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Detecting forest degradation in Marakwet district, Kenya, using remote sensing and GIS

– in cooperation with SCC-Vi Agroforestry

A Minor Field Study

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Master's Degree in Physical Geography and Ecosystem Analysis

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Abstract

Deforestation is a widespread problem and has many negative impacts. The biggest threat to forest is human activities. Despite increasing efforts regarding forest management and forest conservation, the deforestation continues at a high rate to give space for other land uses such as agriculture and pasture. The world's population continues to grow and Africa is the continent with fastest growing population. During the last 100 years this has led to major changes in the African landscape, and Kenya is no exception.

This MFS (Minor Field Study) was conducted in cooperation with the nongovernmental organization SCC-Vi Agroforestry. The study area is located in Marakwet district in western Kenya and the district has one of the largest remaining natural forests in the country. At the same time, the area is experiencing ongoing illegal deforestation.

The aim of the study was to investigate and map the deforestation in the study area during the 23 years period from 1986 to 2009 by using satellite data. Furthermore, the aim was to create a future scenario. Data of the population in the district was then compared with the results to find a correlation.

The result indicates great changes in forest cover. During the 23 years period, 4 149 hectares of forest have been cleared in the study area, representing a decrease of 14 percent. The deforestation rate has decreased but the problem remains. If nothing is done to prevent the ongoing deforestation, 45 percent of the forest in the study area will disappear until the year 2100.

Key words: Geography, Physical Geography, GIS, Remote Sensing, MFS, Kenya

Sammanfattning

Avskogning är ett globalt problem och har många negativa effekter. Det största hotet mot skogen är dessvärre människan. Trots ökade satsningar på hållbar skogshantering och skogsvård så fortsätter avverkningen av skog i snabb takt världen över, för att ge plats åt andra typer av markanvändning så som jordbruks- och betesmark. Världens population fortsätter att öka och Afrika är den kontinent med snabbast växande befolkning. Under de senaste hundra åren har detta medfört stora förändringar i det afrikanska landskapet och Kenya är inget undantag.

Den här studien utfördes i samarbete med biståndsorganisationen Vi-skogen. Studieområdet ligger i distriktet Marakwet i västra Kenya och distriktet har ett av de största kvarvarande naturliga skogsområdena i landet. Samtidigt är området hårt utsatt för illegal avskogning.

Syftet med studien var att med hjälp av satellitbilder kartlägga och beräkna hur stor areal skog som försvunnit i studieområdet under 23-års perioden 1986 till 2009, samt skapa ett framtidsscenario. Resultatet jämfördes sedan med populationsdata i distriktet för att finna ett samband.

Resultatet visar att det skett stora förändringar i skogens utbredning. Under tidsperioden på 23 år har 4 149 hektar skog avverkats i studieområdet, vilket motsvarar en minskning på 14 procent. Hastigheten i vilken skogen försvinner har minskat, men problemet med avskogning kvarstår. Om ingenting görs för att hejda den aktuella avskogningen kommer 45 procent av skogen i området att försvinna till år 2100.

Nyckelord: Geografi, Naturgeografi, GIS, Fjärranalys, MFS, Kenya

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Without the Swedish International Cooperation Agency's (SIDA) scholarship for Minor Field Studies, we would not have been able to perform this study. This scholarship was granted from the Department of Earth and Ecosystem Science at Lund University, which we want to thank for giving us the opportunity to perform the field study.

We would like to express our gratefulness to SCC-Vi Agroforestry in Kenya which supported us with information, material, transportation and friendship. The field work in Kenya was made possible with the help from Bo Lager, Ylva Nyberg, Fred Marani, Robert Musikoyo, Edward Masinde, William Libusi, Juliet Chepto, Stephen Akoto and John Owour. Thank you all.

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Table of Contents

1. Introduction

This study was funded by a scholarship from the Swedish International Development Cooperation Agency (SIDA)[1] and was performed in Kenya during the spring of 2010 as a Minor Field Study (MFS).

The MFS Scholarship Programme is intended to give Swedish students a deeper knowledge about developing countries and development issues. Moreover, it is supposed to improve contacts and increase cooperation between departments at Swedish universities and institutes or organizations in developing countries.

The study was made in cooperation with the non-governmental organization Swedish Cooperative Centre (SCC) Vi Agroforestry in Kenya. Hopefully this may lead to a continued collaboration between Lund University and SCC-Vi Agroforestry in the countries around Lake Victoria.

As a part of the MFS Scholarship Programme, the purpose of the study was to gain knowledge and work experience in a developing country. Furthermore, the field study aimed to highlight the problems associated with forest degradation in Kenya and, in the long run, hopefully improve the livelihood for small-scale farmers.

1.1 Outline of the text

This section will guide the reader through the work. The first chapter gives an introduction to the study and begins with background followed by the objectives and research questions. Chapter 2 continues with information about the study area, with an introduction of Kenya as a country and a description of Marakwet district. In Chapter 3, the theoretical background is described. This is followed by a description of the data and method in Chapter 4. The results are presented in Chapter 5 and Chapter 6 discusses the results and the methods used in this study. Finally, the conclusions are found in chapter 7.

1.2 Background

For many centuries the world's forests have been under pressure due to increasing human population (UNEP, 2001). Deforestation is a process where forests are cut down, burned and damaged. It has been occurring globally for many centuries (Urquhart et al., 2001). Unfortunately, the deforestation rate has increased drastically in developing countries in the last 50 to 100 years (UNEP, FAO and UNFF, 2009).

[1] All abbreviations are found in Appendix 1

Deforestation threatens ecosystems in tropical forests since these processes lead to biodiversity loss (Lung and Schaab, 2009). With a growing population follows expanding agriculture, increasing commercial logging, increase in plantations, mining, industrialization, urbanization and building of roads, which all lead to deforestation in the tropical regions (Duveiller et al., 2008). There are also natural factors that affect the world's forests, such as natural disasters, forest fires, insect attacks and other diseases. Of these factors, the main cause of deforestation is conversion from tropical forest into agricultural land and pasture for livelihoods (FAO, 2010).

Forests are of great importance in order to sustain life support systems on Earth. Forests are also essential for the development of the socio-economic sector for many nations, since forests provide raw materials for industry, timber and fuelwood for the basic needs and employment of the population (UNEP, 2001). There are several criteria for an area to be defined as forest. UNEP's (2001) definition of forested area is not the same for developing countries and developed countries. In developing countries, forests must have a crown cover of at least 10 percent, consisting of either trees and/or bamboo. Wild flora and fauna are also needed, as is a natural soil condition. Furthermore, to be defined as forest the area cannot have ongoing agriculture. The most significant difference in the criteria for developed countries is that a crown cover of 20 percent or more is needed (UNEP, 2001).

Closed forests are defined as areas with a tree cover of 40 percent or more (UNEP, FAO and UNFF, 2009). Forests with an undisturbed ecology and with no indications of human activity are referred to as primary forests. Of all terrestrial ecosystems, primary forests are characterized as the most species-rich and diverse (FAO, 2010). Areas that have a vegetation cover other than forests, but are not under intensive land use, are defined as woodland. The most common land use in woodland areas is pasture (Holmgren, 2006).

At present, the world's forests cover about 4 billion hectares, which accounts for 31 percent of the world's land area. The distribution of the world's forests is shown in **Figure 1.1**. It illustrates the distribution of forests on a global scale. Other wooded land covers about 1.1 billion hectares (FAO, 2010). The areas of the world's forests can be seen in **Table 1.1**.

In Africa, forests cover about 21.4 percent of the land area (FAO, 2009), which corresponds to 674 million hectares (FAO, 2010). In Eastern Africa, approximately 13 percent of the land area is covered by forests and woodlands which make the resources rather limited.

(WRI, 2007).

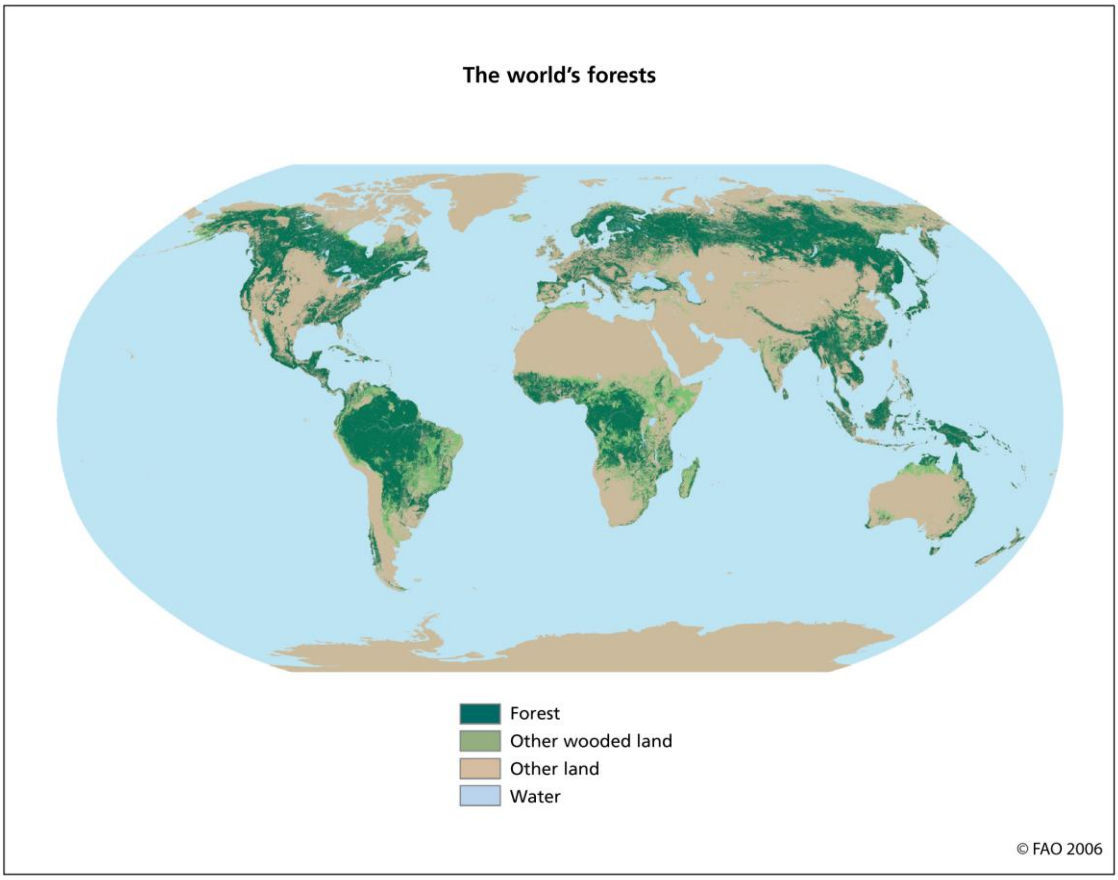

Figure 1.1. *Distribution of the world's forest. Source: FAO, 2006.*

Table 1.1. *Global forest distribution by region. Source: FAO, 2010.*

Region	**Forest area (million hectares)**
Africa	674.4
Asia	592.5
Central America	19.5
Europe	1 005.0
North America	679.0
Oceania	191.4
South America	864.4
World	**4 033.1**

Kenya is the most forested country in Eastern Africa with a forest and woodland cover of 17 million hectares which corresponds to a third of the land area (UNEP, 2006). Despite this fact, closed forest cover only 1.7 percent of the land area in Kenya (WRI, 2007).

Numerous reports and studies have been performed concerning the extension of forested areas and deforestation. However, in many countries, there is no regular monitoring system that collects information about the condition of the forests and trends of the distribution (UNEP, 2001). This makes it difficult to determine the status of the existing forest cover. Particularly within Africa, only a few studies on tropical forest environments focusing on deforestation have been conducted (Lung and Schaab, 2009). Kenya is a good example of a location which it is difficult to obtain accurate and ‘up to date’ data on forest loss and forest degradation (Matiru, 1999). To get a better understanding about change processes in these environments more studies are needed (Lung and Schaab, 2009).

The loss of forest through deforestation has many negative impacts on the environment and climate. Forests hold approximately 70 percent of all land-living animals and plants, and millions of species are affected by deforestation since it destroys their natural habitat (National Geographic, 2010).

Another consequence of deforestation is climate change, since forests affect the composition of greenhouse gases in the atmosphere (National Geographic, 2010). According to Urquhart et al. (2001) deforestation increases the amount of carbon dioxide (CO_2) and other trace gases in the atmosphere.

In the 1990’s, the global reduction of forests was 16 million hectares per year. At the present time, the forest loss has decreased to approximately 13 million hectares per year. The largest net loss of forest occurs in South America and Africa. Between 2000 and 2010, about 4.0 million hectares were lost annually in South America followed by Africa with a forest loss of 3.4 million hectares per year. The net loss of forests has been significantly reduced, mainly because of several projects including forest planting, restoration of landscape and natural expansion of forests (FAO, 2010). But even if the net loss of forests is decreasing in some parts of the world, it still continues at a high rate in other countries (FAO, 2006). In recent times, industrialized countries have experienced a decreased deforestation rate but deforestation has accelerated in developing countries (Boahene, 1998).

In the past hundred years, there have been major land cover changes in East Africa. Between 1900 and 1990 cropland increased 200 percent at the expense of tropical forests. This has a distinct negative effect on tropical forest areas. The deforestation rate in East Africa between 1990 and 2000 was four times higher than the world average. The main reason for the large forest loss in East Africa is the increasing population (Lung and Schaab, 2009).

The world's population continues to grow rapidly and is a driving force of deforestation, which in turn will determine the state of the environment in the future (Lung and Schaab, 2006; UNEP, 2006). The world's population is approximately 6.8 billion, according to estimates from July 2010 (The World Factbook, 2010a). In the year 2000, Africa had a population of 798 million which represented 13 percent of the world's population (UNEP, 2006). Africa is the world's fastest growing region with an annual growth rate of 2.1 percent and is projected to have a population of 1.3 billion in 2025.

The struggle towards sustainable forest management in Africa has during the last ten years shown positive trends, even if some regions still are experiencing negative effects on the forests. Expansion of protected areas with the purpose of conserving biodiversity has led to an overall reduction in deforestation. But problems remain. Overall, forest plantations and protected areas are on the rise, but the loss of primary forests is still continuing at a high rate as these forests are turned into other land uses. Africa is still facing rapid forest loss and most threatened are the primary forests. It is uncertain what will happen with the world's forests in the future (FAO, 2010). If deforestation continues at the same rate as at present all productive forests in Africa are expected to be depleted within the next 100 years (Boahene, 1998).

1.3 Objectives of the study

According to recent reports from both the Food and Agriculture Organization (FAO, 2010) and the United Nations Environmental Programme (UNEP, 2001; UNEP, 2006), the world's forests are decreasing at an alarming rate. Since forests are vital for sustaining life and essential for the socio-economic development of many countries (UNEP, 2001), studies about changes in forest cover and their status are of great importance to inform governments and the public for further work with sustainable forest management (Lung and Schaab, 2009).

The primary aim of this study is to investigate and map the deforestation in the study area in Marakwet district in Kenya. This will be achieved through image interpretation and by conducting a time series analysis based on Landsat data from 1986, 1995, 2003 and 2009. In addition, population data will be collected in order to see if there is any correlation between a growing population and deforestation in the study area. Moreover, an overall deforestation rate will be calculated. This will then be used to create a future scenario, showing how much forest will be left in the area within the next 89 years, 2010 to 2100, if nothing is done to prevent the deforestation.

1.4 Research questions

The objective of the study is to answer the following questions concerning the study area:

- How much forest has been cleared during the 23 years period 1986-2009?
- How much forest has disappeared between the different years (1986 and 1995, 1995 and 2003, 2003 and 2009)?
- How high is the deforestation rate in total and between the selected years?
- Where have the major changes taken place?
- If the deforestation continues at the same rate as between 1986 and 2009, how much forest will be left within the time period of 2010 and 2100?
- What land use has replaced the forest in the deforested areas?
- Does the deforestation correlate with increasing population in the area?

2. Study area

One of the reasons to perform the study in East Africa was the opportunity for cooperation with SCC-Vi Agroforestry. Since Kenya is the most forested country in East Africa, it is an interesting country for forest studies. Furthermore, Marakwet district is one of the most heavily forested districts in the country (Chebet, 2010). It is located in western parts of Kenya. Unfortunately, the district is suffering from severe forest degradation. According to Williams (2007), the ongoing deforestation in Marakwet district has major consequences and threatens the biodiversity of the forest. Another reason to choose Marakwet district is the fact that there have been just a few studies done about the state of the district's forest.

The aim of this study was to map the forest and detect deforestation. The results will hopefully help SCC-Vi Agroforestry to decide where to focus their efforts and dedicate resources to plant trees and educate farmers in sustainable agriculture and forestry.

2.1 Kenya

Kenya is a country situated in the eastern part of Africa (see **Figure 2.1**) (Lindahl, 2007). It is located around 0° latitude (the Equator) and 38°E longitude (Encyclopaedia Britannica, 2010a). The country borders Sudan and Ethiopia in the north, Somalia and the Indian Ocean in the east, Tanzania in the south and Uganda and Lake Victoria in the west (Lindahl, 2007; Encyclopaedia Britannica, 2010a).

Kenya has an area of 582 646 km^2 (Norberg, 2009; Encyclopaedia Britannica, 2010a) with a population of 38.6 million in 2009 (KNBS, 2010). The capital is Nairobi with a population of almost 3 million (Norberg, 2009). The country is divided into eight provinces and 69 districts (WRI, 2007). Two-thirds of the population lives in rural areas, while just one third lives in urban areas (KNBS, 2010).

Kenya is facing several environmental challenges. Some of the current problems are deforestation, desertification, soil erosion, water pollution from wastes, and decreasing water quality due to increased use of fertilizers and pesticides. Furthermore, spreading of the water hyacinth (*Eichhornia Crassipes*) in Lake Victoria is also a concern (The World Factbook, 2010b).

2.1.1 Socio-economy

According to Sachs (2005), an income of between 1 and 2 US dollar per day is the

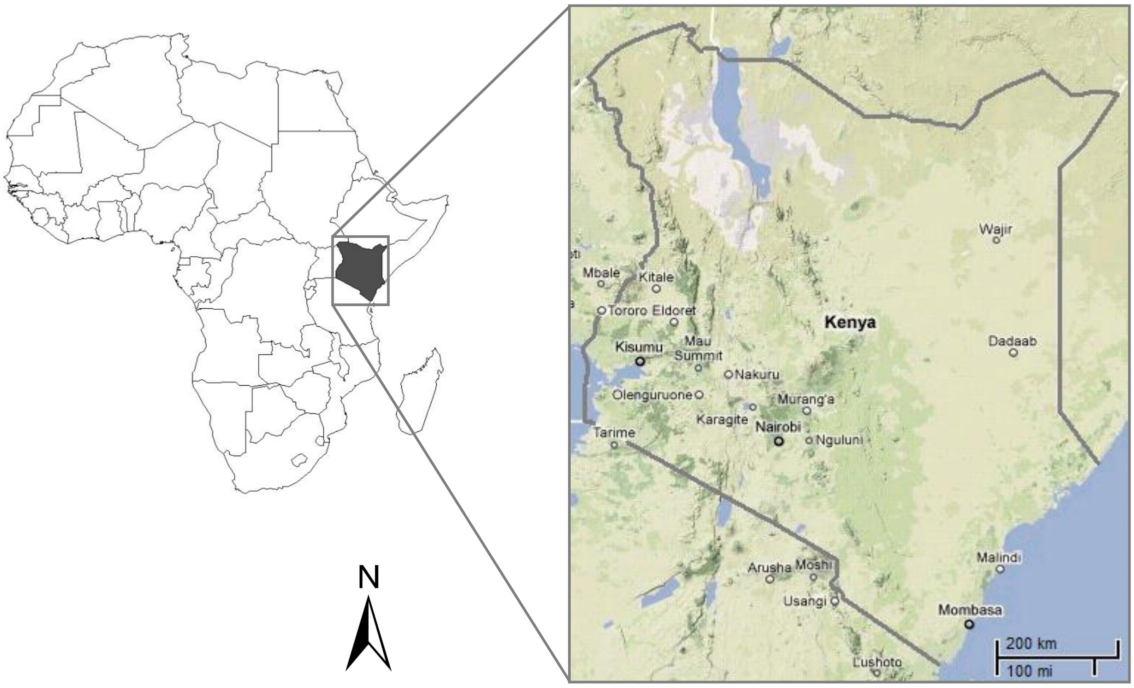

Figure 2.1. *Kenya's position in Africa to the left. Made of data from ILRI, 2007. Terrain map of Kenya with major cities to the right. © 2010 Google - Map Data © 2010 Google, Tracks4Africa.*

general measure of moderate poverty and can be applicable globally. More than half of Kenya's population is living in poverty, most of them on the countryside (Norberg, 2009). A number of factors hinder industrialization and economic development in Kenya as poor infrastructure, growing population and unemployment, increased debt, governmental mismanagement and corruption among others (Encyclopaedia Britannica, 2010a). Kenya is the most industrialized country in East Africa, but even so, incomes are generally small. The industry is ineffective and the capacity is not fully used. Approximately half of industry is owned by foreign companies, most of them British or American. Even though children under 16 years are not allowed to work in the industry, more than 2 million children were working at the beginning of 21st century (Norberg, 2009).

Accelerating population growth in Kenya during the 1960's and 1970's constrained the social and economic development. The growth in population during this period was caused by decreasing mortality rates and the tradition of forming large families. This population growth led to unemployment and higher costs for health services, education and food imports (Encyclopaedia Britannica, 2010a).

The unemployment in Kenya is still high (Norberg, 2009), with an unemployment rate of 40 percent according to estimations from 2008 (The World Factbook, 2010b).

Agriculture plays an important role, building the structure of Kenya's economy (Encyclopaedia Britannica, 2010a; Norberg, 2009). Agricultural products are the dominate export, and the majority of the population is employed in agriculture (Encyclopaedia Britannica, 2010a). Industry and tourism are also important branches of business (Norberg, 2009). Approximately 75 percent of the working population is employed within the agricultural sector, while 25 percent is working with industry and services (The World Factbook, 2010b).

Another important socio-economic factor is that Kenya is severely affected by AIDS (Norberg, 2009). During the late 20th century and early 21st century, the number of deaths from AIDS was increasing (Encyclopaedia Britannica, 2010a). According to official sources, 1.3 million Kenyans had AIDS in the year 2005, and 140 000 died of the virus the same year (Norberg, 2009).

2.1.2 Climate

According to the Köppen classification system, Kenya can be divided into three different climate zones; tropical climates (A), dry climates (B) and temperate climates (C) (Peel et al. 2007). The distribution of the climate zones can be seen in **Figure 2.2.**

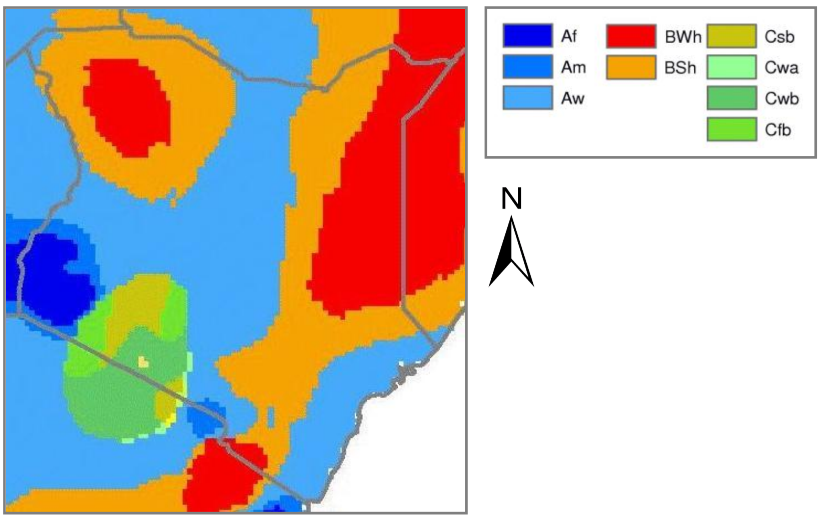

Figure 2.2. *The climate zones of Kenya, according to the Köppen classification system. Adapted from Peel et al. 2007.*

This climate classification map, adapted from Peel et al. 2007, is not detailed; however, it shows the overall pattern in Kenya. The description of Köppen's symbols is found in **Table 2.1**.

Table 2.1. *Description of Köppen climate symbols. Adapted from Peel et al. 2007.*

Symbols	Description
Af	Tropical climate – rainforest
Am	Tropical climate – monsoon
Aw	Tropical climate – savannah
BWh	Dry climate – hot desert
BSh	Dry climate – hot steppe
Csb	Temperate climate – dry, warm summer
Cwa	Temperate climate – dry winter, hot summer
Cwb	Temperate climate – dry winter, warm summer
Cfb	Temperate climate – without dry season, warm summer

Dry climates mainly prevail in the north-western and north-eastern parts of Kenya, where the larger steppe and desert areas are located (Pidwirny and Jones, 2009). As can be seen in **Figure 2.3**, these areas experience low annual precipitation.

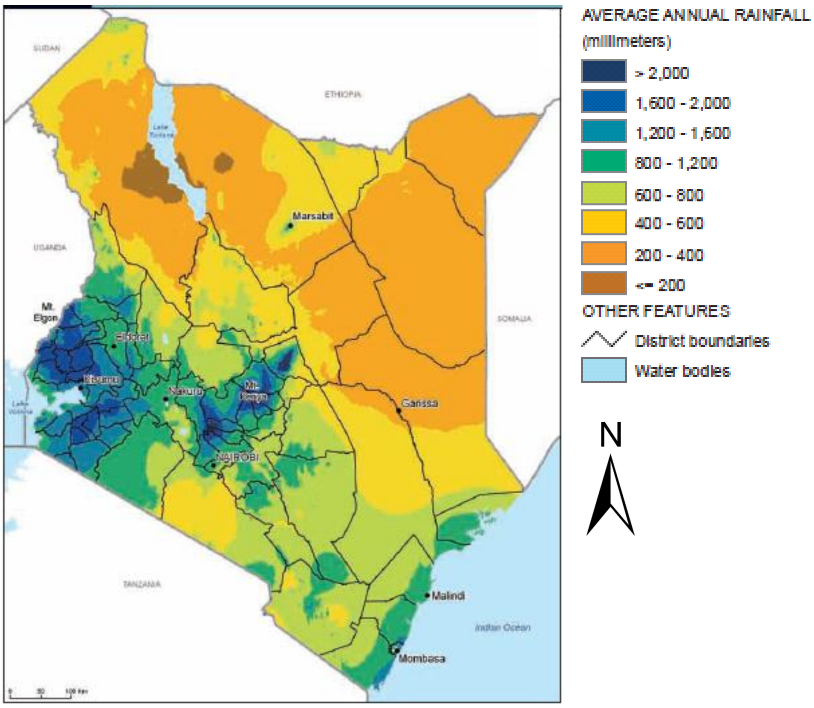

Figure 2.3. *Average annual rainfall in Kenya. Source: WRI, 2007.*

Tropical climates are found from the shore of Lake Victoria in the west to the Rift Valley region in central Kenya and along the coastline in the east (Encyclopaedia Britannica, 2009).

The savanna climate (Aw) is characterized by distinct dry and wet seasons (Pidwirny and Jones, 2009). The dry season can last three to eight months (UNEP, 2006). During the rainy season, the climate is similar to tropical wet climates; it is warm, humid, and thunderstorms occur frequently (Pidwirny and Jones, 2009). The annual rainfall usually varies between 500 to 1 500 mm in the tropical climate zone (UNEP, 2006) with some exceptions. In the Lake Victoria basin for example, the annual precipitation can be as high as 2 000 mm (WRI, 2007).

The most common natural hazards in Kenya are reoccurring droughts and floodings during dry and rainy seasons, respectively (The World Factbook, 2010b), each of which has severe consequences for the country (Norberg, 2009).

2.1.3 Geography

Kenya can be divided into five geographical regions. These are the coast, the Lake Victoria basin, the Rift Valley and related highlands in the central parts, the forelands on the eastern plateau, and the arid and semi-arid areas in the north and south (Encyclopaedia Britannica, 2010a).

The Rift Valley intersects the country and divides the highlands into two parts. The Rift Valley is 50-130 km wide. In the north, the floor is at an elevation of 450 meters, while in the south it is at an elevation of 600 meters. In between, the valley floor rises to over 2 100 meters at Lake Naivasha. During the colonization, the Europeans concentrated their settlements in the Rift Valley, since the soils are fertile and suitable for agriculture. Thus, the region has been important in the historic and economic development of Kenya. Shallow lakes and extinct volcanoes cover the floor of the Rift Valley. The highlands are occupied by deep valleys, mountains and plains (Encyclopaedia Britannica, 2010a).

East of the Rift Valley highlands, there is an immense plateau with ancient rocks called the forelands. This region is characterized by hills and other rock formations and is slightly sloping eastward towards the coast line (Encyclopaedia Britannica, 2010a).

Between the Rift Valley highlands and Lake Victoria, there is a plateau sloping westward towards the lake shore. The lake basin itself is also a plateau and lies between 900 to 1 200 meters above sea level (Encyclopaedia Britannica, 2010a).

The highest peak in the country is Mt. Kenya (The World Factbook, 2010b). It lies in central Kenya, directly south of the Equator. With an altitude of 5 199 meters it is the second highest peak in Africa after Mt. Kilimanjaro (5 895 m) (Encyclopaedia Britannica, 2010b).

2.1.4 Vegetation

According to **Figure 2.2** adapted from Peel et al. (2007), approximately 40 percent of Kenya consists of savanna. Woodlands, bushlands and wooded grasslands are included in the savanna biome. The floristic composition in the savanna biome varies (Mistry, 2000).

However, there are three genus of species constantly reoccurring; *Acacia sp.*, *Commiphora sp.* and *Grewia sp.* (Mistry, 2000). Other common plant species in the savannas in East Africa can be seen in **Table 2.2**.

Table 2.2. *Common plant species in the savannas in East Africa. Source: Mistry, 2000.*

Plant type	Common plant species
Woody species	*Adansonia digitata, Delonix elata, Melia volkensii*
Succulents	*Euphorbia cuneata, E. robecchii, E. grandicornis*
Grasses	*Aristida adscensionis, A.barbicollis, Brachiara eruciformis*

In the Kenyan highlands, evergreen forest is located between 2 100-2 700 meters above sea level. A zone of bamboo is found above the forest up to an elevation of 3 000 meters. Beyond this level, the mountain moorland with heaths stretches out (Encyclopaedia Britannica, 2010a).

Both east and west of the Kenyan highlands, short grass with scattered low trees is found. The baobab tree (*Adansonia digitata*) is typically found in semiarid areas below 900 meters while bare ground and desert scrub is found in the dry regions in the north (Encyclopaedia Britannica, 2010a).

At the coast, the vegetation is mostly savanna with some scattered forests. The southern coast has been subjected to severe deforestation while some residual forests still remains in the northern coastal regions (Encyclopaedia Britannica, 2010a).

2.1.5 Soils

The soils in the Lake Victoria basin consist of fertile sandy loam from lava deposits. North of the Lake Victoria basin, in the vicinity of Mt. Elgon, the volcanic pile has created highly fertile soil. Due to their high fertility, these soils are suitable for coffee and tea production. In the Rift Valley and the neighboring highlands, the soils consist of fertile dark brown loams deriving from younger volcanic deposits, which are suitable for tea plantations (Encyclopaedia Britannica, 2010a).

The most widespread soils in Kenya are the sandy soils covering the area between the Great Rift Valley and the coast. In the arid northern parts of the country red desert soils can be found. These soils are primarily sandy loams (Encyclopaedia Britannica, 2010a).

Soil erosion is a widespread problem in Kenya due to absence of forest cover, overgrazing and cultivation (Encyclopaedia Britannica, 2010a). The soil erosion is primarily a problem in the semi-humid, semi-arid and arid regions (Adams and Watson, 2002), since these areas experience both heavy rainfall and sometimes long-lasting and reoccurring droughts. These zones cover approximately 46 percent of the country's land area (Thomas, 1997).

2.1.6 Agriculture

Agriculture is the most important employment in the country (Jönsson, 2005) and also the main source of income (Nationalencyklopedin, 2009). As mentioned before, it supports more than 75 percent of the working population. However, there is shortage of productive farmland in the country, and consequently, the pressure on the fertile arable land is high. Only about seven percent of the total area of cultivated land is classified as highly productive (Norberg, 2009). The agriculture sector contributed with 26 percent of gross domestic product in 2004 (WRI, 2007).

Although there are more than 3 000 large-scale farms in Kenya, most of the farms are smaller than two hectares (Norberg, 2009; Encyclopaedia Britannica, 2010a). More than 50 percent of the agricultural production is used for householding (Nationalencyklopedin, 2009). The Kenyan highlands have turned out to be one of the most favorable regions for agricultural production in Africa (The World Factbook, 2010b).

Kenya is one of the largest exporters of fresh flowers and black tea in the world (Norberg, 1999). Maize and wheat are the two major crops for domestic use in Kenya (Encyclopaedia Britannica, 2010a). Furthermore, sorghum, cassava, beans and fruit are important food crops (Norberg, 2009) while sisal, cotton, fruits and vegetables are important cash crops (Encyclopaedia Britannica, 2010a).

Historically, coffee was an important product for export (Encyclopaedia Britannica, 2010a). It still contributes to the economy, but coffee production started to decrease in the 1990's due to market instability and low prices on the world market (Encyclopaedia Britannica, 2010a; Norberg, 2009). During the 1970's and 1980's sugarcane was also an export crop but during the 1990's it had to be imported because of supply shortage compared to the domestic demand (Encyclopaedia Britannica, 2010a).

Kenyan agriculture is constrained by shortages of water and arable land and a deficient infrastructure. Even though the Kenyan government has tried to increase water irrigation, it is still not efficiently developed (Encyclopaedia Britannica, 2010a).

Livestock, including cattle, goats, sheep, donkeys and camels, is raised in Kenya and dairy goods are produced primarily for domestic use. The government maintains a reserve supply of these commodities as skim milk powder, cheese, and butter while surplus of animals and dairy products are exported (Encyclopaedia Britannica, 2010a).

2.1.7 Forests

As mentioned before, Kenya is the most forested country in eastern Africa. Forests and woodlands cover approximately 30 percent of the total land area (UNEP, 2006).

Forests are of great importance for the domestic economy of Kenya (Nationalencyklopedin, 2009) and they are essential in order to conserve soil and water resources (Encyclopaedia Britannica, 2010a). **Figure 2.4** from WRI (2007) shows the tree coverage in Kenya divided into percentage intervals.

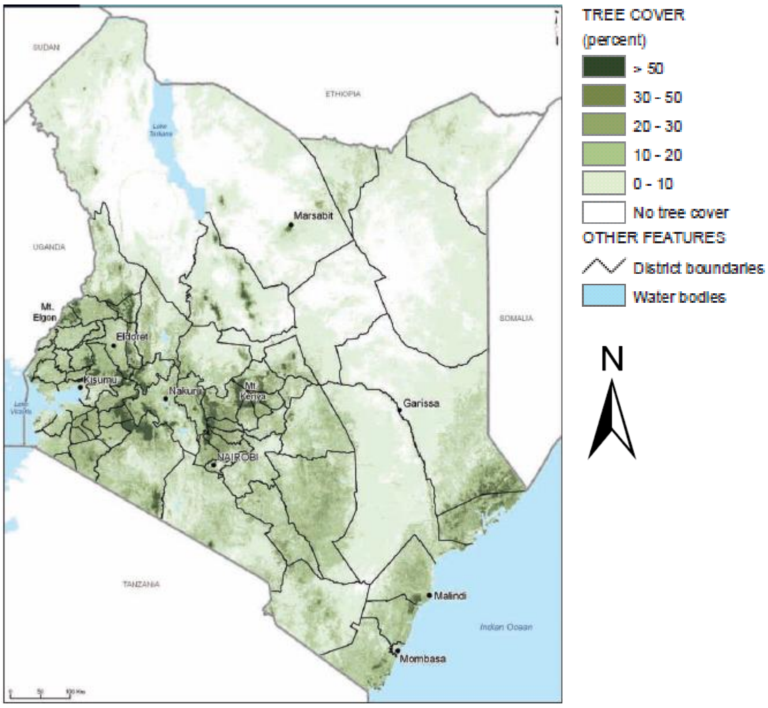

Figure 2.4. *The percentage of tree cover in Kenya. Source: WRI, 2007.*

The forested areas in Kenya have various legal statuses and are managed by different administrations (Wass, 1995). The majority of all closed forests in the country are owned and controlled by the government (WRI, 2007) and under direct management of the Forestry Department or the Kenya Wildlife Service. In most cases, the forests owned by the government have been declared as forest reserves. The five main closed forests areas in Kenya are the Aberdares, Mount Kenya, Mount Elgon, South West Mau, and Cherangani Hills (Wass, 1995).

The fast-growing population requires settlement areas and more fuel for domestic cooking, which threatens the existing forests (Encyclopaedia Britannica, 2009). Wood for fuel and timber are the main forest products. Forests and woodlands supply many families with livelihoods and provide energy, food, and timber (UNEP, 2006). As much as 80 to 90 percent of the wood is used for energy through firewood and charcoal, while the remaining 10 to 20 percent is used for timber, poles and posts. Biomass is the main fuel in Kenya and stands for over 80 percent of the total energy consumption (WRI, 2007). Deforestation threatens not only the remaining forests but also leads to shortage in the supply of fuel (Encyclopaedia Britannica, 2009).

Some areas in Kenya that suffer from deforestation have been reforested, mainly through forest plantations by the government. The management have been focusing on forestry with fast growing species like eucalyptus (*Eucalyptus sp.*), cypress (*Widdringtonia sp.*) and pine (*Pinus Petula*). These species are also common in the commercial forestry in the study area (Masinde, 2010).

However, the establishment of eucalyptus trees has negative effects on the surrounding environment. Eucalyptus demands a lot of water and hence has a negative impact on the water balance. At the same time they are hostile to other species and do not allow anything else to grow nearby (Masinde, 2010; Okella, 2009). Thus, the plantation of eucalyptus leads to water shortage and loss of biodiversity (Okella, 2009).

2.1.8 Agroforestry

Agroforestry is described as cultivation of trees in combination with agricultural crops and cattle breeding. There are several benefits of planting trees in crop fields (Norberg, 2009):

- The tree roots can bind the soil and hence limit soil erosion
- The trees provide shade and wind protection, which leads to reduced dehydration
- Nitrogen-fixating trees feed the soil with nitrogen, which improves the fertility and results in increased yields
- The leaf litter can add organic matter

- Trees provide firewood, timber, fruit, fodder and medicines to farmers

SCC-Vi Agroforestry is a non-governmental organization and was founded in 1983. It aims to develop the method of agroforestry to improve the living standards amongst small-scale farmers around Lake Victoria. Their mission is to integrate agroforestry within the farming systems. From the beginning the goal of SCC-Vi Agroforestry was to stop desertification and soil erosion in Africa. Now the organization has expanded and also works toward poverty reduction. Furthermore, they provide education and guidance to farming families in the Lake Victoria basin, and today they reach approximately 240 000 households. Agroforestry has allowed small-scale farmers to get higher yields from their land, and the households are becoming self-supporting (Norberg, 2009). It can help to reduce the deforestation and save the natural forests.

2.2 Marakwet district

Marakwet district is located in the Rift Valley province in western Kenya, as can be seen in **Figure 2.5**. The district lies in the tropical moist climate zone and the highland climate zone (Pidwirny and Jones, 2009). The district has a land area of 1 588 km^2 (Law, 2010).

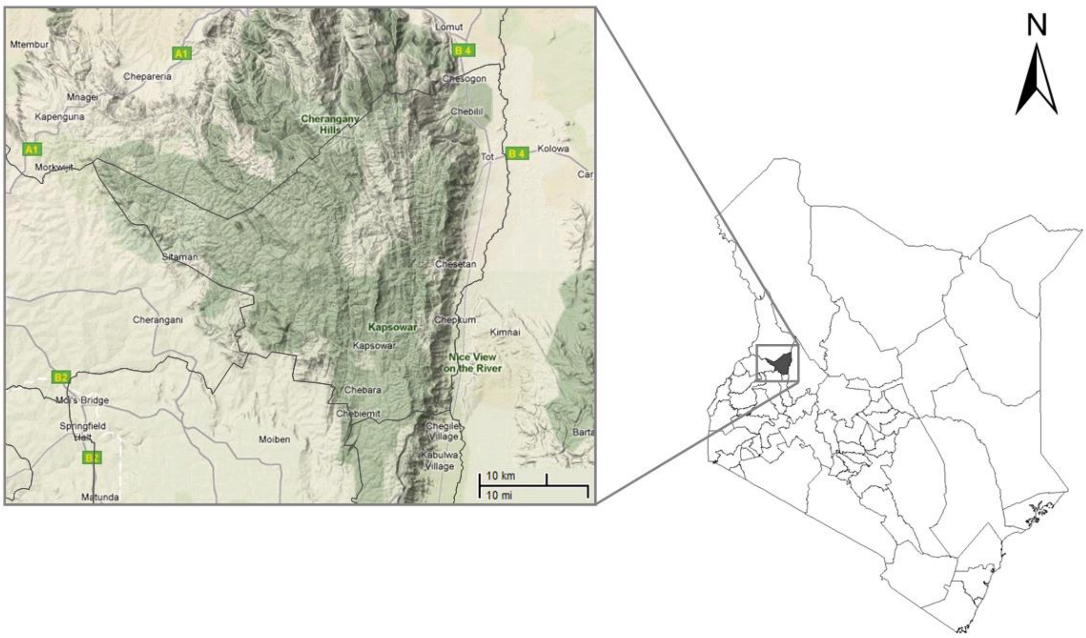

Figure 2.5. *Terrain map of Marakwet district to the left. © 2010 Google - Map Data © 2010 Google, Tracks4Africa. Marakwet district's position in Kenya to the right. Made of data from ILRI, 2007.*

The annual precipitation in Marakwet district is between 850 mm and 1 300 mm. The long rain period in Marakwet district lasts April to June-July while the short rain period occurs in October to November. The season December to March is the hottest period in the area with very limited amount of rainfall (Chebet, 2010).

As mentioned before, the district is one of the most heavily forested in Kenya. The forest is estimated to occupy 40 percent of the district (Chebet, 2010), which represents 65 000 hectares of forest (Williams, 2007). Most of the forest is located in Cherangani hills in the eastern part of the district. It forms one of the largest remaining natural forests in the western part of Kenya. Furthermore, it is an important catchment area for the rivers that flow to Lake Victoria and Lake Turkana (Chebet, 2010).

The forest in Marakwet district is divided into several administrative forest blocks. Most of them are owned by the state and managed by the Forest Department. Unfortunately the district is suffering of severe deforestation. According to Willams (2007) there are no large companies actively exploiting the forest in Marakwet district. The forests are instead exposed for illegal activities such as illegal human settlements, cultivation and overgrazing along the boundaries (Chebet, 2010).

Since the forest in Cherangani hills is a water catchment area and a source of many rivers, it is very valuable, and the local inhabitants are dependent of it (Chebet, 2010). The decreasing forest is affecting the water balance and observations have indicated that it rains less (Chebet, 2010). Furthermore, there are observations of decreased water volume in the rivers due to general forest degradation (Chebet, 2010).

The study area is located inside Marakwet district, close to the town Kitale. It has approximately a size of 675 km^2 (45 x 15 km) which corresponds to 42.5 % of the district. **Figure 2.6** shows an image of the landscape in the study area.

When the study area was defined, there were some geographical limitations. Since some of the forested areas in Marakwet district are unsafe and military unsecure, especially the forest block in the western parts, it forced us to avoid certain areas of the district. Furthermore, some areas were inaccessible due to travel distances, bad infrastructure, hilly terrain and weather conditions. This was especially the case in the eastern parts of the districts in Cherangani hills. Therefore, the area of study is not covering all forested area in Marakwet district.

Figure 2.6. *The image shows a typical view of the landscape in the study area. (Photo: A. Tuomaala)*

3. Theoretical background

3.1 GIS

GIS is the abbreviation of Geographical Information System. According to Harrie (2008), GIS is:

"A computerized information system with functions for collection, storage, processing, analysis and visualization of spatial data".

GIS is used to describe and analyze spatial data and relations over time and space (Eklundh, 2003). All features are coded and stored with coordinates in order to describe their location in the composed map (GIS Centre, 2003).

Geographical objects can be presented as single objects (vector format) or as continuous surfaces (raster format) (Eklundh, 2003). This is seen in **Figure 3.1**.

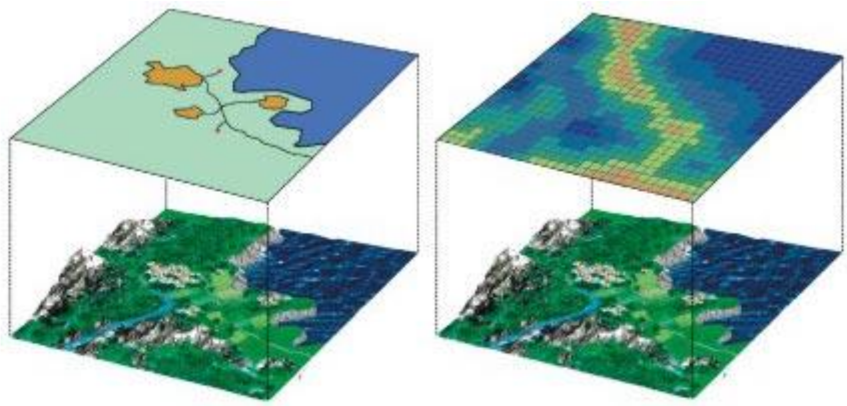

Figure 3.1. *The reality represented in a vector layer (to the left) and raster layer (to the right). Source: GIS Centre, 2003.*

GIS is most commonly used to simply visualize characteristics of a landscape or an environment. GIS could also be used as a tool for analyzing data, optimizing activities, performing risk analyses and test different scenarios (GIS Centre, 2003). It is useful in forestry, agriculture, marketing, energy production, profitmaking business, building and facility business and in the national defense among other things (Eklundh, 2003).

3.2 Remote sensing

According to Lillesand et al. (2008) remote sensing is defined as:

"The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation."

By using satellites one can obtain a lot of information about the Earth's surface (Encyclopaedia Britannica, 2010c). Every feature on the Earth emits and reflects electromagnetic radiation; energy (Lillesand et al., 2008). Remote sensing takes advantage of the fact that diverse materials reflect and absorb the sun light differently, depending on wavelength spectrum (Eklundh, 2003). The sensors onboard satellites measure this spectral reflectance and the acquired data can be analyzed and used for various purposes such as mapping, exploration of resources, land use planning, resource management etc. (Encyclopaedia Britannica, 2010c).

3.2.1 NDVI

Normalized Difference Vegetation Index (NDVI) is an index commonly used when observing global vegetation (Lillesand et al., 2008). It measures the density of the green vegetation and is often used to monitor photosynthetic activity at regional and global scale in order to detect vegetation fluctuations (Seaquist et al., 2002; Weier and Herring, 2010).

Since vegetation reflects visible and near-infrared light it is possible to calculate the NDVI by using following formula:

(Eq. 3.1) $$NDVI = (NIR - VIS) / (NIR + VIS)$$

where NDVI is calculated by subtracting the near-infrared radiation it with the visible radiation and then divide it by near-infrared radiation added with the visible radiation. The visible light is absorbed by chlorophyll in plant leaves and used in the photosynthesis. The near-infrared light is reflected by the cell structure of green leaves. The calculated NDVI results in a value between -1 and +1. Less or no vegetation gives a value of 0 or close to 0 and high density of vegetation results in a value close to 1 (Weier and Herring, 2010). Negative values correspond to presence of clouds, water or snow. A value near zero means in general rock and bare soil. High values of NDVI are generated by temperate and tropical rainforests, varying between 0.6 and 0.8 (ArcGIS Resource Center, 2010).

3.2.2 Landsat Thematic Mapper (TM)

The Landsat Thematic Mapper (TM) is a sensor onboard Landsat 4 and 5 (USGS, 2010a). With its seven spectral bands Landsat TM registers visible and near-infrared radiation reflected by the Earth's surface (USGS, 2009a). Since July 1982 the satellites Landsat 4 and 5 circulate the Earth (USGS, 2010a) at a sun-synchronous, near-polar track (Lillesand et al., 2008). The repeat cycle is 16 days and the Landsat TM sensor continuously attains satellite images (USGS, 2010a).

As mentioned, the Landsat TM images consist of seven spectral bands where bands 1-5 and 7 have the spatial resolution of 30 meters and band 6 has 120 meters (USGS, 2010a). **Table 3.1** lists the spectral bands, their range and resolution. Band 1 effectively penetrates water bodies and is of great use in mapping coastal water. It also discriminates soil/vegetation and is useful when mapping different forest types (Lillesand et al., 2008). The green and red bands (bands 2 and 3) are suitable when detecting healthy vegetation and measuring the absorption of chlorophyll (USGS, 2009a).

Table 3.1. *The Landsat TM data consists of seven spectral bands. Bands 1-5 and 7 have a spatial resolution of 30 m and band 6 has 120 m. The spectral bands have different wavelength range and nominal spectral location. Data from USGS, 2009 and Lillesand et al., 2008.*

Band	Wavelength (µm)	Resolution (m)	Nominal Spectral Location
Band 1	0.45 - 0.52	30	Blue
Band 2	0.52 - 0.60	30	Green
Band 3	0.63 - 0.69	30	Red
Band 4	0.76 - 0.90	30	Near IR
Band 5	1.55 - 1.75	30	Mid IR
Band 6	10.40 - 12.50	120	Thermal IR
Band 7	2.08 - 2.35	30	Mid IR

The near-infrared band (band 4) is useful when to determine different vegetation types and their biomass content (Lillesand et al., 2008) but also to determine the interfaces between land and water. The bands 5 and 7 (the two Mid-IR bands) are used for measuring moisture in the vegetation and in the soil (USGS, 2009a). Band 7 can also be used to distinguish different rocks and minerals. The Thermal-IR band (band 6) is of great use in thermal mapping applications but can also distinguish soil moisture and are of use in analyses about vegetation stress (Lillesand et al., 2008).

Landsat data is used all over the world at all levels; by governments, commercials, industries, scientists and researchers, for educational purposes and by public (USGS, 2009a; USGS, 2010b). Landsat is applicable in many areas and can be used for monitoring land cover changes such as deforestation, natural disasters, agricultural development and urbanization among other things (USGS, 2009a; USGS, 2010b). Moreover it is commonly used when conducting different time series analyses since the temporal resolution is good (USGS, 2010b).

3.2.3 Landsat Enhanced Thematic Mapper Plus (ETM+)

On 15th of April 1999 the Landsat 7 satellite was launched. It is the latest satellite in the Landsat series (Lillesand et al., 2008). The instrument Enhanced Thematic Mapper Plus (ETM+) is carried onboard the Landsat 7 satellite (USGS, 2010c) and has similar orbits and repeating patterns as the Landsat 4 and 5 (Lillesand et al., 2008).

The data from the ETM+ sensor consists of eight spectral bands (see **Table 3.2**). Bands 1-5 and 7 have the spatial resolution of 30 m while the thermal infrared band has a spatial resolution of 60 m (USGS, 2010c). The ETM+ sensor also has a panchromatic band (band 8) with a resolution of 15 m (USGS, 2003a). The features and the possible use of the bands are the same as for Landsat TM.

Table 3.2. *The Landsat ETM+ data consists of eight spectral bands. Bands 1-5 and 7 have the spatial resolution of 30 m, band 6 has 60 m and band 8 has 15 m. The spectral bands have different wavelength range and nominal spectral location. Data from USGS (2010d) and Lillesand et al. (2008).*

Band	Wavelength (µm)	Resolution (m)	Nominal Spectral Location
Band 1	0.45 - 0.52	30	Blue
Band 2	0.52 - 0.60	30	Green
Band 3	0.63 - 0.69	30	Red
Band 4	0.76 - 0.90	30	Near IR
Band 5	1.55 - 1.75	30	Mid IR
Band 6	10.40 - 12.50	60	Thermal IR
Band 7	2.08 - 2.35	30	Mid IR
Band 8	0.52 – 0.90	15	Panchromatic

3.2.4 The Scan Line Corrector

The Scan Line Corrector (SLC) is a component of the Landsat 7 satellite (Parkinson et al., 2006). The SLC is creating a rectilinear scan pattern. Without the device, a zig-zag pattern would be produced instead (NASA, 1999) along the satellite ground track (USGS, 2008a). This can be seen in **Figure 3.2**. The zig-zag pattern occurs since the Scan Mirror runs with an across-track motion at the same time as the spacecraft creates along-track motion when it moves forward. This is compensated by the SLC instrument (Parkinson et al., 2006).

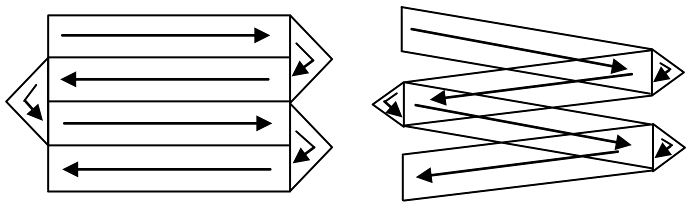

Figure 3.2. *The rectilinear pattern when SLC is on to the left and the zig-zag pattern when SLC is off to the right. Adapted from Parkinson et al., 2006.*

On May 31st 2003 the SLC device failed on the ETM+ sensor onboard Landsat 7 (Scaramuzza et al., 2004). Since then, all acquired data has been collected with the SLC instrument off (Lillesand et al., 2008). With scan lines alternately overlapping the images, large gaps of missing data are created at the edges. However, the coverage in the center of the image is almost full (USGS, 2003b). As a result of this scan gap, approximately 22 percent of the imagery data is lost (Scaramuzza et al., 2004).

The missing data is not possible to correct but there are different methods to use in order to “fill in” the empty pixels with data. One way is by using interpolation algorithms to interpolate the gaps in the imagery. However, this method needs further research and may not be applicable in all cases (USGS, 2003b). Another method is to combine two SLC-off images, preferably from the same season, and make them overlap each other. It is important that the images contain minimal transient data, such as clouds and haze, to get an optimal result (Australian Government, 2009). This would result in an image with either minimal or no gaps at all.

Pixels with no data lead to less useful satellite images. Nevertheless, several scientists have concluded that the data still is useful for a lot of applications, even though the data is incomplete (USGS, 2003b).

3.3 Classification scheme

When working with different mapping projects it is necessary to use classification schemes. By using a classification scheme the map producer can distinguish different features in the landscape such as forests, lakes, built up areas etc. These features could then be identified and recognized by the map user (Congalton and Green, 1999).

There are two things that decide the detail of the classification scheme (Congalton and Green, 1999):

1. The expected use of the map information
2. The spatial resolution and the spectral properties of the data which decides what features of the Earth that can be distinguished and presented in the resulting map

It is also of great importance to assign labels and definitions. The classification scheme used when labeling the collected reference data should be the same as the one applied when producing the map (Congalton and Green, 1999).

A classification scheme should also be as Congalton and Green (1999) describes it; mutually exclusive and totally exhaustive. Mutual exclusivity implies that every mapped area should belong to only one category or class. With a totally exhaustive classification, all areas are labeled in the resulting map and no areas are left unlabeled (Congalton and Green, 1999).

The time and effort needed for conducting the accuracy assessment depend on the level of detail in the classification scheme. A more detailed scheme will give a more time-consuming and expensive accuracy assessment (Congalton and Green, 1999).

3.4 Field sampling

3.4.1 Number of samples

A sufficient amount of field samples must be collected in order to make an analysis statistically valid. In addition, a balance must be found between what is practically achievable and statistically appropriate (Congalton and Green, 1999). According to Congalton and Green (1999) a general rule is to collect at least 50 samples per land cover class in the analysis.

The appropriate amount of samples to use per land cover class can also be adjusted to the importance of each land cover class, the size of each land cover class and the objective of the mapping (Congalton and Green, 1999; McCoy, 2005). It is sometimes better to increase the number of samples in the more important categories and reduce the number in the less interesting categories (Congalton and Green, 1999).

3.4.2 Size of sample

The size of the field sample is important in accuracy assessment. Sample unit is the portion of a map that is supposed to be sampled. There are four common sample units; a single pixel, a pixel cluster, a polygon and a polygon cluster (Congalton and Green, 1999). The most common choice of sample unit is a cluster of pixels. The cluster is often 3 x 3 pixels in a square (Congalton and Green, 1999). According to McCoy (2005), the sample should be at least the size of the ground pixel, preferably larger.

An accuracy error of 15 meters can occur when taking global positioning system (GPS) points, depending on the number of satellites connecting to the GPS receiver. A higher number of connecting satellites leads to a better accuracy as well as a longer time of measurement. The accuracy error has to be taken into consideration when choosing sample unit (McCoy, 2005). McCoy (2005) is describing a formula to determine the size of a sample. According to the concept, when having an accuracy error of 15 meters (0.5 pixels), the minimum size of the sample should be 60 x 60 meters (2 x 2 pixels). The choice of a single pixel sample unit is thus inappropriate when the accuracy error is 0.5 pixels.

3.4.3 Choice of samples

There are different sampling schemes to use when collecting reference data (Congalton and Green, 1999). The five most common ones are simple random sampling, stratified random sampling, systematic sampling, systematic unaligned sampling and clustered sampling (Congalton and Green, 1999; McCoy, 2005). The opinion on which scheme that is appropriate to use varies among researchers (Congalton and Green, 1999). Different factors such as terrain affect the choice of suitable sampling pattern (McCoy, 2005).

Even though random sampling have good statistical validity, this sampling method can be difficult to use in practice since some samples could be hard to access in the field, especially if the study area is forested. Hence, the combination of random and systematic sampling is a good alternative and will give a pleasing balance between practical use and statistical validity as a result (Congalton and Green, 1999).

3.5 Accuracy assessment

Accuracy assessment is used to measure the quality of a map by identifying the errors. With this knowledge it is then possible to find and correct the source of the error. It is important to determine the accuracy of the remotely sensed data, especially if the data is going to be used in decision-making processes (Congalton and Green, 1999). It helps to provide a sense of how accurate or useful the classification is (RS/GIS Laboratories, 2003). The accuracy assessment can either be quantitative or qualitative, expensive or cheap, time-consuming or quick, efficient or inefficient. A quantitative accuracy assessment compares mapped data against reference data for a specific site, where the reference information is expected to be accurate (Congalton and Green, 1999).

In accuracy assessment, error matrices and Cohen's kappa are frequently used as measurements (RS/GIS Laboratories, 2003). This is described in the next sections.

3.5.1 Error matrix

Error matrices are commonly used as a way of expressing the accuracy of a classification. The error matrix is a comparison between information from reference sites and classified map data (Lillesand et al., 2008).

The matrix is a square table with reference data in the columns and map data in the rows. The reference data is derived from data collected in the field and is assumed to be correct, while the map data is produced through classification of remotely sensed data (Congalton and Green, 1999).

Several measures can be computed from the error matrix. Overall accuracy, user's accuracy and producer's accuracy are common measures used in accuracy assessment (Lillesand et al., 2008).

3.5.2 Overall accuracy, User's and Producer's accuracy

The overall accuracy can be obtained by dividing the total number of correctly classified pixels with the total number of reference pixels (Lillesand et al., 2008). Hence, the overall accuracy gives the percentage of how correct the classified pixels are in total (Lung and Schaab, 2006).

When dividing the number of correctly classified pixels in each category by the number of training set pixels used for that category (the column total), the user's accuracy is calculated. If the number of correctly classified pixels in each category is divided by the total number of pixels that were classified in that category (row total) instead, the producer's accuracy is obtained (Lillesand et al., 2008).

Hence, the user's accuracy indicates the percentage of correctly classified pixels per each land cover class while the producer's accuracy gives the percentage of correctly classified pixels per reference class (Lung and Schaab, 2006).

3.5.3 Kappa coefficient

Cohen's kappa can be applied as a measure of how well the remotely sensed classification agrees with the reference data (Congalton and Green, 1999). Kappa is a value less than or equal to 1, where 1 corresponds to a perfect agreement while 0 corresponds to a random classification (Congalton and Green, 1999). Kappa can also be negative. This implies that the agreement is less than would be expected by chance. According to Lung and Schaab (2006), Kappa provides a more accurate measure compared to the overall accuracy.

Kappa is calculated as in **Equation 3.2**:

(Eq. 3.2)

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}{N^2 - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}$$

where N is the total number of samples in the matrix, r corresponds to the number of rows in the matrix, x_{ii} is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column i (RS/GIS Laboratories, 2003).

4. Data and method

This study consists of several parts. The first section describes the collection and preprocessing of satellite data and collection of vector data. This follows with a description of the field work and the collection of population data. Finally the GIS analysis is described. The software used for pre-processing and GIS analysis is ArcGIS 9, IDRISI Andes, IDRISI 32 and Microsoft Excel.

4.1 Satellite data

Landsat data has a good temporal resolution and is easy to acquire and appeared to be the best option of satellite imagery for this study (NASA, 2008). The data has a high spatial resolution of 30 meters which makes it suitable for studying land cover changes (NASA, 2008; Duveiller et al., 2008) such as changes in forest cover (Zhang et al., 2005). Furthermore, it has a seasonal global coverage (NASA, 2008).

Satellite images from Landsat 7 ETM+ and Landsat TM were used in this study. The Landsat data were acquired from the U.S. Geological Survey's (USGS) Global Visualization Viewer (GLOVIS). The selected satellite images were all pre-processed with the Standard Terrain Correction by USGS. This process gives systematic, radiometric and geometric corrected images by using ground control points and Digital Elevation Models (DEM). The geodetic accuracy of the product will therefore depend on the available local ground control points and DEM. The DEM is also used for the topographic accuracy (USGS, 2009b).

USGS uses a score to determine the quality of Landsat scenes. The scene quality score stretches from 0 to 9, where 9 are defined as a perfect scene with no errors (USGS, 2008b). All the selected scenes used in this study had a quality score of 9 with less than 10 percent cloud cover.

Since the study is a time series analysis, satellite data from different years were selected. To obtain the best quality of the satellite data a few criteria had to be achieved. The available set of satellite images were thoroughly gone through and chosen according to the following criteria: they needed to be from the same season, totally or at least almost cloud free and easy to acquire.

The NDVI was used to find the suitable season in which it is easy to distinguish between cultivated land and forest. The conclusion was made that the right season is just before the rainy season begins in March, since the forest is easy to distinguish during this period. This is also confirmed in Akotsi et al. (2006).

Due to limitations in both the accessibility and quality of the data, the images could not be obtained at even intervals. Satellite images from 1986, 1995, 2003 and 2009 were selected, according to the criteria mentioned above. **Table 4.1** shows the selected satellite images and the date of registration.

Table 4.1. *The selected Landsat images and date of registration.*

Year	Landsat images (scene)	Date of registration
1986	169/059	1986-01-28
1995	169/059	1995-02-06
2003	169/059	2003-02-04
2009	169/059	2009-02-20
2009	169/059	2009-03-08

The collected data from 2009 had gaps in the images due to the failure of the SLC device onboard the Landsat 7 (see section 3.2.4 for more detailed information). To solve the problem with missing data, another image from the same year and season was selected. By combining the two scenes, a full coverage satellite image was created. This scan line correction is further described in section 4.2.3.

4.2 Pre-processing of satellite data

This section describes the pre-processing of data. It involves the reduction of satellite data through cutting out the study area from the selected scenes, georeferencing, preparation of FCCs and correction of scan lines.

When the extension of the study area was set the satellite images were clipped according to the coordinates 0° 40' 24.833" N to 1° 24' 39.954" N and 35° 5' 15.120" E to 35° 44' 21.885" E. This corresponds to an area of 72.5 km by 81.6 km.

To be able to separate forest from other land uses during the manual interpretation, FCCs were prepared. **Figure 4.1** shows the FCCs of the study area in Marakwet district from the different years 1986, 1995, 2003 and 2009. The FCCs were produced by combining the green, red and near-infrared band for each satellite image (see **Table 3.1** and **3.2** for more information about the different spectral bands).

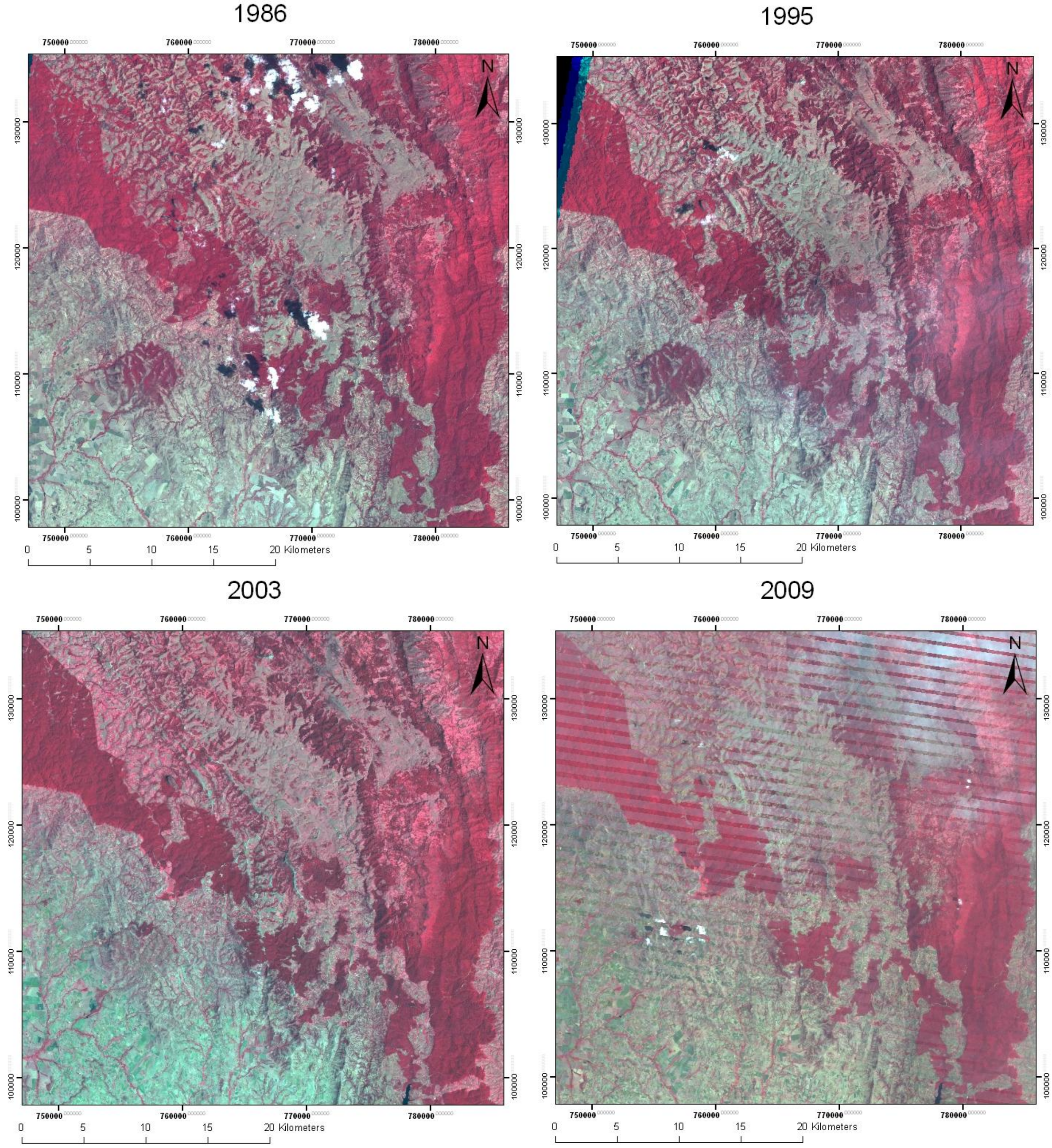

Figure 4.1. *FCC of the study area in Marakwet district from 1986, 1995, 2003 and 2009. Based on data from GLOVIS.*

4.2.1 Georeferencing

The downloaded satellite images had the global reference system World Geodetic System 1984 (WGS84) and the projection Universal Transverse Mercator (UTM) 37N. Since the study area is located in western Kenya in another UTM zone, the data needed to be projected from UTM 37N to UTM 36N.

The next step was the spatial georeferencing. Even if the satellite images did not differ more than one pixel (~30 m) in the center of the scenes compared to each other, it was decided that a transformation should be performed. Since there were no available topographical maps of the study area, the newest satellite image from 2009 was chosen as reference for the other satellite images. The satellite images from 1986, 1995 and 2003 were then synchronized with the one from 2009. Fifty reference points were selected.

The spatial georeferencing of the images from different years resulted in a root mean square (RMS) between 1.9 and 2.5. The RMS error is an indication of how well the selected ground control points match between the reference image and the target image (Eastman, 2006). Since it was impossible to achieve better RMS values due to lack of good reference data, the RMS error was accepted. However, one has to keep in mind that the error might affect the result of the transformation and further analysis.

4.2.2 Image restoration

The selected satellite images contained some radiometric errors such as haze and clouds. This can be seen in **Figure 4.1**. However, it was concluded that the haze would not affect the manual interpretation. Therefore no atmospheric correction was made.

The satellite image from 1986 had some clouds covering the forest. In the 1995 image one cloud existed. The study area was cloud free in the satellite image from 2003. In the 2009 image there were some clouds as well. Since the forest covered by clouds and cloud shadows could not be interpreted, this disturbance had to be distinguished. Therefore, the clouds and the cloud shadows were identified, interpreted and removed from the analysis. The clouds and shadows occupied a total area of 2 347 hectares of the study area.

4.2.3 Scan line correction

As described in section 3.2.4 the SLC device failed on 31 May 2003. In order to fulfill the analysis, it was necessary to compensate for the data loss in the scene from 2009. Due to the benefits of the combination of satellite scenes, the same method as the Australian Government (2009) is using was used in this study. The 2009 image was combined by using two satellite scenes from 2009, in order to fill in the gaps of the scan lines. As seen in **Table 4.1**, the two selected satellite scenes are registered 20 February 2009 and 8 March 2009. For the final image, the maximum values of the selected satellite scenes were used. By this method the final image resulted in full coverage.

4.3 Vector data

The vector data used in this study was collected from International Livestock Research Institute's website (ILRI, 2007). ILRI has a database with spatial data layers and the data is available for free download.

The polygon layers used in this study was:

- Country boundaries in Africa
- District boundaries in Kenya

The geographic coordinate system for the vector data was WGS84. The two layers were projected to UTM Zone 36N.

The data was used to create maps over Kenya's position in Africa (**Figure 2.1**) and the location of Marakwet district in Kenya (**Figure 2.5**).

4.4 Field work

The field work mainly focused on collecting field samples and information about the forest and its extension, but also conversations and interviews with both employees at the SCC-Vi Agroforestry and the Kenya Forest Service.

Since the purpose was only to separate the forest from the rest of the land use, two categories of land cover were used in this study; "forest" and "other land use",. The forest category was classified as described in the classification scheme in **Table 4.2**.

Manual interpretation of different sizes of forests was tested and the decision of a size limit of 3 hectares (~ 33 pixels) was done. Hence, forested areas had to be at least 3 hectares to be interpreted. It was realized that a more detailed manual interpretation of forested areas smaller than 3 hectares would be too time-consuming to achieve.

4.4.1 Field sampling

The collection of field samples was limited. Due to hilly terrain and poorly maintained roads in the district, a lot of areas in the field were inaccessible. Moreover, there were a limited amount of roads through the forests and the few roads that intersected the forests were unfortunately in bad shape. In addition, no road network data was available in advance, which made the planning of the route and locations of field sampling hard. Some days, some roads were not accessible due to heavy rainfall. Furthermore, some areas were unsafe due to conflicts between different tribes and the

Table 4.2. *Classification scheme for the category "forest".*

Classification scheme
• For the sampling of field data, the forested area must be at least 100 x 100 meters (~9 pixels)
• For the manual interpretation, the forested area must be at least 3 hectares (~33 pixels)
• The area must consist of a coherent forest and should not be scattered
• The tree coverage should be estimated to be at least 75 percent
• Trees along rivers with a total width of less than 60 meters (~2 pixels) are not classified as forest
• Roads inside forests are considered as forest
• Forest plantations and reforested areas are included

military, which were not known beforehand. For the safety, it was decided that staff at SCC-Vi Agroforestry followed to areas where field sampling was possible. Since random sampling was not possible due to the circumstances, a combination between random and systematic sampling was used instead. Along the roads, stops were made when a homogeneous land cover appeared. The field samples were taken close to the road for several reasons. First of all, the forest was hard to access and walk inside. Secondly, there was limited connection between the GPS receiver and the satellites inside the forests due to dense vegetation. Thirdly, to enter cultivated fields and such, the owner of the land had to be informed and leave an allowance.

Each sample location was registered with GPS receiver. Notes on land cover were taken as well as photographs and general descriptions. Additionally, notes and photos over the land cover were linked to the GPS points.

As mentioned before, the field samples were chosen in areas with homogeneous land use. The land cover had to be the same in at least 50 meters in each cardinal direction from the point where the GPS coordinates were taken (see **Figure 4.2**). This makes the sample size 100 x 100 meter, which almost corresponds to 3 x 3 pixels in the Landsat images.

The total number of collected field samples was 106 points. According to Congalton and Green (1999), this should be a sufficient and statistically appropriate number of points.

Since Kenya is located around the Equator, the satellite coverage is good and this makes the GPS data more accurate. The GPS receiver always had connection to at least four satellites and the accuracy error was always 15 meters or better, according to the GPS receiver, when collecting the field samples.

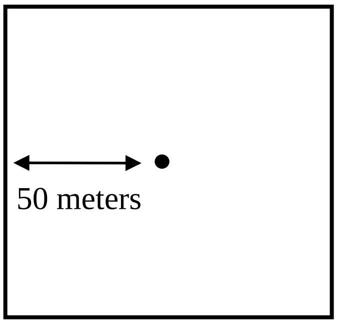

Figure 4.2. *Illustration of a field sample. The point represents the center of the sample. The total field sample size is 100 x 100 meters.*

4.4.2 Other information

In addition to the collection of field samples, interviews and meetings were made with employees at SCC-Vi Agroforestry and with recruits at Kenya Forest Service during the stay in Kenya. At these meetings, valuable information about the study area was collected.

During the days in field, two meetings were held with the Kenya Forest Service; one meeting with the forester in charge in Kapcherop, and one at the head office in Kapsowar. In Kapsowar a number of reports and other valuable information were collected.

Several meetings were also held with staff at the SCC-Vi Agroforestry office in Kitale, mainly with the Project Manager, the Deputy Manager and the supervisor. Here, crucial information about the study area and the deforestation issue were gathered. At the same time the performance of field work was discussed and planned.

4.5 Population data

Kenya National Bureau of Statistics (KNBS) is a government agency and a center for statistics production and management. Their mission is to collect, compile and analyze statistical information (KNBS, 2010). The establishment of a statistics unit in Kenya took place in 1961.

A census is a complete count of the population in a country. Since 1969, KNBS have performed censuses every tenth year in Kenya (KNBS, 2010).

The population data used in this study is collected from KNBS and origins from the censuses of 1979, 1989, 1999 and 2009. The data consist of the population distribution by district.

Population data covering both Marakwet district and Keiyo district was used in this study, since these two districts were together as Elgeyo/Marakwet district until 1994, and then split into Marakwet district and Keiyo district (Kagoech Foundation Trust, 2010).

Since the population data stretches from 1979 until 2009, the last two censuses are affected by the change in district boundaries. Therefore, the population data from these two districts were put together for the years 1999 and 2009 during the analysis, in order to make a comparison.

4.6 GIS Analysis

The following section describes the technical part of the study. The GIS analysis includes manual interpretation, area calculation, accuracy assessment and production of maps.

4.6.1 Manual interpretation

Different classification methods were tested before the choice of manual interpretation was made. Since the study area is heterogeneous, it was hard to achieve a good result with unsupervised classification methods. Therefore, unsupervised classification methods were excluded. In addition, supervised maximum likelihood classification was tested and evaluated for a part of the study area, and the results were not good enough. When manual interpretation was tested, the results were satisfying. Hence it was determined that a manual interpretation would give the best result.

The four FCCs of the years 1986, 1995, 2003 and 2009 were interpreted manually in ArcMap 9.3.1. The classification scheme (**Table 4.2**) was used to decide whether an area was forest or not. The manual interpretation resulted in four polygon layers showing forest cover, one for each year.

According to Rotich (2010) at Kenya Forest Service, some areas in Marakwet district have been reforested the last 20 years through commercial forest plantations, reforestation projects and natural regrowth. These areas were easy to detect in the FCCs and were included in the manual interpretation of forest. The forested area was calculated for each interpreted vector layer.

4.6.2 Deforestation rate

The total forest loss was calculated for the intervals 1986-1995, 1995-2003, 2003-2009 and for the total period 1986-2009. The annual forest loss was also calculated for the intervals and the whole period. Finally, it was possible to obtain percentage values of the yearly deforestation rates.

4.6.3 Future scenario

The future scenario made in this study stretches from 2010 to 2100 and consists of forest area calculations. These calculations were made with the assumption that the yearly deforestation rate is fixed during the time period. The overall annual deforestation rate calculated for the interval 1986-2009 (described in the previous section) was used to create the future scenario.

4.6.4 Accuracy assessment

An accuracy assessment was done in order to evaluate the final maps. The manual interpretation from 2009 was used for the accuracy assessment since it consists of the most up-to-date information about the forest extent in the study area. The other years were then assumed to have the same accuracy. The 106 sample points collected in the study area were used as reference data.

Five measures of accuracy were performed: error matrix, overall accuracy, user's accuracy, producer's accuracy and kappa coefficient. These methods are described in section 3.5.

5. Results

5.1 Manual interpretation

Figure 5.1 illustrates the manual interpretation of the forested area in the different years 1986, 1995, 2003 and 2009. Comparing one year to another, the changes are not that easy to spot. But some changes can easily be distinguished. Between 1995 and 2003 a big forest block has almost completely been cleared as can be seen in the southwest corner of the map. In the year 1995 the total area of this forest block was around 1 048.8 hectares and in the year 2003 only 140.6 hectares remained. **Table 5.1** contains information about the total area of the forests for the four years. This is also illustrated in Appendix 2. In 1986 the area consisted of 29 240.3 hectares of forested land. The total area of the forest has since 1986 gradually reduced and in the year 2009 the forested area was approximately 25 091.4 hectares. Consequently, during this time period around 4 149.0 hectares has been deforested and converted into other land uses.

Table 5.1. *Total area of forested land for the different years.*

Forested area	
Year	**Total area (ha)**
1986	29 240.3
1995	27 657.3
2003	25 859.2
2009	25 091.4

The change in forest cover between 1986 and 2009 is presented in **Figure 5.2.** The red area represents the extension of the forest in 1986 while the green area is the border of the existing forest today. Hence, the red area corresponds to areas where the forest has disappeared and where the major changes have taken place. Except for the coherent forest block in south west where almost the whole forest has been cleared, the gradual deforestation has taken place along the borders of the forest. Furthermore, smaller forest blocks have been completely cleared. In 1986 the forest was more scattered and widespread. In 2009 the larger forest blocks have become more distinctive.

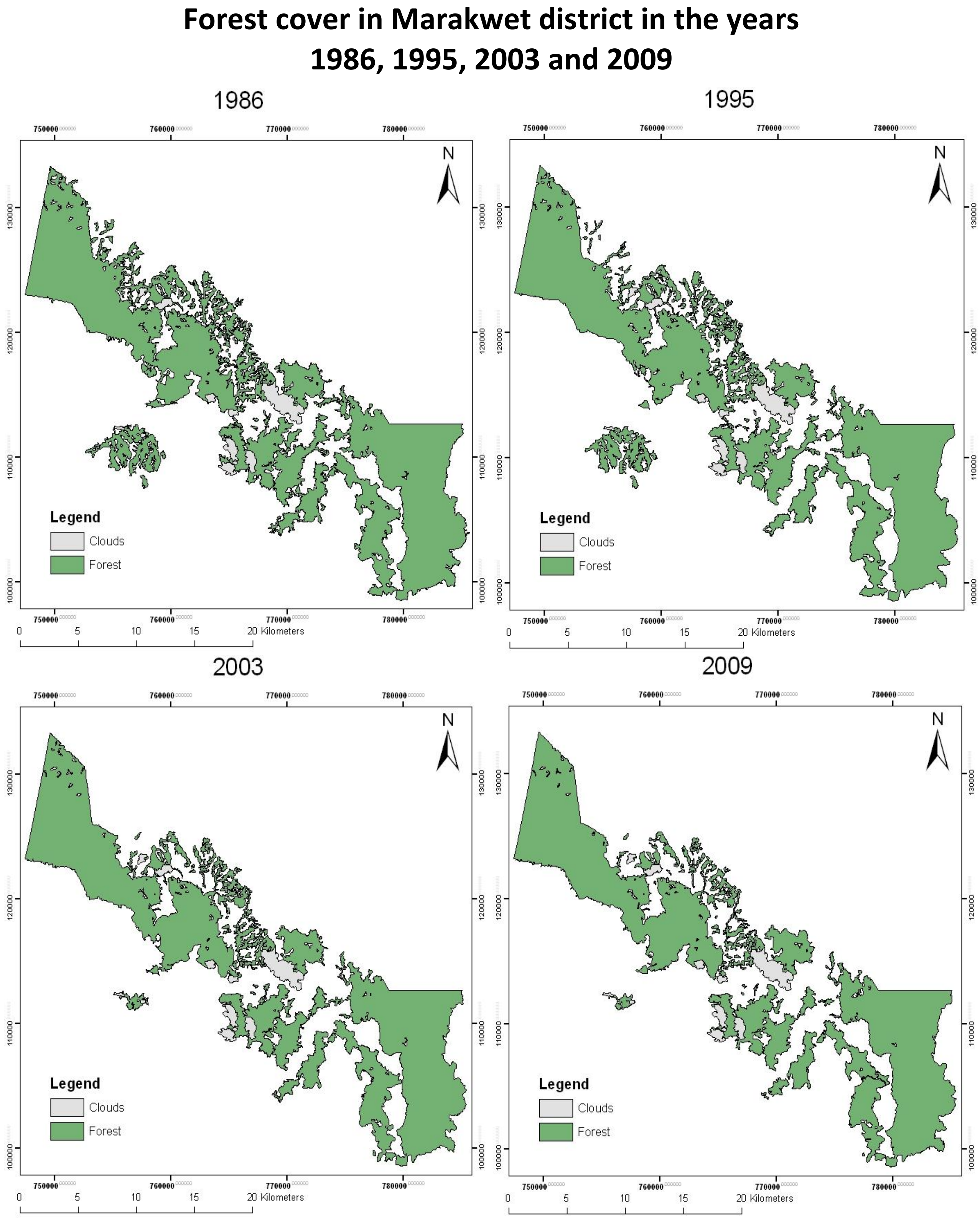

Figure 5.1. *Manual interpretation of the forest cover in the study area in Marakwet district. The maps represent the forest cover in four different years: 1986, 1995, 2003 and 2009. Based on Landsat data from USGS.*

Forest cover in Marakwet district comparing 1986 and 2009

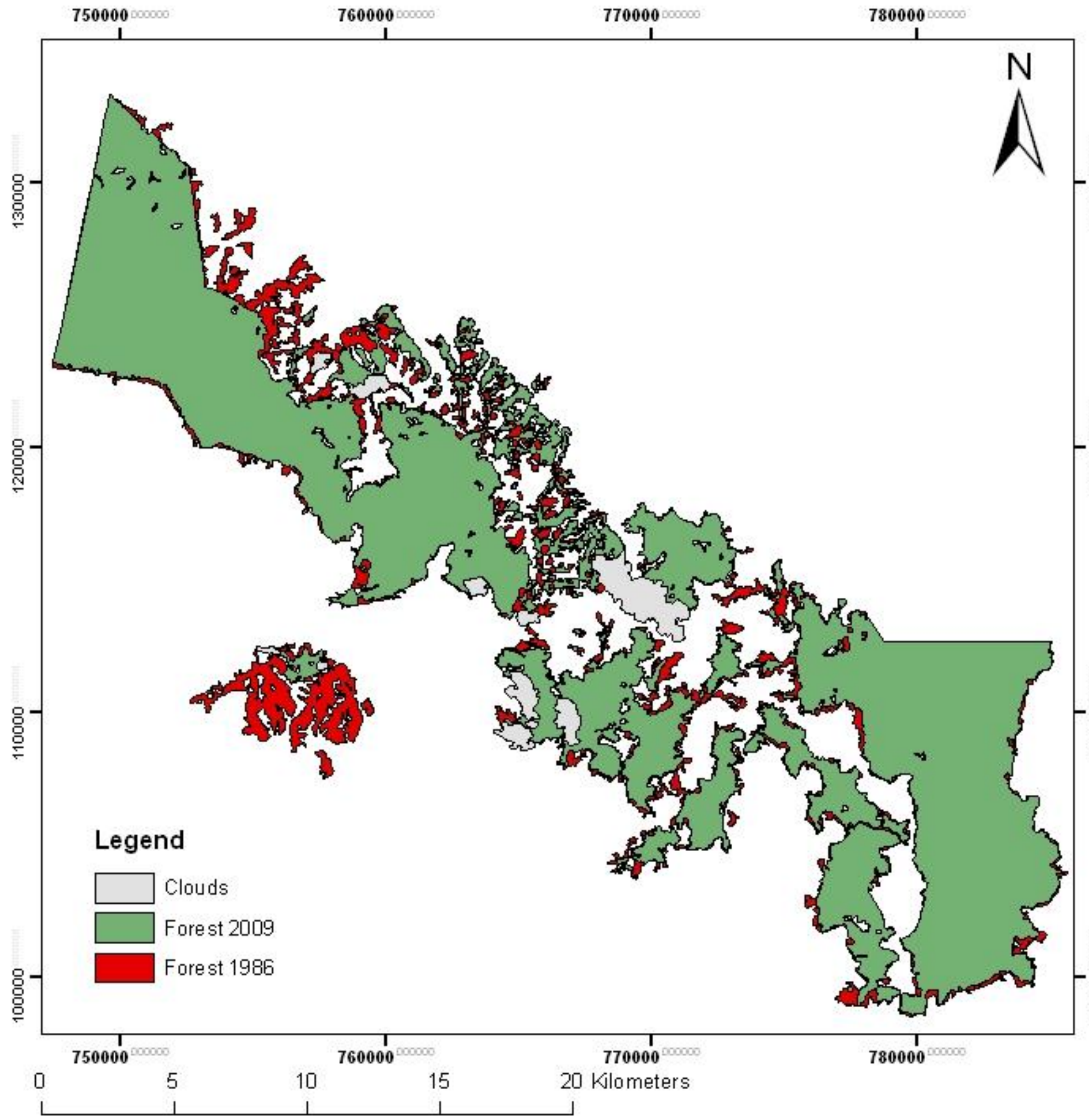

Figure 5.2. *Map illustrating forest cover in Marakwet district comparing the year 1986 and 2009 based on Landsat data from USGS. The green area is the forested land in 2009 while the red area is the forested land in 1986.*

In those cases where the forest has been cleared to that extent that only a narrow line of trees remains along a river or a water stream, the forest was excluded from the analysis according to the existing classification scheme (see **Table 4.2.**) This was made since it was too difficult and time-consuming to interpret these narrow lines of trees in the satellite data with 30 meters resolution.

Even though the best accessible images were selected from the Landsat archive, some of the images contained clouds. The cloud cover has on the other hand not affected the final result, since the areas affected of clouds were removed from the manual interpreted forest maps.

5.2 Deforestation rate

The image interpretation and field visit in the study area in Marakwet district has clearly shown that the area is experiencing an ongoing deforestation. The yearly deforestation rates were calculated based on the area calculations from **Table 5.1** between the different years. The rates are presented in **Table 5.2**.

Table 5.2. *Calculated annual deforestation rates and forest loss between the different years, the annual forest loss and an overall annual deforestation rate from the period 1986-2009.*

Deforestation			
Year	**Rate (%)**	**Annual forest loss (ha)**	**Forest loss in total (ha)**
1986-1995	0.6	175.9	1 583.0
1995-2003	0.8	224.8	1 798.2
2003-2009	0.5	128.0	767.8
1986-2009	**0.7**	**180.4**	**4 149.0**

Between 1986 and 1995 the yearly deforestation rate was 0.6 percent and during this period 1 583.0 hectares of the former forest was cleared. Between 1995 and 2003 the yearly deforestation rate increased to 0.8 percent. Hence, larger forested areas were cleared, approximately 1 798.2 hectares. In later years the deforestation rate has decreased and between 2003 and 2009 the yearly deforestation rate was 0.5 percent. The deforested area during this period was 767.8 hectares.

Totally, during the time period from 1986 to 2009, the total forest loss was 4 149.0 hectares, which corresponds to a loss of 14 percent of the total forested area that existed in 1986. The overall annual forest loss for the same time period was 180.4 hectares. This corresponds to a mean annual deforestation rate of 0.7 percent.

5.3 Future scenario

In the last section, an overall annual deforestation rate from 1986 to 2009 was calculated. This annual deforestation rate (0.7 %) was used to create the future scenario (by calculating the forested area in Marakwet district in a possible future).

The future scenario stretches from 2010 until 2100 and is based on the fixed deforestation rate of 0.7 percent.

The annual loss of forest was calculated. The second figure in Appendix 2 illustrates the decrease in forested land between the years 2010 and 2100. The predicted forested areas are shown in **Table 5.3**. By the end of this century the forested area will consist of only 13 695.6 hectares compared to 25 091.4 hectares in 2009.

Table 5.3. *Predicted forested areas from 2010-2100.*

Year	Forested Area (ha)
2010	24 925.0
2020	23 320.6
2030	21 819.5
2040	20 415.0
2050	19 101.0
2060	17 871.5
2070	16 721.1
2080	15 644.8
2090	14 637.8
2100	13 695.6

This means that the area will have lost 45 percent of its forests in the year 2100 compared to 2009. It should be mentioned that this is a simplified future scenario, where no other factor than the deforestation rate is taken into account.

5.4 Accuracy assessment

In order to evaluate the results an accuracy assessment was made. The evaluation was made for the year 2009. The manual interpretation of the previous years has been evaluated visually and is assumed to have the same accuracy as the manual interpretation from 2009. To provide the accuracy of the classification, the field samples were used for the evaluation of the two classes “forest” and “other land use”.

In **Table 5.4.**, the error matrix is presented. The columns represent the reference data and the map data is seen in the rows. The reference data is the 106 sample points and the map data is the manual interpretation from 2009.

Table 5.4. *Error matrix, columns are reference data, rows are predicted.*

		Reference data		
		Forest	Other land use	**Total**
Map data	Forest	**31**	0	31
	Other land use	3	**72**	75
	Total	34	72	**106**

From this error matrix the Producer's and User's accuracy was calculated and this is presented in **Table 5.5.** The Producer's accuracy gave a value of 91.2 percent for areas classified as forest and 100.0 percent for areas classified as other land use (n=106) while the User's accuracy gave a percent value of 100.0 percent for the classification forest and 96.0 percent for the other land uses.

Table 5.5. *Producer's and User's accuracy of the manual interpretation of the forest in Marakwet district, based on the error matrix.*

Classification	**Producer's accuracy**	**User's accuracy**
Forest	91.2%	100.0%
Other	100.0%	96.0%

The overall accuracy considering the two land cover classes resulted in a value of 97.2 percent and an overall kappa index of 0.93 make the classification adequate.

5.5 Population growth

A compilation of the data from the available population censuses provided the following results. In 1969 Kenya had a population of 10.9 million people. Ten years later the population increased with 40.4 percent and the country had a population of 15.3 million people. The population had increased to 21.4 million in 1989 and 28.7 million in 1999. The country has experienced a rapid population growth of 35 to 40 percent between every tenth year resulting in a population of 38.6 million people in the year 2009. Compared to the population in 1969 it is an increase of approximately 254 percent. The population in Kenya can be seen in **Table 5.6.**

Table 5.6. *Population in Kenya every tenth year from 1969 to 2009 and the population growth in percent. Data from the KNBS.*

Population in Kenya		
Year	**Population (million)**	**Increase (%)**
1969	10.9	-
1979	15.3	40.4
1989	21.4	39.9
1999	28.7	34.1
2009	38.6	34.5

The population growth in Elgeyo/Marakwet district follows the same trend as the one for the whole country. In Elgeyo/Marakwet district the censuses were not provided until 1979. In 1979 the district had a population of almost 149 000 people. A population growth of 45 percent resulted in a population of 216 500 people in the year 1989. Since 1989 the increase in population has been around 30 percent every tenth year and in 2009 the population consisted of approximately 370 000 people. The population growth for the district Elgeyo/Marakwet is presented in **Table 5.7**.

Table 5.7. *Population in the Elgeyo/Marakwet district, Kenya every tenth year from 1979 to 2009 and the population growth in percent. Data from KNBS.*

Population in Elgeyo/Marakwet district		
Year	**Population**	**Increase (%)**
1979	148 868	-
1989	216 487	45.4
1999	284 494	31.4
2009	369 998	30.1

According to the data in **Table 5.6**, the population in Kenya increases with at least one third every tenth year. The same trend appears for Elgeyo/Marakwet district, as seen in **Table 5.7**. Furthermore, in a time period of 40 years, the total population of Kenya has increased more than 250 percent. In Elgeyo/Marakwet district the population increased with approximately 150 percent in a time period of 30 years.

Since the available population data were only covering Kenya as a country and Elgeyo/Marakwet district, it was not detailed enough to get a statistically significant correlation between the deforestation and the increasing population in the study area. Nevertheless, the results show a trend on a continuing growing population, both on national and on district level. If the population growth continues as in present, this might in turn lead to a continuing deforestation in the area. **Figure 5.3** illustrates the population growth.

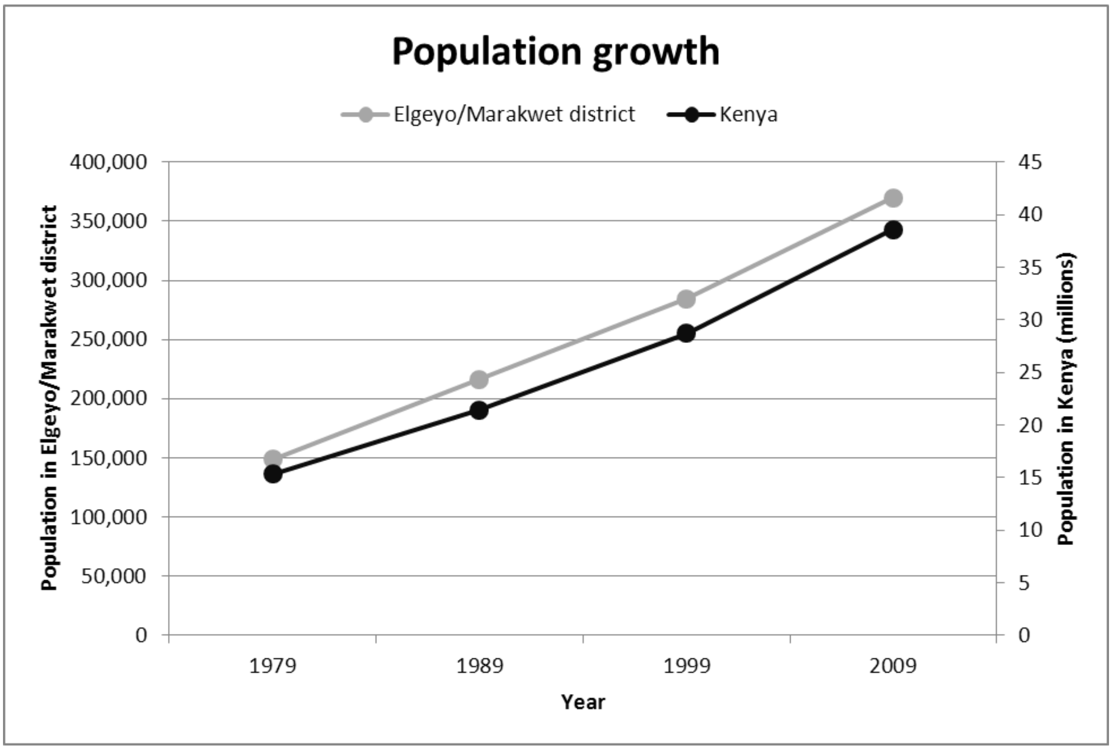

Figure 5.3. *Population growth in the Elgeyo/Marakwet district and Kenya between the years 1979-2009. Data from KNBS.*

5.6 Summary of results

In general, the ongoing deforestation in Marakwet district is a process that have been occurring gradually. From one year to another, the changes are not that significant. However, during a time period of 23 years major changes have taken place. Around 4 149 hectares (14 percent) of the forested area in 1986 has been cleared and one large forest block has completely vanished and been converted into pasture and cultivated land. The mean annual deforestation rate during this 23 years period was 0.7 percent.

The results regarding the yearly deforestation rates are showing that there is severe deforestation going on in the study area in Marakwet district. Largest amount of forest was cleared between 1995 and 2003 since the annual deforestation rate during this time was at its peak. The rate was 0.8 percent and approximately 1 798 hectares were cleared. The deforestation rate has been decreasing in later years but the forest is still disappearing at a higher rate than areas being reforested.

The future scenario stretches from 2010 until 2100 and shows an average annual decrease of 180.4 hectares. With a fixed annual deforestation rate of 0.7 percent, the forest is predicted to have decreased with 45 percent in the year 2100. This results in a loss of forest from approximately 25 091 hectares in 2009 to 13 696 hectares in 2100.

An evaluation of the results was made through accuracy assessment. Achieving an overall accuracy of 97.2 percent and a kappa value of 0.93 the manual interpretation was concluded to be statistically valid and sufficient.

The population trends for Kenya and Elgeyo/Marakwet district show legible signs of a steady growth. In 40 years, the total population of Kenya has increased with approximately 250 percent and projections show signs of a continuing population growth. Lack of detailed population data has made a statistical significant correlation between deforestation and population growth impossible. However, by looking at deforestation trends and population growth it is obvious that a greater number of inhabitants in the area would lead to a continuing deforestation.

6. Discussion

Deforestation is a widespread problem around the world. Kenya is no exception. The need for new settlements, more land to cultivate and more land for grazing, threatens the existing forest. Furthermore, local communities use the forest to extract wood for fuel and for production of charcoal. This might be the greatest contribution to the deforestation in the country. In addition, commonly used methods for fencing cultivated land also demand a lot of timber. These practices have led to an unsustainable management of the forest.

Deforestation has severe consequences. The forest degradation has for example been shown to have a negative impact on the local climate. According to Chebet (2010), Masinde (2010) and Rotisch (2010) it rains less in Marakwet district due to the ongoing deforestation. This has led to a decrease in water level in the rivers, and water table levels have dropped as well. In addition, soil erosion is a growing problem. The landscape in Marakwet district is characterized by a hilly terrain, and there is a risk that some areas may be completely destroyed as a result of soil erosion.

SCC-Vi Agroforestry has in recent years been introducing the agroforestry technique in Marakwet district as a way of stopping the deforestation. The goal is to help the local communities to plant trees and produce fuel, timber and fodder on their own farms, instead of being dependent on the forest. The Kenya Forest Service has also started several reforestation projects, as a way of mitigating the loss of forest.

6.1 Field sampling

When collecting field samples one should, according to Congalton and Green (1999), have at least 50 samples per each land cover. In this study, two land cover classes were used ("forest" and "other land use"), which required the collection of at least 100 samples. After finishing the field work, 106 samples were collected. Of these, 34 samples were collected in the forest and 72 samples in the other land cover class. Since forest was the land cover of interest, more samples should have been considered for collection in this land cover class.

Even though a random sampling method would be the most convenient and statistically correct, it was not possible to apply to the field sampling in practice due to the inaccessible land in the study area. It was only possible to obtain field samples along the available road network. This is a major drawback, since random sampling is preferred due to good statistical properties. The non-random sampling method might affect the results of the accuracy assessment. This is important to keep in mind.

The circumstances that limited the field sampling were the bad accessibility in the study area due to hilly terrain, poorly maintained roads, unsafe areas and weather conditions. Furthermore, time was also a constraining factor. Due to the time limitations, it was difficult to collect a larger amount of field samples and be able to reach more remote places in the study area.

According to Congalton and Green (1999), it is important that reference data is collected using the same classification scheme as was used to generate the map. This was the plan in this study as well, but when the manual interpretation was started, it became clear that the existing classification scheme could not be applied. The level of detail that was initially intended for the manual interpretation could not be achieved due to time limitations. Therefore, the classification scheme had to be adjusted so that it was possible to apply on the manual interpretation. Unfortunately, this was realized after finishing the field sampling, and the samples could not be collected again.

6.2 Manual interpretation

Before the selection of the classification method was made, different options were examined. The heterogeneous landscape in the study area made it difficult to achieve satisfying results when testing the unsupervised and supervised classification methods. Therefore it was decided that a manual interpretation would give the best result in this case.

In those cases where the forest has been cleared to the extent that only a narrow line of trees remains along a river or a water stream, the trees was excluded from the analysis according to the existing classification scheme (see **Table 4.1**). A narrow line of trees is not covering an area large enough to be classified as forest. This exclusion was also made since it was not possible to interpret these narrow lines of trees in the satellite data with 30 meters resolution.

Furthermore, the interpreted borders of the forest are expected to deviate from reality by ±60 meters (±2 pixels). If time were not a limitation, it would have been interesting to calculate the resulting error. However, these deviations should be the same for the different years, which makes the deviation negligible when comparing the different years against each other.

The forest in Marakwet district consists of approximately 65 000 hectares. Of this around 25 000 hectares of forest were manually interpreted. This corresponds to nearly forty percent of the total forest cover in the district and can be said to be representative of the area.

The RMS values from the spatial georeferencing were unfortunately higher than desired, due to inadequate reference data. It has to be taken into consideration that this error might affect the result of the transformation and additional analysis.

6.3 Deforestation rate

Since there are only three values of yearly deforestation rate to compare, it is not possible to determine any trend. However, FAO and UNEP have mentioned in their latest reports that it seems like the deforestation rate is decreasing in Africa. According to FAO (2010) one reason could be the progress in sustainable forest management.

But even though the deforestation rate has decreased in the area since the time period 1995-2003, the forest is still disappearing faster than it is reforested and hence the problem with deforestation remains.

As mentioned before, the Kenya Forest Service has made a few attempts to stop the deforestation through projects involving restoration of indigenous forest on a small scale. Unfortunately, several reforestation projects have not succeeded since the local farmers illegally allow their animals to graze on the newly planted land. This issue was discussed with the Kenya Forest Service. One possible solution would be to fence and protect the tree nurseries and the new plantations with guards.

To get a more precise deforestation rate, additional years could be used in the time series analysis. This would lead to better continuity and would make it easier to distinguish trends.

6.4 Future scenario

If the deforestation continues at the same rate as between 1986 and 2009, there will only be approximately 13 700 ha forest left in the year 2100. Today there is approximately 25 100 ha. Evidently, there is no existing sustainable forest management in Kenya. To stop this trend, investments in forest conservation must be made.

It should be emphasized that the future scenario in this study is simplified. The scenario is made with the assumption that the annual deforestation rate is fixed without variations. If time was not a limitation in this study, it would have been interesting to create a more complex model of the future scenario, based on the deforestation trends between 1986 and 2009. Socio-economic factors such as population growth and changes in the demand of fuelwood could be included in the model as key factors affecting the future deforestation in the area. This would have generated in a more realistic future scenario.

6.5 Population data

Population data was examined for correlation to deforestation in the study area. The population data used in this study was collected from KNBS and covers the former district Elgeyo/Marakwet. This former district covers a larger area than Marakwet district, in which the study area is located. This is of course a drawback, since it affects the accuracy of the population growth estimation in the study area.

It would have been much better with detailed population data with maybe 1000 x 1000 m resolution. However, a better resolution of population in the study area does not exist and could not be collected within the allotted time.

The population data consists of actual counts of the Kenyan population and not projections. This makes the calculations of population growth more accurate. The censuses were taken in 1979, 1989, 1999 and 2009, and hence a comparison can be made with the extent of deforestation between 1986 and 2009.

Even if it is not possible in this study to statistically prove the linkage between the deforestation in Marakwet district and an increasing population in the area, there have been several studies, such as Barnes (1990) and UNEP (2006), which state that deforestation actually is linked to population growth.

6.6 Data and quality

After considering different options, Landsat TM and ETM+ data with 30 meters resolution was chosen for the study. Overall, the data has good quality and the conclusion was made that 30 meters resolution was suitable for the purpose of this study. Landsat data is known to be good for detection of land cover changes, since it has both good temporal, spatial resolution and a global coverage. This data has been used in other studies of deforestation in Africa such as Akotsi et al. (2006) and Duvellier et al. (2008). Landsat data is easy to acquire since it is available for free download. Unfortunately, there was no good available topographical map that could have been used for re-sampling. Furthermore, the vector data collected from ILRI had insufficient resolution and was therefore not suitable for re-sampling either. However, the vector data was applicable for production of maps of Kenya.

6.7 Final discussion

According to Willams (2007) there are no large companies actively exploiting the forest in Marakwet district. Instead, the deforestation activities in the area are mainly carried out by members of local communities. People in the communities gradually clear trees to expand their land, which results in the forest being narrowed.

The observed population trend in Kenya shows legible signs of a continuing increase. This fact is also confirmed by employees at the SCC-Vi-Agroforestry and the Kenya Forest Service. A decrease in forest cover combined with an increasing population results in less forest available per person, which most likely could increase the pressure on the forest.

One way to decrease and prevent further deforestation is to involve the local communities in forest management. Education and information might be a good solution in order to increase the public awareness of the importance of forests. Not only is good forest management necessary to protect the forest, but also forest conservation has to be included. Until the public understands the importance of forests, forests will continue to be cleared and degraded. But increased awareness is not the only solution. In order to stop the illegal deforestation people in the area still need an alternative source to collect fuelwood and charcoal.

The SCC-Vi Agroforestry put much effort in educating farmers and introducing agroforestry to local communities in Kenya. By planting trees on farms and adopting energy saving technologies to reduce the amount of firewood used, the organization contributes to a self-sustained food and fuelwood production for families. However, as mentioned before, more efforts are still needed. National governments around the world should strengthen activities that protect closed forest areas and come up with reasonable plans to hinder a global continuing deforestation.

If there would have been more time, it would have been interesting to use satellite data from 1970’s as well, to get a longer time series in the analysis. According to the Kenya Forest Service and SCC-Vi Agroforestry the deforestation was severe during that decade.

It is convenient to use satellite images with high spatial resolution to detect deforestation over time. Manual interpretation is a suitable method of measuring deforestation and it can be applicable all over the world. However, manual interpretation of high resolution satellite images demands time and should first of all be recommended for studies on local and regional scale.

7. Conclusions

The aim of the study was to investigate and map the deforestation in the study area by conducting a time series analysis. The solutions to the research questions are presented below.

- *How much forest has been cleared during the 23 years period 1986-2009?*

Between 1986 and 2009, 4 149 hectares of forest were cleared. This corresponds to 14 percent of the forested areas in 1986.

- *How much forest has disappeared between the different years (1986 and 1995, 1995 and 2003, 2003 and 2009)?*

Between 1986 and 1995, 1 583 hectares of forest were cleared. The next interval experienced an increase in deforested area and totally 1 798.2 hectares were cleared. Between 2003 and 2009, 767.8 hectares were deforested. Comparing the intervals is not possible since they consist of various number of years. However, the annual forest loss for each interval was calculated and used for a comparison. When these values are compared, you can clearly see that the annual loss of forest is largest between 1995 and 2003; 224.8 ha of forest disappeared in average each year, compared to 175.9 ha between 1986 and 1995, and 128.0 ha of annual forest loss between 2003 and 2009.

- *How high is the deforestation rate in total and between the selected years?*

1986-1995 the annual deforestation rate was 0.6 percent. 1995-2003 the rate increased to 0.8 percent. Between 2003 and 2009 the annual deforestation rate declined to 0.5 percent. The total mean annual deforestation rate between 1986 and 2009 is 0.7 percent. Giving only three values of yearly deforestation rate it is not possible to see any trends. However, according to reports from FAO and UNEP the deforestation rate seems to have decreased in Africa the last 10 years. But even though the annual deforestation rate has decreased in later years, the forests are still disappearing faster than they are being reforested.

- *Where have the major changes taken place?*

The deforestation tends to occur along the border of the forest at the same time as small forest blocks are disappearing, as seen in **Figure 5.2**.

- *If the deforestation continues at the same rate as between 1986 and 2009, how much forest will be left within the time period of 2010 and 2100?*

The forest in Marakwet district risks to be highly reduced until year 2100, if the deforestation rate continues as between 1986 and 2009. According to the results only 13 696 hectares of forest will remain in 2100 compared to a forest cover of 25 091.4 ha in 2009. This corresponds to a loss of 45 percent of the existing forest in 2009. The future scenario was based on a fixed annual deforestation rate. Even if other factors such as population growth were not considered in the calculation, the trend is very alarming. The situation is severe and something must be done to prevent further damage of the existing forest.

- *What land use has replaced the forest in the deforested areas?*

According to several sources such as Masinde (2010), FAO (2009), Williams (2007) and our own observations in field, the deforested areas have mainly been converted into agriculture and pasture.

- *Does the deforestation correlate with increasing population in the area?*

A conclusion about a correlation cannot be made in this study due to insufficient population data. However, according to other studies and reports a correlation between deforestation and population growth exists.

In conclusion, the situation with the deforestation is severe. Immediate action must be taken in order to save the rest of the forest in the district. Since the relocation of local communities is not an option, something must be done to prevent the ongoing deforestation. Over the next 100 years there will otherwise be severe impacts on the land cover in the area.

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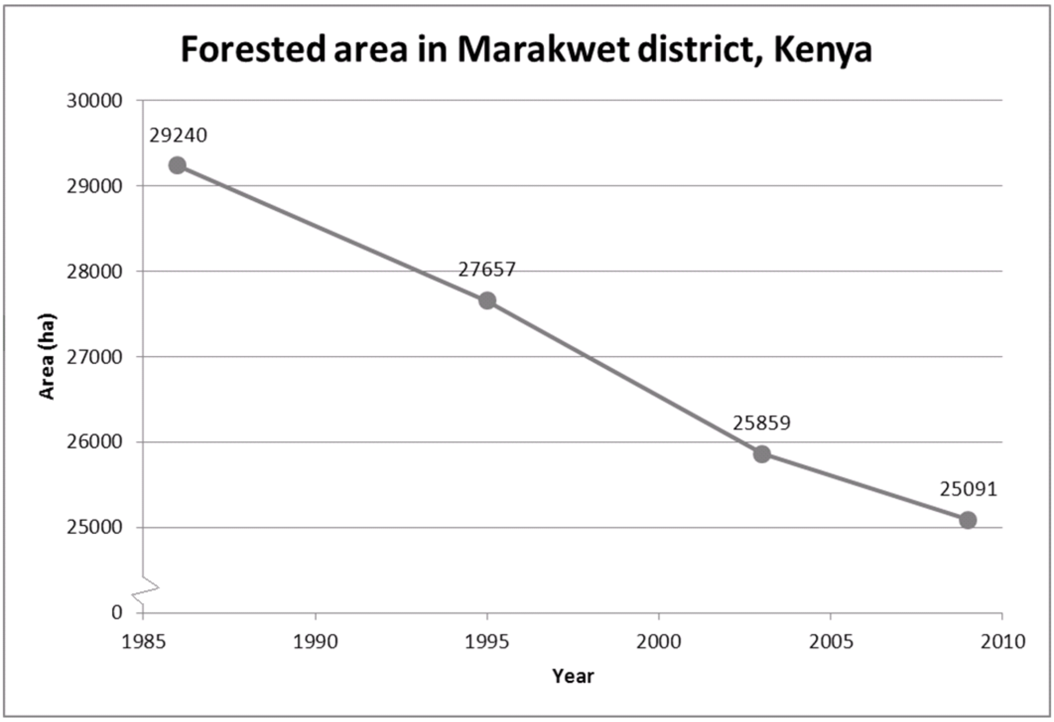
Appendix 1

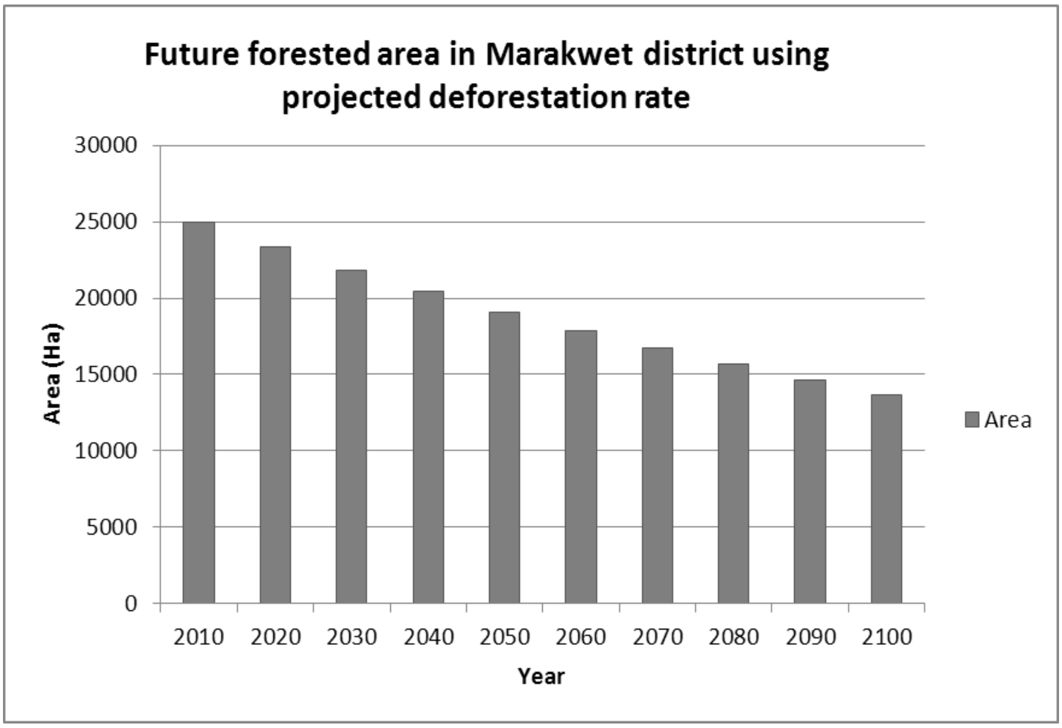
Abbreviations

DEM – Digital Elevation Model
FAO – The Food and Agriculture Organization
FCC – False Colour Composite
GIS – Geographical Information Systems
GLOVIS – Global Visualization Viewer
GPS – Global Positioning System
ILRI – International Livestock Research Institute
KNBS – Kenya National Bureau of Statistics
Landsat ETM+ – Landsat Enhanced Thematic Mapper Plus
Landsat TM – Landsat Thematic Mapper
MFS – Minor Field Study
NASA – National Aeronautics and Space Administration
NDVI – Normalized Difference Vegetation Index
NIR – Near Infrared Radiation
RMS – Root Mean Square
RS – Remote Sensing
SCC-Vi Agroforestry – Swedish Cooperative Centre Vi Agroforestry
SIDA – Swedish International Cooperation Agency
SLC – Scan Line Corrector
UNEP – United Nations Environment Programme
UNFF – United Nation Forum of Forests Secretariat
USGS – United States' Geological Survey
UTM – Universal Transverse Mercator
VIS – Visible Radiation
WGS84 – World Geodetic System 1984
WRI – World Resources Institute

Appendix 2



Forested area in Marakwet district, Kenya, in the years 1986, 1995, 2003 and 2009.



Future scenario showing how much of the forest that will remain in study area in Marakwet district by the year 2100. The areas were calculated by the use of the overall deforestation rate between 1986 and 2009 (0.7 %).

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