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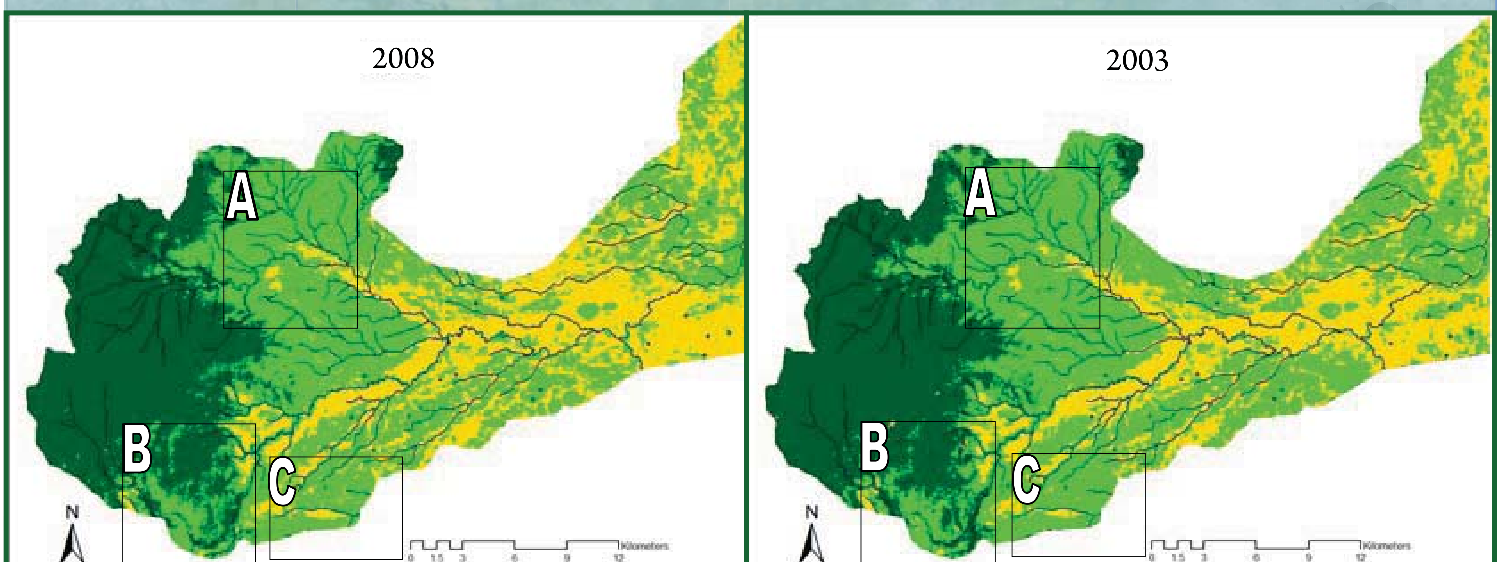
An Investigation of Land Cover and Land Use Change in Stung Chrey Bak Catchment, Cambodia



CHANN Sopheak, Nathan WALES and Tim FREWER

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Acronyms and Abbreviations

ADB	Asian Development Bank
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BDP	Basin Development Plan
CBNRM	Community-based Natural Resource Management
CBNRMLI	Community-based Natural Resource Management Learning Institute (presently known as the Learning Institute/ LI)
CDRI	Cambodia Development Resource Institute
CPA	Community Protected Area
ELC	Economic Land Concession
FA	Forestry Administration
FAO	Food and Agricultural Organisation
FDI	Foreign Direct Investment
GIS	Geographic Information System
GPS	Global Positioning System
IECM	Integrated Environmental Control Model
IR	International Rice
JICA	Japan International Cooperation Agency
KR	Khmer Rouge
LMAP	Land Management Assistance Programme
LULC	Land Use and Land Cover
MoE	Ministry of Environment
MOWRAM	Ministry of Water Resources and Meteorology
MRB	Mekong River Basin
MRC	Mekong River Commission
NDVI	Normalised Difference Vegetation Index
NGO	Non-government Organisation
NI	Newly Industrialised
NIR	Near Infrared
NIS	National Institute of Statistics
PRK	People's Republic of Kampuchea
RECOFTC	Regional Community Forestry Training Centre
RGB	Red-Green-Blue (Composite Imagery)
RGC	Royal Government of Cambodia
RS	Remote Sensing
UN	United Nations
UNOHCHR	United Nations Office of the High Commissioner for Human Rights
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WCED	World Commission on Environment and Development
WRI	Water Resources Institute
WRMRCDP	Water Resources Management Research Capacity Development Programme
WWF	World Wildlife Fund

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EXECUTIVE SUMMARY

This working paper presents the findings of research undertaken on land use and land cover (LULC) change in Cambodia, with a focus on water resource development and local livelihoods in Stung Chrey Bak catchment, Kompong Chhnang province. The research aims to provide improved information of LULC to researchers, policy makers, and other stakeholders and was undertaken as one of three research components of the Water Resource Management and Research Capacity Development Programme (WRMRCDP).

This study investigates the interaction between water resources, LULC, and local livelihoods over two decades within an agricultural catchment in the upper and middle sections of Stung Chrey Bak (a tributary of the Tonle Sap) catchment. The time period examined was 1989 to 2008. Research focused on two aspects: i) investigation of the physical characteristics of land cover changes using satellite image classifications; and, ii) interviews and field observations at the local level and qualitative analysis of on the ground changes. Changes in land cover were quantified using satellite remote sensing imagery; however, drivers of changes in land use, including land conversion, were harder to measure through quantitative analysis. The qualitative research aimed not only at understanding changes on the ground, but also the possible reasons or drivers behind such change. By combining qualitative and quantitative research a more comprehensive understanding of change at different spatial locations and across multi-temporal periods was gained.

The results of this research indicate that LULC across the study site has changed considerably over the last two decades. The three satellite image classifications in 1989, 2003 and 2008 suggest that LULC has changed across the majority of the catchment. Fragmentation and a decline in the quality of evergreen forest has occurred in the upstream part of the catchment, though some areas of evergreen forest have been retained in areas which correspond closely with the boundary of the Phnom Aural Wildlife Sanctuary. The field interviews revealed that both quality and quantity of the evergreen forest had declined over the study period within most of the Chrey Bak catchment. Findings also showed a steady decline of remaining secondary forest in the midstream and some upstream areas. Such disturbance is a result of forest encroachment and illegal logging by local people and outsiders[1], charcoal production, and commercial agriculture (large scale plantations). The implications of such disturbances must be taken into consideration if sustainable catchment management objectives across the catchment are to be achieved.

Various players have contributed to LULC change across the catchment. Poorly conceived water resource development and agricultural expansion during the Khmer Rouge (KR) period from 1975 to 1979 influenced the patterns of land use and land cover seen today[2]. The KR, which occupied some areas in the study site until the 1990s, contributed to rapid forest clearing, including the removal of high value timber, particularly in the upstream catchment.

Institutional and organisational changes, including the adoption of the Land Laws in 1992 and 2001, and the Laws on Forestry in 2002 and 2005, have also shaped current land use practices and attitudes towards land and forests. For example, the 1992 Land Law allowed people who cultivated a specific plot for five years or longer to claim ownership of that land.

1 It was unclear who this refers to but may include external operators from as far afield as Phnom Penh.

2 Imagery for the period prior to 1975 showing forest cover and land use was not available at the time of this research.

Such claims commonly led to conversion of land from secondary forest to rice fields, the results of which are still evident across the catchment today. In addition, the 2002 Law on Forestry has provided improved security to local communities throughout Cambodia by allowing the government to confiscate land that has otherwise been claimed illegally through land grabbing. Other factors that have influenced LULC change in the catchment include land grabbing, charcoal production, illegal logging and economic land concessions[3].

Even as irrigation system development played a minor role in agricultural land expansion, the expansion of irrigated land for rice production and other more water intensive agriculture poses a threat to hydrological processes within the catchment, in particular the availability of water resources. The irrigation system is constrained by water availability, but irrigation demand is growing with the potential to create increased competition for water between upstream and downstream users. Concerns over increased competition for water were a key issue raised in the interviews for this research. Changes to land use and land cover have the potential to impact on water availability and quality, limiting the opportunities for more sustainable catchment management.

The key messages of this research are that:

- Effective methods to assess land use and land cover change in Cambodia are needed to ensure that suitable data is available for sustainable catchment management and monitoring.
- Land use and land cover change assessment and monitoring need to involve technically sophisticated quantitative methods such as remote sensing; however, these methods alone do not provide a comprehensive tool for measuring land cover change.
- A combination of quantitative methods such as remote sensing and qualitative methods such as interviews is essential to provide a complete picture of land use and land cover change in Cambodia.

Key actions that the Cambodian government can take to improve land use and land cover data are:

- Encourage and invest in the integration of high quality technical quantitative and qualitative approaches using local knowledge and ground truthing to avoid over simplification and to understand local nuances and specificity. Attention should be paid to strengthening local expertise in LCLU change analysis and ensuring quality data.
- Draw upon the Royal University Phnom Penh (RUPP) and CDRI for the capacities that these institutions have built through this project by using the mixed methods approach to advance knowledge and understanding of LULC change in Cambodia.

3 It is not within the scope of this research to examine in detail these issues relating to LULC change.

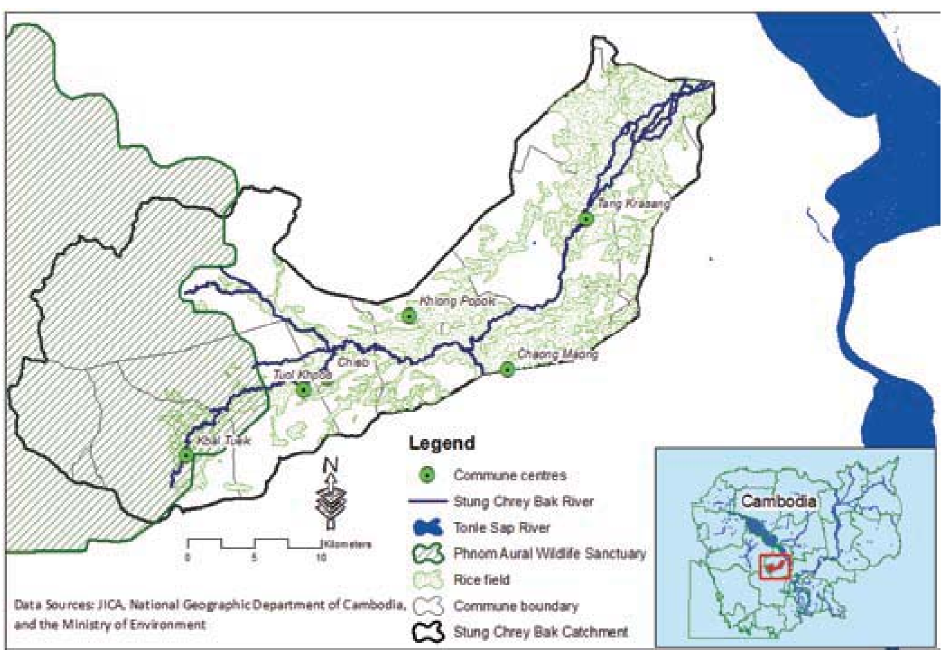
1 INTRODUCTION

1.1 Problem Statement

The quality and quantity of water resources are strongly linked to land cover and patterns of land use within a local catchment. Some of the challenges facing water resource management in Cambodia include unsustainable natural resource development, agricultural expansion and forest loss associated with commercial timber exploitation (see, for example, Ashwell *et al.* 2004; Kim Phat *et al.* 2001). A major concern is the conversion of forests to farmland, which can result in disturbance of habitats, soil erosion, sedimentation, and other problems associated with water availability and quality.

The Stung Chrey Bak catchment, located in Kompong Chhnang province, is recognised by the Royal Government of Cambodia (RGC) as an important area for agricultural investment and development. A range of stakeholders have invested in land and water resource "development" in Stung Chrey Bak, including local farmers, donors, national and local government agencies and business communities. Small scale Khmer Rouge era (1975-1979) irrigation projects have been rebuilt and expanded. Agricultural production, in particular paddy rice production, has had significant expansion and intensification. As a consequence, the catchment has experienced intensive land use and land cover (LULC) change, particularly in the last 20 years. An investigation of the changing patterns of LULC is needed given the increase in forest exploitation and other unsustainable land use practices. The study site identified for this project incorporates the catchment's middle and upper regions. The study area boundary, created from topographic features within the catchment, was used to examine the geography of the site[4] (Figure 1).

Figure 1: Map of Study Area



4 All analysis and area calculations are restricted to the extent of this boundary.

1.2 Aims and Key Research Questions

This research aims to provide improved information on LULC change across the middle and upper regions of the Stung Chrey Bak catchment using a mixed methods approach. It has been demonstrated that significant vegetation modification can have a negative impact on hydrological processes (see, for example, Houet *et al*. 2010; Latterell *et al*. 2006; Kasai *et al*. 2005). Identifying change in LULC can be used to assess the impacts of such change on hydrology[5] and local communities. For example, changes in water quantity and quality, changes in morphological conditions, the clearing of forests, and the removal of access rights to forest resources for local people impact on local communities' ecological health/ productivity and livelihood opportunities – a phenomenon that has been demonstrated in a wide range of research (see, for example, Mahdi *et al*. 2009; De Lopez *et al*. 2002). The research addresses three main research questions:

1. What are the spatio-temporal patterns of LULC change in the middle and upper regions of the Stung Chrey Bak catchment?
2. What are the processes influencing LULC change?
3. How can improved knowledge gained from this research contribute to better understanding the impacts of LULC change on water resource management in the catchment?

The research questions contribute to the Physical Component of the Water Resources Management Research Capacity Development Programme (WRMRCDP) by:

- Identifying the implications of catchment land use changes and flow diversion schemes for downstream water uses (Objective 3 of the programme);
- Deepening the understanding of land use and land cover change, and the factors driving change in the Stung Chrey Bak catchment (activities 1.1.10); and
- Providing baseline LULC data at the catchment scale (activities 1.1.9.1 and 1.1.9.3).

1.3 The Study Site – Kompong Chhnang

The study site is located southwest of the provincial capital of Kompong Chhnang province, one of the six provinces surrounding the Tonle Sap Lake. The total land area of the province is approximately 5,500 km^2 and the population is about 470,000 (NIS 2008). Much of the province is located on ancient, low fertile soils which are characteristic of much of the lowland areas of Cambodia. However, there is a stretch of highly fertile soils which extends approximately five to ten kilometres inland from the network of streams that feed the Tonle Sap.

The province usually experiences a six month dry season followed by a six month rainy season, but heavy rainfall usually only occurs from August to November. Since rainfall gauges were first set up in the province ten years ago, rainfall levels have been highly inconsistent, ranging from 800 mm per year to 1850 mm per year. The province has experienced severe

5 It is not the intention of this working paper to examine the implications of LULC change on hydrological processes and irrigation development. This is explored in more detail in the CDRI working paper *Use of Hydrological Knowledge and Community Participation for Improving Decision-making on Irrigation Water Allocation,* by Chem Phalla and Someth Paradis.

droughts and floods (sometimes within the same month), which have resulted in significant crop losses.

Kompong Chhnang province itself comprises a small, flat area of low elevation that has access to the nutrient rich water of the Tonle Sap. It is surrounded by flooded forest and lacks other natural resources such as minerals. The main livelihood is rice farming, the majority of which is done in the wet season. Increasingly, however, dry season rice farming and vegetable and fruit crops are grown in paddy fields located close to major rivers, especially those surrounding the Tonle Sap. Apart from agriculture, the province is well-known for its pottery production, with Kompong Chhnang literally meaning “pot village or pot waterfront”.

A land use map developed by the Japan International Cooperation Agency (JICA) in 2002 identified a small portion of remaining evergreen forest in the western region of the province, located where the Phnom Aural Wildlife Sanctuary shares borders with two other provinces - Pursat and Kompong Speu. There are also significant patches of deciduous forest which border the sanctuary to the northeast. Based on interpretation of the JICA map, the majority of land in the province consists of shrubland, secondary and disturbed forest, *chamkar* (areas under permanent or temporary cultivation except paddy rice), and paddy fields.

In the early 2000’s a large economic land concession of 30,000 ha was established across an area comprising parts of Pursat, Kompong Chhnang and Kompong Speu provinces. A large area of this economic land concession is located in Stung Chrey Bak catchment[6], and a considerable part has been cleared for acacia plantations. The full extent of the forest clearing and replanting that occurred as part of this concession cannot be determined because, for reasons unknown, the company ceased operations in 2008 and the current legal status of the concession land remains unclear. There is also a small (approximately 70 ha) jetropha plantation in the midstream area, and a number of commercial rice farms of unknown size are located in the midstream and upstream regions of Stung Chrey Bak catchment (see Figure 2 in Section 3).

The Stung Chrey Bak Catchment

Given the focus of this research is on LULC and its relationship to water, the study uses the catchment boundary as the unit of analysis. The Stung Chrey Bak catchment consists of approximately 790 km^2 of land, and follows the Stung Chrey Bak River. Its headwater originates in the Chrieve Mountain in the west of the province. The river then flows eastward approximately 76 kms towards the Tonle Sap. The western part of the catchment is the steepest, with a slope up to 0.37 percent. The headwater of the river is within the Phnom Aural Wildlife Sanctuary. The sanctuary, located within a protected area of high conservation status, supposedly comprises large areas of primary evergreen forest. However, according to provincial authorities and local accounts, most high value trees have long been removed from this area by commercial and small-scale logging. Land classification maps and observations during this research indicated that there are few or no agricultural activities on the higher slopes of the protected area, though rice paddies and small areas of *chamkar* do exist. In addition, an acacia plantation is located in the western region of the catchment but the exact size is unknown. The midstream region is almost completely flat, with a slope of less than 0.11 percent, and is dominated by rice paddies. Some parts of the lowland contain a network of roads, as well as residential and commercial structures.

6 The exact location and hectare area of this concession within Stung Chrey Bak catchment could not be determined.

2 LITERATURE REVIEW

This section reviews existing literature related to land use and land cover (LULC) change in the regional and local contexts, followed by a discussion of the qualitative and quantitative research methodologies used in the study.

2.1 Land Use and Land Cover Change

2.1.1 A Regional Perspective

Southeast Asia has experienced major changes in land use and land cover over the last two decades (Fox & Vogler 2005). With the exception of Myanmar, the Mekong countries have all recently had major economic reforms, resulting in a shift from subsistence agrarian modes of production to market-based agricultural production and industrialisation (Rigg 2006). In the case of Cambodia, Laos and Vietnam, the emergence from cold war rivalries has resulted in a shift to economic systems which are heavily integrated into regional and global trade systems (Lang 2001). These three countries had among the highest economic and population growth rates in the region by 2010 (ADB 2010). Although each nation has gone through these changes in different ways, as shaped by their unique history, geography and national politics, the political and economic changes have undoubtedly given rise not only to profound social and economic change, but also to significant changes in the way the physical environment is managed and used (Hirsch & Warren 1998).

The Mekong region experienced extensive loss of primary forest from the period 2000 to 2005 (FAO-UN 2005). Empirical evidence shows that commercial logging and fuel-wood collection for heating and cooking are the leading causes of deforestation in the Mekong sub-region. Other underlying factors include demographic shifts (population growth, in-migration), market demand, institutional and policy changes (ban on logging, weak enforcement), poverty and small land holdings, agricultural expansion, and lack of other alternative energy supplies (ADB 2000). The Mekong sub-region countries are among the 17 countries listed in the recent World Bank Report having a high percentage of illegal logging as part of their total wood harvest (World Bank 2006). Despite the logging ban in most of these countries, the flow of timber, legal and illegal, across borders continues due to strong demand and rent-seeking (Lang 2001). Cambodia, Thailand and Vietnam in particular were characterised as having among the highest rates of deforestation in the world during this period. Since 1990, Southeast Asia has had an average annual deforestation rate of 1.2 percent, resulting in an average annual loss of 216,000 hectares of forest (FAO-UN 2005).

Given the lack of reliable data on intra-regional trade in forest products, quantity and quality of forest, and the actual rate of deforestation, and because of different definitions of forest/ vegetation types, quantitative assessment of the likely impacts on forest cover and its ecological and economic values is extremely challenging. Data reliability and availability are affected by suppression, distortion or misrepresentation due to economic or political concerns and other technical reasons (Lang 2001; ADB 2000). For example, land classified sometimes as “forest’ is in some cases actually shrubland with little economic or ecological value (ADB 2000).

Available remote sensing data shows that Vietnam's Central Highlands, Laos, Yunnan and Cambodia remain relatively well endowed with forest resources, though current data shows that forest cover in all Mekong countries is changing rapidly. For example, in Laos, the estimated forest cover in 1970 was 70 percent, which had gone down to less than 47.2 percent or 11.6 million ha in 1989 (ADB 2000). Forest resources rapidly declined in Cambodia in the 1990s as well. During the peak of deforestation, the rate ranged from 1.5 percent to 3.5 percent of the total forest area annually (ADB 2000). The forest cover change forecast is based on the observed deforestation rates from the 1960s to the 1990s. The actual deforestation rate for the coming decades depends on many factors, such as:

1. Changes in market demand;
2. Changes in forestry management – forest concession policy; reforestation, monitoring and control of illegal logging and forest clearing; monitoring actual logging operations; improved data on the extent and composition of forest; harmonising regional policy and practice regarding control of illegal timber trade, and regional cooperation in capacity building, and exchange of information and best practices; and,
3. Changes in spontaneous growth of agricultural settlement (ADB 2000).

With such high levels of forest loss, the international community (i.e., aid donors, non-government organisations/NGOs and independent researchers) have identified deforestation as a major issue in ongoing dialogues with relevant governments in the Southeast Asian region (see, for example IECM 2004; World Bank 2007; Le Billon 2007). Numerous development institutions such as the World Bank, Asian Development Bank (ADB) and bilateral donors have specific requirements for ecological sustainability, including forest protection, written into proposed projects. The loss of forest cover and associated processes of LULC change have become key political issues for both the Mekong country governments and the donor organisations who support development projects. This is particularly true for Cambodia.

2.1.2 Schools of Thought on Forest Cover Change

There are a number of competing schools of thought on the causes of LULC, particularly in relation to forests. These views continue to provoke debate within the academia, government and civil society. It is perhaps too simple a conclusion to suggest that LULC change is an inevitable part of economic development. Hirsch (2000) and Lambin *et al*. (2001) remind us that within the academia there has often been a popular association between deforestation, poverty incidence and high population. It is held that high levels of deforestation in tropical countries are primarily caused by population pressure and poverty, where low income farmers are "stuck" in a pattern of slash-and-burn agriculture[7]. In the past, this view also influenced policy makers within the Mekong countries. In Laos and Cambodia, for instance, governments have justified highland relocation schemes under the rhetoric of reducing what is considered unsustainable slash-and-burn agriculture (Lang 2001). Some sectors within civil society, most notably conservation NGOs such as the World Wildlife Fund (WWF) and WildAID have also subscribed to this thinking, investing extensively in programmes aimed at regulating and preventing local users from exploiting natural resources in areas of high biodiversity (WWF 2008).

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7 Also referred to as swidden agriculture, shifting cultivation or non-permanent *chamkar* (farm/garden) in Cambodia

At the opposite end of the scale is another popular stance which argues that local communities' dependence on natural resources is the key to conservation and sustainable natural resource management (see, for example Diokno 2008; CBNRM 2005). It asserts that top-down large-scale development initiatives, both state and private, interfere with local communities' ability to sustainably manage natural resources. Within Cambodia, this has led to the establishment of various programmes restoring management rights to local communities, including the establishment of over 228 community forestry sites (Sunderlin 2006). Various NGOs have been closely involved in this process of encouraging local management of natural resources with significant funds and human resources being invested in training and supporting community forestry and indigenous groups to manage natural resources. Like Thailand, and to a lesser degree, Vietnam and Laos, this emphasis on local communities has played out in the context of domestic and international criticism over state and private exploitation of natural resources that is both damaging to the environment and brings few benefits to local communities (see, for example, UNOHCR 2007; World Bank 2007).

These polarised perspectives dominate the mainstream discussions on LULC in Mekong countries, and as such have had a profound influence on natural resource management strategies. Few actors remain dedicated to a single view when attempting to understand the causes of, and finding solutions to this issue. It is reasonable then to assume that the opposing assertions described here are reconcilable. This is discussed further in Section 5.

2.1.3 Academic and Policy Debate on Land Use and Land Cover Change Drivers

Rapid population growth and environmental change are two topics that have been the subject of substantial debate over the past several decades. Today, population and environmental concerns are often subsumed within the dialogue of "sustainable development," to address the needs and aspirations of today's population without compromising the well-being of future generations (WCED 1987; Ness 1994). The "population neutralists" maintain that population growth has some impact on economic performance and resources depletion only in combination with other intervening factors.

Discussing the relationship between population and the environment is not simple (Hunter 2001). "Population" is a multidimensional concept that can relate to the size, distribution, density or composition of an area's inhabitants as well as their level of income. In addition to the multi-dimensionality of population and environment, the relationship is also influenced by other "mediating" factors, including technological (e.g. energy production and consumption), political (e.g. policy environment), and cultural factors (e.g. ways of life, attitudes towards nature) (Boberg 2005). Each demonstrates how the interaction of population and the environment operates at a different spatial scale – while climate change is a global issue, land-use change operates at the local and national levels. While climate change is primarily shaped by population size and growth, land-use transformation often arises from shifts in population distribution (Hunter 2001).

There are numerous studies on land use and land cover change in Southeast Asia (see Fox & Vogler 2005). The most recent reports on lowland Southeast Asia indicates that significant conversion of forested land to cultivated and residential land has taken place (see, for example, Giri *et al.* 2003 Dhas 2008).

Table 1 shows the percentage of land that is not available for cultivation in Southeast Asia over time. In Indonesia, Vietnam and Singapore, the amount of land not available for cultivation has significantly increased, primarily due to urban expansion (Samek *et al*. 2006).

Further research is needed to understand the reasons for this increase, particularly in Vietnam and Indonesia. Conversely, the amount of land available for cultivation has dramatically increased in both Cambodia and Malaysia over the same time period (Dhas 2008; Samek *et al.* 2006). It is argued that this is due to an increasing labour force, increased technology for large-scale forest conversion and, in the case of Cambodia, increased security, infrastructure and mine clearance (Hughes 2003; Abdullah & Nakagoshi 2007).

Table 1: Land Use Trends in Southeast Asia, 1972-1998

Particulars	Country	Year						
		1972	1975	1980	1985	1990	1995	1998
Share of arable land and permanent cropland to total land area (%)	Indonesia	14.35	14.35	14.35	15.18	17.65	16.66	17.11
	Vietnam	18.97	19.17	20.18	19.73	19.61	20.76	22.27
	Philippines	25.48	28.00	32.29	32.70	33.14	33.20	33.54
	Thailand	28.48	32.65	35.82	38.85	44.24	39.95	39.98
	Myanmar	15.88	15.19	15.24	15.31	15.31	15.38	15.43
	Malaysia	13.79	14.24	14.61	16.83	21.00	23.14	23.15
	Cambodia	10.59	10.88	11.73	13.43	21.50	21.57	21.57
	Laos	2.90	2.90	2.99	3.77	3.68	3.68	3.69
	Singapore	18.03	13.11	13.11	8.20	1.64	1.64	1.64
	Brunei	2.28	2.28	1.52	1.33	1.33	1.33	1.33
	Total	16.58	17.15	17.97	18.95	21.28	20.63	20.95
Share of forest and pasture land to total land area (%)	Indonesia	74.38	74.23	71.54	68.81	68.94	68.21	67.87
	Vietnam	42.93	42.47	37.60	30.73	29.91	30.66	31.62
	Philippines	54.65	48.02	45.12	49.50	49.97	49.90	49.90
	Thailand	41.59	37.27	33.64	30.96	30.82	29.95	29.95
	Myanmar	49.48	49.48	49.30	49.53	49.82	49.79	49.82
	Malaysia	65.11	65.13	65.16	68.53	68.56	68.57	68.58
	Cambodia	78.06	78.01	77.84	78.18	77.75	77.61	77.61
	Laos	66.29	64.99	62.98	63.82	62.39	57.84	57.95
	Singapore	4.92	4.92	4.92	4.92	0	0	0
	Brunei	86.53	86.53	86.53	86.53	86.53	86.53	86.53
	Total	62.07	60.94	58.69	57.37	57.33	56.73	56.64
Share of land not available to total land area	Indonesia	11.26	11.42	14.11	16.01	13.41	15.13	15.03
	Vietnam	38.10	38.36	42.22	49.55	50.47	48.59	46.11
	Philippines	19.87	23.98	22.59	17.80	16.89	16.89	16.56
	Thailand	29.53	30.08	30.54	30.19	24.93	30.10	30.17
	Myanmar	34.64	35.34	35.46	35.16	34.87	34.83	34.75
	Malaysia	21.10	20.63	20.23	14.64	10.44	8.28	8.27
	Cambodia	11.34	11.11	10.44	8.40	0.75	0.82	0.82
	Laos	30.81	32.11	34.03	32.41	33.93	38.47	38.35
	Singapore	77.05	81.97	81.97	86.89	93.44	98.36	98.36
	Brunei	11.20	11.20	11.95	12.14	12.14	12.14	12.14
	Total	21.34	21.90	23.34	23.67	21.39	22.65	22.38

Source: FAO Yearbook 2001

Research conducted by the Japan Science and Technology Agency in the Mekong Region (see, for example, Sokhem & Kengo 2008, 2008) observed that statistics on land areas and arable land can be misleading about the land use potential. For example, the total catchment area in the Mekong River Basin is over 795,000 km^2 (795 million ha), but much of the land in upper Lancang in China, in the Central Highlands of Vietnam, in many provinces of Laos, and in parts of Thailand and Cambodia are mountainous and only about 227.5 million ha are classified as Class A land i.e. suitable for upland or irrigated agriculture (Mainuddin & Kirby 2008).

Countries have different potentials and physical and financial constraints for agricultural expansion (Table 2). There are also environmental constraints such as flood and drought, salinity in coastal regions, and acid sulphate soils in some areas. Vietnam presents an interesting case. Statistically, it has the lowest ratio of water availability per person, but it has been successful in increasing food production for domestic consumption through high crop productivity and water and land use intensity. Cambodia and Laos may increase paddy production as they have unrealised natural potential for paddy area expansion, but they need more substantial investment in irrigation systems, transport infrastructure and market access (BDP 2002a) while land suitability, irrigation viability (cost and access), market prices and market access remain potential barriers (BDP 2002a).

Table 2: Summary of MRB's Agricultural Potential and Constraints

Basin Area	Area suitable for upland agriculture (ha)	Area used (%)	Area suitable for irrigation (ha)	Area used (%)	Irrigation ratio	Constraints
Cambodia	2,941,300	5	11,242,700	31	7 – 10%	- poor management and low inputs - poor access to market and high loss - high operation cost and low return - land mine and small landholding - low irrigation efficiency
Laos	3,051,400	25	2,317,100	35	7 – 10%	- poor access to market - high operation cost and low return - low irrigation efficiency
Vietnam Highlands	1,131,300	51	360,900	36	12%	
Vietnam Delta	10,100	68	3,256,200	88*	60%	- water shortage, salinity, acid sulphate soil - low irrigation efficiency - high post harvest losses
Thailand – northeast region	3,600,500	75	12,156,600	95	12%	- high labour cost - low quality soil and salinity - low irrigation efficiency.
Yunnan province of China	233,333**	n.a	566,366 ***	n.a	n.a	- flat and gentle slope area is about 6% and irrigation potential is marginal - 41.8 is high slope greater than 25^{o}, high erosion

Note: * 3 crops rice per year on 300,000 ha, 2 crops of rice per year on 1,080,000 ha (Source unknown)
** pasture land; *** farm land – 93% mono- and 3% double rice cropping (Lukang 2001)

It is often suggested that population plays a vital role in the amount of available cultivation land and levels of forest cover (Dhas 2008). Some countries with smaller populations historically tend to experience lower rates of forest conversion (Lambin *et al*. 2001) as the conversion of forest to arable land is constrained by the size of the labour force, which might correlate with the size of the population (Giri *et al*. 2003). As populations have increased considerably over the last century, agricultural expansion in many Southeast Asian countries has progressively become motivated by market demand and competition for land rather than labour. This has resulted in large scale conversion of forest land to agricultural land. In Cambodia, land conflict and contestation over land has occurred predominantly since the 1980s and 1990s as a result of massive internal displacement, rapidly increasing population, decrease in the area of land accessible to people due to land mines, and large scale natural resource exploitation including industrial logging (Hughes 2003).

2.1.4 Scale Issues with Land Use and Land Cover Change

Applying broad scale hypotheses to specific locations on the ground is often problematic. Frequently, the categories of land use developed for mapping at broad geographic scales often fail to capture local nuances. Dhas (2008) and the FAO (2009) for instance, group arable land and land under permanent crop production as a single category. In addition, single land use categories such as "non-arable land" and "non-permanent crops" sometimes include pasture, residential and commercial land. Categorisations such as this are not well suited to understanding land conversion over time. Land use maps (and forest cover estimates) commonly used by development agencies and governments are typically based on models using these categorisations.

Accurately differentiating between primary and secondary forest types in classification maps is complicated by a number of factors. First, the adopted classification schemes are influenced by the selected imagery, the scale of imagery, and the computer programmes and methodology used (Samek *et al*. 2006). Second, to distinguish between primary and secondary forests often requires extensive field verification, which has not been carried out in many places within Southeast Asia. Furthermore, as the FAO estimates of forest cover change are dependent on national estimates, figures lend themselves to subjectivity, preference and political interference. Cambodia and Indonesia, for instance, include rubber and oil palm plantations as forest in their national forest cover estimates (Lang 2001). Also, by focusing on land use and forest estimates at the national scale, regional patterns are often obscured. For example, forest cover in Vietnam has reportedly increased in the period from 2000 to 2005 due to an extensive reforestation programme (FAO 2008); however, this ignores the increase in timber imports sourced illegally from Cambodia and Laos.

Smaller-scale studies at village or commune level can provide more accurate and realistic estimates of forest cover by drawing on a combination of geographic information systems and remote sensing (GIS-RS) with substantial ground truthing. The combination of land use maps and detailed interviews with local stakeholders reveals a pattern of land use which contrasts with other accounts of land use in the region that are based on observations at broader geographic scales.

2.2 Qualitative and Quantitative Methodologies

2.2.1 Geographic Information Systems and Remote Sensing in LULC studies

GIS-RS science provides many opportunities for investigating the physical characteristics of LULC change (see, for example, Miller and Rogan *et al*. 2007; Victor 2007). However, while these techniques have been demonstrated to be effective in many studies of LULC (see, for example, Aplin 2005; Jianwen and Bangan*et al*. 2005), constraints relating to data availability, data comparability and scale exist. This section discusses the remote sensing techniques adopted in this research, image classification and vegetation indices, and the constraints associated with using these techniques.

2.2.2 Land Use and Land Cover Characterisation

The characterisation of land use and land cover is important for understanding the earth's surface, and its relationship to human activities. While land cover relates to the features on the earth's surface, land use is primarily concerned with human activity or economic functions associated with a specific area of land (Lillesand *et al*. 2008).

Change in land cover is traditionally measured using quantitative science such as GIS techniques combined with substantial ground truthing and statistical analysis. There are various remote sensing change detection methods that can be used to quantify change in land cover. Commonly, this involves subtracting the spectral reflectance values observable in the different bands of images captured at different dates that contain matching spectral and spatial resolutions.

Change in land use, however, is much more difficult to quantify (Verburg *et al*. 2009). Social and political dimensions become important when attempting to differentiate land use and land cover. Different actors have different views on the contemporary and historical use of land. Methods for understanding change in land use therefore cannot be constrained merely to physical science but rather must also rely on a range of qualitative methods.

Typically, land use mapping involves classifying land uses into generalised categories in order to provide an overall picture of land use patterns (see, for example, JICA 2002; Roy *et al*. 2006). While there are studies available that examine broad scale land use change at the regional and national scale, they often lack details. Results of such studies can differ significantly depending on the research method adopted and the scale of observation; thus caution and acknowledgment of the methodological limitations should be considered when using them.

Land use categories are frequently grouped into classes similar to the following:

1. Arable Land – land available for agricultural production
2. Land under Permanent Crops – cultivated land that is cropped for long periods
3. Non-arable Land and Non-permanent Crops – includes meadows, pastures and built up areas such as residential areas
4. Primary Forest – forest areas that have not been cleared for 100 years and have complex structures with multiple layers of vegetation
5. Secondary and Degraded Forest – forest areas which have either been cleared and subsequently experienced regrowth or have been selectively logged.

2.2.3 LULC Mapping Using GIS-RS

Remote sensing can be integrated with GIS technology to classify and map both land use and land cover to identify patterns and understand processes that underlie observed patterns (Lillesand *et al*. 2008). In the last three decades considerable advancements in space technology have improved the variety and availability of remotely sensed imagery across various spatial, spectral, and temporal scales (Rogan and Chen 200). Coupled with such advances are improvements in the ability to detect LULC change. While studies of LULC using remote sensing can generate a snapshot of the characteristics of land cover at a given point in time, land cover classification and mapping conducted over multi-temporal periods provides an understanding of change, such as types of land conversion (Rogan and Chen 2004).

Remote sensing image classification is a well used and accepted technique for quantifying land cover and land use at a single point in time, and across multi-temporal periods (see, for example, Yuksel *et al.* 2008; Kahya *et al*. 2008; Aynekulu *et al.*. 2008; Alphan *et al.*. 2009; Alpin, 2004).

2.2.4 Opportunities and Constraints of Remote Sensing Classification

Supervised classification using the maximum likelihood classifier has been demonstrated by many authors to be effective in mapping land cover (see, for example, Kahya *et al*. 2008; Alphan *et al*. 2009; Yacouba *et al*. 2009). Maximum likelihood is a classification algorithm that calculates both the variance and covariance of category spectral response patterns when unknown pixels are classified (Lillesand *et al*. 2008). Supervised classification commonly involves using field collected GPS (global positioning system) points to classify a satellite image by identifying areas in the image from known field locations. Representative sample areas (called “training sites”) are used to compile a numerical interpretation key describing the spectral attributes for each class of a classification (Lillesand *et al*. 2008). Sample sites that are representative of the range of land cover types are essential to accurate classification (*Lillesand et al. 2008.*). To account for spectral variability across different land cover classes, sufficient samples as well as existing knowledge of the land cover are required (Rogan and Chen*et al* 2004).

Accuracy in mapping land cover is often challenging, both spatially and temporally, depending on the nature of the study site. Characteristics of vegetation can vary considerably due to annual climatic variability. The nature of tropical environments is such that fluctuations in rates of photosynthesis, associated with extremes in rainfall and temperature, are significant. In addition, where landscapes are actively managed at fine scales, LULC change can result over short time periods. Accounting for such variability between and across years is a significant challenge in analysing change using remote sensing. A further challenge relates to the time of ground data collection relative to the time of image capture. These two activities should occur within the same season and ideally as close together as possible. Seasonal differences across images used in change detection studies have the potential to increase the degree of error (Alphan *et al*. 2009).

2.3 LULC in the Cambodian Context

2.3.1 Overview

Cambodia, like the rest of Southeast Asia has experienced considerable forest loss and forest degradation over the last decade (FAO 2009). As mentioned above, over the last twenty years, there has been a close association between forest loss and changing socio-economic patterns. Political stability and peace dividends, institutional and policy changes, investment and introduction of market economy, mine clearance and demographic changes have all played a role.

In many ways, Cambodia follows the generalised pattern of newly industrialised (NI) economies of Southeast Asia (commonly involving recent economic liberalisation, increasing gross domestic product and increasing foreign direct investment (FDI)). However, unlike its neighbours, there are circumstances distinct to Cambodia which has produced a unique pattern of LULC. In particular, its emergence from civil war, the donor driven nature of development and the country's unique institutional formation are all fields of analysis and study for those interested in understanding the evolution towards contemporary patterns of LULC in the country

2.3.2 Logging, Investment and Governance Linkage to LULC

Land cover change in Cambodia may be described as having occurred in phases corresponding to the political, economic and security-related circumstances of the country. These phases consisted of i) the anarchic logging of the 1980s and 1990s characterised by opportunistic exploitation by the state elite during the period of political uncertainty; and, ii) institutional reform where the patron-client system became entrenched within the government system through the creation of numerous institutions, laws, and regulations.

Anarchic Logging – The 1980s and 1990s

Since the end of the Khmer Rouge period in 1979, forest resource extraction, and logging in particular, has played an important role in shaping the politics of post-conflict Cambodia and in providing an important financial base for state actors and elites (Le Billon*et al* 2002; Gottesman 2005; Ear 2007). Cambodia lost more than a third of its primary forest cover from the 1960s until the end of the century (FAO 2009), with most occurring in the 1980s and 1990s.

During the 1950s and 1960s, large areas of evergreen forest could be found in the northeast, southwest and central part of the country. There were few commercial timber operations and though small-scale clearing of forest areas for farming was widespread, it caused limited change to the overall forest cover. Rubber plantations dating back from the French Colonial period were also extended during that period, which caused significant localised changes in forest cover but had a minimal impact on the overall amount of forest cover loss (Baird 2009).

Forest cover changed slightly during the Khmer Rouge period. The majority of the population was involved then in non-mechanised, collectivised rice production in the lowland areas, though some of the population were mobilised for converting forest area into plantation (cassava, rubber, corn), for example in Battambang (Fox 2008 *et al*. 2008).

After the downfall of the Khmer Rouge, the new People's Republic of Kampuchea (PRK) became increasingly dependent on logging as a source of state revenue due to an international aid embargo (Le Billon 2002. During that period, the Khmer Rouge, which was increasingly being pushed into the peripheral forest areas in the west and north of the country, were also using forestry revenues to fund their resistance to the PRK.

The government rebuilt Cambodia's administration and legal system to regulate the extraction of natural resources after the UN sponsored elections in 1993 and the demise of the KR in the late 1990s (Ear 2007). In response to increasing pressure from donors, the government announced a moratorium on logging activities in 2001 (Global Witness 2005). Logging operations, including illegal logging, have continued in Cambodia, however, since 2000 (McKenney *et al*. 2004, Royal Danish Embassy/Development Cooperation Section and Royal Government of Cambodia Forestry Administration (2004). Logging activities over the last 30 years have had a significant effect on LULC change in Cambodia.

2.3.3 Speculation and Investments in Land

Other activities apart from logging such as investment in land for agriculture, construction and plantation have also had a significant effect on LULC change. With the creation of a system for classifying land as part of the Land Law (2001), and of a number of institutions to manage natural resources, Cambodia has become an increasingly attractive location for investments in land. In addition, low labour costs, tax exemptions – especially under the economic land concession system, limited capacity to regulate laws, patron-client systems and the business opportunities that arise out of them, have also attracted certain investors to the Cambodian land market.

The establishment of a land concession system has had profound effects on land use change over the last ten years. In 2008, approximately 2.8 million ha of land were under land concessions and mineral exploration licences – representing approximately 14.9 percent of Cambodia's arable land (NGO Forum 2009). The factors that have lead to this rapid increase in land investment have arisen from multiple scales – from local infrastructure development, mine clearance and repopulation, to national economic liberalisation and saturation of the land market at international level. The pattern of land use change has shifted from one of subsistence (e.g. swidden farming) to one that is market-driven due to the investments of interconnected, multi-scalar networks. The investors within these networks range from local rural elites to foreign government departments and private companies from land-poor countries.

Cambodia has also seen a recent increase in foreign business investments in plantation production of jatropha (a biofuel), acacia (used for pulp), palm oil and most significantly, rubber. There also has been increased investment in rice production from countries such as China, India and Kuwait (see, for example, Klein 2010). The introduction of new policies on rice production combined with increased investment in rice has the potential to put further pressure on forest land with increased land conversion likely. Such changes represent the biggest threat to sustainable forest management and play a large role in Cambodia's recent loss of forest.

2.3.4 Natural Resource Governance

A number of laws, sub–decrees, policies and administrative bodies have been created to manage forests and land resources in Cambodia following the national election of 1993. Community management, such as community forestry and decentralisation, has evolved as well. However, the effectiveness of Cambodia's laws, institutions and overall approach to managing natural resources continues to be debated. Rights over private property that were non-existent throughout Cambodia under the KR (1975-1979) and later under the PRK throughout the 1980s were reintroduced with the adoption of the Land Law (1992) (Gillespie 2010), as well as the Land Law (2001 revision) and the Law on Forestry (2002). The current regime for the governance of property stems from the Land Law (2001), and a national-level land titling process has been in place in Cambodia since then. The Law on Forestry (2002) recognises user rights for local communities, such as for the collection of firewood; however, there have been issues in regard to its compliance and enforcement.

The Land Law (2001) classifies land into five categories:

1. State public land – which carries a public interest and is held in trust by the state and cannot be sold
2. State private land - which does not carry a public trust and can be leased by the state to private entities
3. Indigenous land – where indigenous communities have to be formally registered and manage land according to tradition and private land.

The Law on Forestry (2002) further classifies forested areas into:

4. Production forest – degraded forest for sustainable timber harvest and NTFP collection
5. Protection forest and conversion forest – a temporary category for forest which has not yet been classified.

Apart from a low capacity to enforce and manage the different categories of forest, a major impediment to the implementation of these laws and this classification system is the arbitrary manner in which maps have been produced to classify different land types and the often low correlation between classifications and land use on the ground (Adler 2009). Hence, it remains unclear how much influence the laws have on LULC change on the ground.

Community forestry is also important in discussions on LULC change in Cambodia. With the discourse of community-based natural resource management (CBNRM) becoming popular within mainstream development (Li 2001), Cambodia has seen a wide range of government and NGO initiatives promoting CBNRM. At the time when the community forestry sub-decree was passed as part of the Law on Forestry (2002*),* there were already 83,000 ha of land under community forestry management in 228 sites (Sunderlin 2006). Furthermore, the activities of NGOs and civil society such as the Community-based Natural Resource Management Learning Institute (CBNRMLI) and the Regional Community Forestry Training Centre (RECOFTC) have widely promoted the concept of CBNRM among civil society and government. Given that there are both protected forest zones and community forest areas in the research study site, these considerations are important in investigating the patterns and causes of LULC on the ground.

2.3.5 Rice Policy in Cambodia

The pattern of rice cultivation is an important consideration in studies of LULC change within the Cambodian context. This is particularly so for the research study site, which is located in an area where the predominant livelihood activity is rice cultivation.

The majority of Cambodia's rice is rain-fed (*srow vasaa)* and is usually planted at the end of May or early June when the first monsoon rains begin to fall. Wet-season rice requires little water infrastructure apart from canals which can be used to regulate the allocation of water to paddies. In times of drought, however, irrigation schemes can be essential to rice cultivation by ensuring consistent timely water supply to areas with insufficient rainfall. Irrigation schemes also allow for earlier or later planting and the possibility of planting multiple crops in a single season, or provide irrigation during the drought spell that occurs in the rainy season. Dry season rice is almost always dependent on irrigation systems, including such infrastructure as small dams, canals and dykes which feed water from streams and rivers into rice fields.

The expansion of water infrastructure and the introduction of high yielding short-season rice varieties have played an important role in the growth of rice production. The average yield of rain-fed paddy rice in the 1980s was around one tonne, by 2008 this figure had tripled. And, whereas the vast majority of Cambodian farmers have traditionally only produced one crop per year, it has become possible with newly introduced varieties to produce two or three crops within the wet season alone. In 2008, around 40 percent of farmers were using IR/hybrid varieties – a remarkable 25 percent increase since 2003 (USDA 2010).

According to the Ministry of Water Resources and Meteorology (MOWRAM), investment in water infrastructure has allowed more land to be cultivated in the wet-season while also contributing to an increase in dry-season production, as monsoon rain can theoretically be stored throughout the dry months. MOWRAM also notes that the area under irrigation in 2007 had increased by 162 percent since 1996 (USDA 2010). On the other hand, the World Bank, the United States Agency for International Development (USAID), the Australian Government Overseas Aid Programme (AusAID) and other promoters of certified international rice (IR) rice varieties claim the introduction of new rice varieties is the primary driver behind higher yields and multiple cropping per year, not water infrastructure initiatives (see, for example, CGIAR 2010).

3 PROCEDURE AND METHODS

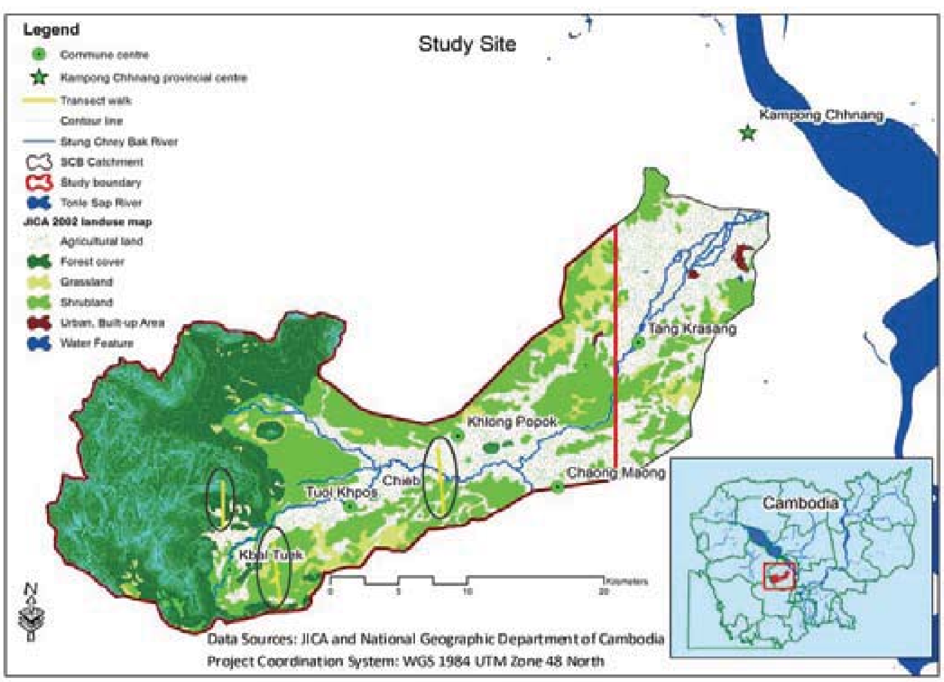
This section outlines the adopted research methods, and the process of developing a framework for investigating land use and land cover change.

3.1 Site Selection

The geographical boundary of the study site was determined based on watershed features[8], the extent and availability of satellite imagery, and characteristics of the agricultural landscape such as patterns of land conversion. Preliminary field research confirmed that the upper and middle sub-catchment areas are experiencing extensive land use conversion for agriculture. In the lower reaches of the catchment, located in the Tonle Sap floodplain, agricultural activities have existed for a long period of time. Change in land use and land cover in the upper and middle reaches potentially impacts on hydrological processes and water availability in areas downstream (see, for example, Wang *et al.* 2006; Zhan *et al.* 2011). In this regard, the upper and middle sub-catchment areas, which supply irrigation water to areas downstream, are particularly important, and as such were the focus of this research[9] (Figure 2).

The upstream refers to the region west of Tuol Khpos which consists predominantly of the mountainous areas, while the midstream includes the area east of Tuol Khpos and includes the area where there is significant branching of the Stung Chrey Bak River (Figure 2).

Figure 2: Study Site Map Showing Catchment Boundaries, Land Use Characteristics and Transect Walks



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8 The catchment for Stung Chrey Bak was delineated using both natural and cultural features, including topography, rivers, roads and artificial irrigation networks.

9 The 2008 ASTER image used in this research only covers the upper and mid stream of the catchment.

3.2 Data Collection

Both quantitative GIS-RS and qualitative data was collected for this research. GIS-RS methods, including image classification, vegetation indices, GPS data capture, and a number of GIS procedures were used to collect and analyse information on land cover and land use. Semi-structured interviews were used to collect ethnographic data on land use from villagers and information from key informants. This information assisted in understanding the causes and processes influencing land cover and land use change. Three field trips were conducted, including one preliminary field trip and two in-depth field survey trips. Details of the preliminary and in-depth fieldwork are in Appendix A.

3.3 Remote Sensing Data Collection and Image Processing

The Landsat satellite remote sensing data collection and image pre-processing involved downloading a 1989 Landsat-5 TM and a 2003 Landsat-7 ETM+ images[10], and combining bands within each image in preparation for image processing. In addition, a 2008 advanced spaceborne thermal emission and reflection radiometer (ASTER) satellite image was identified and acquired. Pre-processing of the ASTER image involved geo-referencing[11] the image, ensuring accuracy in mapping and analysis. The 1989 Landsat image corresponds to the period immediately prior to extensive clearing of vegetation across the catchment which, according to interviews with MOWRAM staff, occurred between 1990 and 1993. The 1989 image therefore provided good baseline data representing the period prior to extensive clearing. The 2003 Landsat image[12] corresponds to the time when considerable land use change occurred across the catchment, and also aligns closely to the date of the 2002 JICA land use map[13]. See Appendix A presents more detailed information on RS data collection and image pre-processing.

10 See Appendix A.

11 Geo-referencing minimises geometric distortions that may be present in a satellite image. Such distortions result from variation in the earth's surface or the view of the satellite sensor.

12 This was the latest available Landsat image.

13 JICA data assisted during the process of image classification.

4 FINDINGS

4.1 Overview

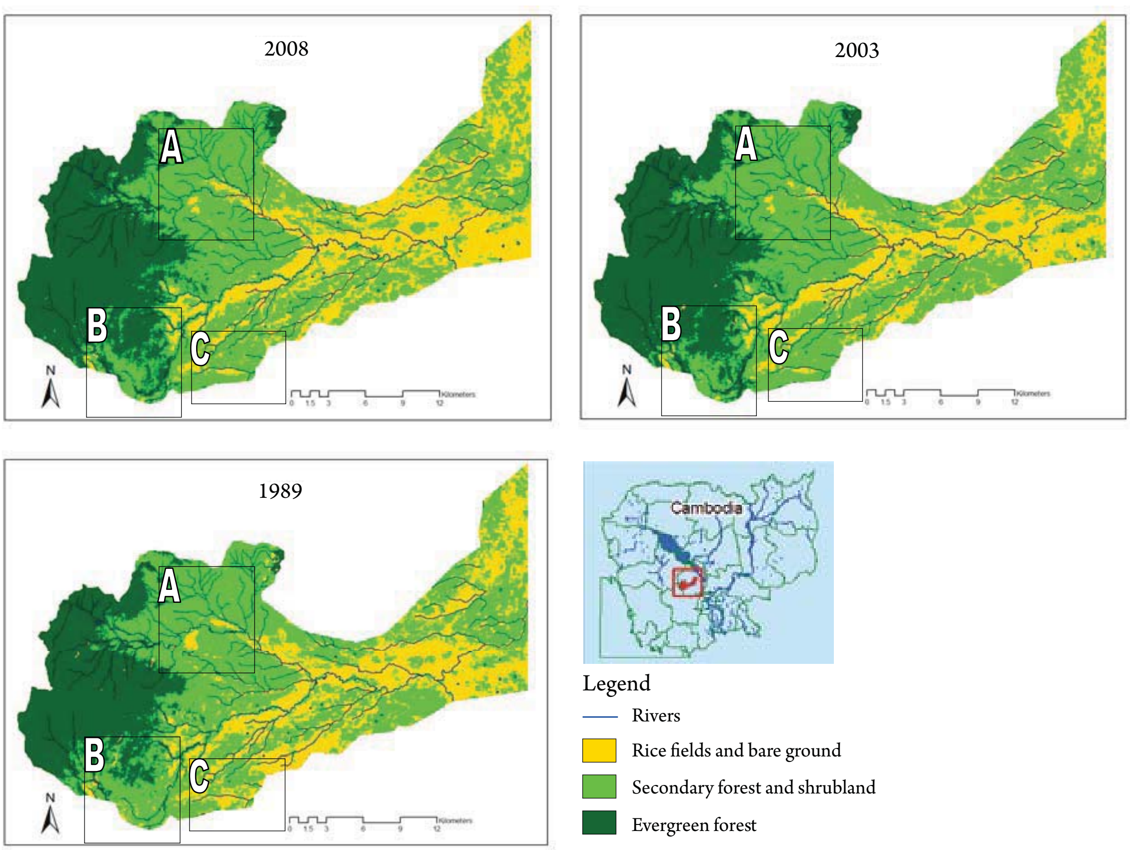
This chapter presents the findings on LULC change across Stung Chrey Bak catchment (upstream and midstream areas) over the study period 1989-2008. The results of the remote sensing image classifications and GIS techniques are presented, including assessment of the accuracy of the classified images (see, for example, Lunetta *et al.* 2006). Quantitative results are cross-examined or triangulated in light of the results of the interview process. The combination of qualitative and quantitative results confirms that LULC has changed significantly over the last two decades across the catchment.

4.2 Remote Sensing Results

4.2.1 Supervised Classification

Figure 3 illustrates the results of the three image classifications for 1989, 2003 and 2008 (upper left ASTER image captured December 2008, upper right Landsat ETM+ image captured February 2003, and lower left Landsat TM image captured January 1989).

Figure 3: Image Classifications from ASTER and Landsat Imagery for 1989, 2003 and 2008



The upstream mountainous area to the west – as shown in Figure 3 1989, 2003 and 2008, is dominated by evergreen forest. Overall, the change in "rice-field and bare ground" occurs for the most part in the midstream sub-catchment, especially in the riparian areas (along river and streams). The change in "secondary forest and shrub-land vegetation" occurs in various locations across the catchment, and is often associated with the location of rice-fields in the midstream sub-catchment, and near the boundary of evergreen forests in the upstream region.

Box A in each of the images in Figure 3 indicates the location of the most significant areas of deciduous forest, which is commonly intermixed with secondary forest and shrubland[14]. Box B highlights the inverse relationship between evergreen forest and secondary forest, while Box C ilustrates the high proportion of rice fields and bare ground.

The main findings are:

- With the exception of the upstream areas, vegetation change occurred across the majority of the catchment over the two decades of this research
- Areas containing rice-fields and bare ground changed notably in each of the three images.

Across the entire catchment, the pattern of rice-fields and bare ground was similar between 1989 and 2008; however a decline in the area of rice-field is evident in the 2003 image, particularly in the middle and lower reaches of the catchment. In the midstream, there was a general decline in rice fields and bare ground in 1989 and 2008. In the upstream, however, there was a decreasing trend in rice fields and bare ground area between 1989 and 2003, with an increase between 2003 and 2008 (see Box C).

- Areas of rice field and bare ground, intermixed with secondary forest, appear to be more fragmented in 2008 and 1989 compared to 2003[15] (see Figure 3).
- Evergreen forest has an inverse relationship with secondary forest, in that as the area of evergreen forest increased between 1989 and 2003, the area of secondary forest decreased.

  The area of evergreen forest seemed to remain relatively stable between 2003 and 2008. However, field observations in 2010 at the location shown as Box B identified large amounts of bamboo in the areas classified as evergreen forest in the 2008 image. Bamboo was particularly common on the perimeter of evergreen forests, at the base of steep slopes and in riparian areas, and appeared to increase where selective logging had removed forest overstory species. Due to the similarity in reflectance properties of bamboo and evergreen forest, the increase in the evergreen class, particularly notable between 1989 and 2003, may have been partly a result of the misclassification of bamboo as evergreen forest. Field observation and key informant interviews suggested that in general the quality of evergreen forest has declined; this is despite the increase in the area of evergreen forest, as depicted in Figure 3.

14 Due to time constraints, deciduous forests were not identified during fieldwork. The JICA (2002) land use map of Cambodia was used to estimate the extent of deciduous forest within the case study.

15 As observed in the image classifications and during field survey.

4.2.2 Accuracy Assessment

The accuracy of land cover maps derived from remotely sensed imagery can be assessed based on the producer's, the user's and overall accuracy (Shao, G., & Wu, J. 2008). Producer's accuracy is the percentage of a given land cover class that actually exists on the ground and is correctly classified in a classified image. In contrast, the user's accuracy is the percentage of the class contained in the classified image that matches with the occurrence of that class on the ground (Shao, G., & Wu, J. 2008). Overall accuracy is the percentage of the number of correct pixels from all of the samples for all classes.

Figure 4: Bamboo in Riparian Areas in Mid and Upstream Stung Chrey Bak Catchment

Table 3 summarises the accuracy assessment of the supervised classifications described in section 4.2.1. Forty-nine points collected in the field with a GPS were used to assess the overall precision of the classified images. Overall, the accuracy of the classified images was greater than 70 percent. The classification derived from the 2008 ASTER image was more precise than the classifications derived from the 1989 and 2003 Landsat images. Both the user's accuracy of the land use class "rice field and bare", and the producer's accuracy of the land use class "secondary forest and shrub" in the classified 1989 Landsat image are very low compared to producer's and user's accuracy of other classes in the classified 1989 Landsat image. This indicates that the area classified as "rice field and bare" on the map, may be larger than the actual area on the ground and that secondary forest and shrub land may have been incorrectly classified as rice fields and bare ground.

Table 3: Accuracy Assessment

2008 (ASTER)					
Class	Reference totals	Classified totals	Number correct	Producers' accuracy (%)	Users' accuracy (%)
Rice field and bare land	10	13	9	90	69.23
Secondary forest and shrub	25	21	19	76	90.48
Evergreen forest	14	15	13	92.86	86.67
Total	49	49	41		
Overall classification accuracy = 83.67%					
Overall Kappa statistics = 0.7448					
2003 (Landsat ETM+)					

Class	Reference Totals	Classified Totals	Number Correct	Producers' Accuracy (%)	Users' Accuracy (%)
Rice field and bare land	9	12	7	77.78	58.33
Secondary forest and shrub	26	22	19	73.08	86.36
Evergreen forest	14	15	13	92.86	86.67
Total	49	49	39		
Overall classification accuracy = 79.59%					
Overall Kappa statistics = 0.6757					

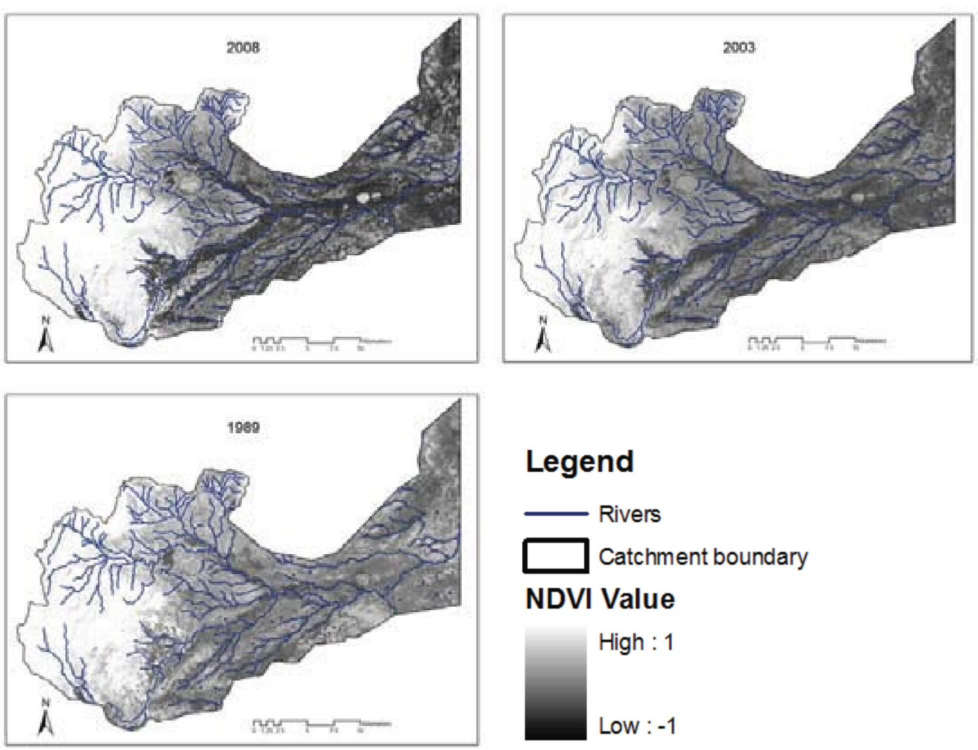
1989 (Landsat TM)

Class	Reference Totals	Classified Totals	Number Correct	Producers' Accuracy (%)	Users' Accuracy (%)
Rice field and bare land	10	19	9	90	47.37
Secondary forest and shrub	28	20	17	60.71	85.00
Evergreen forest	11	10	9	81.82	90.00
Total	49	49	35		
Overall classification accuracy = 71.43%					
Overall Kappa statistics = 0.5548					

4.2.3 Normalised Difference Vegetation Index

Normalised difference vegetation index (NDVI) supplemented the image classifications in examining LULC change across the study site. NDVI provides an indication of the change in the amount of green vegetation cover between the different dates (Figure 5).

Figure 5: NDVI Images from ASTER and Landsat Imagery for 1989, 2003 and 2008

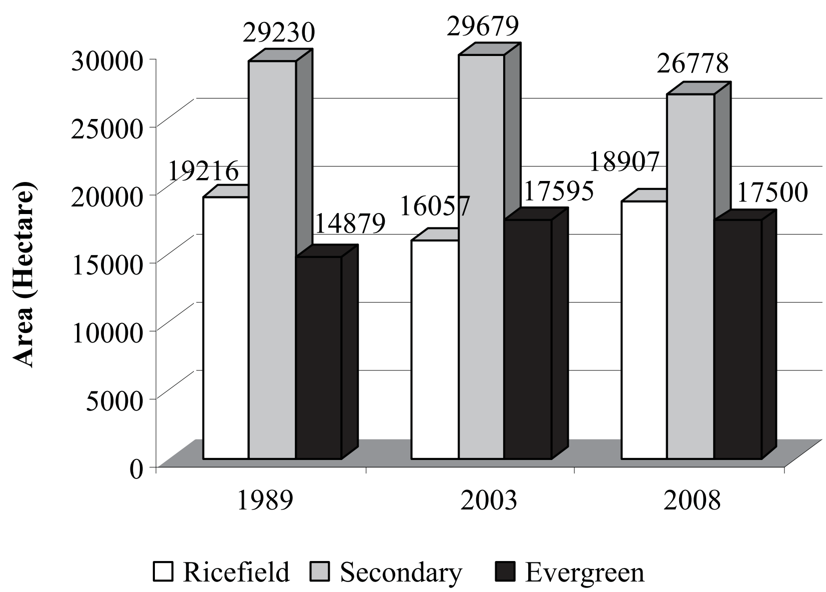


Areas classified as evergreen forest have higher green vegetation values on the NDVI maps, than areas where rice fields have encroached on evergreen forest (typically in riparian zones in the upstream regions). Brighter areas (shown as positive NDVI values) indicate greater amounts of green vegetation, while darker areas (shown as negative NDVI values) indicate lesser amounts green vegetation.

4.2.4 Area Calculations

Change in the area of each land cover class across the different image dates was calculated from each of the classified images described in section 4.2.1 (Figure 6).

Figure 6: Area of Each Land Cover Class for 1989, 2003 and 2008 (ha)



A number of observations can be made from an examination of Table 4. First, the area of "rice field and bare ground" was similar in 1989 compared to 2008, while a distinctive decline in the area of this class occurred in 2003. Second, the total area of "secondary forest and shrub" was similar in 1989 and 2003. This class decreased in 2008 by approximately 10 percent of the area observed in 1989 and 2003. The area of "evergreen" increased by approximately 15 percent from 1989 to 2003, and remained stable between 2003 and 2008. These findings are interpreted in the discussion that follows.

Table 4: Area of Each Land Cover Class for 1989, 2003 and 2008 (ha)

Land cover class	Area of cover (ha)		
	1989	**2003**	**2008**
Rice field and bare ground	19216	16057	18907
Secondary forest and shrub	29230	29679	26778
Evergreen	14879	17595	17500
Total	63330	63330	63183

4.3 Group Discussions, Informal Interviews and Key Informant Interviews

The qualitative results assisted in explaining the findings from the quantitative results outlined above. Key informant interviews provided important insights into management at the site, the history of land use and the various policies and regulations influencing management, thus verifying the quantitative assessment of change. The findings are summarised below.

A low population across the study site prior to 1975 meant there were only small areas of rice-fields, most occurring near rivers as annual flooding supplied nutrient rich silt and water to the rice fields.

Between 1975 and 1979, there was extensive clearing of forests for agricultural expansion. This was associated with Khmer Rouge reforms such as *Sre Sameiy* which encouraged large rice cultivation areas. Local people were forced by the local Khmer Rouge cadres to convert forest land into agricultural land. The decision and process was poorly studied and anarchistic, but did lead to numerous irrigation schemes being built. The new irrigation systems, however, were often poorly designed and constructed. Reservoirs supplied irrigation water for agriculture via a series of channels and dykes. Many of these channels and dykes later failed or collapsed due to poor design and lack of proper maintenance as well as from erosion and morphological changes.

Figure 7: Dyke (left) and Channel (right) Constructed During the Khmer Rouge Era (1975-1979)

Extensive logging of upland forests occurred throughout the 1980s, a time coinciding with the presence of the Khmer Rouge in the area. Active clearing of forests, predominantly in the upstream reaches of Stung Chrey Bak catchment, encroached into naturally occurring evergreen forests on the higher slopes, and to a lesser extent deciduous forests on the lower slopes.

Figure 8: Evidence of Past Clearing and Burning, Stung Chrey Bak Catchment

Key informant interviews indicated that the majority of clearing in the catchment occurred between 1979 and 1989. The decline in the area of evergreen forest along the foothills and higher slopes throughout the 1980s led to a decline in overstory species. One location where the decline in the area of evergreen forest is particularly clear can be seen in a subset of the classified Landsat 1989 image, Figure 12 in Section 5. This area represents the transition between evergreen and secondary/deciduous forest.

Forest clearing in the 1980s and early 1990s, according to interviews, was not for rice field expansion, but was mostly associated with the removal of high value forest species such as *shorea obtusa* (phchoek), *afzelia xylocarpa urz* (beng), *dalbergia bariensis Pierre* (neang noun) and *dalbergia cochinchinensis Pierre* (kra nhoung) for commercial purposes. Much of this clearing is reflected in the classified 1989 Landsat image (Figure 3). Considerable regrowth of evergreen forest occurred after this period, evidence of which can be seen in the 2003 image, particularly near the boundary between evergreen and secondary forests (see Figure 12 in Section 5).

4.3.1 Local Views on Land Use Change in Stung Chrey Bak Catchment

Interviews were conducted with local people to establish their perspectives about land use change. The pattern of land use change observed over the study period (1989-2008) differs between the six communes located within the study site. However, a general pattern of selective logging of primary forest, degradation of secondary forests, especially in the mid stream catchment area, and land conversion to rice-fields, was described by all interviewees.

Interviewees/ informants from the two eastern communes (Chaong Maong in midstream area and Tang Krasang in downstream area) stated that rice-fields had been established since the French Colonial era. They confirmed that the rice fields closer to the Tonle Sap and its tributaries had been in existence for a long time. This observation corresponds with observations from the JICA 2002 land use map (Figure 9). In the Cardamom Mountains (Phnom Aural) to the west, rice-fields tend to be concentrated in close proximity to year-round water sources, and have been established more recently than those in the east of the catchment (closer to the Tonle Sap Lake).

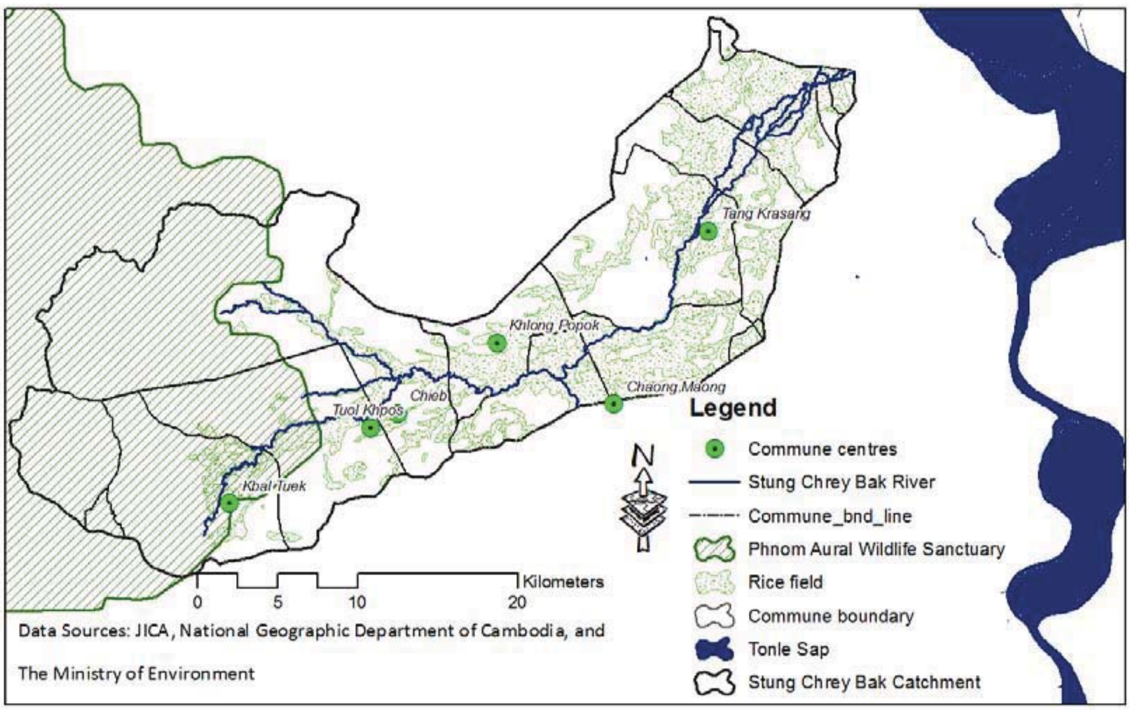
The vast majority of the informants indicated that significant land use change had occurred during the Khmer Rouge era:

Before the Khmer Rouge came to power, this area was just a forest… when I was a child we even had to look out for tigers. During the Khmer Rouge period, we had to clear much of the forest and participate in collective rice cultivation. – Elder from group discussion 2

Key informants, especially in the western upstream areas, also talked about encountering wild animals when they were children and described the forest surrounding their villages as *prey sraong* (evergreen forest) or *sot tai prey thom thom* (forest dense with larger trees). All interviewees spoke of forced labour during the Khmer Rouge era which involved forest clearing, digging canals or dam building (participant, group discussion 1). Others mentioned constructing water infrastructure (which is currently still in place) to supply water to the expanding rice-fields established along the river. They also noted, however, that the Khmer Rouge fell well short of their goal of converting massive tracts of forest in the district into rice-fields:

Ultimately, they [the Khmer Rouge] failed – we never delivered all the rice-fields they wanted and the yield was very low. – Participant, group discussion 3

Figure 9: Commune Centres and Rice Fields in Stung Chrey Back Catchment



The way in which the Khmer Rouge era opened up previously inaccessible areas was repeatedly raised during interviews (spot interview in Chaong Maong). It was not only the conversion of forest for rice farming, the construction of new roads, expansion of villages and logging which substantially increased the changes in forests cover:

The Vietnamese troops came in 1989, but the Khmer Rouge were still here [Chieb]. They went to the forest and made us fell the trees and transport them for selling. – Water community head, Chaong Maong

Village interviews revealed that during the 1990s, the Khmer Rouge cadres were forced further west into the forested areas of Phnom Aural where they became increasingly dependent on logging for income. Unlike the majority of the country, the communes close to Phnom Aural were not liberated until the late 1990s. Khmer Rouge structures remained in place here and villagers were largely involved in cutting and transporting luxury timber.

> *During that time (the 1990s) I would always have to go to the forest and cut trees. If they asked me to go, I would just go. Often I would get wood for myself, as well as getting some money from them.* – Spot interview, Chaong Maong

It was also clear that many villagers cut and sold timber not only because they were forced to, but because it was a secure livelihood option.

With the disbanding of the Khmer Rouge after 1979, there was a period of unregulated "anarchic logging" (see, for example, Amariei (2004)), where local people and outsiders freely exploited large tracts of primary forest for timber revenues:

> *After the Khmer Rouge left in the late 1990s and onwards, we lost most of the forest. There were many people who came to cut the forest. Small companies, private operations, military and local people would often help.* – Deputy village chief, Chaong Maong

This was also a period of increased migration, especially in the western areas where land was abundant:

> *After the war, people could come back and return to their homelands. But in fact it wasn't just people coming back to their former homelands. People from marginal areas would also come and claim new lands – where there was open space. They could establish a family on land for free. Later they would often call on more relatives to come. This still happens today.* – Community chief, Chaong Maong

Even after government bodies were established to oversee the management of natural resources, forest degradation continued across the catchment (albeit to a lesser degree):

> *They have community forestry groups and the FA and MoE but people still cut trees. There were some concessions, but they are mostly cancelled now or happen secretly. It is possible that the military still cut the trees but probably the biggest problem is local people. Most of the forest is degraded where people have to go very far to find any remaining luxury timber.* – Deputy village chief, Chaong Maong

Multiple use of land arising from external investment has occurred since 2005 in Stung Chrey Bak catchment. This includes the construction of larger roads and construction related to electric power generation. Interviews with local villagers, the Tang Krasang commune chief and the district governor reveal that the spatial scale of agriculture has increased including, for example, the planting of jatropha and eucalyptus plantations. According to the district governor, approximately 100 ha of jatropha plantations have been established in the catchment in the past four years. Land ownership in the area is comprised of rice fields owned by local people and large tracts of land owned by private companies.

4.3.2 Rice and Irrigation Infrastructure

Many villages practiced *srai chamkar* (shifting cultivation) prior to 1975 and the beginning of the Khmer Rouge period. During the Khmer Rouge period however, people were collectively forced to move to paddy rice (*srai vasaa)* cultivation. Whereas shifting cultivation produces a mosaic of small fragmented plots of rice surrounded by primary and secondary forest, permanent paddy rice tends to occur as large tracts of interconnected rice fields around water sources:

Before we had small rice field plots scattered in the forest. Yield was very low but it was enough. We would also plant fruits and vegetables. However the Khmer Rouge didn't allow us to have small plots and now hardly anyone does srai chamkar because the yield is too low. – Spot interview Chaong Maong

Rice fields tended to be concentrated along the main rivers and reservoirs, with gradual expansion into the degraded shrub land which typically surrounded long-established rice fields and villages. Newcomers would often establish rice fields in forest areas where the soil was suitable and water accessible. The dependence by many villagers on natural rainfall for paddy rice fields is a major concern, particularly in regards to food security:

We have not transplanted the rice yet. It's probably too late. Usually we've already transplanted by the end of June. It is almost August. What are we going to do? People here are totally dependent on rice. – Spot interview with the owner of a newly established rice field in Khlong Popok

After the Khmer Rouge era, people were granted ownership of rice fields according to family groups. The entire rice growing process is an extremely labour intensive livelihood option. For this reason, there were significant barriers to clearing new land for farming. Most interviewees stated that, on average, under half a hectare of new land could be cleared by a family group for rice cultivation in a single year:

It is very time consuming to clear new land. The land must be flat and we must construct embankments to make sure the flood level will be correct. Sometimes we can clear maybe half a hectare in one year but often it won't be ready for the first season and we'll have to fix and upgrade over the next one or two seasons. – Rice farmer, Chaong Maong

Although there have been significant investments in water infrastructure in the district, very few farmer interviewees practiced dry season rice cultivation. The primary reason for this appeared to be the amount of water that could be stored over the long dry season:

The story of water use here is a complicated one. People here in the downstream simply don't get enough. Many years ago it was not a problem. Maybe the people in the upstream area know something about this. Sharing water and water rights are a big problem in this district. – Chaong Maong District governor

As is the case with all rice production in Cambodia, monsoon floods play an extremely important role – not only by providing water, but also by providing nutrients which can lead to higher yields and contribute to soil fertility. Many interviewees felt that there had been significant changes in the hydrological system which in turn had led to decreased yields:

In the past, the river would flood and water and nutrients would be trapped in the rice fields. Now the flow of the river is reduced by more than half. So people use fertilisers instead, but this is not the same and the soil will become degraded quickly. It doesn't fix the problem of water shortages. – Village chief, Sliang

4.3.3 Land Tenure and Security

Initiatives designed to improve land titling, security of tenure and land ownership in Cambodia were established with the introduction of the Cambodian Land Law (2001). The most significant of these initiatives was the Land Management and Administration Project (LMAP), established in 2002. Land titling programmes, such as LMAP, are designed to improve property rights and the use and productivity of land. A CDRI (2008) case study in Prey Nup district and Sihanoukville municipality reports that the introduction of LMAP reinforced patterns of landholding inequality, but simultaneously strengthened property rights. Furthermore, it was found that larger landholders in Prey Nup district owned a disproportionate share of agricultural land, meaning they benefited from land titling more than small landholders.

The Cambodian government has had a land titling project in place for rural Kompong Chhnang for a number of years. Despite recognition of land titling, most of the people in Kompong Chhnang are yet to receive titles and few of the informants could differentiate between the land documents they currently possessed, and the land titles issued under the new system. People held various forms of land title proof, ranging from official documents obtained from local authorities to verbal confirmations from village chiefs who had given approval for them to clear land for agricultural purposes. Many people still depend on documents provided in the early 1980s.

After the downfall of the Khmer Rouge in 1979, the government instigated a system of forced communal rice production where cultivation was done in small groups *(krom samakii)* and where land was the property of the government (see, for example, Boreak 2000). The ownership of land was often granted on an individual basis earlier than 1988 when collectivised rice was officially abandoned:

> *We would have to ask the local chief, if we knew them and they knew we had been here for a long period of time and just want to do rice farming, they would give us a document. If someone disputed ownership we would go back to the chief and it would be sorted out* – Spot interview, Chaong Maong

Most interviewees claimed that the practice of cultivating rice has always been an extremely important method for securing land. Many newcomers attempted to establish rice fields as a means of appropriating land when the official decision was made to change from *krom samakii* to individual ownership in the late 1980s. There was much land grabbing[16] in the district in the period leading up to the 1993 elections. It was generally understood – regardless of the law – that local people could expand their existing rice fields as long as they did not encroach on other people's established properties.

In the western region of the catchment, towards Phnom Aural (see Figure 9), few people understood where the boundary between the protected area and their village was. Most people treat the boundary as a "paper boundary" which exists only on official maps and documents within provincial government offices. It was clear from field observation that rice fields existed inside the boundary of Phnom Aural. Some interviewees confirmed that rice fields had been established in recent years within the Phnom Aural. Although both Forestry Administration (FA) and Ministry of Environment (MoE) rangers are stationed in the district, their effectiveness in stopping encroachment into the protected area is severely limited:

> *There are only eight of us and we do all our patrols on foot so we cannot go far from here. As for FA, they are just stationed along the road and focus on stopping the transportation of illegally cut timber.* – MoE patrol leader

Like other authorities, there also appeared to be some flexibility in what crimes they actually prevent:

16 Land grabbing usually involves the forced sale of land to those in positions of power, with original owners being evicted.

> *If we find people cutting the forest by hand for rice we allow it. These are Khmer people – Khmer people do rice farming. As long as they do not use machinery and only clear small plots of land for their family groups it is fine.* – MoE patrol leader

Land prices rose rapidly in the late 2000s and large areas of previously forested land were cleared and fenced. Speculation over land prices resulted in both local people and outsiders claiming land:

> *This land belongs to a man from Phnom Penh – he came here some years ago and bought it from the local people and then fenced it and partially cleared it to show it was his. Now he just keeps it and is waiting for the land prices to rise again.* –Villager interviewed near Phnom Aural

Appropriating land in this way has created many land disputes, with some people selling land, including shrub land surrounding rice fields, without clear land title.

During the most recent group discussions, many interviewees spoke of the limited availability of land: "All land – forest or rice field – is now owned by someone. There is no public land available to be claimed anymore". Thus, people turn to the forested or protected areas for farming. This pattern of ownership and land claiming has taken place since around 2000. Land conversion across the catchment typically begins in low-lying areas containing secondary forests where rain water can be retained for wet season rice cultivation. Small plots of land that have been cleared for rice fields are scattered across the catchment, with people frequently claiming additional areas surrounding their land for cultivation (a practice known as *dey kbal srea* in Khmer).

Figure 10: Land Cleared for Rice Cultivation (left), and Later Fenced to Claim Ownership (right)

Land ownership is important not only for rice field expansion, but also to ensure land is passed down through generations within the same family, with one informant stating: "we have nothing besides rice fields to share with our children". Thus more and more land is being converted into rice fields so that the current generation will have something to pass on to their children and grandchildren.

5 DISCUSSION

5.1 Overview

This section examines the trends and patterns of LULC change in Stung Chrey Bak catchment by combining the results from the qualitative and quantitative research data.

Key events identified during the qualitative phase of the research influence the patterns observed in the imagery (see Section 4). However, the extent to which these key events affect the current patterns of land use and land cover (LULC) is difficult to quantify. Nonetheless, it is clear that land use in Stung Chrey Bak catchment has not remained static over time. LULC change has been driven by multiple factors which determine the relationship between people and their relationship with the local natural resources base and landscape.

5.2 The Khmer Rouge and Deforestation

Some literature argues that disturbance to forest cover in Cambodia during the KR (1975-1979) period was minimal as the majority of the population was involved in subsistence-based agriculture in the lowlands (see, for example, De Lopez 2002; McKenney *et al*. 2004). However, interviewees in Stung Chrey Bak catchment indicated that the forest clearance activities of the KR in fact resulted in the clearance of large tracts of forest for irrigation infrastructure projects, plantation and farming, and later on for commercial logging to fund their war efforts against the Phnom Penh government backed by the Eastern Bloc. Changes that took place during the KR era had the unexpected result of opening up previously inaccessible forests to exploitation. For example, in the turmoil following the collapse of the KR, a range of people including local villagers and powerful groups engaged in the removal of high-value timber from Cambodia's forests. This degraded forest was later cleared for land ownership both by local communities and wealthy people from the cities.

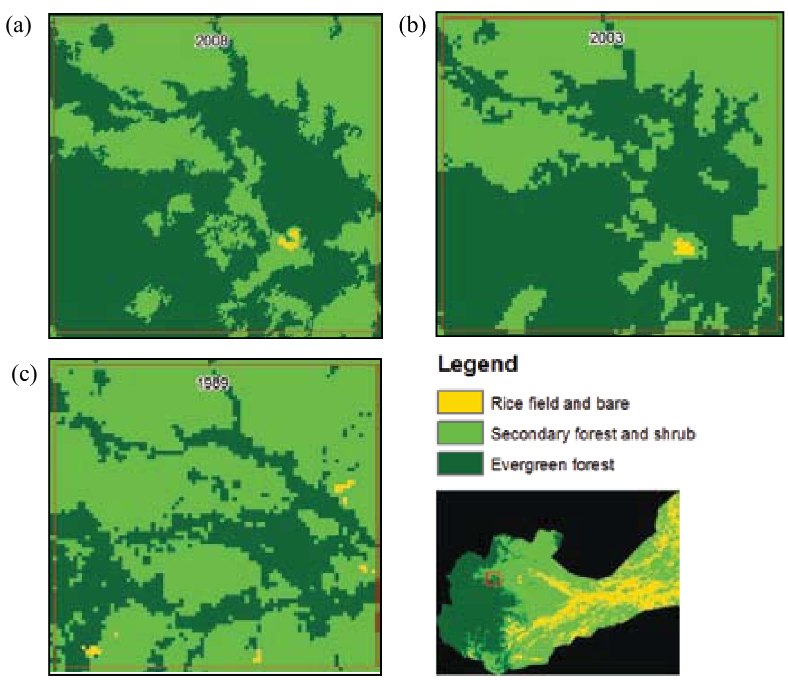
The expansion of large scale rice agriculture during the KR era has shaped the pattern of rice fields seen today. Rice fields located in riparian areas generally occur in a dense pattern and are frequently of a large scale (Figure 11). Local villagers practiced paddy rice cultivation within the midstream of the catchment prior to the KR era, as confirmed by the interviews. Most paddy fields in that area were dispersed and fragmented into small plots among dense riparian forest where annual flooding brought nutrient rich silt and water for wet season rice cultivation.

Logging and intensive agricultural activities that took place during and after the KR era impacted on areas of evergreen forest, resulting in the conversion of larger areas of forest to plantation and farming in the upper sub-catchment. Interviewees stated that between 1979 and 1993 forestry was the main source of income for the KR. Many areas were cleared of forests. According to the MoE, a large amount of timber was collected during that period and roads built to transport timber from the Community Protected Area (CPA) in Stung Chrey Bak catchment.

Figure 11: *Chamkar* Agriculture with Evergreen Forests on the Higher Slopes, Stung Chrey Bak Catchment

Key informant interviews with representatives of the MoE and with local villagers maintained that some areas of previously managed forest land were abandoned after the KR left in 1993, allowing the forest to re-grow. This may explain the increase in the areas classified as evergreen forest seen in the 2003 Landsat image. However, interviewees also suggested that since 2005 up until the time of study, land encroachment has intensified and resulted in the re-cultivation of large areas of land.

Figure 12: Land Cover in the upstream region of the catchment Classified from Landsat Images for 1989, 2003 and 2008



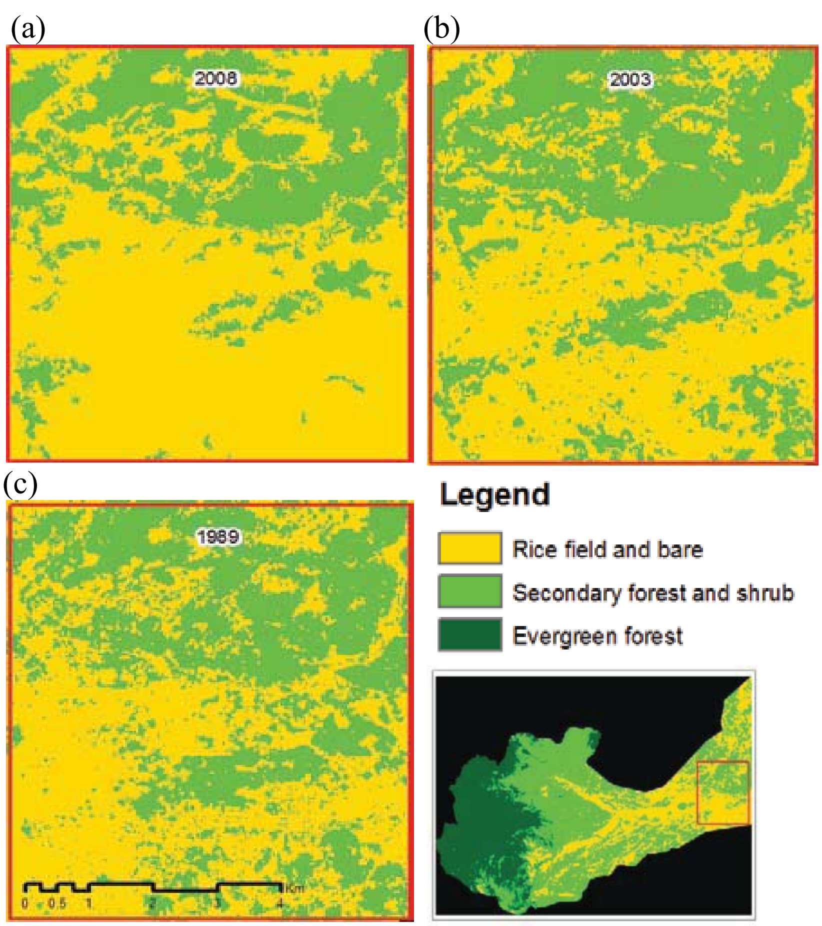
Note: Figure 12 (a, b and c) show zoomed extent of case study

5.3 Rice Fields and Land Use Change

Rice cultivation and the expansion of rice fields are two of the many important factors contributing to land use change and deforestation. Rice cultivation differs both temporally and spatially when compared to other forms of land use such as forestry. Rice cultivation is labour and input intensive, requiring large amounts of land, and a number of inputs including fertiliser and water. With a rapidly increasing rural population, available land for paddy fields is in limited supply in Stung Chrey Bak catchment. Only a limited area land within the catchment is suitable for rice cultivation. Thus, agricultural land expansion sometimes takes place in areas where forest cover has already been degraded by logging and other infrastructure development. This includes marginal land located in forested mountainous areas.

Rice field expansion across the study site thus poses little threat to natural forests because rice field expansion mostly involves converting existing secondary forests and shrub land, not natural forest. After the KR era, some abandoned rice fields became secondary forests and shrub land. Farmers expanded the perimeter of their existing rice fields after 2000 and began encroaching on nearby secondary forests and shrub land showing that rice fields increased at the expense of secondary forests and shrub land or reclaiming abandoned rice fields). In addition, the area of land containing rice fields appears to have increased over time, and shows a less fragmented spatial pattern.

Figure 13: Land Cover in the downstream region of the catchment Classified from Landsat Images for 1989, 2003 and 2008



Note: Figure 13 (a, b and c) show zoomed extent of case study

Rice field expansion by local communities also has limited impact on forests compared to larger scale intensive forest clearing involving high capital inputs and mechanisation. When compared to plantation agriculture, which involves larger scale clearing of land, the establishment of rice fields for subsistence farming is typically practiced in family groups where land is cleared in one season and burnt in the following season. Whereas plantation agriculture typically involves significant amounts of hired labour where land can be cleared at a rate of multiple hectares in a single day, forest clearance for rice fields is usually practiced in groups of between five and 10 people, where on average only half a hectare of land is cleared per year. Informants indicated that this pattern is common in the research study area.

Current Cambodian land law and informal governance arrangements (government regulations and provincial economic land concession decisions) at the local level often favour intensive land use over less intensive forms of land use, such as local scale rice farming. Farmers are required to undertake a formal process of titling, which places limits on their land and restricts opportunities to increase the area of existing rice fields. According to the law, private agricultural land cannot be located on state-owned forest land and protected areas. However, in the western region (upstream) of the study site, considerable areas of rice fields are found within a designated protected area. In practice, some leniency is given to farmers where land clearing is minimised and does not involve the use of machinery such as chainsaws. Small-scale farmers involved in land clearing are often in a precarious legal situation where they are dependent on the patronage of local government representatives. Larger scale agriculture, such as plantation forestry, typically has the government's and powerful elites' endorsement.

The main finding is that rice field expansion has been one of the many important contributors to LULC change in Stung Chrey Bak catchment, particularly in the past. But the rate of forest conversion has been small when compared with other forms of land use. At the time of study, the availability of land suitable for rice cultivation was diminishing and has likely reached its limit in many populated areas.

5.4 Rice and Irrigation

Much of the existing literature relating to rice cultivation in Cambodia suggests that compared to neighbouring countries, the country generally has a smaller percentage of its arable land under cultivation and irrigation. The areas under cultivation are typically low yielding and only able to produce one crop per year. The small yield is primarily attributed to lack of irrigation infrastructure and other important agricultural inputs such as fertilisers and machinery. As a result, there has been a major effort to increase water irrigation infrastructure to intensify rice production and therefore increase yields. There is currently no irrigation infrastructure capable of storing large amounts of water over the dry season to allow cost-effective irrigation by gravity. Very few farmers consequently practice dry season rice farming. The vast majority of farmers interviewed were only able to produce one harvest of rice per year which is a major impediment to increasing annual rice yields.

Water irrigation projects typically provide unequal benefits to users. This was a recurring theme during the interviews. Water users in the lower parts (eastern part) of the study site indicated that upstream water users had disproportionate water usage, causing water scarcity in downstream areas. In more densely populated residential areas situated along the river the residents stated that some well-off households within the villages often had better access to water. Many of the farmer interviewees were concerned that upstream water extraction or storage affected the annual flooding phenomenon. Streams/rivers and inundated areas were no longer flooded, thus depleting important nutrients in the paddy rice fields. Many farmers choose to use chemical inputs as a substitute for natural nutrients with differing degrees of success.

The farmer interviewees acknowledged that the expansion of rice fields and irrigation has no simple linear relationship. Although older rice fields tend to be established next to significant sources of water, rice fields are not always established in areas which have access to water. Typically rice fields are established in close proximity to villages and roads which themselves are often located close to rivers. Having access to water is no doubt an important strategy in dealing with the uncertainty of monsoon rains (with regards to both the amount of rain and when and for how long it is available). Yet, as almost all the farmers in the study site only have sufficient resources to cultivate wet-season rice, which is dependent on harvesting rainfall as opposed to irrigation water, many are willing to take the risk and establish rice fields in locations far from permanent sources of water. The geographic expansion of rice fields in Stung Chrey Bak catchment does not always occur alongside areas that have access to irrigation water however. This may, at least in part, be because land availability has forced some to claim land in areas further from available water sources.

5.5 Land Ownership and Land Conversion

Land ownership is a significant factor in studies of LULC change. The most common approach to securing land ownership in much of Cambodia is to convert land to farmland or rice fields. It is difficult to claim ownership over forest land without an official land title and often, as a consequence, secondary forest and shrub land is gradually converted into rice fields or totally cleared. An interview with a commune chief in the upstream region of the catchment indicated that land which has been cultivated by local villagers for more than five years can be claimed for ownership. This practice was legally recognised in the past throughout Cambodia; but it is not so today. Based on the 1992 Land Law, people possessing land for five years or longer were able to claim ownership, but even as ownership could be claimed, there were difficulties in transitioning from possession to formal ownership (Gillespie 2010). The Land Law (2001), however, abolished provisions for ownership of land based on five-year possession. In some locations in Cambodia, the influence of this 1992 law provision persisted well into the 2000s (see, for example, Gillespie 2010), and this practice may have persisted until more recently in Stung Chrey Bak catchment.

Land ownership is important in Cambodia for a number of reasons, including agricultural expansion and family inheritance. It is for both of these reasons that secondary forests and shrub land are often converted to rice field. Often, this involves parents from each family dividing their land into portions equal to the number of children in the family, providing each child with enough land to grow rice for subsistence. Land surrounding areas previously cleared for rice fields, typically found in scattered locations across the catchment, is often expanded. These areas, referred to as *dey kbal srea* in Khmer, are usually covered by secondary forests or shrubs.

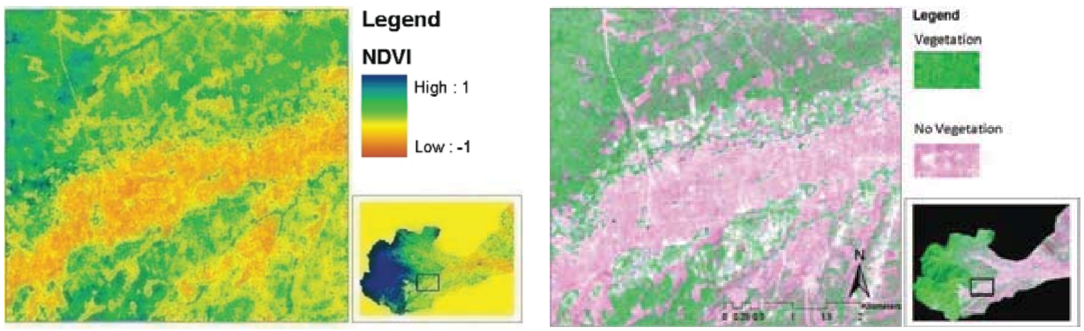
This pattern of land use occurs predominately in flat, low-lying areas. In the last ten years, especially within the upper region of the catchment, large areas of flat land continue to be covered by secondary forests and shrubs. Figure 14 shows rice field expansion in one part of the upper catchment. The 2008 ASTER NDVI image (a) gives an indication of the amount of green vegetation cover. The composite image[17] (b) gives an indication of those areas with

17 The green band of the image is represented by blue, the red band is represented by red, and the near-infrared band is represented by green.

vegetation cover, and bare ground. In both images the areas containing little or no vegetation consist predominately of rice fields.

Figure 14: ASTER December 2008 NDVI image (a), and Red-Green-Blue (RGB) Composite Image showing the Green, Red, and Near-Infrared Bands of the ASTER (b) – December 2008 Image.

(a) NDVI (b) RGB composite image*)*



5.6 Other Factors Contributing to LULC Change

The previous section described some of the major factors that have contributed to change in LULC over the past two decades in Stung Chrey Bak. Given the complex nature of change in LULC, however, additional factors also need to be considered.

Although large areas of land in Stung Chrey Bak catchment continue to be used by local people for small-scale agriculture, there has been a recent trend where land is being bought by private companies and wealthy city folk for commercial agriculture or land speculation. Apart from the protected area in the west of the study site, large tracts of land in the catchment are owned by one local company[18]. The FA manages much of the approximately 30,000 ha of land within two districts that is now owned by this local company. It was unclear from the interviews how long this company had owned land in the catchment.

There is no substantial evidence to date of large-scale land conversion within the catchment. Nonetheless, apart from the protected areas located in the upper region of the catchment and small-scale rice fields, much of the remaining land across the catchment is currently managed as economic land concessions (ELCs)[19]. An increase in commercial scale agriculture and land conversion associated with ELCs, however, would result in serious forest disturbance and changes in land use pattern (from subsistence farming to commercial, from being farmers to "waged labourers" (see, for example, Ashwell *et al.* 2004; Kim Phat *et al.* 2001). A similar pattern of disturbance was described by Chann (2009) in a study in Stung Chinit catchment, Kompong Thom province.

18 Since 2000, however, Pheapimex has been granted large areas of concession land in Kompong Chhnang province, with one of these concessions reportedly more than thirty times the legal limit (See Titthara, M. (2010), "Pursat families defy Pheapimex", article in: Phnom Penh Post, 11 November 2010).

19 Economic land concessions involve a process whereby the government grants rights to companies to harvest forests or convert land for other agricultural purposes.

Another factor that impacts upon LULC is the increasing number of roads. Roads improve access to forested areas upstream, and therefore increase levels of forest disturbance. Key informant interviews and field observations confirmed that increased access to the upstream region of Stung Chrey Bak catchment has occurred in the past five years.

Local demand for fuel wood and charcoal has also contributed to the depletion of secondary forests across the catchment. The railway line connecting the south to the north of Cambodia passes through the midstream region of Stung Chrey Bak catchment and was used throughout the 1980s and 1990s to transport charcoal produced from secondary forests. Today, charcoal production remains a threat to the secondary forests of Stung Chrey Bak. After rice cultivation, charcoal is one of the main sources of income for local villagers. Evidence of clearing secondary forests for the production of charcoal could not be identified from the remotely sensed imagery. Local interviews and observations, however, confirmed that the secondary forests continued to be cleared for the production of charcoal.

Fire has also influenced the pattern of forest cover change across the study site, particularly over longer timeframes. Forest fires occur annually, mainly in the dry season, within deciduous forests and along the boundary of evergreen forests. Forest fires are a crucial factor influencing the extent of evergreen forest because such forests do not recover well from frequent fires. As a result, fire encourages the growth of deciduous forest. Deciduous forests are well adapted to areas that experience frequent fires. The area of deciduous forest at the study site has likely increased over time due to fire. Forests located in riparian areas often retard fire however, as they contain high amounts of moisture. In Stung Chrey Bak catchment, riparian areas containing forests occur predominantly in the upstream region of the catchment. Riparian areas elsewhere in the catchment are dominated by rice fields Networks of trails are used to assist the management of forest fires.

Figure 15: Trail for Management of Forest Fires (left), and Charcoal Kiln (right), Stung Chrey Bak Catchment

5.7 Challenges and Limitations

5.7.1 Image Quality and Image Classification

Despite their different spatial and spectral resolutions, both Landsat and ASTER imagery are well suited to quantifying change in land cover (see Alphan *et al*. 2009). There are, however, limitations when comparing imagery captured from different satellite sensors. Given these limitations, a quantitative analysis of land cover change from comparison of the Landsat and

ASTER imagery was not undertaken in this research. However, patterns of change in LULC, as observed in the Landsat and ASTER imagery, were cross-referenced with interviews and field observations to improve the results. Recent and historical events that have occurred on the ground, as described by the interviewees, corresponded with patterns observed in both the image classifications (land cover maps) and the NDVI images.

Extreme rainfall and drought can influence the patterns of reflectance observed in the imagery. This potential limitation was minimised by selecting imagery at or near the anniversary date between each year[20]. In addition, by comparing rainfall records from Kompong Chhnang province for the month leading up to the capture of each image, any differences between images that may have been caused by climatic variability were observed[21]. Differences between images may be caused by climatic variability and consequential variations in the amount of water retained by vegetation and soils in the image. These differences do not reflect actual land use change on the ground.

Forest fires have likely influenced the fragmented pattern of rice fields, as observed in the upstream region of the catchment. An example where the areas of rice field and bare ground were significantly higher in 1989 compared to 2003 and 2008 is highlighted in Figure 3, Box C. The assessment of accuracy of the classified images confirmed that rice fields and bare ground (class name: "rice field and bare") was likely over-represented in the 1989 image. While the user accuracy of the class "rice field and bare" was low, the class "secondary forest and shrub" had a high producer accuracy. The result of this is that the area containing rice fields and bare ground was over-represented in the 1989 image, meaning that the imageries showed more area containing rice fields and bare ground than actually existed on the ground. The accuracy of the classified 1989 image might have been compromised.

Another constraint with the image classification is that bamboo is commonly misclassified as evergreen forest. Examination of the classified imagery in the field confirmed that a number of areas which were classified as evergreen forest contained large amounts of bamboo. In addition, the greenness of bamboo fluctuates seasonally, and this may have also influenced the image classifications differently over the three years.

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20 The 1989 Landsat image was captured on 31 January, the 2003 Landsat image was captured on 7 February, and the 2008 ASTER image was captured on 12 December.

21 In the month prior to the 1989 Landsat image, 1.5mm of rainfall was recorded, and in the month prior to the 2003 Landsat image no rainfall was recorded. In the month prior to the 2008 ASTER image 275mm of rainfall was recorded. Localised variability of rainfall could not be accounted for using provincial level data.

Figure 16: Land Cover Classifications and Original Images as RGB Composites in Upstream of Catchment (Box C Figure 3)

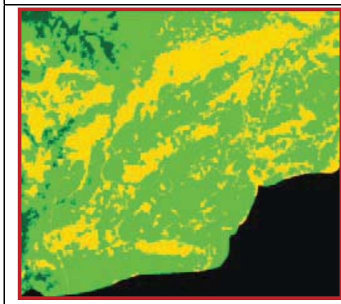
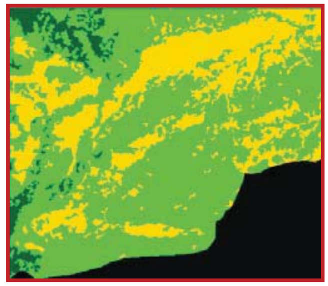
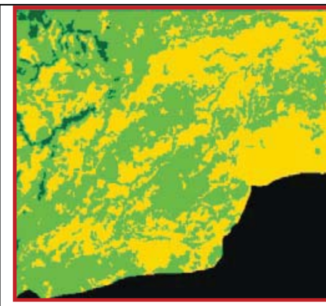
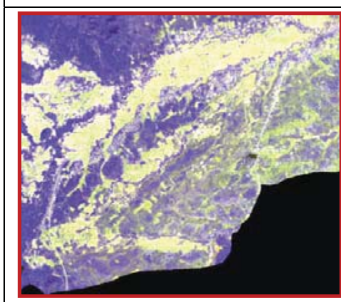
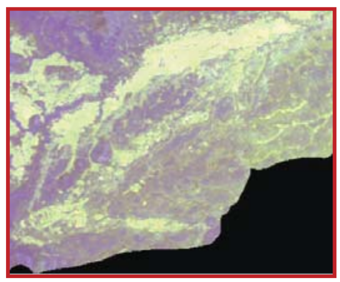
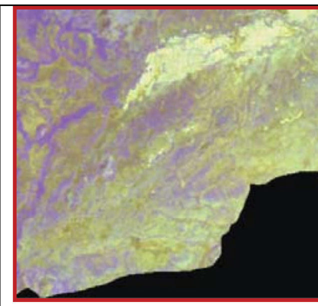
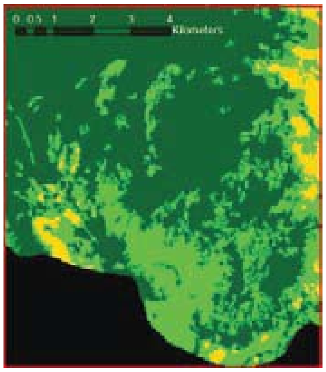
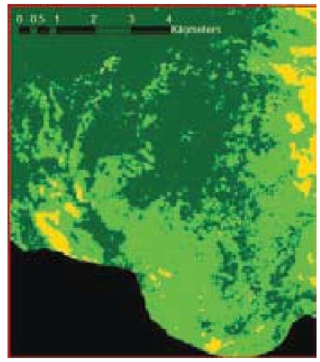
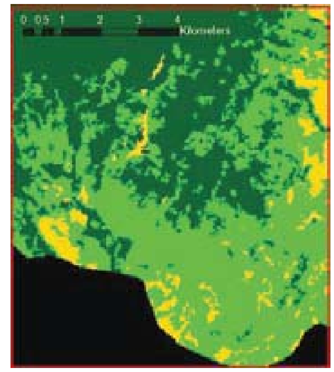
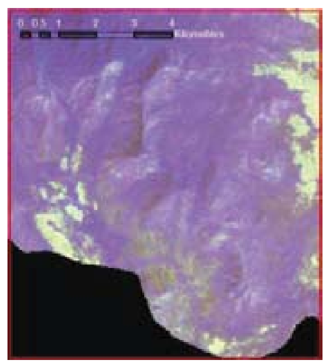
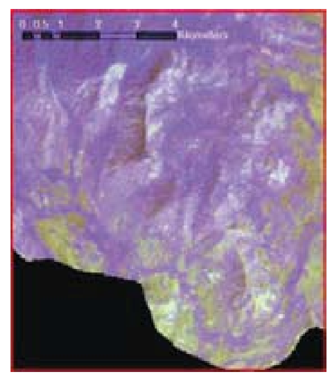
2008	**2003**	**1989**
Classified images Rice field and bare Secondary forest and shrub Evergreen forest		
		
RGB composite image showing the green, red, and near-infrared bands of (a) 2008 ASTER, (b) 2003 Landsat and (c) 1989 Landsat imagery		
		

Figure 17: Land Cover Classifications and Original Images as RGB Composites in Upstream of Catchment (Box B Figure 3)

2008	**2003**	**1989**
Classified Images: Rice field and bare; Secondary forest and shrub; Evergreen forest		
		
RGB composite image showing the green, red, and near-infrared bands of (a) 2008 ASTER, (b) 2003 Landsat, and (c) 1989 Landsat imagery		
		

5.7.2 Uncertainty in Field Data Collection

Correspondence between the date of capture of satellite imagery and the date of field data collection is a frequent constraint to accurate classification of satellite imagery using ground data. Field data was collected in this research in mid and late 2010, and the imagery was captured in 1989, 2003 and 2008. Given that land cover can change rapidly over short time periods, there is a degree of uncertainty when using field data (commonly referred to as "training data") to classify satellite imagery. A number of steps were taken to minimise the uncertainty of field data collection. A key measure was to collect field data at locations where land cover was known, or assumed, to have remained stable for long periods of time. This included the identification of rice fields that were known to have existed during or shortly after the KR era (1975-1979) and identification of evergreen forest where no known disturbance had occurred. Information collected from interviews during transect walks, and extensive field observation, was also essential to this process.

6 CONCLUSION

This research has revealed that the patterns of LULC in the upper and middle regions of Stung Chrey Bak catchment, over the study period 1989-2008, have changed considerably due to various factors. Comparisons can be made with other areas of Cambodia where forest cover has reportedly been in rapid decline (see, for example, Royal Danish Embassy/Development Cooperation Section and Royal Government of Cambodia Forestry Administration 2004; Le Billon 2007; Hansen and Top *et al.* 2006). However, the considerable role the Khmer Rouge (KR) regime played in negatively shaping land use practices and patterns of land cover is contrary to the common belief reported in other literature. The expansion of large-scale plantation and rice production during the KR era resulted in intensive clearing of forests across the catchment, particularly on the lower slopes and plains. Existing patterns of rice fields grown in fragmented areas of forest changed with the introduction of commercial-scale rice production. The result of this change was the considerable reduction in the area of forest across the catchment and increased access to previously less accessible forest lands.

After the KR era, until the early 1990s, illegal logging for high value timber species by former KR members, local villagers and powerful elites caused further degradation of forests, in particular the degradation of evergreen forests in the upstream region of the catchment. At the time of the study, secondary forests and the remaining remnant primary forests in the midstream region had been cleared for different purposes such as charcoal production and rice field expansion. Increasing diversification of land use and the introduction of large-scale plantations in the past five years, such as jatropha and eucalyptus, potentially threaten water quality and availability in the catchment.

The findings of this study reveal that contrary to some reports, irrigation expansion for rice production has only played a minor role in contributing to the decline of forest in the catchment. Further expansion of rice fields across the study site is constrained by water availability and soil quality. In addition, the low yields expected from expanding the area under rice production, as identified during interviews, coupled with unreliable irrigation systems and the labour and costs associated with water pumping, render further forest clearing for rice production economically unfeasible. However, the continuing demand for land ownership due to land speculation, increasing population pressure and the desire to bequeath land to children has meant that remaining secondary forests are actively being converted to farmland and rice fields. The Land Law (1992), which states that people who have cultivated land for five years or longer are able to claim ownership over it, has also encouraged local villagers to continue clearing secondary forests to expand the area of rice fields.

Economic land concessions have the potential to threaten the sustainability of land use (see, for example, ITTO 2005). Concession companies have significant powers to change land use and management practices. This creates uncertainty and can be detrimental to local people.

The integration of GIS-RS and qualitative interview data has improved the findings of this research. Satellite imagery is well suited to detecting changes in land cover and, when combined with field data, for creating land use maps to support informed decision making.

However, land use categories developed for mapping at broad geographic scales often fail to capture local nuances. Understanding local nuances on the ground requires qualitative data such as information derived from interviews. In addition, relying solely on medium and coarse scale imagery such as Landsat and ASTER to determine LULC change can lead to an oversimplification of patterns of change.

Improvements were made to the LULC change maps produced during this research by integrating interview data into the process of classifying the satellite imagery. While the satellite imagery was effective in capturing the overall pattern of change at a catchment scale, qualitative data was essential to understanding issues surrounding management of land and forests at the local scale, such as the scale of the household, village and commune. Affordable access to suitable spatial data can be also a challenge in Cambodia, making information derived from field observation and interviews an essential component to research such as this. An integrated methodological approach that combines quantitative and qualitative data has the potential to enhance the capacity of researchers in studies such as this which are attempting to understand more clearly the dynamic nature of LULC change in particular local contexts.

Given the scope of this research, a detailed discussion on the implications of LULC change on hydrological processes in Stung Chrey Bak catchment was not undertaken. However, the effectiveness and impact of existing irrigation schemes on catchment hydrology, and appropriate management of water within the catchment given the competing demands for water need further consideration, particularly against the current land use practices and the extent of LULC change within the catchment over the time period of this research. Based on the conclusions of research by Chem and Someth (2010) on the hydrology of Stung Chrey Bak catchment, limitations relating to water supply within the catchment pose a number of challenges, particularly to rice cultivation. Stung Chrey Bak catchment currently lacks an integrated management approach, and continued expansion of agriculture requiring large amounts of water, such as paddy rice, has the potential to create further conflict between upstream and downstream water users.

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APPENDIX A

Data Collection

Preliminary Fieldwork

The first period of fieldwork was conducted in May 2010 as a preliminary investigation of land use and land cover across the study site, and to consider the hypotheses for this research in light of observations in the field. Semi-structured and key informant interviews and GPS data collection was carried out during the preliminary fieldwork. The qualitative research techniques used included participation observation; transect walks, spot interviews[22] and key informant interviews (including local authorities and communities engaged in management of the study site).

Three transect walks were conducted (approximately 3 to 5 km each in length) at locations containing a diversity of land uses[23] (Figure 2). Transect walks were carried out with the assistance of a local field guide with good historical knowledge of land use in the area. Routes were chosen that followed a south-north direction through areas containing different types of land use. The different categories were recorded as GPS points in the field. During transect walks the field guide described different aspects of land use, including information about forest composition and the history of land holdings and forest clearing. Information relating to land use and land cover collected was examined and considered during the image classification phase of this research.

Formal, semi-structured interviews were held with various stakeholders from within the catchment. This included: four commune chiefs, two village chiefs, irrigation officer, community forest group chief, water user group chief, two village chiefs, district governor and Ministry of Environment (MoE) patrol leader (forest ranger). Farmers and other local people encountered during transect walks were also interviewed. These interviews, as well as unstructured interviews with people encountered during the course of this research, were classified into the category of 'spot interviews'.

In-depth fieldwork

In-depth fieldwork was conducted for the collection of GPS data of land cover, and interviewing to obtain various types of information relating to land use, such as land use history, and events influencing change in LULC. The in-depth fieldwork was conducted from August through to October 2010.

Prior to collecting GPS data in the field 200 random sample points were generated in ArcGIS using the Create Random Points tool. The purpose of generating points was to ensure there was large enough number of sites for field investigation. These points were selected randomly to ensure that there was no bias in interpretation. The proportion of each class was chosen based on the area of each land use class in the 2002 JICA land use map. Vegetation types were identified from field observations and using information obtained during interviews with local people, government authorities including the Forestry Administration (FA) and MoE, and other stakeholders such as commune chiefs, village chiefs, and villagers. There

22 Spot interviews are unstructured interviews, often conducted in an ad-hoc manner, with local people during fieldwork.

23 Identified from interpretation of the 2002 JICA land use map.

were several considerations during the process of identifying vegetation classes in the field. As stated earlier, the 2002 JICA land use map was used as a guide to identifying the distribution of land cover within the study area. Existing forest classifications by the FA provided insight into the distribution of different forest types, such as evergreen and deciduous forest. Local experts in vegetation identification were employed to assist in vegetation species identification and the identification of land cover. A digital camera was used to visually record all points collected to assist in the process of land cover identification and classification.

Semi-structured interviews and group discussions were conducted with different local actors - village representatives including village chiefs, commune chiefs, the district governor, and others actively involved in agricultural activities across the catchment. The research team spent between three and seven days in each commune, which included Tang Krasang, Chaong Maong, Khlong Popok, and Toul Khpos. In total, three group discussions were conducted including two in the mid-stream communes including Tang Krasang and Chaong Maong, and one in the upstream commune. Six to twelve people were involved in each discussion. The administrative maps were supplied to each group, from which change relating to village or commune centres, roads, river systems and topographical condition were identified by the interviewees/ key informants. The following questions were investigated during the group discussions including:

1. What is the land use history of your village?
2. How has the land been used over the past two decades?
3. Where and when did extensive land use changes occur?
4. What factors have contributed to the land use changes identified?
5. Has local people's occupation of land changed over the past two decades, and if so, why?

Remote Sensing Data and Image Pre-processing

Remote Sensing Data

The Landsat[24] imagery acquired through the United States Geological Survey (USGS) GLOVIS programme (http://glovis.usgs.gov/), and the 2008 ASTER image are listed in Table A1.

Table A1: Details of Satellite Images Acquired for Research

Image Date	Sensor Type	% Cloud Cover	Image ID
31 Jan 1989	Landsat 5 (TM)	10	LT41260521989031XXX02
7 Feb 2003	Landsat 7 (ETM+)	0	LE71260522003038SGS00
12 Dec 2008	ASTER Level 1A	1	AST_L1A.003:2068497847

The acquisition of suitable imagery was restricted to scenes that were largely cloud free and care was taken to ensure the dates of each image could be matched from year to year to minimise phenological variations in vegetation, as described by Elvidge and Lunetta (1998). Further considerations, including differences relating to radiometric performance between sensors and methods of radiometric normalisation, are discussed in Section 3.4.

24 Landsat scenes centre: latitude 11.6 and longitude 104.7; WRS Path/Row 126/52.

While the Landsat scenes selected for this research cover a suitably long temporal period, there was no suitable Landsat imagery for the period between 1989 and 2003, and the period after 2003. The higher resolution ASTER image purchased for this research improved the currency of the available data by providing imagery that corresponds closely to the time when fieldwork was undertaken.

Image Processing

The two primary methods that were applied to the satellite imagery were the Normalised Difference Vegetation Index (NDVI) and maximum likelihood[25] supervised classification to create maps of land cover[26]. Unsupervised classification, not described in detail here, was used in the preliminary stages of this research to gain a better understanding of the characteristics of land cover in the study site, and assisted in the supervised classification procedure. Preliminary research also involved examining the JICA 2002 land use map[27] to understand land use characteristics within the catchment, in particular the extent of rice fields.

Normalised Difference Vegetation Index

NDVI is useful in identifying areas of green vegetation cover, and for estimating change in green vegetation. NDVI, a ratio of the near infrared (NIR) wavelength band and the visible red band, identifies the "greenness" of vegetation, making it a useful tool to highlight vegetation cover density. Healthy vegetation reflects strongly in the NIR as it absorbs red light to produce chlorophyll. NDVI images were created from the uncalibrated Landsat TM, Landsat ETM+, and ASTER images using ERDAS IMAGINE 9.2 software. Uncalibrated NDVI can be used to interpret, qualitatively, the greenness of vegetation in a single image and between images covering different time periods. Values contained in NDVI images range from –1 to 0 where no vegetation is closer to zero.

Supervised classification

The supervised classification technique was used to classify land use from the 2008 ASTER image and the 1989 and 2003 Landsat images. GPS survey data was collected during fieldwork and used to "train"[28] the satellite imagery. Land use classes identified from the JICA 2002 land use map, as well as the collection of additional field survey data, assisted the process of data validation. Accurate classification requires the collection of considerable amounts of field data, the identification of sites in which there has been minimal or no change since the date of the image being classified, and appropriate data validation procedures (including error checking).

Field data collection involved a random stratified point based sampling design, and the collection of points at strategically identified locations to ensure adequate representation of all land cover classes for classification purposes. The classified images generated from this process were generalised and exported to create polygon datasets of land cover. The polygon datasets were used for mapping purposes and to determine the area of each land cover class

25 Maximum likelihood classification calculates the probability that a given pixel belongs to a specific class.

26 For full details of the remote sensing methods used in this research please contact the authors directly.

27 Land Use Map of Cambodia 2002, Japan International Cooperation Agency (JICA).

28 Image "training" involves identifying image pixels with similar properties, often using field collected GIS point data.

over time. Of one hundred points collected during fieldwork, eighty six were used to classify the imagery and assess the accuracy of the classifications. Thirty eight points of the eighty six points were used in the supervised classification as data to "train" the imagery. Pixels within each image that contain similar spectral signatures are identified using the training data. The process of identifying locations that contain similar spectral signatures was done separately for each image. Three discrete classes were identified which included evergreen forest, secondary forests and shrub land, and rice fields and bare ground. Ten training points were used to identify each class from the imagery.

After classifying the most recent (2003) Landsat image (using the procedure described above), a supervised classification on the earlier (1989) image was completed by extrapolating from the signatures derived from the latest image, as recorded at corresponding locations in the GPS field survey points. A library of spectral signatures representing each land cover class was created from the 2003 image to assist in classifying the earlier (1989) image. This method of extrapolation assumes that the values recorded in the earlier image follow logically from the known values (as derived in the first instance from the later imagery).

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