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Different GIS and Remote Sensing Techniques for Detection of Changes in Vegetation Cover

- An MFS Study in the Nam Ngum and Nam Lik Catchment Areas in the Lao PDR

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ABSTRACT

The Lao People's Democratic Republic (Lao PDR) is a small landlocked country in South-East Asia, where virgin forest still covers almost 47 % of the country's total area (1991). Logging offers the potential to improve the economy of the Lao PDR. Besides legal logging activities, illegal logging to provide the population with agricultural land, pasture and firewood is taking place. Since the Lao PDR is mainly comprised of mountainous terrain, and has a poor infrastructure, accessibility to remote areas in the country is limited. To be able to survey the extent of the changes in vegetation that is taking place in these inaccessible areas, remote sensing is an alternative. This study has evaluated some different methods and courses of action to approach the problems of detecting vegetation changes within the Remote Sensing and GIS (Geographical Information Systems) disciplines. Four different satellite image data sets, with differing spatial resolution, have been analysed in the study; the NOAA/NASA Pathfinder AVHRR Land Project 8 km data set, the 1 km AVHRR Global Land Data Set and Landsat MSS and TM images. Depending on the purpose of study, each of the methods tested have their benefits. The results indicate that the 8 kilometre data set provides an extensive temporal coverage, which will never be achieved by the finer resolution data. It is also possible to detect and locate changes in the vegetation cover with the 8 km resolution, assuming that the changes cover a large areal extent (minimum of 32 km^2). The finer resolution images (the 1 kilometre data set and the Landsat MSS/TM scenes) benefit however from the gain in spatial precision which facilitates the task of locating smaller areas as well as improves the visual interpretation, although short time-series and higher costs may be a limiting factor.

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Preface

This study has been carried out within the framework of the Minor Field Studies (MFS) Scholarship Programme, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a Third World country on a basis of a Master's dissertation or a similar in-depth study. These studies are primarily conducted within areas that are important for development and in a country supported by the Swedish programme for international development assistance.

The main purpose of the MFS programme is to increase interest in developing countries and to enhance Swedish university students' knowledge and understanding of these countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the Swedish personnel resources for recruitment into international cooperation.

The Centre for International Environmental Studies, CIES, at the Royal Institute of Technology, KTH, Stockholm, administers the MFS programme for all faculties of engineering and natural sciences in Sweden.

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1. Introduction

Deforestation is known to cause severe problems such as soil erosion. In the tropics where the rains are heavy and intense, the rate of erosion is highly increased if the vegetation cover is removed. Mountainous areas are more prone to soil erosion due to the steepness of the slopes. In South-East Asia, forest cover is decreasing due to legal and illegal logging. The forests in the Lao PDR (Lao People's Democratic Republic) are still relatively untouched, compared to neighbouring countries. The Lao PDR's cautious approach toward a market economy will probably lead to an increasing pressure on the forests and other natural resources, since the economy benefits from commercial logging, hydropower plants, etc.

Apart from the legal logging, illegal logging to provide the people with agricultural land, pasture and firewood is taking place. These activities often occur in remote areas, which are hard to survey due to poor infrastructure. According to two new laws, dated November 1996 and March 1997, the Lao PDR wishes to control the activities that cause erosion so that sustainable land use is obtained:

"Article 1 of the Forestry Law (no. 01-96 dated 11/01/96): The forestry Law determines principles, regulations and measures on the use, management, protection, conservation, regeneration and increase of forest resources and forest land in Lao Peoples Democratic Republic. The forestry Law is aimed at achieving and maintaining natural equilibrium, making forest and forest land a sustainable base for people's livelihoods, ensuring the protection and conservation of watersheds, guarding against soil erosion, protecting plant and wildlife species and the environment and contributing to national economic and social development". (MRC & Douglas I., 1997)

"A translation of the Water and Water Resources Law, effective on 3rd of March 1997, Article 41 states: Agencies responsible for water and administrative authorities at all levels must augment their leadership in preventing and fighting erosion. It is prohibited to carry out activities which cause erosion, e.g. construction, cutting trees, rock quarrying, gravel quarrying, soil, sand minerals etc. In addition, in order to preventing erosion impact, such agencies must have a plan to prevent erosion where necessary, e.g.: reforestation on shorelines and undertaking various other measures". (MRC & Douglas I., 1997)

Many projects aiming at sustainable land use are taking place all over Laos. The catchment areas of Nam Ngum and Nam Lik are two areas where several of the projects are carried out, since this is the location of the Lao PDR's first hydropower plant. The dam is filling up with sediment and it is of interest to find the sediment sources, and prevent the erosion within the catchment areas.

To locate areas of deforestation, Geographical Information Systems (GIS) and Remote Sensing are useful tools. Aerial photographs or satellite images give a good overview of the deforested areas, and in areas located in inaccessible terrain, they might be the only way to estimate the extent of the deforestation. Modelling with the help of GIS is also a helpful tool to predict future changes in the vegetation cover. This study has concentrated on evaluating three different methods of detecting the areas where the changes in the vegetation cover is taking place, by using satellite images readily available at nominal costs.

2. Aim

The original aim of this study was to find a method suitable for identification of river sediment sources in the Nam Ngum Dam. The idea evolved after reading the environmental report, 1997, for the Mekong River Commission (MRC), in Bangkok, Thailand. They wrote: ”*the catchment area of the Nam Ngum reservoir in the Lao PDR is known to be affected by deforestation and erosion problems, although the negative effects have not yet become critical*” (MRC, 1997a). A suggestion from the same report, on how to detect areas prone to erosion, was: “*to produce maps showing soil erosion hazards areas, applying GIS (Geographical Information System), based on mapping of key parametres such as vegetation cover, slope, rainfall erositivity, soil erodibility, land use, population pressure and farming practise*”.

In the preparatory communications with the MRC in Bangkok, digital databases covering sediment data from the selected study area, were reported to exist in the Lao PDR. The study was to be based on these data sets. On arrival in the Lao PDR the databases appeared to be inaccessible and could not be used in the study. The study area, selected by the MRC in Bangkok, turned out to be unsuitable for field studies, since the area was to large to cover due to the time-limitations in this project. Furthermore the area is very remote and inaccessible, with only few roads and it was not considered safe, for different reasons, by the Swedish Embassy in Vientiane.

Due to the above limitations, the project was reformulated; to concentrate on one of the original key parameters, namely the temporal changes in the vegetation cover.

The aim therefore is to test and evaluate three different methods for detecting changes in vegetation, since the existence of vegetation cover is considered the most important factor when it comes to preventing soil erosion (Morgan R.P.C., 1986). The study area is the two adjacent drainage areas selected by the MRC in Bangkok, namely the Nam Ngum and the Nam Lik catchment areas in the Lao PDR. The methods for finding the vegetation changes are based on remote sensing and GIS analysis of satellite images with different resolutions:

1. The NOAA/NASA Pathfinder AVHRR Land Project 8 km data set
2. The 1-km AVHRR Global Land Data Set
3. Three Landsat TM/MSS scenes (resolution 30/80 m)

3. MRC

The Mekong River Commission (MRC) was founded in 1957 to establish an intergovernmental development programme between four of the riparian countries of the Mekong River: The Lao PDR, Cambodia, Thailand and Vietnam. The Committee's mission was to deal with sustainable development of water and related resources in the Lower Mekong Basin and to maximise the social and economic benefits. The MRC is at the moment situated in Bangkok, Thailand, but in 1996 it was decided to move the location of the office on a rotational basis every five years, between the cities of Phnom Penh in Cambodia and Vientiane in the Lao PDR starting with Phnom Penh next year (Kammerud T. A., 1997).

Financially the committee receives support from international development funds from among other countries; Sweden, the Netherlands, Australia, Finland, Japan and also from the UN (Skoglund E., 1993). The staff comes from all of the riparian countries and they work in collaboration with international experts. MRC concentrates on areas such as hydroelectric power generation, irrigation, flood control measures, drainage, watershed management, water supplies and training programmes (Http://www.gsf.de/UNEP/mek.html). Data are being collected by all the riparian countries to build up databases covering meteorological, hydrological, geographical data and socio-economic data for environmental impact assessments.

In September 1991, the MRC implemented a GIS project, with financial aid from the Asian Development Bank and the Government of Switzerland (Kammerud T. A., 1997). Included among the aims is to further upgrade and maintain spatial databases on geomorphology, soils, land use, vegetation and other selected environment related factors, obtained through remote sensing techniques. Further aims are to encourage application of GIS techniques and facilitate environmental impact assessment studies, training of technical staff and improve the co-ordination of mapping and monitoring projects.

A GIS centre is located at the MRC in Bangkok, Mekong GIS Centre (MEKGIS). Thailand, the Lao PDR, Vietnam and Cambodia have national networks of GIS Centres responsible for the national databases of water and land data. In Lao PDR, the centre is called the Integrated Resources Mapping Centre (IRMC), and is an institution of the Science, Technology and Environmental Organisation (STENO) located in Vientiane, the capital of the Lao PDR (Kammerud T. A., 1997).

4. Background

4.1 The Lao PDR

The Lao People's Democratic Republic is a small landlocked country in South-East Asia, bordering Thailand, Vietnam, Cambodia, Burma and China. The country covers 237 000 square kilometres, which is about half the size of Sweden (Oughton G.A. 1993, Rosell A. 1992). The population was estimated to 4.5 million in 1991. The population is growing at 2.9 % per year, and the density is roughly 19 persons per square kilometre (SIDA, 1994). The capital of the Lao PDR is Vientiane (figure 1).

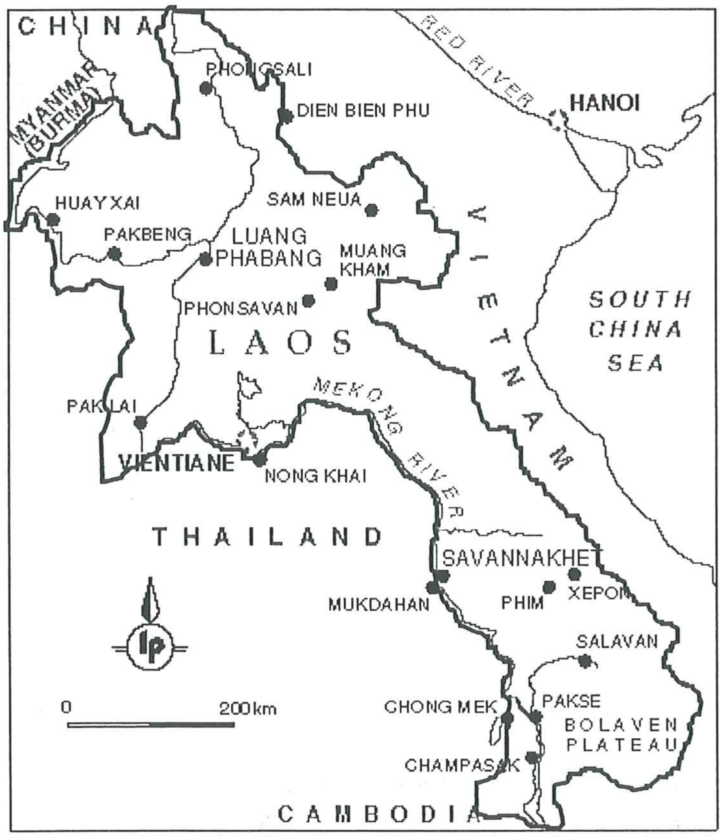


Figure 1. A Map of the Lao PDR. The Nam Ngum Dam is situated 90 km north of the capital Vientiane (Lonely Planet, 1996).

4.1.1 History

Throughout the years the migration to South-East Asia has contributed to a population of mixed ethnic groups. In the 1890's, the Lao PDR was, together with Vietnam and Cambodia, colonised by France. After World War II, the French had lost some of their influence, and later tried to regain it, while the resistance against the French grew. In 1953 France was forced to declare the Lao PDR independent. The years that followed were turbulent with civil war, political coups, electoral riggings and imprisonings, as well as the Vietnam War. During this war over 2 million tons of bombs were dropped over the Lao PDR, which is more than the total sum dropped by the USA during the World War II. After the war was over and the USA left Vietnam, the communist party took control in the Lao PDR on the 2nd of December 1975 and the Lao People's Democratic Republic was proclaimed (Rosell A., 1992).

4.1.2 Population

The plains in the Lao PDR cover about 22 000 square kilometres of the area, while almost 80 % is mountainous. Most of the population is concentrated in the lowlands. The Lao PDR population consists of 68 different ethnic groups all with different history, traditions and languages. Usually the population is divided into three main groups; the Lao Loum, Lao Teung and the hill tribes; Lao Sung, Hmong and Yao (Rosell A., 1992). The Lao Loum is the largest group, and they live on the lowlands of the Mekong River. Lao Teung stays on the slopes up to the mountains and the hill tribes live further up on the steeper slopes. The main crop among the lowland inhabitants is wet rice, while in the mountains the main crop is hill rice.

4.1.3 Natural Resources

The natural resources in the country are rich and unexploited and include forest, water, minerals and probably oil and gas (SIDA, 1995). The forest cover in 1991 was 47 % of the country area. Although the cover is extensive compared to the neighbouring countries, it is decreasing every year, due to illegal and legal logging, or shifting cultivation for subsistence crops or cash crops.

Logging and forest products are a possibility for the Lao PDR to improve their economy. Figure 2a shows the figures of production of forestry products in the country for the years 1961 - 1996. The production increased in the early 1990s for all products, which is due to an increase in the areal extent of logging. The years corresponding to the satellite images used in this study, 1982-1997, should, according to figure 2a and 2b show a corresponding decrease in the vegetation cover over the years. It is important for the government to gain control over where and why the logging is taking place, in order to minimise the negative effects on the environment. This is one of the reasons why the Forest Law, and the Water and Water Resources Law in chapter 1 has been constructed.

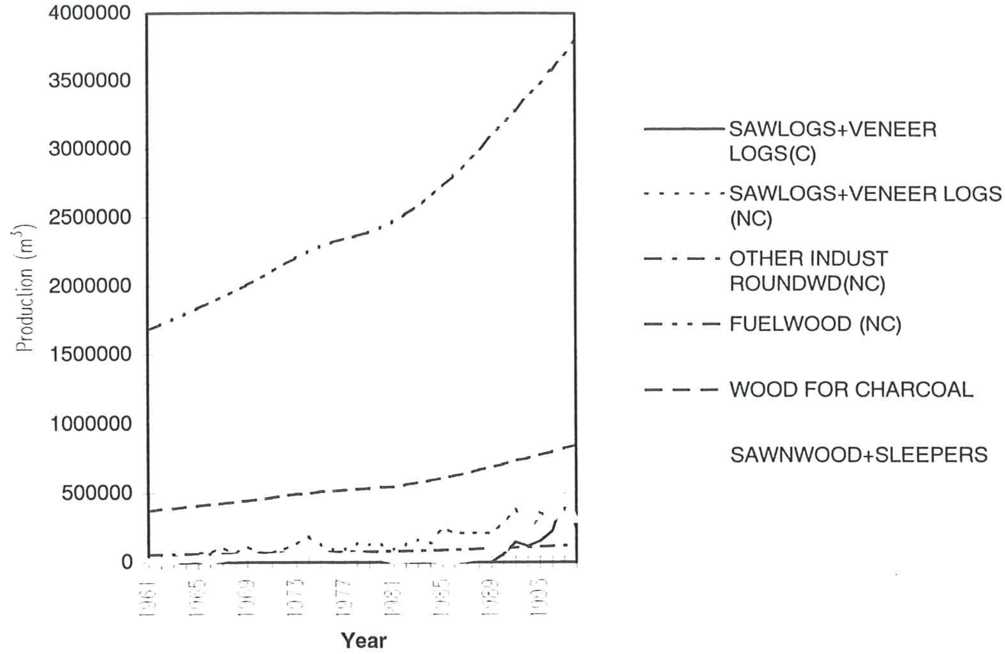


Figure2a. Production in cubic meters for forest products in the Lao PDR., C stands for Coniferous forest and NC for Non Coniferous, 1961 - 1996 (FAO, Statistical Database).

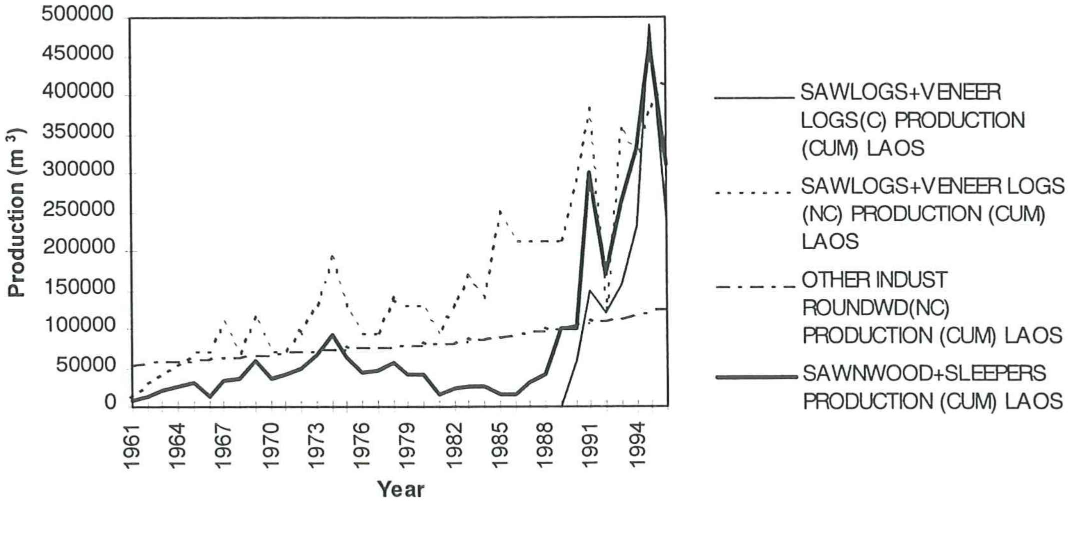


Figure 2b. Two of the products (Fuel wood and Wood for Charcoal) have been removed to better visualise the variations of the other products.

The Lao PDR has large potential for the construction of hydropower dams. In 1995 only 200 MW of the estimated possible 18 000 MW hydrological power were exploited (SIDA, 1995). Many dams have been constructed and hence large areas have been flooded. A goal has been set to expand the hydropower to 1 500 MW until the year 2 000. This would benefit the economy of the Lao PDR, but may also have a negative impact on the environment. The country is moving toward a market oriented economy, which has encouraged neighbouring countries to intensify their contacts, and thereby utilise some of the natural resources in the Lao PDR. The environment in the neighbouring countries has already been exploited and degraded (Mossberg C-G, 1990).

4.1.4 Infrastructure

The infrastructure in the Lao PDR is poorly developed. There are only a few main roads, which are often in poor repair due to frequent heavy rains. The infrastructure is under development, with the help of international development aid. Roads to Vietnam will be improved and bridges to Thailand will be built, which will increase the pressure on the Lao PDR to improve the road work to access the natural resources. Roads will probably be built to reach large areas of now virgin forest, i.e. logging will start (Mossberg C-G., 1990)

4.1.5 Climate

The Lao PDR has a tropical monsoon climate, the rainy season lasting from May until October. In the humid summer mean temperatures are approximately 27° C, while during the dry season mean temperatures are 16 –21° C. The climate in the Lao PDR varies considerably depending on elevation (SIDA, 1995). The mountainous areas has an average annual rainfall that exceeds 1 500 mm (MRC & Douglas I., 1997).

The most frequent rainfall in the Lao PDR are brought by the monsoon that comes in from the southwest and forms convective thunderstorms that last approximately one hour. There are also cyclonic low pressure systems that form in Vietnam, and which follow the Mekong river up to the northern parts of the Lao PDR. These rains can last for days, and cover large areas. The first storm is usually followed by a second, and so on, leaving the rain to last for weeks or months. Two mountain ranges, one in Vang Vieng the other in Paksane, are responsible for blocking the progressing of the low pressure systems (Sogreah, 1995).

4.1.6 *Vegetation*

The vegetation map of South-East Asia (figure 3) shows that the Lao PDR is covered by extensive forest. The forests are mainly located in the mountainous areas of the country (NOFIP, 1992).

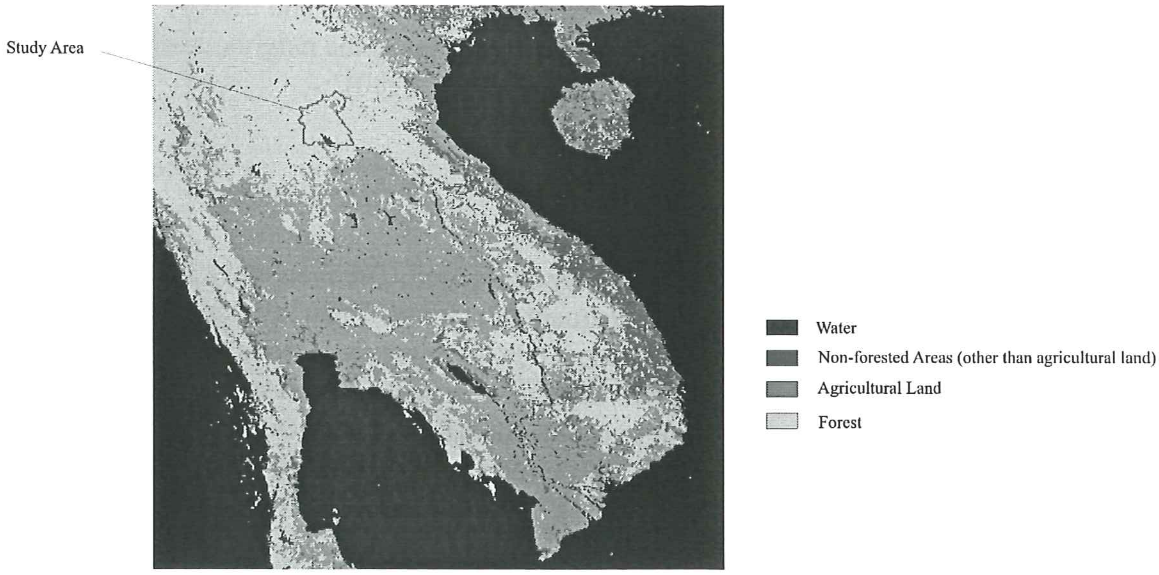


Figure 3. Vegetation map over part of South-East Asia (Olson World Ecosystem, 1997).

The dominating vegetation type in the mountainous regions is mainly Deciduous and Evergreen forests. These two types can be divided into different classes, that occur on different elevations (table 1).

Table 1. Forest Type according to altitude (NOFIP, 1992).

Forest Type	Altitude (m.a.s.l.)
Dry Dipterocarp	0 - 200
Upper Mixed Decidous	200 - 1 000
Upper Dry Evergreen	500 - 1 000
Coniferous	1 000 - 1 500

Extensive forest inventories have been undertaken in the Lao PDR by the National Office of Forest Inventory and Planning, and was finished in 1992, in which five main land use groups are found. The five groups are:

- Current Forest: Areas with a crown cover exceeding 20 %.
- Potential Forest: Areas previously covered with forest, with a crown cover now below 20 %. Hill rice and other temporarily grown crops are included here.
- Other Wooded Areas: Areas with a crown cover less than 20 %, but with too poor site conditions for forest growth.
- Permanent Agriculture Land: Areas that are more or less permanently used for crops or grazing.
- Other Non-Forest Land: Areas such as urban land, rock, grassland and swamp areas.

The extent of these five groups are shown in figure 4.

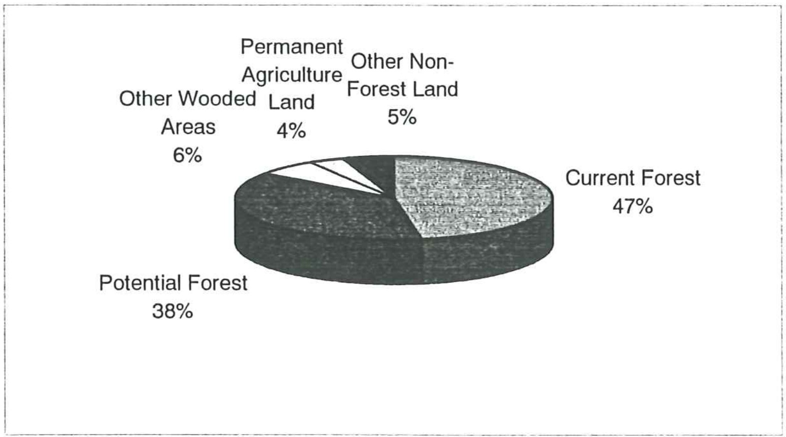


Figure 4. Land use and vegetation types in the Lao PDR, 1989.

The results of the forest inventory study indicate that the total area of closed forest cleared between 1982 and 1989 is estimated to be 4 250 km^2, with the greatest losses in the central region of the Lao PDR, in terms of magnitude. This study ignored areas with only partial loss of forest cover, such as selective logging areas (NOFIP, 1992).

4.2 Vegetation degradation

The causes of deforestation can be divided into seven factors (TREES, 1994);

1) Slash-and-burn agriculture
2) Government sponsored resettlement schemes
3) Fuel wood gathering and charcoal production
4) The conversion of forested areas for cattle ranching
5) Inefficient commercial logging operations
6) Provision of infrastructure
7) Large and uncontrolled forest fires

There is no single cause of deforestation; rather it results from a chain of several different causes, and they are in their turn driven by a number of different factors, although many of them are functionally linked. The factors are for instance population growth, unjust social conditions, misguided government policies, economic pressures and inappropriate technology.

Deforestation can be said to have an impact on four major issues; physical and ecological processes, soil and water resources (soil erosion), the local and the global climate, and species diversity.

There are also economic effects of deforestation. Most often people in the rural areas in developing countries are the ones to suffer most, since they depend on the forests for collection of fuel wood, wildlife hunting and in longer terms agriculture land since the soil loss will cause land degradation.

However, not all deforestation should be regarded as a problem. For instance, from a socio-economic point of view it provides room for cattle raising, hydropower plants and logging which improves the economic situation (TREES, 1994).

4.2.1 Deforestation in the Lao PDR

In the Lao PDR, approximately 3 000 km^2 is used for shifting cultivation. Every year approximately 800 km^2 is deforested to make way for cropping. Moreover, thousands of square kilometres of forest are cleared for other purposes (Appendix 2, figure VI & VII).

The reason for deforestation has three main causes in the Lao PDR (Mossberg C-G, 1990):

- Deforestation for agricultural land.
- Logging, both legal (approximated to 300 000 m^3) and illegal (150 000 m^3), which adds up to a total of 500 square kilometres per year.

- Forest fires, often started to clear areas that are to be used for cultivation, grazing land etc. Several hundred thousand hectares are destroyed every year due to fires. The fires do not only stop the regeneration of trees, but also has an impact on the number of species that are to be found in the environment. Many are exterminated on a local scale due to the fires.

Large areas in the northern part of the Lao PDR has been classified as "green desert", due to the shifting cultivation and fires that have been going on for generations. The air is sometimes polluted by the smoke from the fires that prevail throughout the dry season, sometimes to the extent that domestic flights have to be cancelled (Mossberg C-G, 1990).

Figure 2 in chapter 4.1.3 shows the forestry production in the Lao PDR during the years 1961 - 1996. The leading figure is the production of fuel wood which almost reaches 4 million cubic metres per year. This means that approximate 1 m^3 per person and year is estimated to be used as fire wood (Mossberg C-G, 1990). In Sweden, the productivity of forests is assumed to be 1000 cubic metres per km^2 and year. If the figures are equal for the Lao PDR, this would mean approximately 100 million m^3 produced forest in the whole of Lao PDR per year. If use of fire wood is 1 m^3 per person with a total of 4.5 million inhabitants in the Lao PDR, the clearing for fuel wood would not be a problem. Nevertheless these numbers are not accurate and in sparsely forested areas like Xieng Khouang, the consumption has to be monitored. It is possible that the planting of firewood will be needed.

The Lao PDR also have problems with damages caused by the felling of bombs during the Vietnam War. The bombs have, apart from the large scars from the explosion, also had a chemical defoliation impact on the trees. The scars are today, still, completely non-vegetated due to the chemical residuals in the ground (Appendix 2, figure V). Most bombs were dropped in the northern provinces of Houaphan and Xieng Khouang, and the eastern border of the country (UXO Lao, 1996).

4.3 Shifting Cultivation

Shifting cultivation is also called slash-and-burn cultivation and swidden farming. It is an old farming system still used in the tropical world, and is a traditional method to decrease the soil erosion by rotating the fields (Morgan R.P.C., 1986). The forest area is cleared by slash-and-burn and afterwards, the soil is loosened up through hoeing by hand. The crop is planted and the area is used for a couple of years before being left to return to scrub and secondary forest. This cropping system partly restores the fertility of the soil during the fallow period, and may have lower erosion rates than large areas set aside for cash crops (Hansen P.K. & Sodarak H., 1997). If, however, the cropping is continued for too long, or the fallow period is shortened radically, the cropping system will instead increase the rate of soil erosion. A fallow with a traditional length of between 7 to 50 years, is commonly reduced to 3 years or less at present which results in increased erosion and decreased soil fertility.

4.3.1 Shifting Cultivation in the Lao PDR

Shifting cultivation is practised all over the country, although it predominates in the northern and eastern provinces. There is no exact information on how big the area used for shifting cultivation in the Lao PDR is. It is practised in all upland areas and is, according to one source, the main farming system for 90 % of the farmers in the Lao PDR (Souvanthong P., 1995). Another source shows that the shifting cultivation is currently practised by more than one third of the population (Mossberg C-G, 1990). It is practised by all ethnic groups, but with different traditional methods.

The Lao Loum traditionally hold wet rice-crops, but have due to an increase in demand, moved up the slopes to cultivate upland rice. The higher demand is partly due to increased lowland population and limited agricultural improvement techniques, with a low soil fertility as a result. Cultivation at higher elevations has not accompanied a suitable shift in cultivation techniques and is resulting in soil infertility and decreasing yields.

The Lao Theung have traditionally cultivated upland rice with shifting cultivation techniques. The traditional system is believed to be sustainable with fallow periods of between 5 to 15 years as well as other precautions to be able to return to the same area after the fallow. In the north however the population density is high and, although larger areas are available, the fields tend to be cleared of all trees to maximise the crop yield and since the fields often are located on steep hills, this results in high rates of erosion.

The Lao Sung usually live on very inaccessible land at high altitudes. The fields are often situated on very steep slopes where the soil cover is shallow. To maximise the yield, the fields are many times cleared from all the trees. This is done by slash-and-burn, where the fires often are uncontrolled and get out of hand. The cultivators do not let the fields rest in fallow for a few years, instead they cultivate the land until the fertility is too low (usually after 5-6 years) and then chooses a new area for their crops. After approximately 20 years the village is moved to a new site (Souvanthong P., 1995).

4.4 Soil Erosion

Erosion is a function of the rain erosivity and the soil erodibility. Erosivity is the ability of the rain to cause the erosion, erodibility is a measure of how easily the soil is eroded.

One main factor that influence the erosion is the rainfall. The intensity of the rain and the size of the rain drops influence the erosivity, as well as the amount of rain that falls. For instance, a small amount of rain will probably be taken up by the vegetation, or not have an impact on the soil, because of its low erosivity. The erosion increases up to 1 000 mm of annual precipitation, as long as a natural vegetation cover exists. At places where the annual rainfall exceeds 1 000 mm, the vegetation cover is often dense enough to prohibit the erosion. If, on the other hand, the vegetation is removed, the erosion will increase with increasing mean annual rainfall (Hudson N., 1981). Erosion by water is caused by the raindrops splashing detaching soil particles. Furthermore, surface run off known as interill erosion, may occur, followed by rill erosion and gully erosion. Erosion can also be caused by wind, which mainly effects the dry soils that may be blown away.

Factors that influence the erodibility of the soil are physical features, topography and the management of the land. A steeper slope is more vulnerable than a less steep slope. The management of the land is an important factor, since if it is not kept in mind, the erosion could become severe. An all year round vegetation cover protects the soil (Hudson N, 1981).

4.4.1 Soil Erosion in the Lao PDR

In the Lao PDR, soil erosion is not considered to be a problem on more than a local scale. Measurements of sediment in the Mekong river does, however, show that soil is eroded and added to the river as sediment (Mossberg C-G, 1990).

4.5 Soil Conservation

Vegetation principally reduces the soil loss by the interception of rain drops, by reducing their kinetic energy. Furthermore vegetation reduces wind and water-velocity, by creating a rough surface. Roots have a cohesive effect on soil cover as well as providing infiltration channels leading deep into the soil. The best protection of the soil against erosion is given by a forest or a dense growth of grass. A forest provides good protection by maintaining high rates of evapotranspiration, interception and infiltration, resulting in lower runoff. The erosion rate on cultivated land depends on the type of crop, cultivation methods and also maturity of the crop (Morgan R.P.C., 1986). Cultivating on steep slopes, cultivating in rows running up and down the slope and putting to much pressure on the land with too short fallow periods increases the rate of erosion.

Soil conservation includes covering the soil to reduce the impact from the rain splash erosion, reducing the runoff by increasing the infiltration in the soil, improving the aggregate stability of the soil and reducing the wind and water-flow speed by increasing the roughness of the ground. Reducing the impact of erosion on cultivated land includes introducing farming systems such as agroforestry, tree plantations, contour cropping (cultivating along the contour lines and not up-and-down the slope), mulching (leaving crop residuals on the ground) as well as building terraces and windbreaks. When planning what method to apply, its cost, effectiveness and integration into existing farming systems has to be considered (Hudson N., 1981).

4.5.1 Soil Conservation in the Lao PDR

In the Lao PDR a major part of the erosion occurs on the areas that are cleared for shifting cultivation practises. Soil erosion on a slash-and-burn field tends to greatest in the first year, when the soil has the highest erodibility. If rice straws are left to protect the soils, these have some impact until the end of the dry season. During the first years, sheet erosion is clearly seen on the fields. If the field is left unattended, the vegetation will slowly return. The fallow vegetation shows a gradual succession from grass towards different bamboo species and trees. If the forest contains bamboo, which does not produce organic litter, top soil erosion will only be reduced after a re-growth of six to seven years (JICA, 1997).

4.6 The Study Area

4.6.1 Location

The Nam Ngum and Nam Lik catchment areas are situated in the northern part of the Lao PDR, between 18° 40' N - 19° 80' N and 101° 90' E - 103° 50' E (figure 5).

The Nam Ngum Dam is found in the lower part of the Nam Ngum catchment. The dam is the Lao PDR's first hydroelectric power plant, built in 1973. The dam site is situated approximately 90 km north of Vientiane. The Nam Ngum catchment area is 8 460 km^2 and Nam Lik to 5 915 km^2 (Hirsh P. & Masixonxay P., 1997).

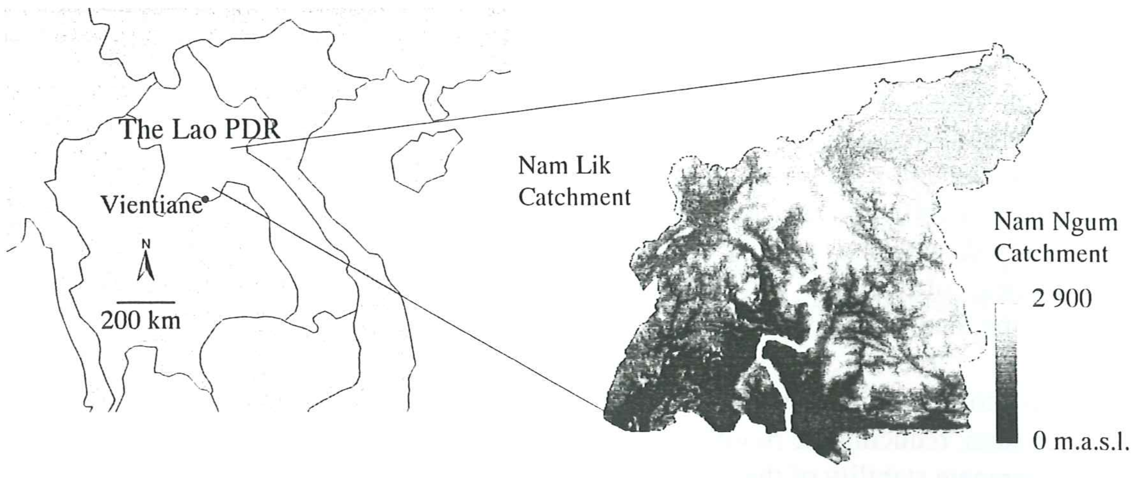


Figure 5. The geographical location of the study area, situated 90 km north of Vientiane, capital of the Lao PDR.. In the Digital Elevation Model to the right, bright colours indicate high altitudes and dark colour low. Legend in metre above sea level.

4.6.2 Population

The Lao PDR is sparsely populated, but the density in most uplands is already critical, due to the shifting cultivation, that requires large fallow areas (Hansen P.K. & Sodarak H., 1997). Within the Nam Ngum catchment a number of different ethnic groups are found. Depending to the ethnic group and topography, the farming system can be divided into lowland, intermediate and upland as described in chapter 4.3.1. The population pressure between the the catchment areas differs, with 14 persons per square kilometre in Nam Lik, and 50 persons per km^2 in Nam Ngum (IRC & Watershed Management Section, 1994).

4.6.3 Infrastructure

In the uplands and highlands of the Lao PDR, the infrastructure is poorly developed. A better developed road net work would probably lead to changes in land-use. For instance, access to the market would lead to an increase in cash cropping, and better roads to the virgin forests might increase the logging (Hansen P.K. & Sodarak H., 1997).

4.6.4 Topography

The study area ranges from an altitude of 160 m, the highest mountain in the Lao PDR, Phou Bia, 2 820 m. The catchment areas also includes the Xieng Khouang plateau in the northern part of Nam Ngum Catchment area, with an elevation of 1 200 m. Many steep areas are found within the catchment, with slopes exceeding 55 degrees. But although the Lao PDR is considered a mountainous country, nearly 80 % of its area is situated below 1 000 m altitude and only 2 % above 1 500 m (NOFIP, 1992).

4.6.5 Soil

The soil in the study area is highly influenced by geological and climatic factors and varies within the drainage areas, but Leptosols, Ferralsols and Fluvisols are worth mentioning. In the Nam Lik catchment Acrisols are most widely spread, with Alisols in the hilly regions (SMEC/SEATEC, 1996; JICA, 1997). According to the Soil Survey Centre in Vientiane the soils that are found within the catchment area are; Mollic Gleysols, Gleyic Luvisols, Eutric Fluvisols and Haplic Alisols.

4.6.6 Climate

The drainage areas are characterised by tropical and sub-tropical climates, with varying elevations, where high elevations give hot days and cool nights. Mean temperatures in the highlands are about 4° C cooler than areas closer to sea level, with the difference between up- and lowland being generally larger during the dry season than the wet season (SMEC, 1996). The weather is divided into a season of cold weather from November to January, a summer from February until April and a rainy season from April until October. Following the rainy season, floods can occur during August to October. (SMEC/SEATEC, 1996)

One obstructing mountain range for the low pressure systems coming in from Vietnam (see chapter 4.1.5) is found within the drainage area (Sogreah, 1995). This results in orographic precipitation around the Vang Vieng area (for location see figure 7). At the station in Vang Vieng the annual rainfall ranges between 2 800 - 3 800 mm. This is approximately double the amount that falls over Vientiane. The rainfall between May to October accounts for 90 % of the annual rainfall.

The humidity follows the same pattern, with higher values during the rainy season and lower during the dry season (JICA, 1997). The relative humidity is high in the study area; ranging from 70 % during the dry season and 85 % in the wet season, where August has the highest humidity and March the lowest. Relative humidities close to 100 % may occur during mornings all year around. More elevated areas may have similar humidity during the dry season, but higher humidities during the wet season (SMEC, 1996).

4.6.7 Vegetation

Within Nam Ngum drainage area, two main types of forest dominate; the Moist Upper Mixed Deciduous Forest and small areas of Montane Rain Forest. (SMEC/SEATEC, 1996).

The Nam Lik area belongs to the tropical forest zone, but the vegetation degradation due to, among others, commercial logging and slash-and-burn cultivation, the distribution of such vegetation is reduced. According to JICAs studies forest and potential forest areas cover 93% of their study area in the Vang Vieng area (JICA, 1997).

4.6.8 Land use

Within the Nam Ngum catchment, the income can be divided into three main types: non-agricultural, agricultural and a fisheries. The fishing industry mainly takes place in the Nam Ngum Dam, where fish farming is carried out. Non-agricultural earnings can be employment in or outside the village, for example logging, hand sawing wood, trading, handicrafts and forest products. The agricultural income is, for example, rice production and other cash crops as well as livestock and poultry (Pals R., 1993).

The ratio between the shifting cultivation fields and the lowland paddy fields within the reservoir area is eleven to one (Pals R., 1993). According to the studies of JICA it takes the forest in the Nam Lik area, 15-20 years to be regenerated after a slash-and-burn (JICA, 1997).

Sustainable land use within the study area is threatened by the clearing and cultivation of steep slopes, due to lack of lowland and midland slopes for cultivation. Some of the land was lost to the Nam Ngum Dam when this was built, in other places, resettlement of migrants from Thailand has contributed to an increased population pressure. The natural river flow has changed due to water being led into the dam to keep the water level above minimum. Irrigation on upstream land plots withdraws water from fields further downstream. The clearing of forests on slopes have had a declining effect on the streams (Hirsch P. & Masixonxay P., 1997).

4.6.9 Deforestation

The forest cover in the Nam Ngum Watershed is known to be decreasing. Almost the whole area around Hin Heup (for location see figure 7) has been deforested for shifting cultivation practices with fallow periods often less than six years. There have been problems in the Nam Ngum catchment concerning for example, the shifting cultivation practices with fallow cycles that range between 2-7 years (tend to be shorter in the lower part of the Nam Ngum catchment area). The short fallow does not allow the natural forest to grow up between the cropping periods and grass and weeds dominate the fallow land. There is also a resource use conflict between the different ethnic groups of the catchment. Additionally, pressure for external hydropower, logging and agricultural interest exist (Oughton G.A., 1993).

In the Xieng Khouang province (the northern part of the drainage area), the population has been burning vast areas of the natural forest, leaving grassland. This has been going on for so long that many people have no idea that the natural vegetation in the area is forest, and that the forest would re-grow if they stopped burning the areas. The winters are often characterised by a dry, persistent wind, and without the forest, the bare soil is exposed and eroded, which leads to a large amount of dust circulating in the air.

4.6.10 Erosion and Land Pressure

The human activities in the Nam Ngum catchment area have been concentrated in smaller areas and the majority of the area is untouched. The valleys do not provide enough cropping area for rice paddies, so shifting cultivation is being practised to provide hill rice and other crops. The pressure on the slopes is high and the fallow period has been reduced to three years. This is producing rill erosion and soil loss on the slopes, with a lower yield as a result. The slopes are burnt as well, to provide grazing land for cattle (MRC, 1997b).

A report from 1992 estimated that with the sedimentation rate of the Nam Ngum Dam at that time, it would take more than 1 000 years to fill 50 % of the reservoir storage in the Nam Ngum Dam, below the present mean low-water level, with sediment (Axelsson, V., 1992). In another report, from 1996, the sediment flow into the dam was estimated to be 328 700 tonnes per year, which means that, at that rate, the dam will be filled up in 1 000 years (SMEC/SEATEC, 1996). This could be an indication that the erosion rate in the catchment area has increased during these four years. The rate is still quite low compared to other catchments in the Lao PDR.

4.6.11 Soil Conservation

In 1993 it was noted that cultivators in the study area knew little about nursery and planting techniques, nor did they know of the contour cropping benefits (Oughton G.A., 1993). They tended to burn the grass and weeds instead of considering mulching or composting, and did not use manure to fertilise the soils. Most farmers were however willing to give up their old traditions of shifting cultivation if they were given alternatives that would guarantee food security for their families.

There are many projects in the Nam Ngum and Nam Lik catchment areas with the purpose of increasing the knowledge of sustainable farming in the area. Many international development aid projects are helping out financially and international experts are called in to participate. Pilot studies are carried out in a few villages within the catchment areas. In a project by the MRC, (MRC, 1997b), the villages have started with agro-forestry, the so called “taungya”-system, where fruit and pulpwood trees are planted in the hill rice fields. They have also started with other systems to provide a sustainable growth, for example fencing the cattle, planting tree-seedlings, building “self-building”-terraces, clearing of fire-paths etc.

5. Material and methods

5.1 Satellites

In this study the satellite images used were:

1. The NOAA/NASA Pathfinder AVHRR Land Project 8 km data set (Jan 82 - Aug 94)
2. The 1-km AVHRR Global Land Data Set (Apr 92 - Sep 93 and Feb 95 - Dec 95)
3. Three Landsat TM/MSS scenes from different years (Mar 86, 89 and Feb 97)

5.1.1 The NOAA AVHRR

The AVHRR (Advanced High-Resolution Radiometer) is a multispectral radiometer. The sensor is carried aboard by the NOAA satellite platform which were originally designed for meteorological, hydrological and oceanographic use (Richards J.A., 1993). The spectral bands are selected for detecting cloud cover, surface temperature, vegetation condition and density, ocean temperatures and snow cover. The swath width is approximately 2 400 km and provides a global coverage, twice a day (12 hours apart). The pixel size is 1.1 x 1.1 km at nadir but because of the large viewing angle the pixels at the far end of the scanning swath is 2.4 x 6.9 km (Seaquist J. and Olsson L., 1998). The larger pixels off-nadir have severe geometric distortions, because of the wide view angle. The channels collected by the sensor is seen in table 2.

Table 2. The channels and the wavelength they record on the NOAA AVHRR, (Richards J.A., 1993).

Channel	Wavelength	Portion of the Spectrum
Channel 1	0.58 - 0.68 μm	Visible
Channel 2	0.72 - 1.10 μm	Near Infrared
Channel 3	3.55 - 3.93 μm	Thermal Infrared
Channel 4	10.30 - 11.30 μm	Thermal Infrared
Channel 5	11.5 - 12.5 μm	Thermal Infrared

The satellites used for compiling the data sets are NOAA-7, -9, -11. They were launched in 1981, 1984 and 1988 respectively. The orbit is sun-synchronous and the satellites orbit the earth at an altitude of 833 km.

The first data set used in this study is an 8 x 8 kilometre resolution data set of NDVI-images from the NOAA/NASA Pathfinder AVHRR Land Project (University of Maryland) and the Distributed Active Archive Centre. The 8 x 8 kilometre data set contains four different data sets: a Daily data set, a Composite data set, a Climate data set and Browse images. For this study the NDVI (Normalized Differentiated Vegetation

Index) composite data set has been used. The composite data set is provided as 10-day composites or monthly composites, of which the monthly sets were used.

The 1 x 1 kilometre resolution data set used for the study comes from the 1-km AVHRR Global Land Data Set (http://edcwww.cr.usgs.gov/landdaac/1KM/1kmhomepage.html). The data set consists of daily registrations from the National Oceanic and Atmospheric Administration (NOAA).

The 1 x 1 km AVHRR global land data set consists of, among others, 10 day maximum composites of NDVI-scenes. In this study the data set used was the ten day maximum value composite images of NDVI. Further compositing was carried out, to obtain monthly images.

Aboard the satellite, full resolution AVHRR data (1.1 x 1.1 km at nadir) is recorded and transferred to a station without any transformation (Campbell, 1996). This data is named Local Area Coverage (LAC) and only 10 minutes at a time can be stored before it must be transferred to a receiving station at ground (Eklundh, 1996).

In order to increase the amount of data stored, but with a deteriorated resolution, a further processing on board can be carried out, before transmitting the data to ground stations. One such processing method produces the Global Area Coverage (GAC), where the average of the first four pixels in a row are stored, then skipping the fifth pixel, averaging and storing the next four pixels and so on until the end of the line. The next two coming lines are passed and then, on the fourth line the averaging starts over again the same way it was carried out in row one. This procedure produces data with an approximate 4 x 4 km resolution, i.e. 3.3 by 5.5 km at nadir (Campbell, 1996).

The 4 x 4 km GAC data is then further processed into 8.8 x 8.8 km pixels, where in the case of NDVI values the input pixel with the largest value that is found within 42° from nadir, is chosen as the output value in the 8.8 x 8.8 km PAL pixel (Lind M. and Fensholt R., 1997).

For both data sets, the projection is the Interrupted Goode Homolosine, which has an equal area projection that is good for spatial analysis. To minimise any spatial distortion in the images, only the pixels within 42 degrees of nadir have been used.

The images were already corrected radiometrically for signal degradation of AVHRR sensors and atmospheric and geometric corrections had been carried out (chapter 5.1.5-5.1.6). The geometric corrections for NOAA AVHRR is necessary since the swath width of the AVHRR is very broad and large geometric distortions occurs towards the outer edges. When carrying out the geometric registration, the multi-temporal (image to image) registration has been of more importance rather than absolute positional accuracy, to facilitate overlay operations. The RMS (Root Mean Square) error of image to image registration is less than 1 pixel (EROS Datacenter 1998).

5.1.2 The Landsat

The Landsat satellites were primarily designed to provide regular registration of land resources like vegetation, land use and drainage (Campbell J.B., 1996). The early Landsat satellites had two sensor systems; the RBV (Return Beam Vidicon) and the MSS (Multispectral Scanner). The later (4&5) had the MSS as well as the TM (Thematic Mapper). The first three Landsat satellites were launched in the 1970's and they all had the same orbit, a sun synchronous, near polar orbit at an altitude of 920 km. The period was 103 minutes and the repeat cycle of 18 days then they cover the same area again.

When Landsat 4 and 5 were launched they were given another orbit than the satellites before them. They have the same sun synchronous and near polar orbit, but a lower altitude, only 705 km. This results in a shorter period of 98.9 minutes and a shorter repeat cycle of 16 days as well as a better resolution in the images. The Landsat 4 was launched July 1982 and the Landsat 5 in March 1985. The following satellite, Landsat 6 was destroyed at launch, and Landsat 7 is planned for 1998. The Landsat provides full coverage between the latitudes of 81°N and 81°S.

The Multispectral Scanner (MSS) scans the ground from west to east and produces a ground swath of 185 kilometres which lies perpendicular to the satellite track. The pixel size for the MSS is 79 x 79 m (Campbell, 1996).

The MSS of the first five Landsats recorded the bands according to table 3:

Table 3. The different spectral bands recorded by the MSS (Richard J.A., 1993).

Channel	Wavelength	Portion of the Spectrum
1	0.5 - 0-6 μm	Green
2	0.6 - 0.7 μm	Red
3	0.7 - 0.8 μm	NIR
4	0.8 - 1,1 μm	NIR
(8	10.4 - 12. 6 μm	Thermal *only on Landsat 3*)

The pixel size of the Thematic Mapper (TM) is 30 x 30 metres for all bands, except the thermal infrared which has a resolution of 120 x 120 metres. The TM has the same scanning device as the MSS, but better spectral, spatial and radiometric characteristics. The scanning is done in both west-east and east-west directions (Richards J.A., 1993).

The Thematic Mapper sensor of the Landsat 4 and 5, registers the bands seen in table 4:

Table 4. The different spectral bands recorded by the TM (Richard J.A., 1993).

Channel	Wavelength	Portion of the Spectrum
1	0.45 - 0.52 μm	Blue
2	0.52 - 0.60 μm	Green
3	0.63 - 0.69 μm	Red
4	0.76 - 0.90 μm	NIR
5	1.55 - 1.75 μm	MidIR
6	10.4 - 12.5 μm	Thermal
7	2.08 - 2.35 μm	MidIR

5.1.5 Radiometric correction

Images recorded by a satellite are always influenced by the sensor itself as well as the characteristics of the atmosphere. To reduce these effects, a radiometric correction has to be made. The radiometric pre-processing of the satellite images, tries to adjust for the atmospheric influence, as well as systematic errors caused by the sensors recording the images. The sensor related errors in the scenes are usually corrected for at the receiving station. The atmospheric influence on the satellite scenes is due to particles in the atmosphere, as well as atmospheric gases (H_2O, NO_2, O, O_3, CH_4, CO_2, N_2O, CO, O_2, NH_3 and SO_2) which scatters the reflected sunlight and disturbs the signal to the satellite sensor. Radiometric correction aims to correct theses atmospheric distortions (Campbell J.B., 1996).

5.1.6 Geometric Correction

Raw digital images contains geometric distortions due to satellite and sensor motion as well as earth rotation during recording, scan angle, the non-spherical surface of the earth, topographic effects etc. Geometric corrections are needed for enabling operations of e.g., area calculations. If overlay operations are to be carried out between the images, a correction to give the scenes the same geometric qualities is also needed.

Geometric correction can be divided into two steps, first a correction of the systematic errors is carried out, and secondly a correction for the random errors. The systematic errors are easily compensated for by correcting the image with a formula. To correct for the random errors, a correction has to be made by stretching one image to fit another, by selecting corresponding Ground Control Points, (GCPs) in each image (Lillesand T.M. & Kiefer R.W., 1987).

The resampling method chosen to correct the image to the GCPs, depends on what qualities the output image needs. The Nearest Neighbour resampling method determines the new grey value from the nearest pixel, this way maintaining the grey level, but at the expense of the geometric accuracy. Bilinear Interpolation calculates a distance weighted average for the four closest pixels. Cubic Convolution takes the 16 closest pixels into account. The last two methods do not keep the grey level unaltered which effects the visual interpretation of the image (PCI, 1994).

5.1.7 The spectral properties of the Vegetation

The spectral differences of different vegetation types depends on the inner and outer structure of the leaves, and the type of chlorophyll they contain. In the visible portion of the spectra, the spectral signature of the leaf is characterised by the chlorophyll. The highest quantity of absorption is in the blue and the red spectra, while in the green and the near infrared the reflection is high (figure 6). The reflection of the green light is what gives the leaf its green colour in the eyes of the observer. In the near infrared spectrum, the waves are scattered efficiently, mostly upwards (almost 60 %) as reflected energy and the rest downwards as transmitted energy (Campbell J.B., 1996).

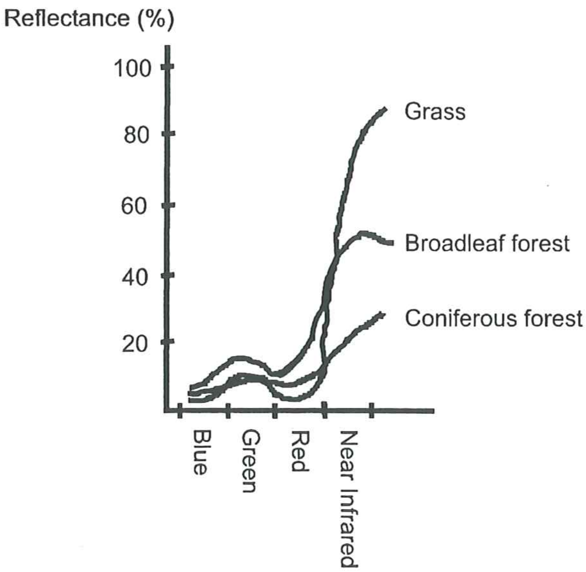


Figure 6. Interaction of leaf structure with visible and near infrared radiation (source: Campbell, 1996).

A canopy is composed of several layers of leaves, all in different directions and some shadowing others. This results in a reflectance differing from the reflectance of one single leaf. The shadowing decreases the reflectance, but the decrease in the near infrared part of the spectra is relatively less than in the visible portion. This is probably due to the amount of transmitted energy that is reflected upward on the next leaf-layer encountered.

When the plant matures or is affected by insect infestation, diseases or moisture shortage, the spectral signature is changed, and can therefore be interpreted in visual comparison on aerial or satellite photos. In vegetation studies with aerial or satellite images the visible and the near infrared parts of the spectrum are of main interest.

5.1.8 Vegetation Indices and NDVI

To facilitate the measurements of biomass and vegetation from satellite images, a vegetation index is often calculated. This is done by adding, multiplying or dividing the different spectral bands. The simplest form of an index is a ratio between two different spectral bands. For living vegetation this is most efficiently done if one takes in regard the relationship between the spectral values in the red and the infrared parts of the spectrum, since vegetation has a high absorption in the red band and the infrared waves are reflected efficiently (Campbell J.B., 1996).

The NOAA AVHRR measure the spectral bands 0.58 - 0.68 μm in the visible region (VIS) and 0.72 - 1.10 μm in the near infrared region (NIR). These bands are used to form a measure of the vegetation called the Normalised Difference Vegetation Index (NDVI). The equation used to calculate the NDVI is:

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

This gives resulting NDVI values between -1 and 1, with higher values representing green vegetation and negative values representing non-vegetated surfaces such as water, bare ground, ice, snow or clouds (http://edcwww.cr.usgs.//landdaac/1km/1kmhomepage.html).

5.1 9 Compositing

Both the clouds themselves, and the shadows caused by them, interferes with the original NDVI values and leads to pixels with lower values than the true values. Large dense clouds produces very low NDVI values as they reflect nearly equally in the in both the visible and the near infrared wave lengths. Small dense clouds influence the NDVI values by getting averaged in with the underlying land cover reflection of each pixel. Thin clouds cause greater red reflectance while still letting some of the underlying land cover signal reflect through (Moody A. and Strahler A. H., 1994).

To mask out the influences from the clouds a maximum composite method is used. The maximum composite method selects pixels with as little cloud influence as possible by choosing the pixel with the highest NDVI value during the compositing period (EROS Data Center, 1998).

The number of days in a compositing period is a trade off between the need for cloud free observations, while restricting the observations to a narrow time period so as to ensure that the vegetation status has not changed significantly.

5.2 Precipitation data

Precipitation data was collected from the Hydrology and Meteorology Department in Vientiane, as well as from different other sources, such as the Hydrological Yearbook at the MRC in Bangkok. Difficulties were found when trying to compile the information from the different sources. For example, many precipitation stations lack coordinate data, and had to be omitted. Other stations with the same names had different coordinates recorded. The translation of the stations from the Laotian alphabet, into the Latin alphabet has introduced a variety of spellings for the same station, which can lead to confusions. Another problem faced was missing values within time series.

When collecting the precipitation data the original aim was still not changed so only records for a ten year period, covering 1987 until 1997 was chosen. In some places hand-writing was the "technique" to be used for copying the daily data, so only a restricted amount was possible to record.

Figure 7. The location of the 6 recorded precipitation stations.

Five precipitation stations within the drainage areas were finally selected (figure 7) and one just outside (Tad Leuk, in order to increase the aerial extent of the recorded measuring stations). Most of these contained daily records, but were recalculated into monthly records. These were compiled into a digital database (Appendix 3). The precipitation stations were plotted into the drainage area with the help of the IDRISI for Windows Software.

The altitude of the six precipitation stations located within the drainage area, does not differ much between the stations (table 5). This could be a bit misleading since the study area is very mountainous with altitudes ranging from approximately 160 m.a.s.l. to 2 820 m.a.s.l. (chapter 4.6.4) .

Table 5. A list of the precipitation stations used in this study, with their coordinates in Latitude/Longitude and their altitude in metre above sea level.

Precipitation Station	**x-coordinate**	**y-coordinate**	**altitude**
Ban Pak Kanhoung	102°26'00''	19°32'00''	190
Ban Hin Heup	102°27'00''	18°56'00''	200
Vang Vieng	102°20'00''	18°88'00''	215
Pha Tang	102°34'00''	19°08'00''	160
Tad Leuk	103°04'01''	18°24'01''	200
Nam Ngum Dam	102°48'00''	18°54'00''	185

5.3 Digital Elevation Model

A DEM (Digital Elevation Model) was provided by the Watershed Classification/FCMP Project, MRC, 1997. The DEM was handed over as 47 tiles in a UTM 48 and 47 N projection which had to be compiled and reprojected into the Goode Homlosine's Interrupted Sinusoidal projection in order to use it together with the AVHRR satellite scenes.

5.4 Digitising the drainage area

Topographic maps were manually interpreted to delineate the Nam Ngum and Nam Lik drainage areas, and the study area was then digitised with the PC Arc/Info Software (Version 3.4.2.). A few smaller parts of the drainage area were not possible to digitise due to missing map sheets. To digitise the missing parts, the DEM was used as background information in the IDRISI Software (4.1).

To be able to overlay the drainage area on the 1 and 8 km images, a re-projection of the digitised drainage areas from the original UTM 48N to the Goode Homlosine's Sinusoidal projection was undertaken with the programs Goodeinv and Projectv (Appendix 4).

For the 8 km data, an area around each precipitation station of 3 x 3 pixels (576 km^2), was digitised to extract NDVI values for corresponding precipitation records. For the 1 km data set an area of 20 x 20 pixels was selected (400 km^2).

5.5 Field Studies

Field studies in the Nam Ngum and Nam Lik catchments, had to be concentrated to a few areas. In the south of the study area, the field studies were concentrated to the road from Nam Ngum Dam to Vang Vieng, and furter north approximately 25 kilometres until the village (Ban Kaiso 2) as well as 4 km eastwards from Vang Vieng (to Ban Nalao). A few islands and shores were visited in the Nam Ngum Dam area. In the north, villages in the Phonsavan area, Xieng Khouang Province, was visited. The villages were of varying ethnicity.

The purpose of the field studies was to obtain an overview of the study area, since a more rigorous field study was not feasible due to the difficulties mentioned in the aim (chapter 2).

6. The NOAA/NASA Pathfinder AVHRR Land Project 8 km data set

6.1 Material

The images selected for this study range from January 1982 until August 1994, and covers the area between 17° 00' N - 21° 00' N and 101° 00' E to 104° 00' E. The digitised drainage areas of Nam Ngum and Nam Lik, were overlayed with the NDVI-images to extract the study area from the 8 kilometre data set (Appendix 1, figure I).

6.2 Method

6.2.1 Correlation and time-lag

The vegetation's response to precipitation is not immediate, but delayed by a number of months (Eklundh L., 1996). To identify this time-lag, a cross correlation was carried out between the precipitation data and the NDVI values for each station. This procedure was done first without any time-lag, then with one month delay, and so on until the highest correlation coefficient was found. The test used was the Pearson's correlation test in Minitab Software.

6.2.2 Standardisation

A standardisation was carried out on the images to enable a visual comparison of the images to detect any spatially distributed changes in NDVI over the years. The standardising was done on the mean value images for each year. These images were produced with the T_ser program (Appendix 4), which calculates, among others, a mean value image and a standard deviation image.

The standardising was done according to the equation;

$$z_i = \frac{X_i - \mu}{\sigma}$$

where z_i is the required z value, X_i the raw data value to be converted, μ the mean of the variable X and σ the standard deviation of the variable X (Shaw G. & Wheeler D., 1994). This calculation is performed for each and one pixel in the images.

A mean value image and a standard deviation image for all the mean value scenes per year were calculated, and the standardising was carried out with the overlay function in IDRISI Software (Version 4.1). The result was twelve standardised images, one for each year (1994 is not included here since the time series ends in August 1994, i.e. 1994 is not a complete year).

To make a comparison between the NDVI values and the precipitation data, an extraction of the NDVI around each station was carried out and the values were plotted against each other in Microsoft Excel Software.

For further analyses, each month was standardised against the same month every year, e.g. all the images from January, between the years 1982 until 1994 were standardised etc. This time the standardisation was done with the program Tserz program (Appendix 4). This program provides standardised images from a list of the NDVI images that should be included.

The standardisation was also done for the mean NDVI values extracted from each month, in the digitised 3 x 3 pixels around the precipitation station. From these values, the high and low values respectively, were extracted from each series of standardised months. This was done since these values were considered to be extreme values for this month, compared to the other same months, other years. The limit, subjectively chosen, for the extraction of the extreme values was 1.96, respectively -1.96.

6.3 Results

6.3.1 z-scores for NDVI (Annual)

Producing standardised NDVI images of the whole drainage area shows the anomalies in each pixel over the years 1982-1993. The values from the whole study area in each new image was summarised and the sums were plotted to facilitate the interpretation of the values (figure 8).

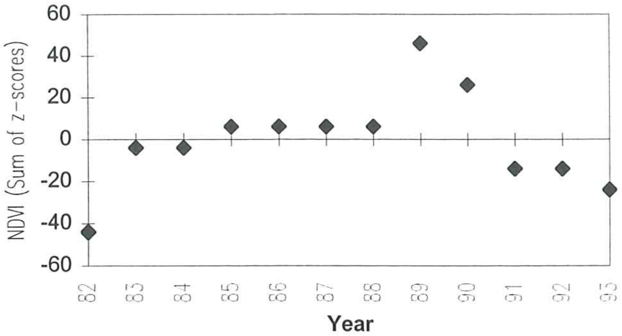


Figure 8. The summarised standardised NDVI values for the whole drainage area, 1982-1993.

Figure 9 shows the spatial distribution of the differences in NDVI for the years 1982, 1987, 1989 and 1993. The first and the last years have an lower overall NDVI than the years in between. The year 1989 (figure 9c) has conspicuously high values.

To examine how much of the change in NDVI was caused by changes in precipitation, we extracted the standardised NDVI values in an area of 576 km^2 around each precipitation station (chapter 5.4). In figure 10 the mean-values for each station (of the standardised NDVI) are plotted for each year in the time series. The standardised NDVI values were extracted from the standardised images over the whole study area.

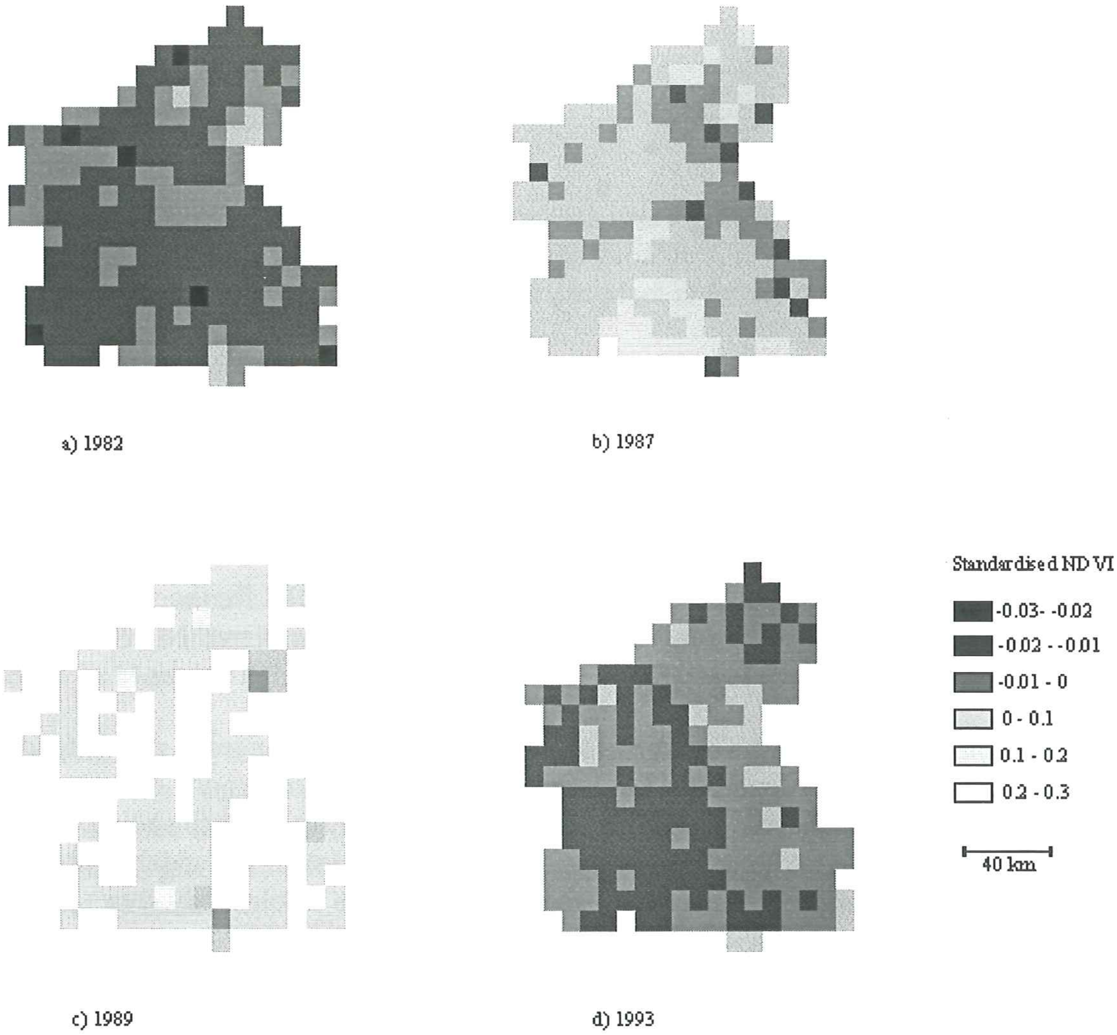


Figure 9. The spatial distribution of the standardised NDVI in the drainage areas in a) 1982, b) 1987, c) 1989 and d) 1993.

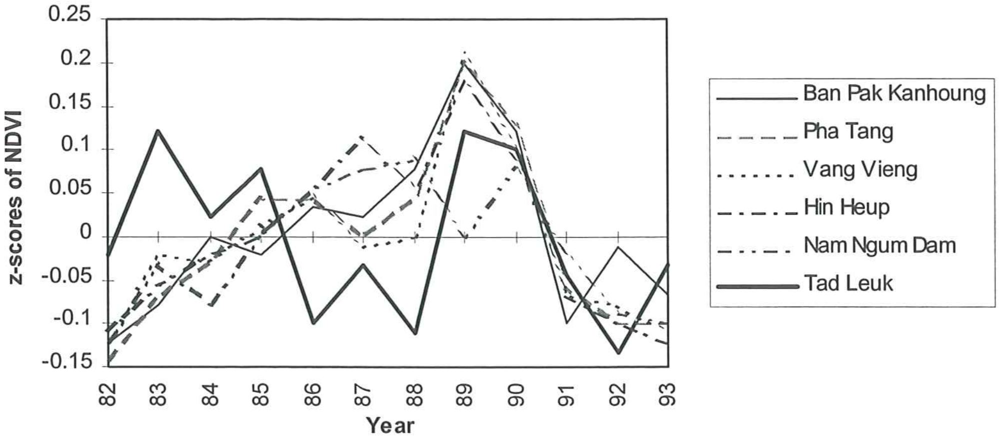


Figure 10. The standardised NDVI values extracted around each precipitation station, 1982-1993.

Since the meteorological data over time is not complete for all the precipitation stations, we were only able to plot the precipitation against the standardised NDVI values for three of the six stations within the drainage area. In figure 11 the results from the stations Vang Vieng, Hin Heup and the Nam Ngum Dam site are plotted. The low values in the beginning of the NDVI time series can not be compared with the precipitation due to the lack of data for this period. From 1987 to 1993, the NDVIs and precipitation records match well for all three stations, and the increase in the NDVI at the end of the 1980s can be seen in the precipitation data as well. In all of the diagrams the year 1989 seems to have had less rainfall than 1990. Nevertheless, in all images the NDVI is slightly higher in 1989, compared to 1990. This could indicate a non-climatological induced change in the vegetation.

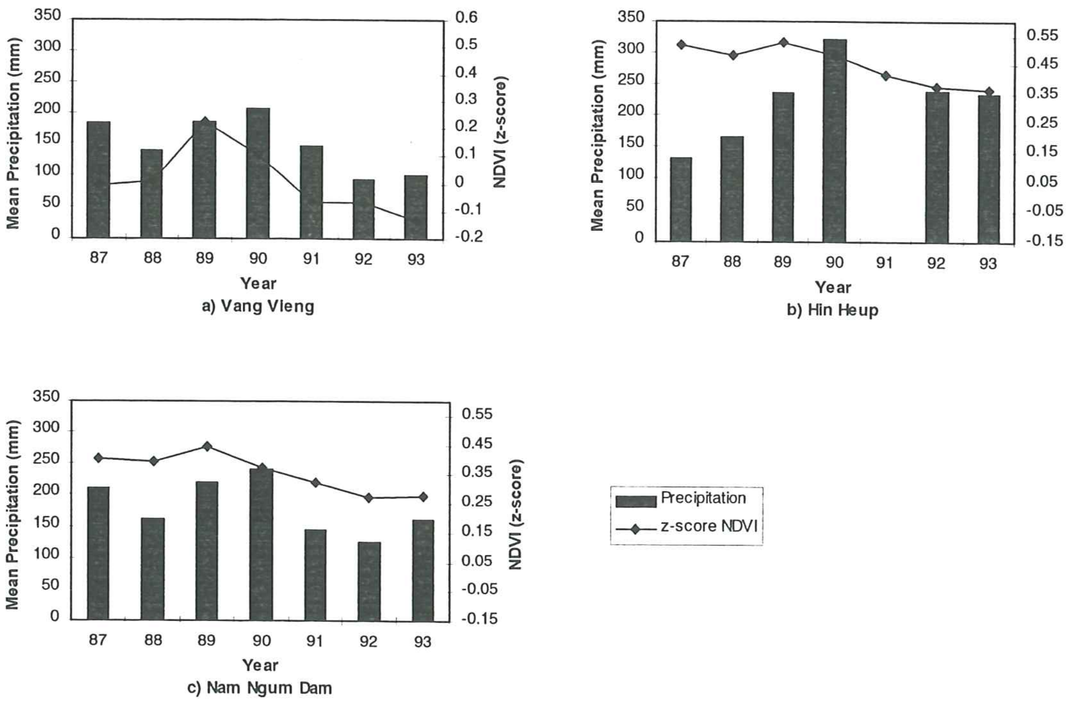


Figure 11. Mean Precipitation in mm and NDVI standardised values for the three precipitation stations; Vang Vieng, Hin Heup and the Nam Ngum Dam. The mean precipitation is calculated by summarising the mean values of each month for one year and divide the total with the number of months, i.e. twelve, (1982-1993).

Looking at each precipitation station, figure 11b, the higher NDVI values around the Hin Heup area in the years 1987-88 are not supported by high values in precipitation for the same time. This could mean that there has been a re-growth of the vegetation from a cleared area during this time, since the highest degree of vegetation gain occurs in clear cuts where shrubs and small trees rapidly occupy cleared sites (Green K., Kempka D. and Lackey L., 1994) which results in high NDVI values if the cover is dense.

6.3.2 Time-lag

The Pearson's correlation test between NDVI values and time-lagged precipitation data gave different results for different stations (table 6). The critical value for the Pearson's correlation coefficient at 150 observations is 0.160 at the 95% significance level (Shaw G. & Wheeler D., 1994). As can be seen in table 6, the resulting values are well above this limit. The overall the time-lag tend to give high correlation coefficient (r) values, which can be explained by the high autocorrelation in the data series (Eklundh L., 1996). Autocorrelation is the cross correlation between different observations in a time series.

Table 6. The number of months before the vegetation responds to a change in precipitation, i.e. the time-lag for each station, according to the highest correlation coefficient given by Pearson's Correlation Coefficient.

Precipitation Station	Time-Lag (months)	Correlation coefficient
Ban Pak Kanhoung	3	0.78
Pha Tang	-	-
Vang Vieng	5	0.52
Hin Heup	3	0.43
Nam Ngum Dam	3	0.51
Tad Leuk	4	0.39

Since the average time-lag seems to lie around three months the time-lag for each station was set to three months.

6.3.3 Z-scores for NDVI (Monthly)

After standardising the mean NDVI values around each precipitation station for each month in the time series, it was decided to look at the z-scores lower than –1.96 or higher than 1.96, listed in table 7. These z-score values were then compared with the time-lagged precipitation data (figure 13 and figure 14). For many of the observations, there was once again the problem with missing precipitation data for the first five years and for the station Pha Tang.

Table 7. The extreme monthly standardised NDVI values for the precipitation stations, 1982-1994.

Number	NDVI z-scores	Month	Year	Precipitation Station
1	2.27882	January	1982	Tad Leuk
2	-2.15109	February	1986	Tad Leuk
3	-2.67144	February	1994	Ban Pak Kanhoung
4	-2.45802	February	1994	Pha Tang
5	-2.82473	February	1994	Vang Vieng
6	-2.21005	February	1994	Hin Heup
7	-2.09203	February	1994	Nam Ngum Dam
8	-2.14935	March	1988	Tad Leuk
9	-2.07083	April	1984	Pha Tang
10	-2.13900	April	1984	Vang Vieng
11	-2.11856	April	1984	Nam Ngum Dam
12	-2.01122	April	1992	Tad Leuk
13	-2.04186	May	1982	Pha Thang
14	-2.23483	May	1982	Tad Leuk
15	-2.43178	May	1992	Hin Heup
16	-2.45901	June	1992	Hin Heup
17	-2.22383	June	1994	Tad Leuk
18	-2.40291	July	1994	Ban Pak Kanhoung
19	-2.61267	July	1994	Pha Tang
20	-2.04819	July	1994	Vang Vieng
21	-2.17317	July	1994	Tad Leuk
22	-2.64277	August	1994	Ban Pak Kanhoung
23	-2.12737	August	1994	Pha Tang
24	-2.32970	August	1994	Vang Vieng
25	-2.52467	August	1994	Hin Heup
26	-2.07587	August	1994	Nam Ngum Dam
27	-2.59995	August	1994	Tad Leuk
28	-2.12232	October	1988	Vang Vieng
29	-1.98501	October	1988	Tad Leuk
30	-2.21381	November	1984	Tad Leuk
31	1.97956	December	1990	Tad Leuk
32	-2.03810	December	1991	Vang Vieng

As can be seen in Table 7, 32 values in the NDVI series are extreme enough to be extracted from the normalised picture. In many cases a low pixel value is followed by lower values over the whole study area, as can be seen when more than one station has low values during the same month, the same year (table 7). For many of the extreme values in the table, high/low standardised NDVI values at the other precipitation stations are not listed in the table, since they are just below the 1.96/-1.96 limit. In figure 12 the standardised image of August 1994 is shown for further interpretation. As can be seen in table 7 the overall values tend to be low during this month. Looking at the image a visual interpretation indicates that the NDVI was low for most of the area during this time.

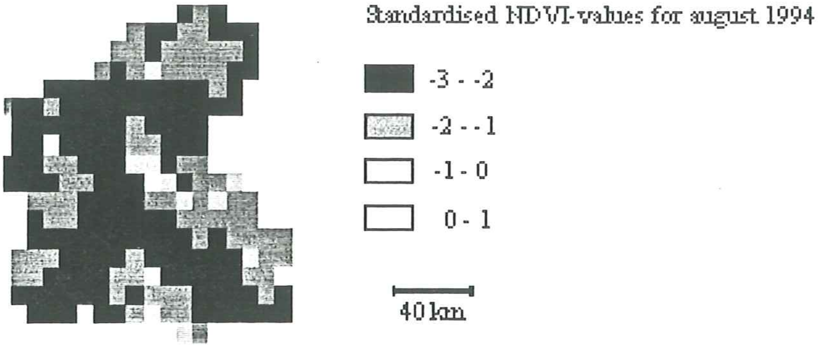


Figure 12. z-scores of NDVI values for August 1994, standardised against August NDVI 1982-1994.

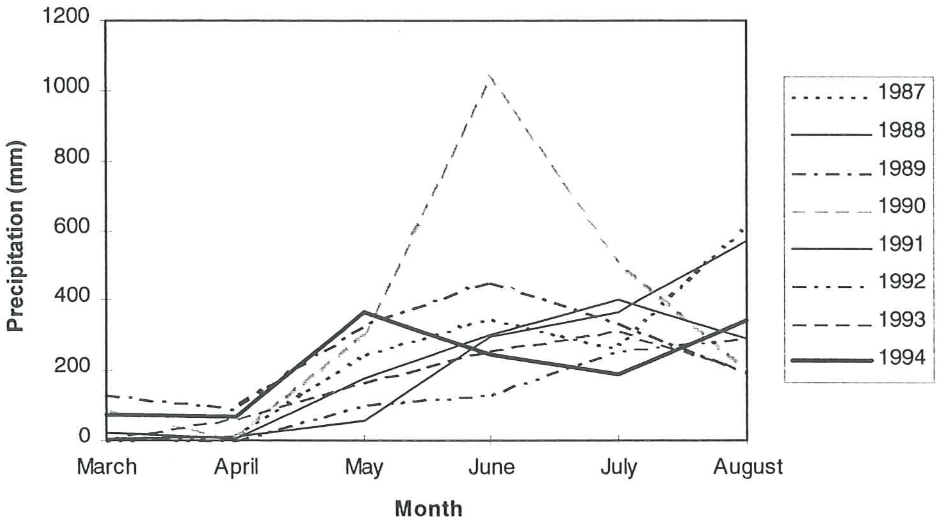


Figure 13. Precipitation data from March-August for the Vang Vieng precipitation station, 1987-1994.

In figure 13, comparing the values of precipitation from this year, with the usual precipitation during this season shows that the values were somewhat lower during the period June and July. The precipitation values were rather high in May, which should, considering the three months time-lag, be the cause of the NDVI values in August. Even considering a five month time-lag, which had the highest correlation in the calculations of time-lag for Vang Vieng (see table 6), the precipitation values of March are not exceptionally low compared to the other years. Nevertheless, the vast extent of the low NDVI values all over the drainage area, as seen by visual interpretation in figure 12, indicates that the values cannot be caused by human induced degradation of the vegetation.

With regards the five months time-lag for the Vang Vieng station, this could be the explanation why the low values of NDVI in July and August do not appear in the September data of the NDVI, which then probably is due to the peak in precipitation in May. This would indicate that the precipitation in March is the cause of the NDVI values in August. Since the precipitation in March is normal for the season, it should not contribute to either higher or lower NDVI values. Another factor that must be considered is the possible occurrence of clouds in the image.

Considering this, it could be reasonable to believe that the lower NDVI values are a cause of climatological factors, rather than man made changes.

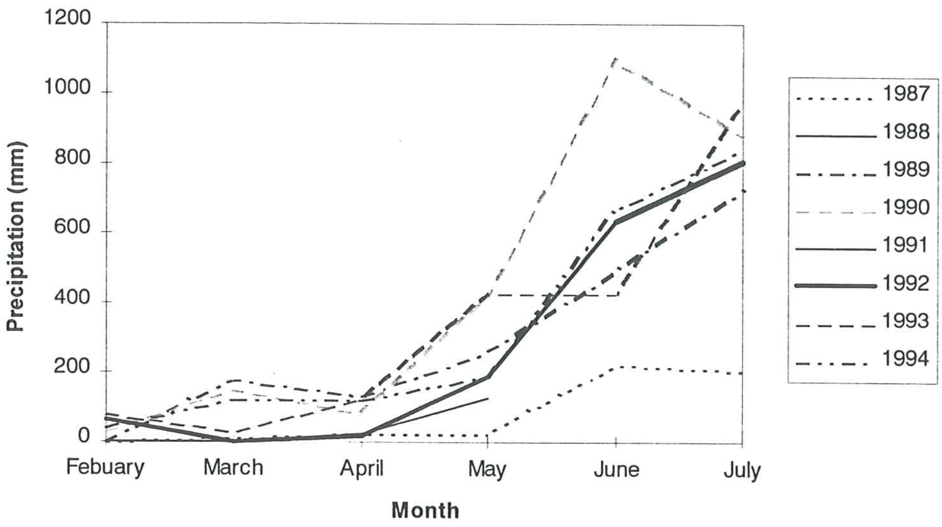


Figure 14. Precipitation data from February - July at the Hin Heup precipitation station, 1987-1994

As for changes which only occur at a single precipitation station, at one month in one specific year, it is not possible to say that the change is made by humans here either. The low value is probably due to a cloud cover over the station. To detect anthropogenic change, the value ought to be found, not over the whole study area (which probably, as for august 1994, can be explained by the lack of precipitation) but at one single station and then re-appear at the same location for a couple of following months as a low value. After the next rain period the pixels should reach very high values as the vegetation starts to re-grow, since dense fresh green vegetation generally have high NDVI values.

An example of where low NDVI values that occur for a couple of months at a single station, are found at the Hin Heup precipitation station in May and June 1992. The precipitation data for this station during the months February to July, in the years 1987-1994, are visualised in figure 14. Considering the time-lag, we have to look at the precipitation values in February and March, to correspond for the NDVI-values in May and June 1992, since Hin Heup have 3 months time lag (table 6). The precipitation in March 1992 was quite low compared to the other years, which supports the idea that the low NDVI values in May and June 1992 at the Hin Heup station are caused by low precipitatoin in March. The higher values that ought to be found in May and June the following year, 1993, to support the theory that vegetation re-growth on a clear cut area gives higher values the following rain season, do not exceed the 1.96 limit. From these facts, the negative values of standardised NDVI in May and June 1992 are not considered to be a cause of man made changes.

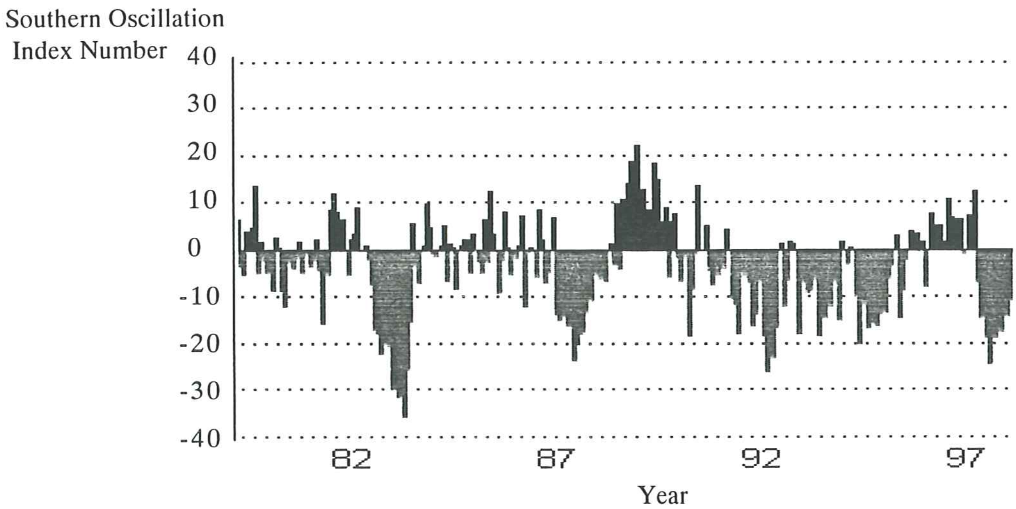


Figure15. The Southern Oscillation Index Number is a comparitive measure of the sea level pressure measured at Darwin, Australia and at Tahiti. The difference between the two gives a negative number when an "El Niño" occurs and a positive when an "El Niña" occurs (http://www.vision.net.au/~daly/elnino.htm).

Another climatological factor that probably effects the study area, is the "El Ninõ Southern Oscillation" phenomena. Normally in January, the pressure decreases steadily along the ITCZ (Inter Tropical Convergence Zone), from the west coast of South America to the east coast of Australia and Indonesia. This causes heavy rains in Indonesia (their rain season) and droughts in Peru (in extreme cases called the El Niña). In some years, this low pressure over Australia is replaced by high pressure, causing drought to effect Australia and rains to fall over the east Pacific region. This event is the El Niño Southern Oscillation (Strahler A.H. & Strahler A.N., 1992).

El Niño patterns vary irregularly in their frequency and intensity. In 1982-3 the El Niño was especially severe (figure 15) and in 1988-89 the El Niña was extreme. This corresponds well with the pattern of precipitation (and following that, the NDVI values) in the study area (with low values in 1982-83, and high in 1989). The low NDVI values in our study area in 1994 could be caused by the El Niño effect, which supports the theory that the low NDVI values were induced by climatological factors, rather than human induced.

6.4 Discussion

With the 8 x 8 km resolution images we were able to detect changes in the NDVI values between the years, as well as spatial differences within the catchment area. The areas showing the changes in the vegetation cover cannot be under half the pixel size (32 km^2) in order to have an impact on the 8 x 8 kilometre pixel, which means that this is not a useful method to detect smaller cleared areas. In other words it is probably possible to detect areas of commercial logging or big grassfires, but not smaller areas that are cleared to be used for slash-and-burn cultivation, illegal logging or likewise.

Studying the previously mentioned figure of 4 250 km^2 of closed forest that has been cleared between the years 1982 - 1989 (Chapter 4.1.6) in the whole of the Lao PDR, this adds up to approximately 66 pixels in the 8 km resolution. Since the study area is approximately 6 % of the country's total area, this means that only approximately 4 pixels of cleared area could be expected to be found within the study area, *if* an evenly distribution of closed forest is expected.

There is also a problem to know if the low NDVI values are to be blamed on the existence of clouds. The maximum value compositing method does not guarantee that all the clouds are removed from the images. The likelihood for cloud free images is enhanced with longer compositing period, i.e. there is a greater chance that the monthly maximum composite images are cloud free than the ten day composite images. Nevertheless, during the rainy season when the low pressure systems approach from Vietnam the clouds can remain for months and impact on the monthly composite image quality.

7. The 1-km AVHRR Global Land Data Set

7.1 Material

The original 87, 10 days composite images, range between April 1992 until September 1993 and February 1995 until December 1995. The geographical area was choosen to cover the same area as the 8 kilometre data set; 17° 00' N - 21° 00' N and 101° 00' E - 104° 00' E. From these scenes, the reprojected, digitised drainage areas of Nam Ngum and Nam Lik was used to extract the study area from the scenes (Appendix 1, figure II).

7.2 Method

The monthly maximum composited NDVI images, from April to September in each year, were added and their averages for 1992, 1993 and 1995 were calculated. In order to study the change in NDVI values, and thus the change of vegetation in the whole of Nam Ngum and Nam Lik catchment areas, the average images were subtracted from each other. A subtraction was carried out since this, according to Green K., Kempka D. and Lackey L. (1994), is a simple method for assessing land cover change is in forested areas.

Comparisons between 1995 - 1993, 1993 - 1992, and 1995 - 1992 were undertaken. The result from a subtraction would give negative NDVI values if there has been a degradation of the vegetation cover and a positive value if there has been a re-growth in the area (figure 16).

To make a comparison of the NDVI values with the precipitation, NDVI for an area of 400 km^2 was extracted around each precipitation station (20 x 20 pixels) (chapter 5.4). For visual interpretation, the NDVI data and the precipitation values were plotted (figure 18).

7.3 Result

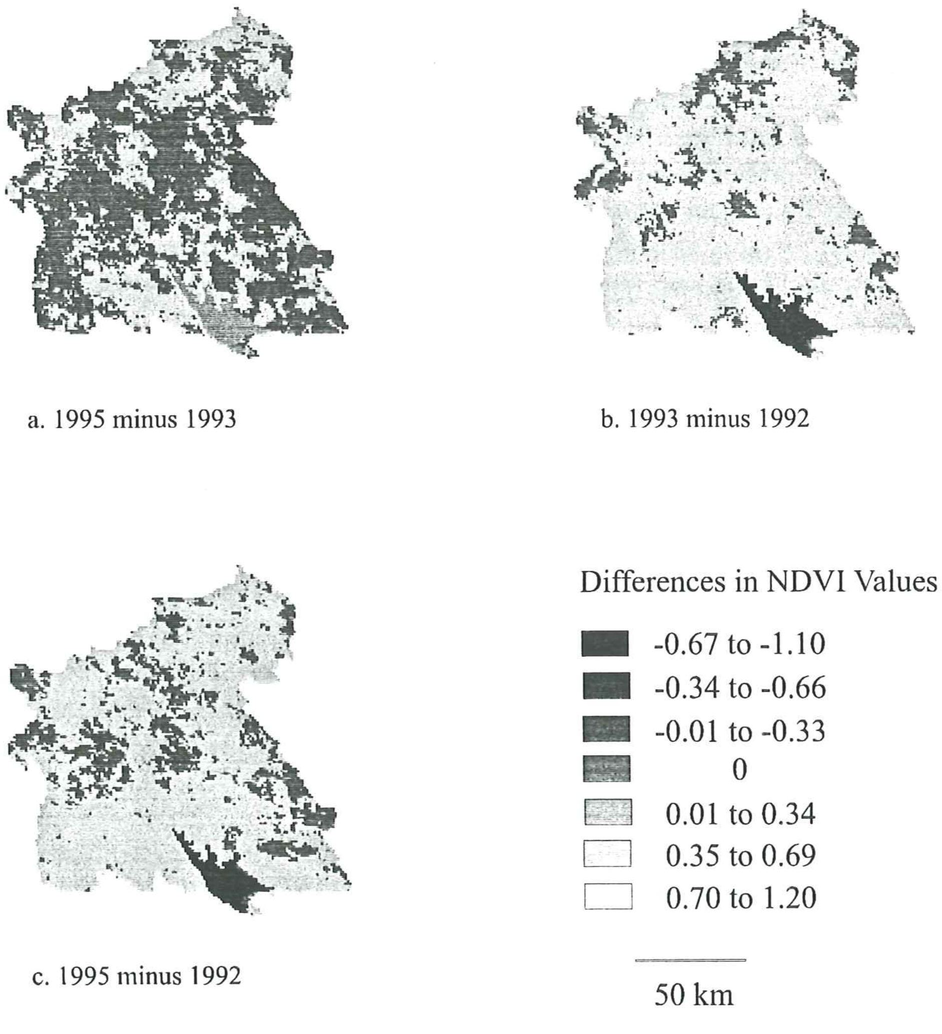
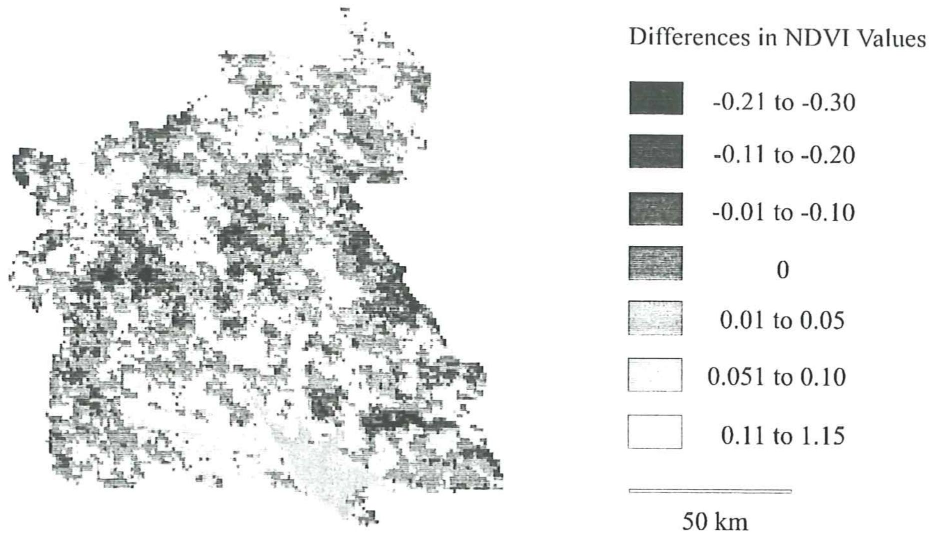


Figure 16. Comparison or 1995, 1993 and 1992 years April - September average NDVI values images in different combinations.



Figur17. Differences in average NDVI values for April - September, between the years 1995 and 1993.

Figure 16 compares the three years of averaged April to September NDVI values. At a first glance there seems to have been an extensive decline in NDVI values in 1995 compared to 1993 (figure 16a), over the whole drainage area, while the other year intervals show an overall increase (figure 16b and 16c). An explanation might be found in the differences in the amount of precipitation for the different years. Figure 16a is overall darker (negative NDVI values) than figure 16b and c, which could indicate that the NDVI values has decreased in 1995, compared to 1993. Inbetween the years 1992 and 1993 there seems to have been an increase in the NDVI (positive NDVI values), so that 1993 shows higher NDVI values than 1992. Subtracting 1995 from 1992 (figure 16c), there is no corresponding negative NDVI values as in the results of the 1995 - 1993 analysis, which could mean that 1992 has quite low overall NDVI values. The conclusion to be drawn from the results above is that the overall mean NDVI values increases from 1992 to 1993, and then decreases again in 1995.

Another distinct feature to notice is the dam. The thin bright outlining to the left side of the dam in figure 16a and c could be a sign of water level change between the different years. The water level has probably been higher in 1992 and 1993 than in 1995, which means that in the image from 1995 vegetation were growing where, in 1992 and 1993, the area was flooded with water.

In order to find smaller areas of NDVI change, the image was reclassified into more narrow class intervals, to facilitate the visual interpretation. Figure 17 shows the difference of two years, an overlay operation that subtracts the mean values for April to September in 1993 from 1995. In figure 17 it is possible to detect smaller areas of NDVI change. Dark colour in the image represents a possible resent clear cut in 1995, while bright colours could indicate that a clear cut has been taking place in 1993 or 1994.

A comparison was made with precipitation data for the same months (April to September), in the years 1992, 1993 and 1995 (figure 18).

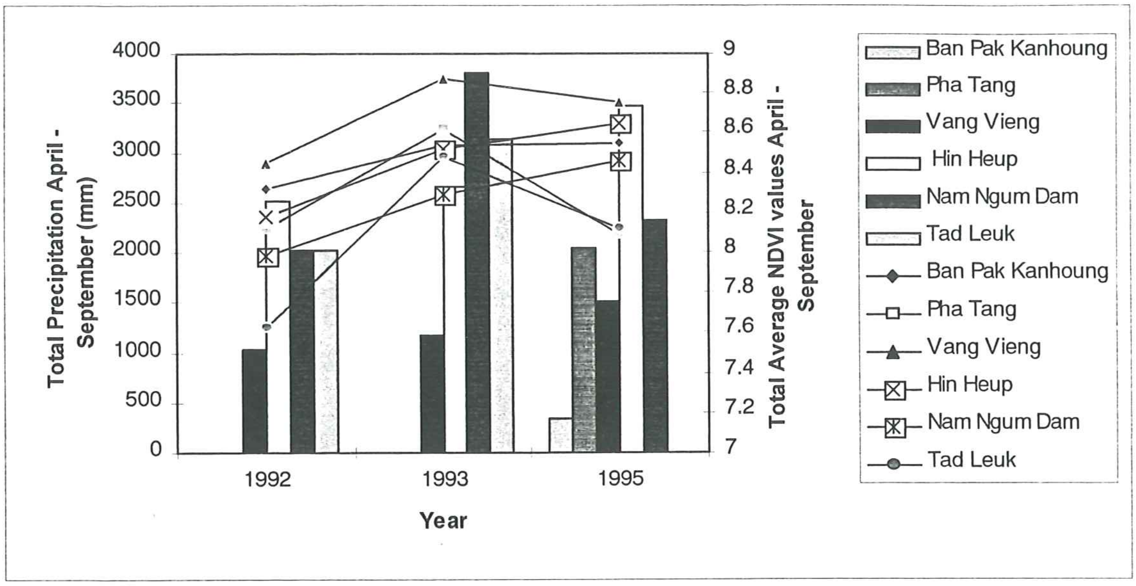


Figure 18. Precipitation and NDVI relation for the months April - September in the years 1992, 1993 and 1995. The bars indicate the precipitation values and the lines describe the NDVI.

There seems to be an overall good correspondence between the precipitation and the NDVI during these months and years. This would indicate that the main changes in NDVI, seen over the whole drainage area between the years, are a cause of climatological factors, and not extensiv human-induced deforestation. As seen in figure 16b and c the drainage areas seem to have overall higher NDVI values in 1993 and 1995 than in 1992.

7.4 Discussion

The rainy season, from May to October, means relatively higher NDVI values due to increased vegetation growth. Lower values during this time could on the other hand be explained by the frequent occurrence of clouds during the rainy season. Areas not covered with dense mature forest, such as grassland, cropland etc., responds to the rain with higher NDVI values due to the greening up, than mature forest.

In order to detect these changes in the vegetation cover, the 1 x 1 km data set is a possible method, if the areas of change exceed 0.5 km^2. To be able to carry out time series analyses with the 1 km AVHRR global land data set, the extent of the existing time series is still far too short and incomplete. The 10 day maximum value composite series comprise a total of 29 months with an interruption of 14 months in the middle of the time series. This means that only 3 years are represented, and none of them completely; there are always a few months missing. April to September are the only months that are represented in all three years, which is the reason why these months are the only ones analysed in this study.

No other statistical calculation, such as standardising the NDVI values, on the 1 km data set was estimated as possible due to its short time series.

8. Landsat MSS and TM

8.1 Material

The working material used in this task was one Landsat MSS scene and two Landsat TM scenes, as well as a DEM over the study area. More images were intended for analysis in the study, but had to be excluded because of too much cloud.

The MSS scene covers row 128 and path 47, and was registered on the 18th of March 1986. This scene was not radiometrically corrected so this had to be performed. Since no data on sun azimuth and sun elevation was given in the image header file (EROS Data Centre, 1998), and since this scene was registered almost by the same date as the Landsat TM, the same sun azimuth and sun elevation was used, as was provided for the Landsat TM-scene, i.e. 48 and 125 respectively.

The first TM-scene covers row 128 and path 47, registered on the 2nd of March 1989. According to the purchase guide, this scene was already radiometrically corrected when delivered (EROS Data centre, 1998).

The second TM-scene is from the same row and path as the other two scenes. Image acquisition was made on the 15th of February 1997. For this scene, radiometric corrections had also previously been made.

To be able to carry out multi-temporal studies of the different satellite images with overlay operations, a geometric correction had to be carried out.

The first step was to geometrically correct the Landsat MSS-scene to the Landsat TM 1989 scene by the PCI software module GCP Works, where Landsat TM (89) was given as "Master" (correct image) and the MSS scene as "Slave" (uncorrected image). A number of control points were selected in both images until the RMS error became less than 0.5 pixel.

The interpolation method chosen was the nearest-neighbour interpolation method because it preserves the original values in the unaltered scene, which is important for the visual interpretation of the images (PCI, 1994). Since the first task was to carry out a supervised classification, this was considered the most important factor.

The same geometric correction procedure was carried out with the Landsat TM 1989 as "Slave" and Landsat 1997 as "Master" and the same interpolation method.

To give the three images the correct geographical coordinates a final geometric correction was made with the three images as "Slaves" and the DEM as a "Master".

8.2 Method

The original intention was to carry out a supervised classification of the 3 images and then visually interpret the result as well as with overlay operations detect changes in the vegetation cover. Due to too much cloud in the images this method had to be excluded. A thin cloud cover over a major part of the image made it impossible to separate the different classes. For instance, the interpreted clear-cuts in one part of the image would have the same spectral signal as forest in another part of the image.

Because of this, another approach was chosen and a manual interpretation of the images was carried out; grassland fields were digitised in areas that were cloud free in all three years (appendix 1, figure III and IV) adding up to a total of five different study areas, in the PCI ImageWorks Software. Overlay operations were then carried out with the IDRISI Software (version 4.1), to detect the changes.

8.3 Results

8.3.1 Image Interpretation

The changes in the vegetation cover between the three different year-intervals were investigated, namely 1986 - 1989, 1989 - 1997 and 1986 - 1997 respectively.

Comparing the digitised grassland areas from the three years with overlay functions in the three categories of vegetation showed up as the result:

Unchanged Area - grassland in both two compared years
Deforested Area - forest in the first image and grassland in the second
Re-growth Area - grassland in the first image and forest/shrub in the second

The results from the comparative studies between the Landsat MSS and Landsat TM satellite images from different years are depicted in figure 19 to figure 21.

8.3.2 1986-1989

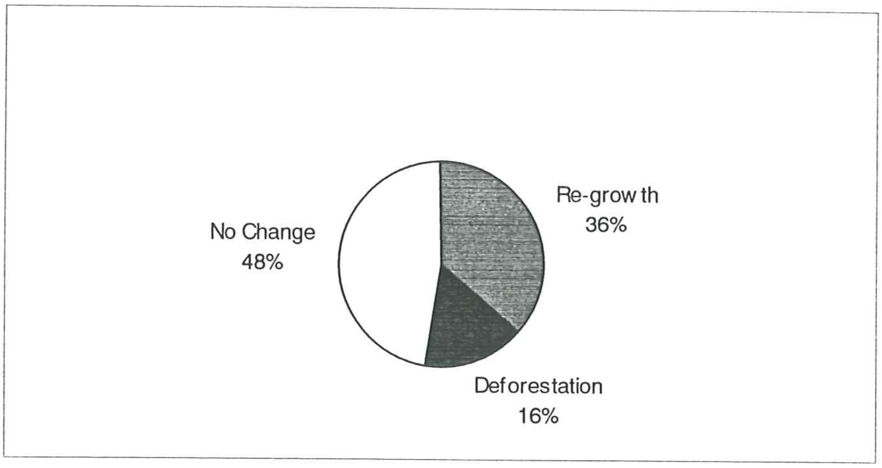


Figure 19a. Total vegetation change between 1986 and 1989, within the digitised grassland areas in all the five digitised areas.

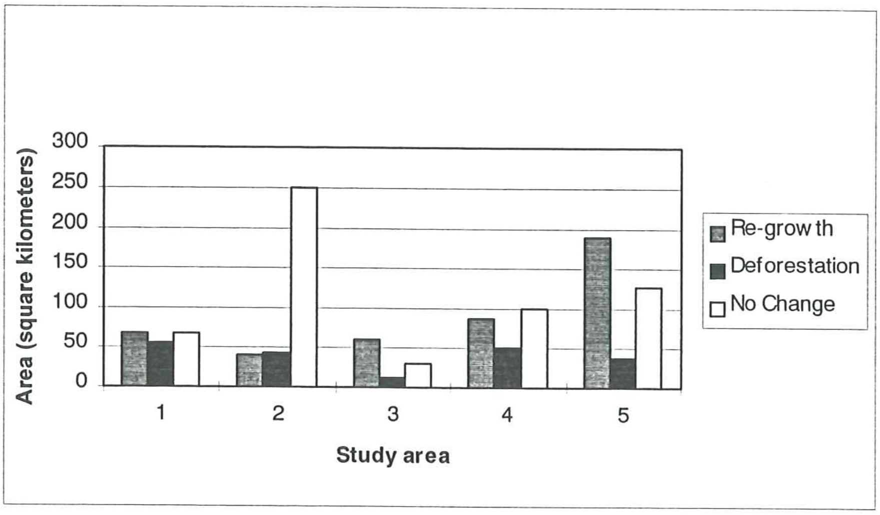


Figure 19b. Vegetation changes within each study area, between 1986 and 1989.

Between 1986 and 1989 the largest part of the area remained unchanged (48%), i.e. there is grassland both in 1986 and 1989, figure 19a. The re-growth within the study areas is larger (36%) than the deforestation (16%).

A look at the individual study areas, figure 19b, show that there are large differences between the study areas, but the general trend is that the re-growth is larger than the deforestation. Study area 2 remains mainly unchanged.

8.3.3 1989-1997

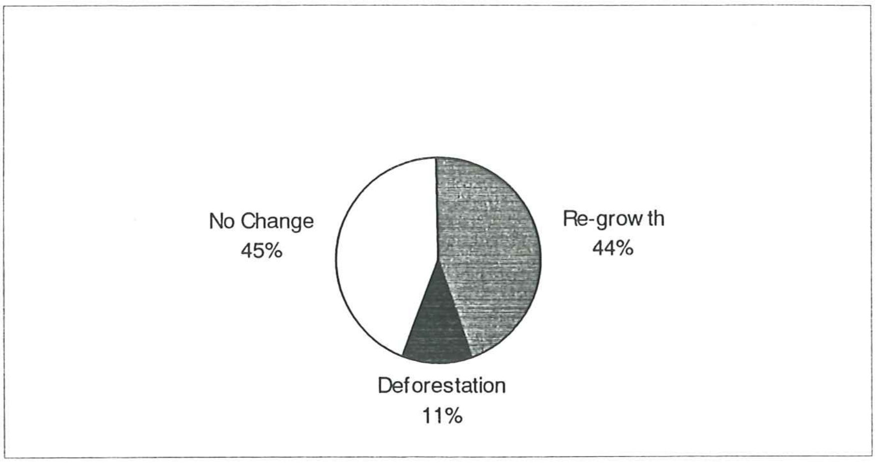


Figure 20a. Total vegetation change between 1989 and 1997, within the digitised grassland areas in all the five digitised areas.

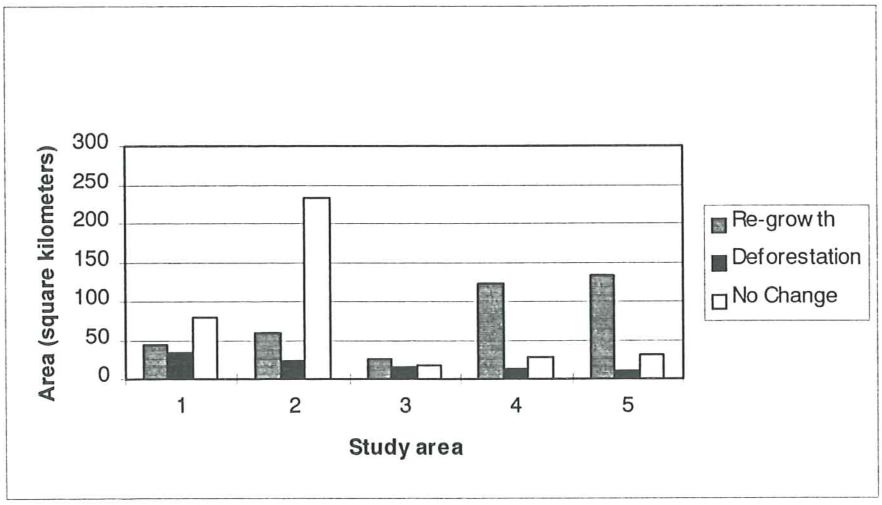


Figure 20b. Vegetation changes within each study area, between 1989 and 1997.

Between 1989 and 1997 (figure 20a), the re-growth area (44%) is almost as big as the unchanged area (45%) while the deforested area (11%) has decreased to some extent compared to the change between 1986 and 1989 (figure 19a).

Looking at the individual areas, figure 20b, there is a clear pattern with a more pronounced re-growth in area 4 and 5, compared with areas 1, 2 and 3. Study area 2 is still distinguished by showing a large total unchanged area.

8.3.4 1986-1997

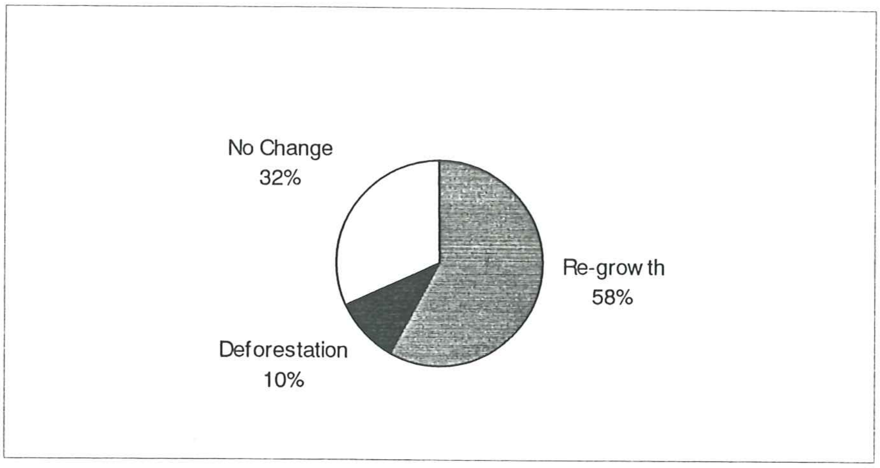


Figure 21a. Total vegetation change between 1986 and 1997, within the digitised grassland areas in all the five digitised areas

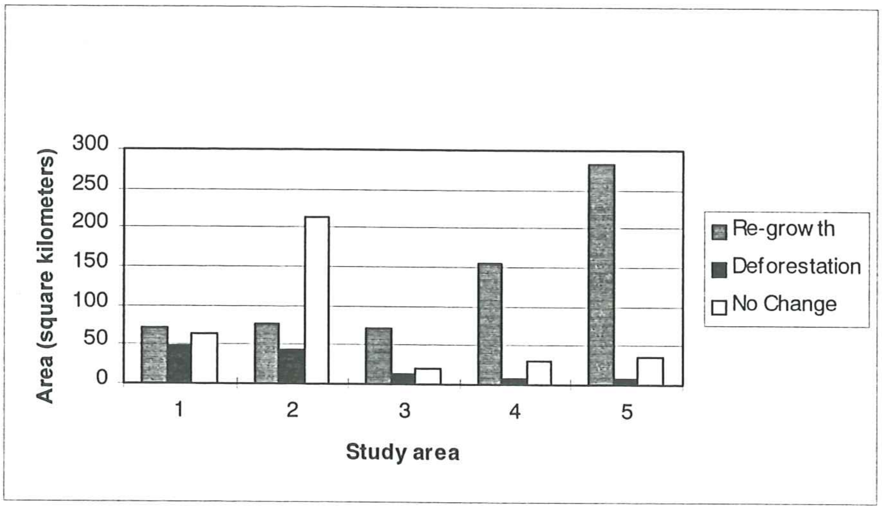


Figure 21b. Vegetation changes within each study area, between 1986 and 1997.

Comparing 1986 with 1997, shows that the outstanding feature in the five study areas is that re-growth is the dominant feature (58%) and that deforestation is very limited (10%), figure 21a.

Looking at the individual study areas, area 2 once again distinguish by its very high proportion of unchanged grassland. Area 4 and 5 distinguish by their high rates of re-growth, figure 21b.

8.4 Discussion

The result from these limited study areas is not to be regarded as an overall truth for the land use change within the Nam Ngum and Nam Lik catchment areas. The goal was to try to find a method for locating new or increasing deforestation areas by looking at satellite images. The choice of study areas was a result of our limited working material (the satellite images) and the frequent occurrence of clouds that they presented.

The study concentrated on larger grassland areas, but it was noticed while working with the images, that a lot smaller areas were easily discerned in both Landsat MSS and Landsat TM (Appendix 1, figure IV). Those small deforested areas are probably of more interest since they possibly represent the illegal deforestation that can be hard to survey and control by surface observation, for example when they occur in remote mountain areas.

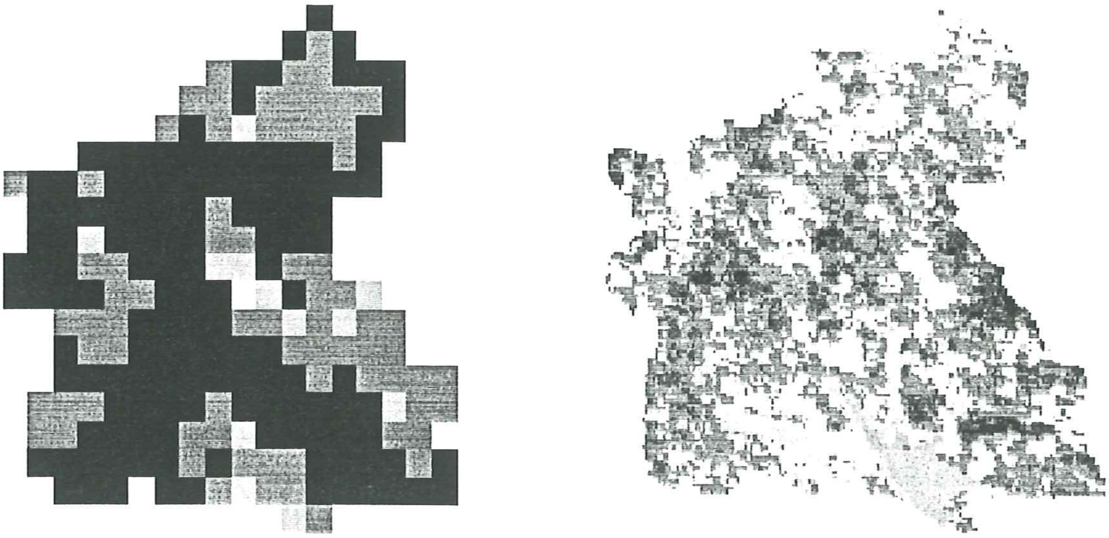
No accuracy evaluation of the classification errors with ground truth data of the study area in the Lao PDR could be carried out due to problems mentioned in the aim that resulted in limited field studies. Possible areal errors in this study are errors introduced during the on-screen digitising such as, for example, wrong interpretation, non-exact boundary tracing, line thickness compared to the resolution etc. The interpretation errors result from the fact that the colour gradation between different phases of re-growth in the vegetation cover presents no distinct and sharp boundaries, so only subjective decisions can be made.

Some interpretation difficulties originates from the difference in resolution between the MSS-scenes and the TM-scenes. The finer resolution in the TM-scenes facilitated the decision of the boundaries, since they were sharper.

9. Discussion / Summary

One of the advantages with satellite images with a broad resolution, especially in the tropical area where it often is cloudy, is that they provide a daily covering (Mayaux and Lambin, 1995). The results from the analysis of the NOAA/NASA Pathfinder AVHRR Land Project 8 km data set indicate that changes in the vegetation can be identified both temporally and spatially. In order for the change to be detectable in the eight kilometre pixel the area has to cover more than half the pixel size, i.e. more than 32 km^2. For areas smaller than this, a finer resolution is needed, for example the 1-km AVHRR Global Land Data Set or Landsat scenes.

Figure 22 emphasises the visual difference between the two AVHRR satellite resolutions (8 x 8 and 1 x 1 km). For each single 8 x 8 km pixel, the area in the 1 x 1 km resolution is instead represented by sixty-four 1 x 1 km pixels, which means that sixty-four different spectral classes can be represented for each one 8 x 8 km pixel value. Another disadvantage is that the 8 x 8 km pixel has a quite poor resolution since it is produced out of processing a number of pixels from the 4 x 4 km GAC data set (Chapter 5.1.1).



a) b)

Figure 22. Nam Ngum and Nam Lik Catchment areas displayed in: a) the 8 km resolution and b) the 1 km resolution.

One major limitation for the 1 km data set is the short time series available. Until more data are included it is not a realistic alternative for any more advanced statistical calculations. The alternative is still the 8 km data set regarding trend analyses of longer time series, especially since the 1 km data set does not extend further back than 1992. As both data sets are constantly being upgraded with new scenes, the 1 km data set will probably not be able to compete with the 8 km data set for quite some time, when it comes to analysing longer time series. For comparisons between the available years the 1 km data set is to be preferred, compared with the 8 km data set, due to its higher spatial resolution, which facilitates the detection of changes in smaller areas (larger than 0.5 km^2) and gives a more precise location of these areas.

The Landsat images, both the MSS and the TM scenes, provides the best spatial resolution. The smallest detectable areas in this resolution is half the pixel size, in this case $45*10^{-5}$ km^2. Consequently, this is the smallest area of change in the vegetation cover, that could be detected with the data sets analysed in this study. A disadvantage with the Landsat images compared to the NOAA AVHRR images is that there are no daily records available. A finer resolution also often results in higher cost if larger areas are to be surveyed. A trade off has to be made between the aim, the need for a finer resolution, and the cost. Justice et al. (1985) has come to the conclusion that the LAC images of 1 x 1 kilometre resolution can give the same amount of information on the vegetation's dynamics as the Landsat images at a regional scale (1:100 000).

In this study all the material has been provided at a nominal cost on the Internet. Regarding the Landsat images they are only provided for non-commercial purposes. As a consequence it was not possible to choose images according to the needs; some images were quite cloudy as well as contained some erroneous lines. Still these might be the best images available, considering the fact that the area is situated in a tropical environment, where rain and the occurrence of clouds are common. To detect a change of vegetation under these conditions, our method of manually digitising the areas of interest and then carry out overlay operations, might be the most suitable. If cloud free images can be obtained a classification is to be preferred.

The lack of precipitation data coverage, both temporally and spatially, makes interpretation difficult. The accuracy of the data used in the study is not always reliable, which has to be kept in mind during the evaluations of the correlations between precipitation data and NDVI values. An extensive and reliable database of precipitation data, with long time series from each precipitation stations would be preferable during this kind of study. Stations at different elevations, land use etc., are needed to give a good overall estimation of the precipitation within an area. An alternative approach on studying the climatological impacts on the vegetation, and thereby the NDVI, is to compare the NDVI variations with temperature variations. In humid areas where water is not a limiting factor, the temperature might have a major impact on the vegetation, especially at higher elevations (Justice et al., 1985).

Other studies that have been carried out with the NOAA AVHRR NDVI data indicate that this can be used for detection and delineation of deforested areas. Information on for example seasonality can also be established from processing of the NDVI NOAA AVHRR (Justice et al., 1985). They also suggested to use the individual spectral bands of the AVHRR, that are also available at GAC and LAC scales.

An example for using other spectral bands of the NOAA AVHRR for detecting vegetation changes is visualised in figure 23. Apart from using the NDVI index for measuring vegetation and changes in the vegetation cover there are other vegetation indices to be used. Figure 23 compares an NDVI image (figure 23a) with an image produced by overlay operations with the second and third channel of the NOAA AVHRR 8 (figure 23b). The image in figure 23b) is derived by using the NDVI equation (chapter 5.1.8), but exchanging the first channel in the AVHRR with the third. The third channel in the NOAA AVHRR measures the wavelengths 3.55 - 3.93 µm. These wavelengths are especially sensitive to vegetation and soil moisture. This index therefore gives a good indication of areas where there recently has been a grass or forest fire, since this causes the moisture content to evaporate. Since many of the clear cut areas in the study area has been exposed to fires, this could be another way of detecting areas where the vegetation has been cleared. A distinct feature to notice in figure 23b compared with 23a, is the improved dynamic range in the image.

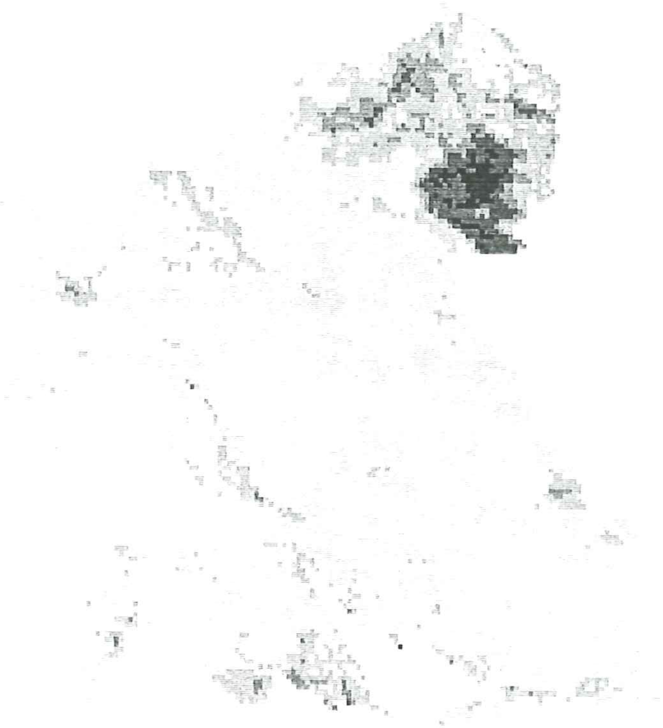


Figure 23a). NDVI image from December 1992. The darker areas are areas with less vegetation.

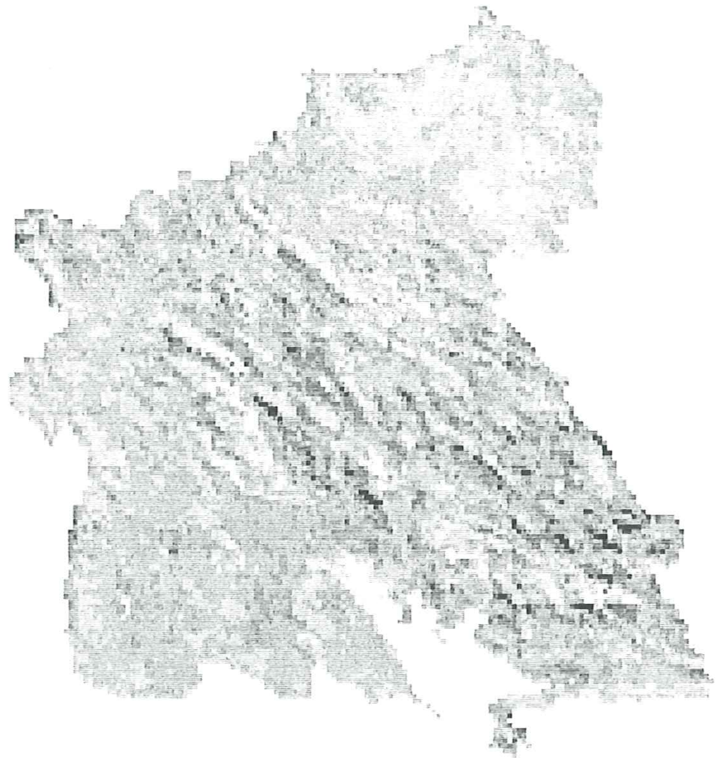


Figure 23b. MIR-index image from December 1992. Darker areas show areas that lack soil moisture, i.e. areas that recently could have been exposed to grass fires.

An area that is easily distinguished in figure 23 as well as in figure 3 (chapter 4.1.6) is the north-east corner of the study area, the Xieng Khouang plateau. As has been mentioned before, the area is characterised by vast grasslands. The grasslands are burnt every year around this time (December). The reason why figure 23b is not showing the dark colours in this area that ought to result from fire, might be explained by higher precipitation for this year or that the fires have not yet started. The NDVI values in figure 23a indicates that the area is not densely vegetated.

Other methods that could be used for studying the vegetation cover is to use other meteorological satellite systems than the AVHRR, for example the METEOSAT (for Africa and Europe) and the Geostationary Meteorological Satellite (GMS, for Western Pacific). The main drawbacks in the case of METEOSAT satellites are the inability of these to select certain spectral bands, which excludes the possibility to calculate vegetation indices like NDVI and others (Justice et al., 1985).

A comparison between the result from the four resolutions is desirable, but unfortunately not possible because;

- The material provided is from different years and different months; at the best a dual comparison can be undertaken between two images at two resolutions, but never at all three resolutions at one time and place.
- Cloud are further limiting comparison between images when images do occur from the same time and place.
- To standardise the material is only applicable for the 8 x 8 km data set, since the other data sets, i.e. the Landsat and the 1 x 1 km data set are too short.

As mentioned in chapter 8.4, the limited field studies prevented any accuracy assessment of the interpretations of the satellite data.

The results from the methods evaluated above can be improved further by combining the areas of vegetation change with the knowledge of other important key parameters in the soil erosion equation. The data can be combined with information of for instance slope, rainfall erositivity, soil erodibility, land use, population pressure and farming practise.

According to this survey, no extensive deforestation areas were found within the study area. This result is consistent with the low sedimentation rate in the Nam Ngum dam, that has been measured and estimated by different research teams.

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Finally we would like to express our sincerest acknowledgements to the following persons, for their help on our way to carry this Masters Thesis through:

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Appendix 1

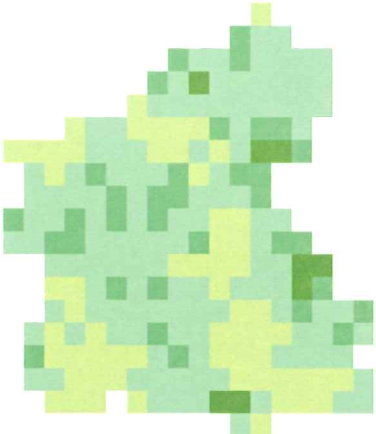


Figure I:
Raw data from the
NOAA/NASA Pathfinder AVHRR Land Project 8 km Data Set
extracted to fit the study area.

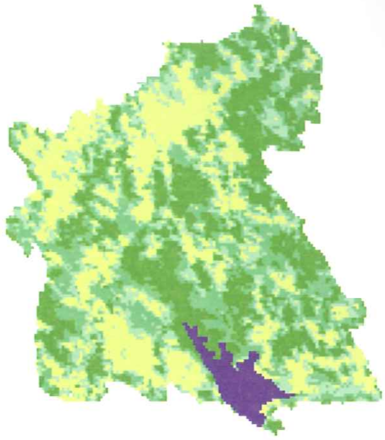


Figure II:
Raw data from the
1 km AVHRR Global Land Data Set
extracted to fit the study area.

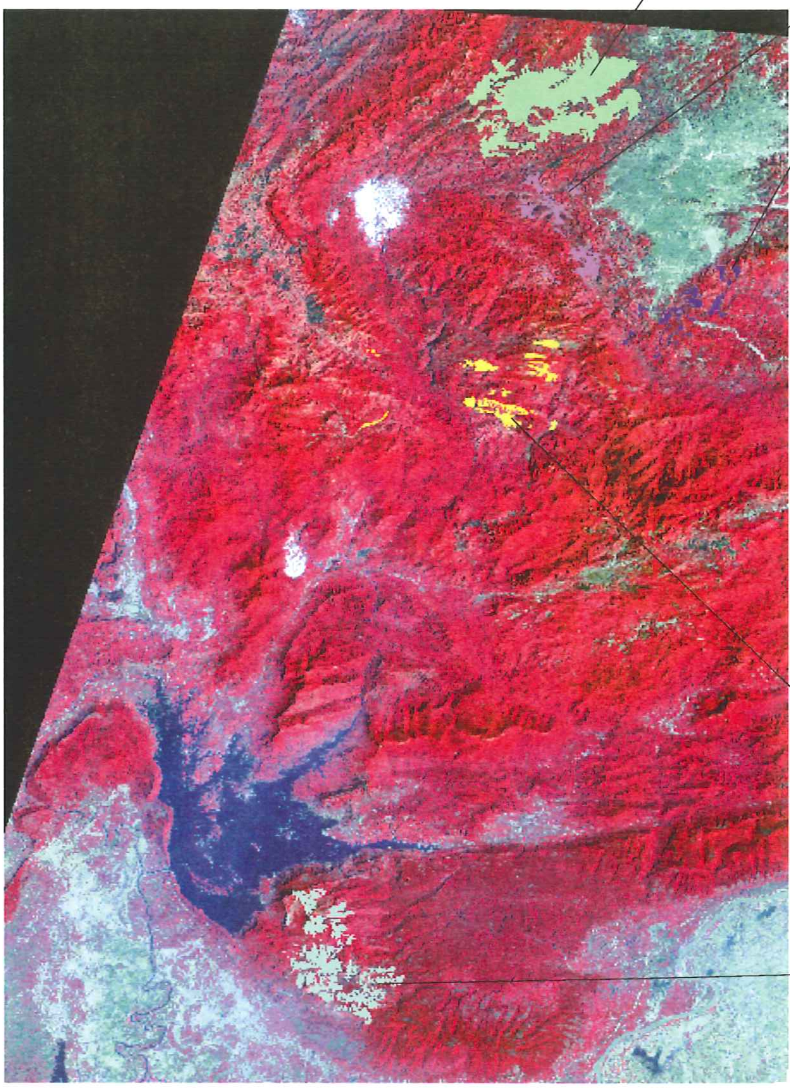
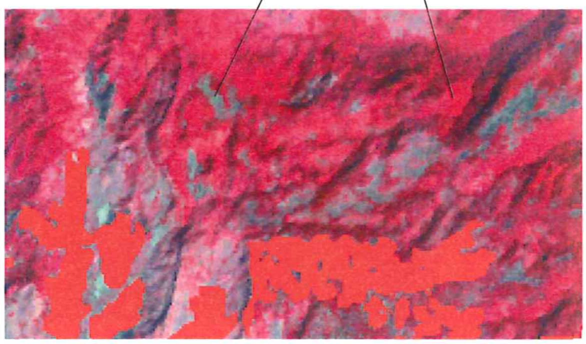


Figure III
The digitised grassland study areas overlaying a Landsat TM 1997 scene.



Figur IV
Landsat TM 1997, showing that even smaller areas
are detectable than what has been digitised in this study.

Appendix 2

Figure V
The Xieng Khouang Plateau, with its characteristic dry grass lands. In the lower left of the image craters from the bombings during the Vietnam War can be seen.

Figure VI
The mountains in the northern part of the study area, where the natural forest cover has been removed from the steep slopes.

Figure VII
The mountainous region of the northern part of the study area. The natural forest cover is still intact in many areas, but it is easy to distinguish the fields that have been cleared for shifting cultivation practises.

Appendix 3

Precipitation (mm)	Pak Kanhoung	Pha Tang	Vang Vieng	Hin Heup	Nam Ngum Dam	Tad Leuk
Jan-87			0	0	26	
Feb-87			0	0	113	
Mar-87			0	9	45	
Apr-87			13	24	49	
May-87			247	23	105	
Jun-87			351	224	603	
Jul-87			265	204	450	
Aug-87			615	559	667	
Sep-87			481	329	277	
Oct-87			132	174	83	
Nov-87			68	14	105	
Dec-87			0	0	0	
Jan-88			0	0	0	
Feb-88			14	1	45	
Mar-88			3	2	9	
Apr-88			13	21	63	
May-88			57	127	221	
Jun-88			300		228	
Jul-88			367	532	472	
Aug-88			572	701	673	
Sep-88			157	283	118	
Oct-88			189	292	59	
Nov-88			3	4	37	
Dec-88			0	0	0	
Jan-89			22	157	18	
Feb-89			9	0	0	
Mar-89			131	176	67	
Apr-89			89	134	187	
May-89			329	259	315	
Jun-89			454	493	541	
Jul-89			336	725	440	
Aug-89			196	317	453	
Sep-89			425	405	372	
Oct-89			218	145	242	
Nov-89			18	10	0	
Dec-89			0	10	0	
Jan-90	0		0	10	19	
Feb-90	32.1		13	26	51	
Mar-90	46		89.2	147	101	
Apr-90	35.2		4	81.5	59	
May-90	317		305	425.4	268	
Jun-90	380.2		1031.6	1100	526	
Jul-90	299.4		514	879	973	

Precipitation (mm)	Pak Kanhoung	Pha Tang	Vang Vieng	Hin Heup	Nam Ngum Dam	Tad Leuk
Aug-90	332.4		196.4	538.1	303	
Sep-90	236.4		238	282.4	398	
Oct-90	63.4		69	151	128	
Nov-90	86		13	204	64	
Dec-90	0		0	0	0	
Jan-91			2		0	0
Feb-91			0		0	0
Mar-91			24		21	0
Apr-91			4		73	0
May-91			176		194	113
Jun-91			305		405	411
Jul-91			401		419	429
Aug-91			294		320	437
Sep-91			280		242	304
Oct-91			280		43	130
Nov-91			0		10	0
Dec-91			2		0	19
Jan-92			26	93	0	33
Feb-92			26	64	0	50
Mar-92			7	0	0	2
Apr-92			1	19	0	20
May-92			102	191	165	201
Jun-92			131	635	227	485
Jul-92			255	803	580	441
Aug-92			293	481	298	669
Sep-92			239	386	194	203
Oct-92			3	138	36	89
Nov-92			0	6	0	0
Dec-92			31	55	0	59
Jan-93			0	0	0	0
Feb-93			3	81	11	16
Mar-93			8	26	0	16
Apr-93			64	119	74	210
May-93			164	429	193	482
Jun-93			258	429	650	654
Jul-93			317	966	548	820
Aug-93			201	400	277	329
Sep-93			157	305	156	633
Oct-93			33	39	18	0
Nov-93			0	0	0	0
Dec-93			0	0	0	0
Jan-94			0	0	0	0
Feb-94			0	41	45	130
Mar-94			75	118	149	117

Precipitation (mm)	Pak Kanhoung	Pha Tang	Vang Vieng	Hin Heup	Nam Ngum Dam	Tad Leuk
Apr-94			70	122	101	174
May-94			364	190	115	315
Jun-94			244	668	338	780
Jul-94			186	841	437	698
Aug-94			345	716	146	651
Sep-94			258	530	116	607
Oct-94			101	157	84	192
Nov-94			1	0	3	0
Dec-94			0	0	50	56
Jan-95	0	0	2	0	0	
Feb-95	0	11	0	0	0	
Mar-95	9	64	13	67	34	
Apr-95	81	93	93	66	118	
May-95	151	226	61	185	253	
Jun-95	287	371	267	762	464	
Jul-95	630	412	485	701	543	
Aug-95	627	641	452	1337	882	
Sep-95	261	293	140	407	64	
Oct-95	117	170	46	137	54	
Nov-95	0	68	3	38	0	
Dec-95	0	0	0	0	0	
Jan-96	0	0	2	1	0	
Feb-96	13	11	0	15	23	
Mar-96	0	52	13	63	61	
Apr-96	164	250	93	0	274	
May-96	134	254	61	0	162	
Jun-96	377	405	267	0	380	
Jul-96	319	433	485	0	763	
Aug-96	273	622	462	1024	732	
Sep-96	404	398	129	562	301	
Oct-96	62	47	47	213	111	
Nov-96	122	271	3	231	0	
Dec-96	0	0	0	0	33	

Appendix 4

Material:

The NOAA/NASA Pathfinder AVHRR Land Project 8 km Data Set
The 1-km AVHRR Global Land Data Set
Landsat MSS/TM scenes
Digital Elevation Model (DEM)
Precipitation Data
Topographic Maps (1:200 000) Lao National Geographic Centre (Service Geographique D'etat)

Data used by the authors in this study include data produced through funding from the Earth Observing System Pathfinder Program of NASA's Mission to Planet Earth in cooperation with National Oceanic and Atmospheric Administration. The data were provided by the Earth Observing System Data and Information System (EOSDIS), Distributed Active Archive Center at Goddard Space Flight Center which archives, manages, and distributes this data set.

The 8 km data set arrived in the format :

Composite Data Set 12 5004 x 2168 HDF (SDS) 35 MB/228 MB Ancillary Data File 4 5004 x 2168 HDF (SDS) 18 MB/50 MB

The DEM was provided by the MRC (Mekong River Commission), Watershed Classification/ FCMP Projects, 1997.

Software:

PC Arc/Info Software (Version 3.4.2.).
IDRISI Software (4.1).
IDRISI for Windows Software (Version 2)
Goodeinv (University of Lund, Department of Physical Geography)
Microsoft Excel Software (Version 7.0).
Minitab Software (Version 11 for Windows)
PCI ImageWorks Software
PCI software module GCP Works
Projectv (University of Lund, Department of Physical Geography)
T_ser program (University of Lund, Department of Physical Geography)
Tserz program (University of Lund, Department of Physical Geography)