.1
Perception (%)				
Yield decline	1.1	25.4	25.8	18.3
Nutrient depletion	1.1	4.2	2.2	2.7
Water pollution	0.0	1.7	2.2	1.3
Decrease of biodiversity	2.2	1.7	0.0	1.3
Livelihood strategies change	1.1	0.0	0.0	0.3
Unaware of changes	94.4	67.0	69.9	76.1

4.4.2 Estimated soil losses from 1989 to 2009 using RUSLE models

The R-factor increased with increasing altitude and the lower values were detected for the valley bottom (Figure 4.2a). The mean R factor was 1923 MJ mm ha^{-1} h^{-1} yr^{-1}. The maximum value of 3887 MJ mm ha^{-1} h^{-1} yr^{-1} was observed in Pinlaung, and the minimum value (998 MJ mm ha^{-1} h^{-1} yr^{-1}) was observed for Kalaw.

The average K-factor was 0.02 t ha h MJ^{-1} ha^{-1} mm^{-1} (Figure 4.2b) with highest values in the mountain areas of the southeastern and northwestern part of Inle Lake and very low values in the floating garden zone. This difference was mainly due to the high soil organic matter content, which decreased from FG to the UP zone. The soil analysis revealed that EC, N_{tot}, C_{tot} and SOM were lowest in the eroded crop land of the UP zone (Appendix 1).

The LS factor (Figure 2c) varied from 0 in the bottom valley to 89.17 on the steep slopes of the mountains (Figure 4.2b).

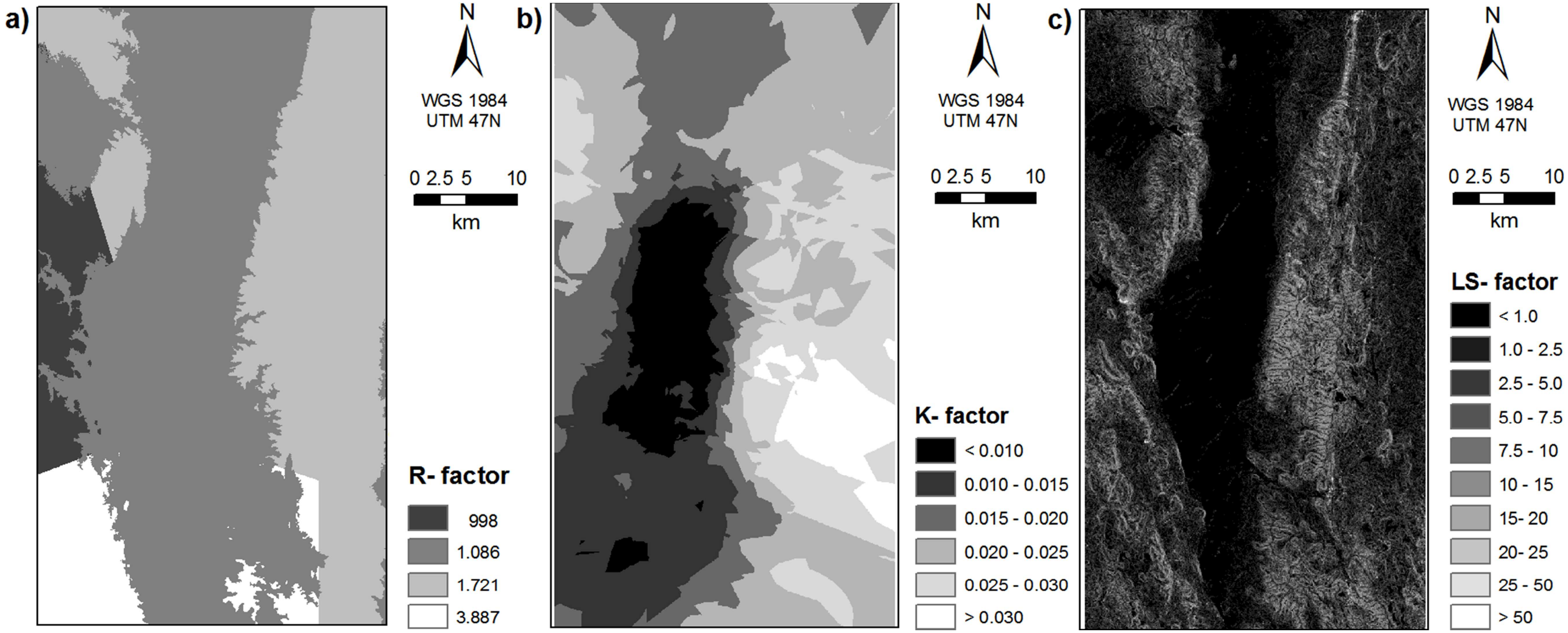

Figure 4.2. Maps of the R-factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K-factor (t ha h MJ^{-1}ha^{-1}mm^{-1}) and LS Factor and for the Inle Lake region, Myanmar. These factors were constant for the period from 1989 to 2009.

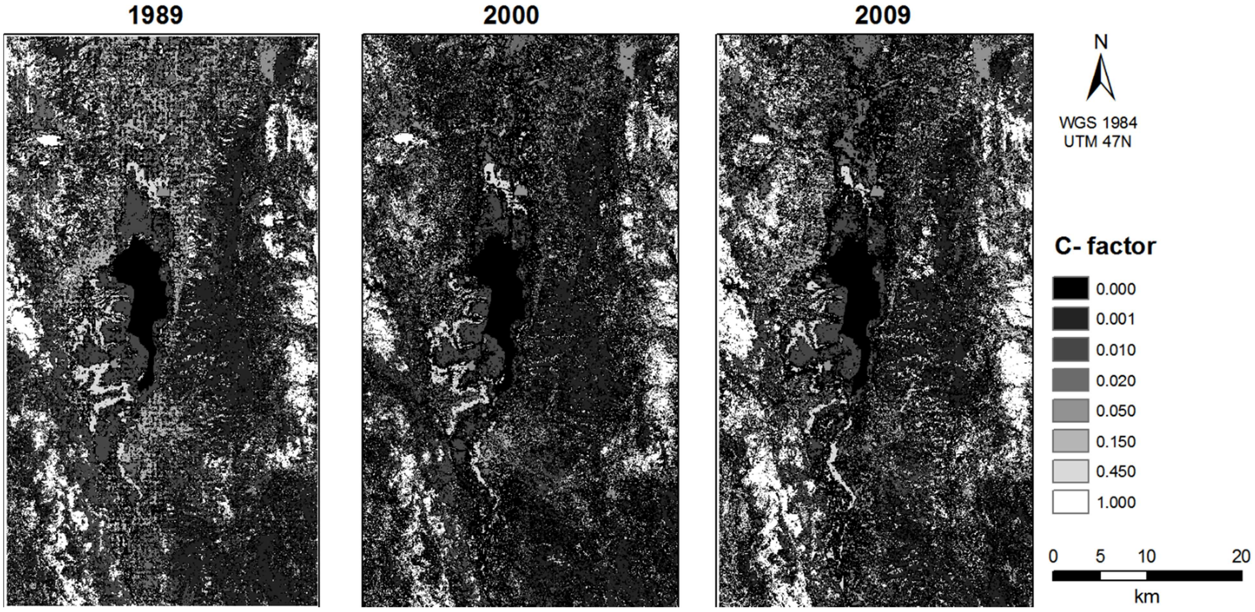

Figure 4.3. Maps of C-factor from 1989 to 2009 for the Inle Lake region, Myanmar.

Land cover changes occurred from 1989 to 2009 with an increase in urban areas, cropland and floating gardens. The forest areas increased from 414 km² to 456 km² in 2000 and decreased again to 337 km² in the year 2009. These changes were reflected by changing C- factors in the RUSLE model (Figure 4.3). The estimated average soil erosion risk was highest for barren land followed by cropland and agroforest areas, whereas nearly nil soil loss risk was estimated for urban areas, marshland and floating gardens (Table 4.3).

Table 4.3. Distribution of land cover classes in 1989, 2000 and 2009 (Htwe et al., 2014), changes (%) in comparison to the previous observation year and average soil loss (mean, standard deviation [SD] and percentage of total area) for each land cover class in the Inle Lake region, Myanmar.

Land cover class	**1989**	**2000**		**2009**		**Average soil loss**		
	Area (km^2)	Area (km^2)	Change (%)	Area (km^2)	Change (%)	Mean (t ha^{-1} yr^{-1})	SD	(%)
Agroforest	400.95	369.48	-7.85	375.78	+1.70	9.30	14.22	11.48
Barren land	299.52	288.18	-3.79	323.18	+12.15	79.75	92.09	77.07
Other cropland	53.88	69.26	+28.55	97.28	+40.45	36.04	56.67	8.11
Fallow land	124.42	151.04	+21.39	171.75	+13.71	0.54	1.16	0.26
Floating garden	49.03	59.49	+21.33	68.69	+15.46	0.04	0.23	0.01
Forest	414.22	456.07	+10.10	336.91	-26.13	0.23	0.20	0.30
Marshland	54.73	28.33	-48.23	16.75	-40.88	0.01	0.06	0.00
Paddy fields	61.41	64.88	+5.64	56.59	-12.78	0.69	6.14	0.14
Shrubland	582.67	535.76	-8.05	549.61	+2.59	1.26	1.30	2.26
Urban	29.47	42.69	+44.86	60.11	+40.81	2.48	4.19	0.36
Water body	45.17	50.28	+11.33	58.78	+16.91	0.00	0.00	0.00

Average annual soil loss rates in the study region ranged from 14.0 t ha^{-1} in 1989 (total = 3165 10^4 t yr^{-1}), 13.0 t ha^{-1} in 2000 (total = 2944 10^4 t yr^{-1}) and 16.7 t ha^{-1} in 2009 (total = 3785 10^4 t yr^{-1}). The temporal dynamics indicated a decrease in soil erosion risk from 1989 to 2000 by – 7%. The soil erosion risk was lowest in 2000, when only 21% of the area was affected by soil losses > 5 t ha^{-1} yr^{1} (Figure 4.4, Table 4.4). Erosion risk was highest for 2009, when soil losses increased again by 29%. In 2009, 7% of the area (295 km²) was exposed to extreme risks (>50 t ha^{-1} yr^{-1}), mostly situated in the upland cultivation zone. The soil loss potential increased from FG with nearly no soil losses to the UP zones (Table 4.5), where highest losses were observed especially for the western mountain region. From 1989 to 2009 more than 95% of the observed soil losses occurred in the upland cultivation zone.

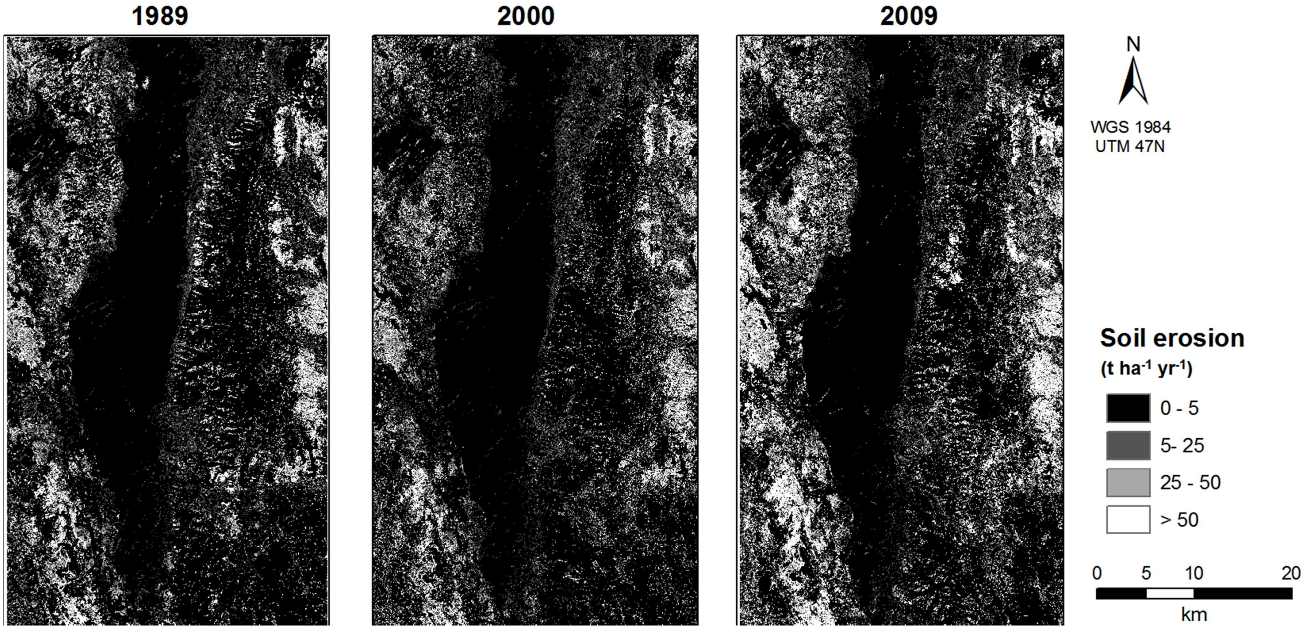

Figure 4.4. Predicted soil erosion risk in the Inle Lake region, Myanmar.

Table 4.4. Distribution of soil loss categories and amount of soil loss (10^4 t yr^{-1}) for each category in the Inle Lake region, Myanmar.

Soil loss category ($t\ ha^{-1}\ yr^{-1}$)	**Area (km²)**			**Soil loss ($10^4\ t\ yr^{-1}$)**			**% Change of soil loss**	
	1989	2000	2009	1989	2000	2009	2000	2009
Low (< 5)	1608	1623	1521	120	118	123	-1.4	+4.1
Moderate (5 – 25)	218	216	258	270	266	331	-1.5	+24.2
High (25 – 50)	104	102	123	337	327	411	-3.1	+25.6
Extreme (> 50)	185	174	213	2437	2233	2920	-8.4	+30.8
Total	2115	2115	2115	3165	2944	3785	-7.0	+28.6

Table 5. Soil losses from 1989 to 2009 in the three agricultural zones of the Inle Lake region, Myanmar.

Agricultural zone	**Mean ± SD ($t\ ha^{-1}\ yr^{-1}$)**			**Soil loss (%)**		
	1989	2000	2009	1989	2000	2009
FG	0.03 ± 0.89	0.05 ± 0.98	0.03 ± 0.76	0.02	0.03	0.02
LL	2.27 ± 9.02	1.83 ± 6.98	1.90 ± 7.59	3.20	2.78	2.24
UP	18.55 ± 51.44	17.32 ± 48.86	22.40 ± 56.87	96.78	97.20	97.75

4.4.3 Soil losses of different cropping systems in 2009

Among the different cropping systems of the surveyed households, rainfed rice (*Oryza sativa* L.) and maize (*Zea mays* L.) cultivation in the UP zone exhibited the highest soil erosion risk, followed by Sebesten (*Cordia dichotoma* G.Forst.) plantations (Figure 4.5). For the floating gardens and lowland cropping systems, nearly no soil erosion risk was determined for the well leveled and bunded paddy fields, whereas soil losses of 2 to 3 t ha^{-1} were observed for sugarcane (*Saccharum* ssp.).

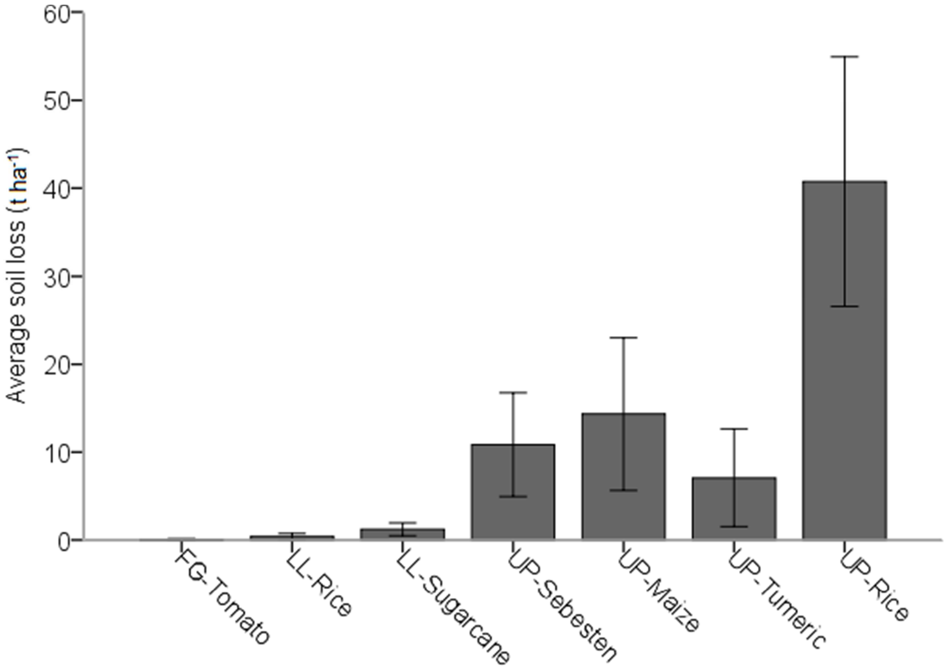

Figure 4.5. Estimated average soil loss for the main cropping systems in 2009. Error bars show 95% confidence interval.

4.5 Discussion

4.5.1 Soil erosion risk from 1989 to 2009

The type of land use, vegetation cover and conservation practices, the nature of terrain and the climatic conditions play a major role in the extent of actual soil erosion risks (Bahadur et al. 2009; Sharma et al. 2011; Kumar et al. 2014; Ma et al. 2014) and were also in our study important input factors for the RUSLE model. The observed fluctuations in soil loss estimations from 1989 to 2009 were mainly due to differences in land cover. Erosion risks were highest for 2009, when deforestation, cropland expansion and urbanization occurred especially in the western and southern part of the Inle Lake region (Htwe et al. 2015b). The western part of the upland zone was one of the hotspots of soil erosion risk because of inappropriate land use practices combined with a steep topography. Furuichi (2008) observed that gully erosion developed on hilly slopes and at the edge of the flatland in the western part of Inle Lake. The western catchment areas of the Inle Lake region (Thamakan and Heho basins) had numerous very large gullies and several deeply eroded areas (GAF 1996).

Our estimated average annual soil loss rate for the Inle Lake region (16.7 t ha^{-1} yr^{-1} in 2009) was higher than soil losses reported for the Miyun watershed in North China

(9.9 t ha^{-1} yr^{-1}; Chen et al. 2011) and the Phewa watershed in Nepal (14.7 t ha^{-1} yr^{-1}; Bhandari et al. 2014), but lower than the reported average soil losses for the Maotiao River watershed in the Guizhou Province of China (28.7 t ha^{-1} yr^{-1}; Yue-Qing et al. 2008).

In our study area, the majority of soil losses (77%) occurred on barren land, which are mostly situated on marginal sites along steep slopes. The estimated average soil loss on barren land in the Inle Lake region (80 t ha^{-1} yr^{-1}) is comparable to the values reported for the Kangra region of western Himalaya (60.3 t ha^{-1} yr^{-1}; Kumar et al. 2014) and the Caijiamiao watershed in China (120.8 t ha^{-1} yr^{-1} Pan and Wen (2014), but much lower than findings in the Phewa watershed in Nepal (206. 8 t ha^{-1} yr^{-1}; Bhandari et al. 2014). These case studies reported similar values for soil losses in croplands ranging between 18.3 to 45.7 t $ha^{-1}yr^{-1}$ (Bhandari et al. 2014, Kumar et al. 2014, Pan and Wen 2014). However, for the Upper Nam Wa Watershed in Thailand, soil losses were even higher (307.3 t ha^{-1} yr^{-1}) for areas affected by shifting cultivation, for shrubland (17.1 t ha^{-1} yr^{-1}) and forest (35 t ha^{-1} yr^{-1}; Bahadur 2009).

The reported differences reflect the prevailing environmental conditions (vegetation composition, climate, soil conditions) in the respective study region, but also the different modelling approaches that have been used such as different equations for the calculation of RUSLE factors, in particular for C-factors.

4.5.2 **Soil erosion problems and farmers' perception**

Similar to other mountain areas in Asia, land degradation is also a major problem (Bahadur 2009) in the Inle Lake region, where deforestation, shifting cultivation, overgrazing and inappropriate cultivation practices on the steep land cause soil erosion, which leads to sedimentation, eutrophication and water pollution (Than 2007; Soe 2012). Recent data show average sedimentation concentrations of 0.24 g per liter in the Indein (Balu) stream in the western part of Inle Lake leading to an average monthly sedimentation of 17009 t (Thuzar 2012). Historical land use changes usually have long-lasting effects on nutrient leaching, acidification and organic matter depletion of soils (Szilassi et al. 2006). It is well known that on eroded slopes available water capacity and organic matter content of soil decrease because of accelerated runoff rates (Duan et al. 2011; Espigares et al. 2011). Our data revealed that N_{tot} and C_{tot} were lowest on eroded cultivated land in the uplands (Appendix 2).

Altogether, 75% of the surveyed farmers were not aware of the consequences that inappropriate management of agricultural systems may have on soil erosion and land degradation, likely because of their low level of education and inefficient extension services (Lwin 2006; Lwin and Sharma 2012). Especially in rural mountain areas attitudes, beliefs, and land use practices are deeply rooted in people's culture and tradition, possibly limiting adaptation of new management approaches in upland farming. To improve knowledge transfer, a soil conservation committee was established in Shan State as early as 1962, but was only active until 1983 (Than 2006). Since then, the forest department established community forest plantations for the rehabilitation and conservation of forest land and soil and water conservation (Than 2007).

Only 3% of surveyed farmers established contour-bunds in their cropland on slope areas or practiced traditional soil conservation techniques such as agroforestry with jackfruit (*Artocarpus heterophyllus* Lam.), mango (*Mangifera indica* L.), orange (*Citrus sinensis* L.), avocado (*Persea americana* Mill.) and banana (*Musa x paradisiaca*) hedgerows or terraced fields. To the majority of farmers, technologies for improved soil conservation and soil fertility management are still unknown.

4.5.3 **Effects of different cropping systems on soil erosion and land degradation**

Among the surveyed cropping systems in the Inle Lake region, average soil loss rates were highest for upland rice cultivation and maize. Even higher erosion rates for upland rice were reported for Thailand with average soil losses between 60 t ha^{-1} yr^{-1} (Turkelboom 1999), 78 t ha^{-1} yr^{-1} (Vien 1997) and 89 t ha^{-1} yr^{-1} (Hurni and Nuntapong 1983).

For sebesten and turmeric plantations, estimated soil loss rates were much lower, because of the long cropping period (several years for sebesten and 10-11 months for turmeric). GAF (1996) reported that soil loss of perennial crops such as tea plantation on steep slopes ranged between 7.5 to 32 t ha^{-1} yr^{-1} in the Southern Shan State.

In the LL zone, sugarcane had the highest soil erosion rate, probably because of the hilly terrain and land preparation techniques with heavy machines, whereas for paddy nearly no soil losses were detected, which is comparable to the results of Bahadur (2009) for Thailand. In Southeast Asia, soil loss rates for vegetable crop land on moderate to steep slopes ranged from 38 - 140 t ha^{-1} yr^{-1} (Sidle et al. 2006).

Household interviews revealed that most upland farmers are regularly confronted with food insecurity and upland rice cultivation yielded the lowest income in our study region (Htwe 2015) but with highest soil losses. For the year 2009, the gross margin (Htwe 2015) was negatively correlated ($r = -0.315$) with total soil loss of the farmers' fields, which can be mainly attributed to the low productivity in upland areas with high erosion risk. Since rural farmers lack the capital to maintain soil resources, which is necessary to avoid erosion-induced nutrient depletion, this will sooner or later result in a poverty trap. Therefore, effective soil and water conservation practices should not only reduce land and soil degradation, but also maintain and ensure crop yields and land productivity to enhance the livelihood opportunities of rural people (Daniel and Karin 2013).

4.5.4 **Methods used for soil erosion risk modeling**

Soil erosion measurement and monitoring approaches are increasingly important for land management planning in developing countries to effectively avoid erosion and soil degradation (Pimentel et al., 1995; Lal 1998), but such monitoring is often limited by the availability of data and budgetary constraints. Therefore, spatial modeling approaches using GIS and remote sensing techniques play an increasing role for rapid risk assessments (Vrieling 2006) but certainly require field verification.

RUSLE can be easily applied as a soil conservation management tool to assess potential soil erosion hazards. Compared to Analytical Hierarchical Process (AHP) or the Pan-European Soil Erosion Risk Assessment (PESERA) models, which are highly data demanding, the necessary input parameters are often available even for remote areas (Morgan 1986; Karydas et al. 2009; Tang et al. 2014). However, RUSLE allows only the estimation of inter-rill or rill erosion from a hill-slope caused by rainfall erosivity; gully or stream-channel erosion are not accounted for (Karydas et al. 2009). Another limitation of the model is its lacking ability to consider the interdependences of soil erosion factors (Alexakis et al. 2013), and fundamental hydrologic and erosion processes cannot be characterized explicitly (Renard et al. 1991).

To better depict the spatial heterogeneity of the Inle Lake watershed area, additional input data would improve the estimation power of our RUSLE-factors, such as a larger network of rain gauges and detailed land use and soil maps. For an accuracy assessment of the erosion maps independent data for validation are required, such as the collection of runoff and sediments from bounded plots or other field techniques for erosion assessment, which are often complicated, cost and labour intensive (Vrieling 2006). For spatial validation, high-resolution satellite images or aerial photographs are helpful to identify erosion or deposition areas and compare them with modelled soil erosion losses (Vrieling 2006). However, such data were not available for the whole study region and the different observation years.

4.6 Conclusions

Soil erosion, sedimentation and lake eutrophication are serious interacting problems in the Inle watershed area as they are triggered by the demographic pressure and a rapid intensification of land use. Because of data limitations, this study estimated only soil erosion loss at the large watershed scale by using the GIS-based RUSLE model. Although, the RUSLE model cannot adequately depict the small-scale spatial heterogeneity of soil erosion risk, the generated erosion maps indicate priority regions from the soil conservation point of view. Such maps may help decision makers to identify appropriate cropping systems for erosion-prone areas and to more effectively design soil conservation strategies for the watershed surrounding Inle Lake.

During the observation period from 1989-2009, soil loss rates fluctuated with changes in land cover; soil losses were highest for 2009, mainly because of deforestation and cropland extension. The identified hotspots of soil erosion risk are situated in the western upland areas of Inle Lake, where soil protection measures are urgently needed to reduce lake sedimentation and maintain the unique wetland ecosystem. Since in these areas smallholders suffer from low income and food-insecurity, soil conservation practices should not only focus on the reduction of soil loss, but also on the improvement of crop yields and alternative livelihood strategies to reduce the poverty trap for rural people.

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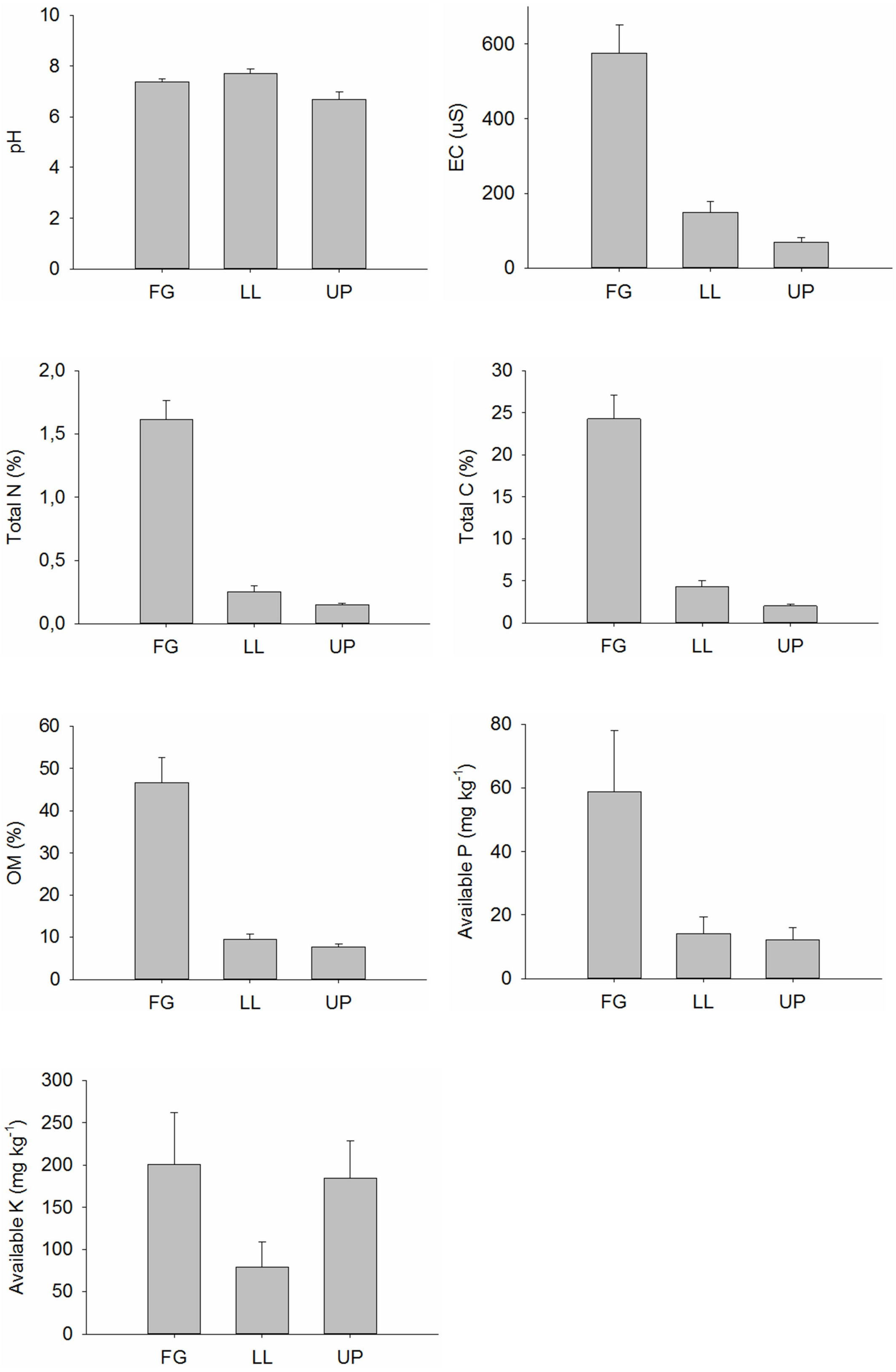
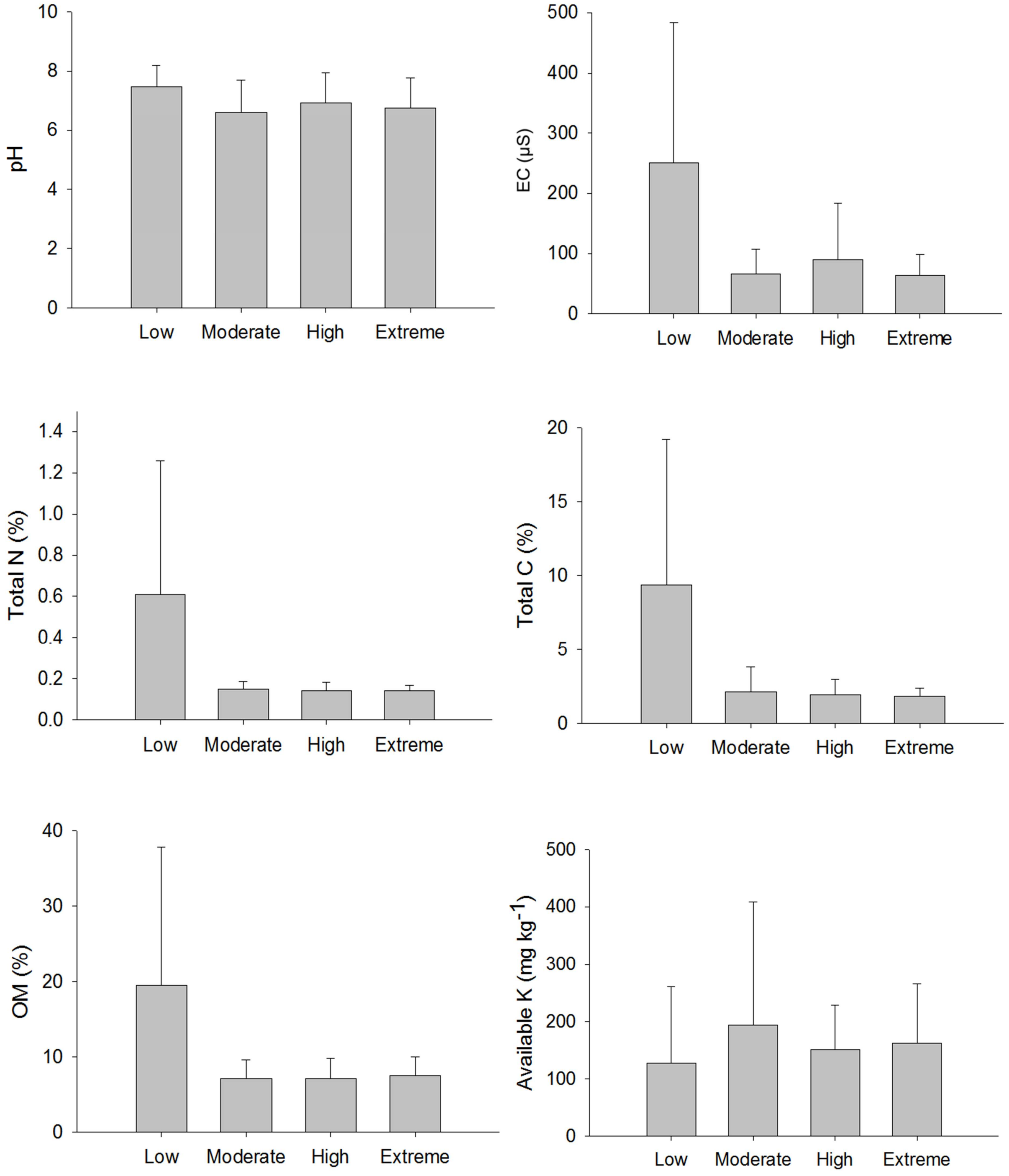
4.9 Appendix

Appendix 1: General soil properties in the different agricultural zones of the Inle Lake region, Myanmar. (FG = Floating gardens zone; LL = Lowland zone; UP = Upland zone)



Appendix 2: General soil properties per soil erosion risk category of the Inle Lake region, Myanmar.



Chapter 5

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5 General discussion and conclusions

5.1 Assessing LUCC through RS and GIS

As the previous chapters indicated, Myanmar shows only poor strategies to protect natural resources and belongs to one of the least caring countries about their natural resources (Mutebi, 2006). Therefore, urgent implementation of a biodiversity preservation plan and sustainable land use management is imperative (Wang et al., 2013). In Myanmar, natural forests degradation problem is increasing due to natural disasters and urbanization (Calkins & Thant, 2011). Furthermore, since 1988 the open market economy has led to agricultural expansion, urbanization and resettlement, mining, hydropower development and a high rate of economic growth and high consumption, capacity constraints, undervaluation of biodiversity and poverty (Than, 2015).

During the last two decades GIS and Remote sensing (RS) have become very useful tools for capturing spatial-temporal data to analyze the dynamics of land use and land cover changes within a short time at low cost. In this study, satellite imagery (Corona KH-4B in 1968 (panchromatic band), TM 1989, ETM 2000 and 2009 (6 bands) from the US Geological Survey's Earth Resources Observation and Science (USGS/EROS) were used for the classification of land use and land cover changes (LUCC) over the past 40 years. The results showed that post-processing of SMAPC produced the highest accuracy of each land use class (overall accuracy, 85%) with a kappa coefficient of 0.83. In 40 years urban areas increased three-fold because of doubled population growth, about 34% expansion of cultivated land since the 1960s, and about half of the forest area reduction compared to the 1960s due to deforestation. The reduction of marshland area was by 83% whereas floating gardens expanded five-fold and lake area shrunk by 15% compared to 1968 (chapter 2). Forest cover decreased from 58% in 1990 to 43% of the total land area in 2015 (Than, 2015). Sidle et al. (2007), however, found a reduction of surface area by 34% from 1935 to 2000, while others reported the surface area of the lake was 23 x 11 km in 1967 and shrunk to 11 x 5 km in 1996 (Su & Jassby, 2000).

Similar to other developing countries in the tropics and subtropics, population growth, agricultural expansion and shifting cultivation, urbanization and industrialization processes, government policies - especially land tenure and economic policies, climate change and socio-economic factors can affect LUCC (Geist & Lambin, 2001; 2002; Lambin & Geist, 2003; Fox & Vogler, 2005; Lambin & Meyfroift, 2011) and increased the pressure on the natural resources of the Inle Lake region. Large scale utilization of natural resources in Myanmar can lead to the loss of biodiversity and will cause environmental changes (Schmidt, 2012). Moreover, land tenure is often unclear. Farmers do not employ unsustainable land use practices because of large scale utilization of natural resources.

They do not know it better or do not have facilities to do so and wildlife trade as a substitute income (Schmidt, 2012).

5.2 Diversification of livelihood strategies

Results from the present study provided insights into the socio-ecological systems in the different agricultural zones of the Inle Lake watershed. The diverse livelihood strategies in relation to varied geographical and socio-economic conditions and agricultural systems of the study areas (chapter 3) represented the divergence in ecological economics of the region. Regardless of the livelihood and crop diversification, the extent of production areas and cropping intensity within each agricultural zone, the FG zone revealed to occupy more economic advantages characterized by the highest average gross margin per hectare than the other zones. High economic benefit was mainly contributed to the highest farming activities and more opportunities of localized livelihood strategies such as tourism and fishery.

Since land with little slope and closer to water bodies increases the probability of households engaging in cash cropping (Panahi et al., 2009), intensive tomato production was a sole mean of major farming practices in the FG zone, accompanied by high inputs of agrochemicals and successive mono cropping. In general, wetlands are, globally, among the most threatened ecosystems on earth being affected by the impacts of agriculture and water management in the wetlands areas (Falkemark et al., 2007; Finlayson, 2007), long term mismanagement in crop production in floating gardens is able to pose a threat to the functional stability of the overall wetland ecosystem of Inle Lake region. It has been observed in Rwanda that inappropriate cropping systems in wetlands can undermine sustainability and have repercussions for the livelihoods of farmers depending on agricultural wetlands (Nabahungu & Visser, 2011). In this regards, diversified livelihoods with the systematic integration of livestock farming and promotion of other off-farm activities which are related to tourism such as selling of handicrafts, antiques, motorboat riding and even hotel services are alternative income sources to intensive farming practices in FG zone, while ensuring to some extent the sustainability of their livelihood and natural environment.

In a study in Rwanda conducted by Nabahungu & Visser (2011), resource poor farmers had to face multiple constraints which included small farm size, competing demands of labor, lack of manure and lack of cash to buy fertilizers. This finding is in line with our study in that resources rich peoples practiced more specialized crop production in large scale farming and can generate more earnings from crop production than those of poor resource counterparts with small scale diversified farming. However, suitable extension staff for utilization of good agricultural practices and education on environmental awareness need to be employed in a consistent fashion through the public private partnership.

Depending on existing geographical location, income opportunities, market access and infrastructure, large scale farmers with specialized agriculture were mainly observed in FG and LL zones, and were generally wealthier than their counterparts residing in UP zone, where the farmers with diversified livelihoods obtained more income than specialized farmers. The total income of the people residing in UP zone was much lower compared to those of FG and LL zones, which was mainly attributed to the lack of infrastructure and primarily depended on rain-fed agriculture. In terms of proportion, contribution of off-farm income opportunities and livestock production were much higher to total household income particularly in the resource poor and intermediate households from UP zone. However, some off-farm incomes observed in UP zone rely mainly on natural resources, especially forests. This reliance has been considered one of the main reasons for forest degradation (Fattahi, 1994; Jazirei & Rastaghi, 2003) which needs to be addressed carefully because high reliance on forest resources and resulting unsustainable uses, and land degradation are important to identify and implement ways for people to break out of poverty (Soltani et al., 2012).

5.3 Soil erosion and land degradation under different conditions

Soil erosion is a common form of land degradation in Myanmar and mostly occurs in upland and dry zone regions. It is aggravated by human interventions such as excessive forest harvesting, mono-cropping practices and shifting cultivation (Than, 2015). In the Inle watershed region, unsustainable land use practices and lack of soil conservation practices which cause severe soil erosion, lake sedimentation, eutrophication, water pollution and reduction size of the water body of Inle lake (Than, 2007; Soe, 2012). The prevailing land use practices and topography play an important role in the extent of actual soil erosion risk. Soil loss risk in each land use class of the Inle Lake area (chapter 2) fluctuated because of LUCC and variable annual precipitation (chapter 4). Historical land use and land cover changes creates effects on soil erosion, nutrient leaching, acidification and organic matter depletion of soils (Szilassi et al., 2006).

According to LUCC, RUSLE model results indicated that erosion was high on barren lands on both sides of the mountainous areas of Inle Lake (112 t ha^{-1} yr^{-1}). It was lower risk compared to the Phewa watershed in Nepal and the Caijiamiao watershed in China and (Bhandari et al., 2014; Pan & Wen, 2014) but was higher amount with the Kangra region of western Himalaya (Kumar et al., 2014). In the different agro-ecological zones of Inle Lake watershed area, different agricultural farming systems with non-similar slope steepness and soil types were considered.

Among the main cropping systems in the three zones, the soil loss was the highest on upland rice with poor soil and water conservation practices (20 t ha^{-1}) and the lowest (0.05 t ha^{-1}) was observed on lowland paddy fields. The present results indicated that the lower erosion risk compared with soil loss for upland rice in Thailand (Hurni & Nuntapong, 1983; Vien, 1997; Turkelboom, 1999). Soil erosion in Inle watershed area have long lasting effects on productivity in agricultural land and water quality in the lake. On eroded slopes land, organic matter content and available water capacity decrease because of accelerated runoff rates (Duan et al., 2011; Espigares et al., 2011).

Deforestation and expansion of agricultural area were the main source to the sediment load originated from the western mountains through the Thandaung and Inndein streams (Lwin, 2006; May, 2007) that led to a substantial reduction in the lake size. Previous studies on sedimentation in the Inle Lake region mentioned that annual sediment delivery to the lake is 0.8 million m^3 (Forestry Consultancy Group, 1993); about 0.65 million m^3 (Su & Jassby, 2000; Pierre & Seema, 2005) and 0.8 to 4.3 million m^3 (Volk et al., 1996). The annual sediment yield for the catchment area (5,612 km^2) of Inle Lake was 10 t ha^{-1} (Downing, 1995) and about 1.5 to 1.8 t ha^{-1} (Sidle et al., 2007). These studies have been based on general information without field surveys, lab analysis and modeling. In the watershed area of the Mara River basin in Kenya, the Water Erosion Prediction Project (WEPP) model used field data from runoff plots to evaluate effectively the effects of various land use practices on sediment and surface runoff (Defersha & Melesse, 2012). Therefore, to get better spatial validity of the present data for the Inle watershed area and to understand the sedimentation and runoff processes under different land use practices, additional input data such as detailed land use and soil maps, actual sediment yields and plot scale runoff data, and high-resolution satellite images or aerial photos are needed.

5.4 Concluding Remarks

Owing to population pressure and economic reforms, land use and land cover had been changed in the region of Inle Lake. Deforestation, agriculture expansion, settlements and poor wetland management practices further aggravated the shrunk of the size of water area of Inle Lake, water pollution and land degradation surrounding the areas. The results from RUSLE model indicated that significant soil erosion variation with land use and using cropping systems was observed in the Inle Lake region.

Soil erosion and land degradation were driven by many factors including agricultural intensification, lack of technologies and capital assets, and poor soil and water conservation practices, which can increase the pressure on natural resources such as forests and wetland ecosystems thereby affecting livelihood strategies of local residents. In Inle Lake region, the differences in the diversification of livelihood strategies between the different agricultural zones were very clearly visible because of geographical location, income opportunities, market access and infrastructure. Farmers were often unaware of the effects of land degradation and the destruction of wetland ecosystem. They have lack of local capital assets to invest and capacity, and weak governance structure and approaches. Moreover, rural people especially in the remote mountainous areas of Inle Lake watershed have no opportunities for skilled jobs and small enterprise development activities to improve household income and well-being. Therefore, they depend only on surrounding natural resources such as land and forest to survive.

This study showed that land cover changes, land use systems and livelihood strategies, and soil erosion risk were interacting each other's in the Inle lake region. Population density, policies and market factors were the main drivers for land use changes. Topography, climate conditions, soil types and cultivation practices were mainly triggering on soil erosion losses. And environmental factors, HH characteristics, technologies effected on land use systems and livelihood strategies. Therefore that leads to change environment, productivity and food security.

The current study improves the understanding on LUCC dynamics, divergent livelihood strategies and different cropping systems as well as the soil erosion risk in each agricultural zone, providing the basis for the development of sustainable management practices in the Inle Lake wetland ecosystem. Therefore the following key challenges need to be addressed: fostering sustainable land use systems, maintaining wetland ecosystem services and functions, strengthening processes underpinning local livelihoods and increasing the diversification of income opportunities to reduce pressure on natural resources, sharing the responsibility for environmental planning between all levels of government as well as promoting the social and economic welfare of the communities.

5.5 Further research needs

Since the three agricultural zones of the Inle Lake region are economically and environmentally closely linked to each other, future research and management plans should be integrated these zones to design comprehensive mitigation strategies to prevent further environmental degradation and subsequent threats to local livelihood strategies. Therefore

- Detailed field surveys, long-term erosion field measurements and high resolution images are required to get more accurate maps of land use and land cover changes and to monitor soil erosion and sedimentation risks.
- Determine the water quality to assess pollution and eutrophication caused by different agricultural practices and other sources such as household waste and effluents from weaving industries.
- The effects soil erosion on farmers' livelihoods and the environment should be studied on degraded lands to foster awareness about land degradation effects on farmers' life in the future.
- Experimental research on soil and water conservation practices should be strengthened throughout the Inle watershed to monitor the benefits of soil conservation practices on crop production, soil fertility and sustainable environmental conditions.
- The results of the study also indicated the need of further research and development to foster the effectiveness of the diversified livelihood strategies of the different ethnic communities living in the Inle Lake region and exploiting forest, land, water and touristic resources.

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Affidavit

“I herewith assure that I completed this dissertation independently without prohibited assistance of third parties or aids other than those identified in this dissertation. All passages that are drawn from published or unpublished writings, either words-for-word or in paraphrase have been clearly identified as such. Third parties were not involved in the drafting of the materials contents, of this dissertation; most specifically I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.”

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