



## Master Thesis

im Rahmen des  
Universitätslehrganges „Geographical Information Science & Systems“  
(UNIGIS MSc) am Zentrum für GeoInformatik (Z\_GIS)  
der Paris Lodron-Universität Salzburg

zum Thema

### **Integration of geo-information technologies and indigenous knowledge structures**

**Development of a monitoring prototype for a community based  
woodland management scheme in eastern Namibia**

vorgelegt von

**Karsten Feuerriegel**  
u1011, UNIGIS MSc Jahrgang 2003

Zur Erlangung des Grades  
„Master of Science (Geographical Information Science & Systems) – MSc(GIS)“

Gutachter:  
Ao. Univ. Prof. Dr. Josef Strobl

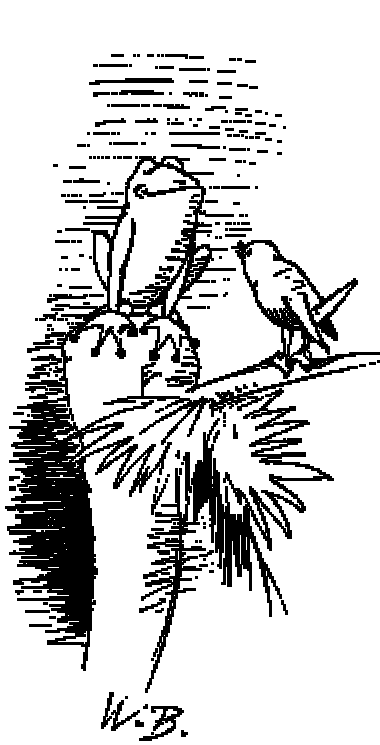
Kanovlei Forestry Station, Namibia, 30.10.2005

## **Erratum**

Page 50 and page 64 are not numbered. But there is no text or what so ever missing. The application simply skipped inexplicably these pages.

# Motto

## Der fliegende Frosch\*



Wenn einer, der kaum  
Gekrochen ist auf einen Baum,



Schon meint, daß er ein Vogel wär,



So irrt sich der.

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\* The referees should permit that the above picture story (The flying frog) is not translated into English. But the wit and wisdom of the German cartoonist and poet Wilhelm Busch, which guided the author throughout this study, must be kept in its original language.

# Abstract

Efforts to develop community based natural resource management schemes to preserve biodiversity and improve simultaneously the livelihood of local communities increasingly require work across disciplinary boundaries. This study describes the approach to develop a monitoring prototype with the !Kung people in Namibia to determine resource availability in the M'Kata community forest (**objective 1**). The prototype attempts to integrate geo-spatial technologies<sup>1</sup> and indigenous knowledge and ought to be a rapid and cost-effectively instrument for land-use planning. There have been few attempts to integrate ecological or geo-spatial based data with indigenous knowledge structures in Namibia, and there is no recognised conceptual framework within which to conduct such work. Consequently, it should be assessed to which extent geo-spatial approaches can be integrated into the proposed monitoring system and used to evaluate the prototype's methodology (**objective 2**).

The approach used to realise the first objective includes the following steps:

1. Participatory development of a survey manual, called the 'monitoring book', designed in A5 format for better handling and equipped with ten different maps and four different data sheets for collection of silvicultural data.
2. Training of young community members including the utilisation of a GPS device and collection techniques for silvicultural data (z-values) along a 1-minute grid (x,y coordinates).
3. Establishment of reference plots to determine different parameters necessary for calculation of the projected yield for selected timber and non-timber products.

After incorporation of the inventory data into a DBF table, surface generation of particular z-values e.g., firewood availability, vegetation type and canopy cover, was executed using two interpolation methods (Spline and Kriging). In a next step, area determination of the interpolated z-value classes allowed to calculate for example the

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<sup>1</sup> Data derived from remote sensing (RS), image processing (IP), spatial analysis (SA) and global positioning systems (GPS).

projected yield for popular Camel-thorn firewood. The utilisation of this species is limited to dead wood products and pods, and the preliminary results suggest particular collection sites for firewood, different harvesting values for each site and a total yield, which should not exceed 325 tons for the community forest. Based on these results, a trial harvesting scheme has been successfully implemented and confirmed the approach in the reference plots and during the survey to a certain degree.

Various enhanced images, such as true and false colour composites, NDVI, Tasselled Cap and texture images, have been produced from two mosaicked, multispectral scenes (Landsat 7 ETM+ 177\_073 and 177\_074). Some of these images were used to classify and map vegetation structures into physiognomic classes based on vegetation type and canopy morphology including: Broad-leaved deciduous woodland, fine-leaved evergreen/semi-deciduous woodland and mixed scrubland. Attempts to refine the classification into further classes was not possible due to similarity of spectrum characteristics in zones with more heterogeneous stands – the mixed pixel problem.

Unfortunately, no up-to-date satellite data were available for the study but only two scenes from April 2000. A temporal analysis with at least four time corresponding images e.g., two from the last dry season in 2004 and two from the last rainy season in 2005 would have eased identification of deciduous woodland classes because of its big annual NDVI difference, while fine-leaved evergreen woodland would maintain a high NDVI average during the dry season. But unfortunately the required scenes have not arrived in time and as a result, generalization of the classification into only five vegetation type classes was essential.

The quality of the prototype's methodology was further assessed by correlating the classification results (distribution and extent of vegetation types) with those of the surface generation maps, and by testing for correlation between canopy cover values and mean pixel values derived from NDVI (objective 2). The comparison between the three different area-generation methods confirmed some substantial differences. In comparison with the classification results the interpolation with the

Spline method overestimated the extent of evergreen woodland and underestimated deciduous woodlands. The Kriging method overestimated the extent of evergreen woodland even more than Spline and compared to the classification results underestimated likewise the amount of deciduous woodlands. The discrepancy between the different methods indicates low quality inventory data as a major flaw in the approach.

This result was confirmed by the regression analysis. The correlation between the average NDVI pixel values and the estimated canopy cover values was not significant at all ( $R = 0.047$ ,  $R^2 = 0.002$ ). Again, the time difference between woodland assessment and age of satellite images and the probable imperfect determination of silvicultural data (z-values) during the inventory must be regarded as the limiting factors for a high correlation. There are indications that in a little while more up-to-date scenes will be made available for the project to perform a more appropriate qualitative and quantitative analysis. Far superior information can further be expected from more professional survey teams following a more strict data collection protocol. It is therefore suggested, to carry out further training for determination of silvicultural data in reference areas, where at least some parameters e.g. canopy cover of trees and shrubs could be more reliable determined with certain sophisticated equipment, such as densiometer or Bitterlich relascope.

Summary table: **Assets and limitations of the monitoring prototype**

<b>Exercises</b>	<b>Methodology</b>	<b>Method of Assessment</b>	<b>Grade</b>	<b>Limiting factors</b>
Yield and area determination for firewood	Reference areas, survey and interpolation (Spline)	Trial harvesting scheme	Fair	-
Distribution and extent of vegetation types	Survey and interpolation (Spline)	Classification and analysis of satellite images	Low	1. Time difference between survey and age of satellite images 2. Imperfect z-value determination and grid size
Determination of canopy cover	Survey and interpolation (Spline)	Regression analysis	Very low	See above

# Zusammenfassung

Ohne lokal akzeptierte Regeln und Institutionen führt die gemeinschaftliche Nutzung natürlicher Ressourcen in der Regel zur Übernutzung und Naturzerstörung. Diese Problematik hat Hardin (1968) so ausgedrückt: „Freedom in a commons brings ruin to all“. Das Gemeingut – Dilemma<sup>2</sup> ('The Tragedy of the Commons'<sup>3</sup>) ist in der Entwicklungszusammenarbeit ein bekanntes Phänomen wenn es um Konzepte zur kommunalen Nutzung natürlicher Ressourcen geht (Feuerriegel & Nuding 2003). Die Berücksichtigung des Nachhaltigkeitsprinzips erfordert, dass natürliche und selbst-erneuerbare Ressourcen, wie Wald und Wild, in ihrem ökologischen Zustand erfasst und in ihrer Nutzung organisiert werden, nicht zuletzt um ihren Schutz zu gewährleisten (Robinson & Redford 1991).

Diese Studie beschreibt den Versuch, gemeinsam mit der lokalen !Kung Bevölkerung einen Funktions-Prototypen für die Erfassung von Holzprodukten in einem Gemeindewald (Woodland Savanna) in Ostnamibia zu entwickeln (Ziel 1). Die Einschätzungen des Ressourcenzustandes wurden mit Hilfe von Methoden der Geoinformationswissenschaften, insbesondere mit Satellitenaufnahmen (Landsat 7 ETM+) überprüft (Ziel 2). Bei der dazu eingesetzten Software handelte es sich um ArcMap/ArcGis 8.3 (inkl. Spatial Analyst) und Erdas Image 8.6.

Zur Erreichung von Ziel 1 wurde in relativ kurzer Zeit eine Methode zur Flächeninventur partizipativ entwickelt und ein lokales Erfassungsteam ausgebildet, um Parameter wie Vegetationstypen, Beschirmungsgrad und Verfügbarkeit von Totholz grob abzuschätzen. Aufgrund der über 86.760 Hektar großen Fläche und der nicht vorhandenen Infrastruktur wurden Reitpferde und GPS-Empfänger eingesetzt, um die Datenaufnahme in 298 Punkten durchzuführen. Die Datenaufnahme beruht auf einem 1-Minuten-Raster, das auf dieser geographischen Höhe einen Abstand von etwa 1.833 km zwischen den Erfassungspunkten bedingt. Zusätzlich zur Punktdatenaufnahme wurden Referenzflächen zur Erfassung von Totholz eingerichtet.

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<sup>2</sup> Auch bekannt unter dem Begriff 'Allmende – Klemme' oder Allmendeproblematik.

<sup>3</sup> Commons: jede Ressource, die so genutzt wird, als würde sie allen gehören.

Die erfassten Punktdaten, sogenannte z-Werte, wurden mit ihren Raumkoordinaten (x- und y-Werte) in eine DBF Tabelle eingefügt, zusammengefasst und mit zwei verschiedenen Methoden (Spline und Kriging) zu einer Oberfläche interpoliert und vektorisiert. Dieser Ansatz erlaubte z.B. die Berechnung der geschätzten Feuerholzmenge auf Gesamt- oder Teilflächen. Nach dieser Abschätzung stehen in der Gesamtfläche 325.000 kg auf unterschiedlich klassifizierten Flächen zur Verfügung. Überprüft wurde diese Aussage mit einer Sammel- und Vermarktungs-aktion auf einer fast 7000 Hektar großen Fläche. Die Abweichung vom Schätzwert (64.12 Tonnen) betrug fast 8 Tonnen, d. h. es wurde 12.5 % mehr Feuerholz gesammelt als erwartet.

Zur Überprüfung der Prototyp-Funktionalität hinsichtlich Erfassung, Analyse und Darstellung der Vegetationstypen und des Beschirmungsgrades wurden zwei Satellitenbilder zusammengeführt und zu Echt- und Falschfarbenaufnahmen mit unterschiedlichen Bandkombinationen weiterverarbeitet. In einem weiteren Schritt wurden ein Vegetationsindex (NDVI), eine Tasseled Cap Transformation und eine Texturdarstellung für das Untersuchungsgebiet erstellt. Zur Klassifizierung der Vegetationsfläche in groß-blättrige laubabwerfende Savanne, fein-blättrige immergrüne Savanne und gemischtes Buschland, war insbesondere die Tasseled Cap Transformation mit der Bandkombination 7-4-2 geeignet. Diese drei Klassen konnten anhand ihres unterschiedlichen Beschirmungsgrades (> 70%, 70-40% und < 40-10%) aufgrund ihrer spektralen und räumlichen Eigenschaften weiter differenziert werden.

Die von dem Funktions-Prototypen ermittelten Vegetationstypen-Interpolationen besitzen deutliche Abweichungen von der Klassifikation. Beide Interpolationen, Spline als auch Kriging überschätzten die Flächenausdehnung der immergrünen Savanne und unterschätzten das Ausmaß der laubabwerfenden Flächen. Die Diskrepanz zwischen dem Klassifikations- und dem Interpolationsansatz indiziert den Prototypen eine geringe Qualität hinsichtlich der Punkterfassung. Dieses Ergebnis wurde durch eine Regressionsanalyse bestätigt, da die durchschnittlichen Pixelwerte des NDVIs mit den geschätzten Werten des Beschirmungsgrades signifikant voneinander abweichen.



Einen weiteren limitierenden Faktor, neben der nicht ausreichenden Qualität der Datenerfassung im Feld, stellt der Aufnahmezeitpunkt für die Satellitenbilder dar (April 2000). Leider standen dieser Studie keine ausreichenden und zeitnahen Aufnahmen zur Verfügung, um eine Zeitreihe erstellen zu können. Jahreszeitliche Unterschiede hätten die Differenzierung zwischen den Vegetationstypen wesentlich erleichtert, da z.B. laubabwerfende Flächen große Abweichungen hinsichtlich ihres spektralen Verhaltens im Jahresverlauf besitzen, während Akazienbestände einen kontinuierlich hohen NDVI aufweisen müssten.

In Zukunft sollten dem Projekt daher ausreichend Mittel zur direkten Beschaffung von zeitnahen Satellitenaufnahmen zur Verfügung gestellt werden. Eine weitere dringend erforderliche Maßnahme zur Verbesserung der Erfassungsmethodik ist die Einrichtung weiterer Referenzflächen zur Erfassung der Vegetationszusammensetzung und des Beschirmungsgrades. Auch eine Verkleinerung des Erfassungsnetzes, z.B. von einem 1-Minuten Raster zu einem 30-Sekunden Netz könnte die Qualität der Ergebnisse verbessern, da sich die Anzahl der Erfassungspunkte mehr als verdoppeln würde. Voraussetzung ist jedoch eine Weiterbildung des Erfassungsteams.

Um die an dem Gemeindewald beteiligten Kommunen stärker an Managementprozessen zu beteiligen, sollte ein Ansatz entwickelt werden, der es ermöglicht, zumindest einige der Flächeninventur-Ergebnisse ohne PC in einfach zu erstellenden Diagrammen und Karten zu visualisieren. Dies könnte dazu beitragen, dass die Nutzergemeinschaft eine ausreichende Motivation zur Veränderung von nicht nachhaltigen Nutzungsverhalten entwickelt. Hier kommt der Entwicklungszusammenarbeit eine wichtige Rolle als Berater und Moderator zu.

# Acknowledgements

This thesis has been submitted in partial fulfilment of the requirements for a Master of Science (GIS) at the Paris-Lodron University of Salzburg – Austria and **I gratefully acknowledge** the help and support of the following individuals:

Mrs. Celestre Espach of the Ministry of Agriculture for providing two Landsat 7 scenes when the order at the South African Imagery Acquisition Centre (SAC) did not arrive in time.

Mr. Michael Singer, Thales, Germany, who provided a MobileMapper GPS unit for the fieldwork.

Mr. Jürgen Praher, University of Salzburg and all the other UNIGIS team members who made it possible for me to postpone several deadlines for submission of module results including this thesis due to the difficult conditions here in the remote 'Bushmanland'.

Mr. Josef Kahimbi, Chairman of the M'Kata Forest Management Committee, Mr. John Nehemina (Vice-Chairman) and Mr. Ruben Gabriel and Mr. Erastus Sagaria (both members of the M'Kata Forest Monitoring Team). It was always a pleasure and a privilege to work together with them in the woodlands and gain from their amazing knowledge and tracking skills. !Kagalla, I am looking forward to spend more time with them in the field.

Finally, the completion of this thesis and modules six to eleven has been done under difficult conditions e.g., irregular supply of water and electricity, the next reliable telephone line is 200 km away in Grootfontein etc. These achievements would never have been accomplished without the support and understanding offered by my wife, Mrs. Ingeborg Boesche. Baie dankie, me vrou!

## Abbreviations

<b>AOI</b>	Area of interest, in this study the M'Kata community forest
<b>CBNRM</b>	Community Based Natural Resource Management
<b>CFNEN</b>	Community Forestry in Northeast-Namibia
<b>DED</b>	Deutscher Entwicklungsdienst
<b>DoF</b>	Department of Forestry
<b>EMR</b>	Electro-magnetic radiation
<b>ETM+</b>	Enhanced thematic mapper
<b>FMC</b>	Forest Management Committee
<b>GSC</b>	Geographic coordinate system
<b>GIS</b>	Geographic information system
<b>GPS</b>	Global positioning system
<b>IP</b>	Image processing
<b>KfW</b>	Kreditanstalt für Wiederaufbau
<b>MAWF</b>	Ministry of Agriculture, Water and Forestry
<b>MET</b>	Ministry of Environment and Tourism
<b>MLRR</b>	Ministry of Land, Resettlement and Rehabilitation
<b>NAD</b>	Namibian Dollar
<b>NDVI</b>	Normalized difference vegetation index
<b>PRA</b>	Participatory Rural Appraisal
<b>RS</b>	Remote sensing
<b>SA</b>	Spatial analysis
<b>SAC</b>	South African Imagery Acquisition Centre
<b>ToC</b>	Table of Content (ArcMap)
<b>TC</b>	Tasseled Cap
<b>VI</b>	Vegetation index

# Glossary

## **Absorption**

Radiation is absorbed through electron or molecular reactions within the medium encountered. A portion of the energy incorporated can then be re-emitted (as emittance), largely at longer wavelengths, so that some of the sun's radiant energy engage in heating the target gives a thermal response.

## **Band**

Data values for a portion of the electromagnetic spectrum, sometimes called a channel.

## **Buffer**

A zone of specified distance from selected features.

## **Classification**

Hierarchical system of user-defined classes for the classification of remote sensing imagery.

## **Database**

Data structure used to store, query, and retrieve (digital) information.

## **Enhancement**

Techniques used to make a remote sensing image more interpretable.

## **Ground-truth Data**

Ground truth data are simply observations or measurements made at or near the surface of the earth in support of a remote sensing survey e.g., to provide reference data for supervised classification. The location will be acquired by GPS to identify the location on RS image. Ground truth may consist of several types of data acquired before, during, and after an image acquisition.

## **Image**

Picture or graphical representation. In remote sensing and GIS as a term that describes usually digital representations of earth features.

## **Image Processing**

Manipulation of an image to improve or change some quality of the image.

**Landsat 7 and ETM+**

Earth observation satellite and the sensor.

**Layer**

Distinct map theme. Usually a separate GIS file.

**Remote Sensing**

"Remote sensing is the science of deriving information about the earth's land and water areas from images acquired at a distance. It usually relies upon measurement of electromagnetic energy reflected or emitted from the features of interest (Campbell 1987)."

**Resolution**

The degree of discrimination between objects. It can be spatial (what is the smallest size and object needs to be observed). It can be spectral (number and size of area of the electromagnetic spectrum is required). It can be temporal (how often does the subject need to be observed).

**Supervised classification**

Image classification procedure in which the analyst selects groups of pixels, determines their spectral signatures, and trains an IP application to recognize pixels based on this spectral response pattern.

**Thematic Data**

Qualitative and categorical raster data, usually map or land cover classes.

**Unsupervised classification**

Image classification procedure in which the IP application identifies inherent patterns in the spectral data and uses a clustering algorithm to order pixels into discrete classes.

**Vector**

Common GIS data model made up of points, lines, or polygons, with associated attributes.

**Interpolate**

In the context of surface generation: to predict values for a surface from a limited number of sample data points.

**Spline**

A geostatistical interpolation method based on statistical models.

# Spelling

Most Namibian place or feature names beginning with an 'O' – e.g., Otjondjupa, Okavango or Omatako - are derived from the Herero language.

The San and Nama dialects, also known as the Khoisan languages are characterised by 'click' elements. Clicks are made by compressing the tongue against different parts of the mouth to produce different sounds, which make the San dialects difficult to learn for most foreigners<sup>4</sup>. Nonetheless, the written representation of the click sound e.g., the exclamation mark in !Kung, the # in N#a-Jaqna or the tilt line in Ju/hoansi have been accepted by linguistics and found their way in the international alphabet.

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<sup>4</sup> Fortunately, younger San can speak additionally to their own dialect either a Bantu language, Afrikaans and/or English.

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# 1. Background

In the last two decades of the 20th century a new wave of programmes were promoting the decentralisation and devolution of governance in Africa and beyond. Particularly, in eastern and southern Africa integrated conservation and development projects occurred widely and are important components of the various land reform processes in the different countries. The dramatic rise in 'community participation' projects for wildlife, forest and savanna management still marks and carries this trend (Blackie et al. 1999, Corbett & Jones 2000, Dubois & Lowore 2000, Wily 2000a & b, Feuerriegel & Nuding 2003).

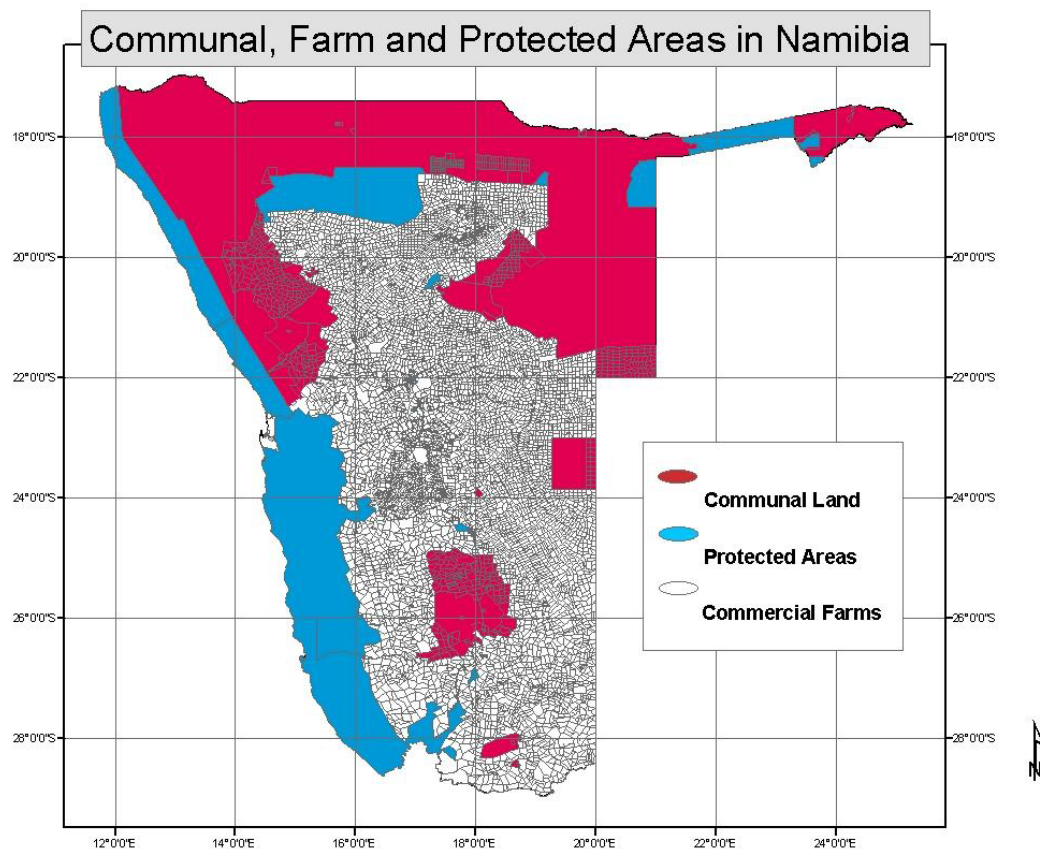


Figure 1. Distribution of three major land use categories in Namibia. Communal land is owned by the Central Government. With a few exceptions land utilisation remains a collective issue and traditional authorities are still a major political factor. Commercial Farms are owned privately. Source: Atlas of Namibia 2003

## **1.1 Communal land reform in Namibia**

Most of the land in Namibia is subdivided into the commercial farming area (ca. 36.2 million ha) on freehold land and the so-called communal areas on state land (ca. 33.5 million ha)(Figure 1). The topic of land reform has been on the development agenda in Namibia since independence in 1990 with the focus on the intention of transferring agriculturally usable land to the 'landless majority' (commercial land reform). Land reform issues in the communal areas (communal land reform) have up to now not received so much public attention although, various new laws, such as the Communal Land Reform Act (2002), the Forest Act (2001) and the Wildlife Amendment Act (1999) as well as a host of different 'Community Based Natural Resource Management' (CBNRM) projects, aim to resolve the jurisdiction of conservation and property rights in the communal areas. Nonetheless, the establishment of conservancies and community forests in the communal areas are the central elements in the context of the communal land reform. The first 13 community forests in Namibia were granted conditional use rights on timber and related non-timber products by the Ministry of Environment and Tourism (MET) in October 2004. This study focuses on M'Kata community forest, which has an area of over 86765 ha and is located in the eastern communal areas of Namibia, in an area known previously as 'Bushmanland'.

## **1.2 Eastern Namibia: The Land and its People**

Most visitors to 'Bushmanland' are probably struck by the rather flat landscape covered with apparently, fairly uniform woodland. The climate is hot and dry for much of the time, and there is not a great deal of wildlife to be seen. The roads are dusty and the worst of them are tracks of soft, deep sand. And so, this area may not be a terribly inspiring place and most tourists indeed pass by. However, a good number of fascinating people live here and their livelihoods largely depend on two commodities: water and woodland resources. The San people have been here for a very long time and their traditional, nomadic hunter-gatherer lifestyles reflect their occupation of a landscape where there is little accessible water and where food often has to be obtained from sources spread far and wide. Their population density has

been low and their societies have probably never been much structured into tribal leadership systems.

Over the past 50 years, various government and non-government organisations (NGOs) have attempted to 'develop' the San. Schools, clinics and permanent boreholes have been established, they have been given cattle and introduced to crop cultivation in effort to turn the different San groups, e.g. the !Kung, Vasikele and Ju/hoansi people into resident, subsistence farmers. The influence of these activities has been considerable and one can see now a society very much in transition. The transition is uncomfortable in many ways, because it is happening so fast and the San struggle to adapt to new ways of living. This is a society that is being thrust into the 21st century.

Socio-economically, their present land-use system can be characterised as an agro-pastoral-gatherer system that combines millet cultivation, livestock rearing and last but not least the gathering of tubers, leaves, nuts and edible fruits<sup>1</sup>. Under the local socio-economic conditions diversification can be regarded as a major strategy in coping with low soil fertility and high uncertainty (climate, economy). The main environmental limitations and problems identified by the author are:

**Environmental limitations:**

1. Lack of perennial surface water resources within the region.
2. Low and often erratic rainfall with a very long dry season.
3. High potential evaporation rate.
4. Most arable areas are covered with sandy soils with low fertility and low water retaining capacity.

**Environmental problems:**

1. Uncontrolled bush fires.
2. Deforestation around most densely populated areas.
3. Local depletion of grazing land around water points.
4. Unsustainable use of groundwater resources in some areas.
5. The virtual disappearance of wildlife as a former major resource.

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<sup>1</sup> San people usually describe food gathered in the bush or woodlands by the Afrikaans expression 'veldkost'.

### 1.3 Community Based Natural Resource Management (CBNRM)

Valuable tree species, such as Kiaat (*Pterocarpus angolensis*) and Camel-thorn (*Acacia erioloba*), can still be found in the woodland savannas in and around M’Kata, but are subject for over-exploitation. Kiaat, so-called African Teak, is in high demand for a variety of purposes, but mostly as timber on a commercial basis (e.g. carpentry and joinery). In the last decades the rate of wood removal in Northeast-Namibia was so high that only enforced permit systems could save the woodland conditions from the worst. A further problem, probably due to extensive use of wild fires in the past decades, is that the natural regeneration of Kiaat is extremely poor. The hard and termite-resistant Camel-thorn wood is much sought-after as firewood, building and fencing poles. But most benefit brought by Kiaat and Camel-thorn is only apparent decades if not centuries after establishment. Only then they begin to produce valuable timber, appreciably affect soil quality, create large patches of shade, and produce pods, gum, and fuel wood.

Most community members in the study area have the impression that both tree species are still wide-ranging and it is therefore difficult for the communities to support protection of these trees. Most people see only a ‘snapshot’ in time, however, and for long living, slow growing species, uncontrolled harvesting for commercial use can easily be exceptionally damaging. Kiaat and Camel-thorn are both protected by forestry legislation and consequently, the current conditional use rights on timber granted by the Directorate of Forestry (DoF) include dead wood utilisation only. Nonetheless, commercial harvesting and marketing, even with the intention to improve the livelihood of local communities, must be based on natural resource assessments and a permit system (Figure 2). Consequently, M’Kata community needed assistance to develop an adequate monitoring system to determine resource availability in the community forest to meet the legislative requirements and preserve biodiversity. A development cooperation, called ‘Community Forestry in Northeast-Namibia’ (CFNEN), between the Directorate of Forestry (DoF), the German Development Service (DED) and the German Development Bank (KfW), supports this process.



Figure 2. M’Kata community members using long cross-cut saws to produce planks from dead Kiaat trees (*Pterocarpus angolensis*). The current conditional use rights on timber granted by the Department of Forestry (DoF) focus on dead wood utilisation only. A monitoring prototype is currently implemented to determine resource availability in the community forest.



## 2. Objectives of the study

When it comes to the implementation of community forests as a development project several questions arise. One of the major one is: to what extents are local communities and their emerging institutions able to support these altered patterns of forest ownership, utilisation and control? To keep up with legislative demands and avoid resource degradation of collectively owned goods, commonly known as the 'tragedy of the commons' (Ostrom 1990), it is essential to determine resource availability and develop tools for local assessments. Consistent with the shift to participatory modes of development the incorporation of local knowledge is increasingly viewed as central to the development of such management tools.

The value of elaborate evaluation techniques for local communities are usually limited, as they tend to be time consuming, complicated and require specialist training. For M'Kata community forest there was a need to develop a user-friendly woodland evaluation tool, which is simple, rapid, inexpensive and concurrent with the local woodland management objectives. Hence, this study aims to develop a monitoring prototype, which allows iterative assessment procedures based on silvicultural sampling, indigenous knowledge and geo-spatial techniques (**objective 1**).

There have been few attempts to integrate silvicultural and geo-spatial based data with indigenous knowledge structures in Namibia, and there is no recognised conceptual framework within which to conduct such work (Verlinden & Dayot 1999). Consequently, the extent to which geo-spatial data, from remote sensing (RS), image processing (IP), spatial analysis (SA) and global positioning systems (GPS) can be integrated into the proposed monitoring system and also be used to evaluate the prototype's methodology should be assessed (**objective 2**).

### 3. Material and Methods

#### 3.1 Project area

##### 3.1.1 Location and Extent

M’Kata community forest has an extent of over 86750 ha and is located in the centre of the constituency western Tsumkwe, the western part of the former ‘Bushmanland’, in the Otjozondjupa Region of Namibia (Figure 3 and 4). Except of a small part of western Tsumkwe the whole constituency has been declared a communal conservancy (N#-a-Jaqna) in 2003. The term Area of Interest (AOI), derived from GIS and IP applications, is used in this study to describe the location of M’Kata community forest.

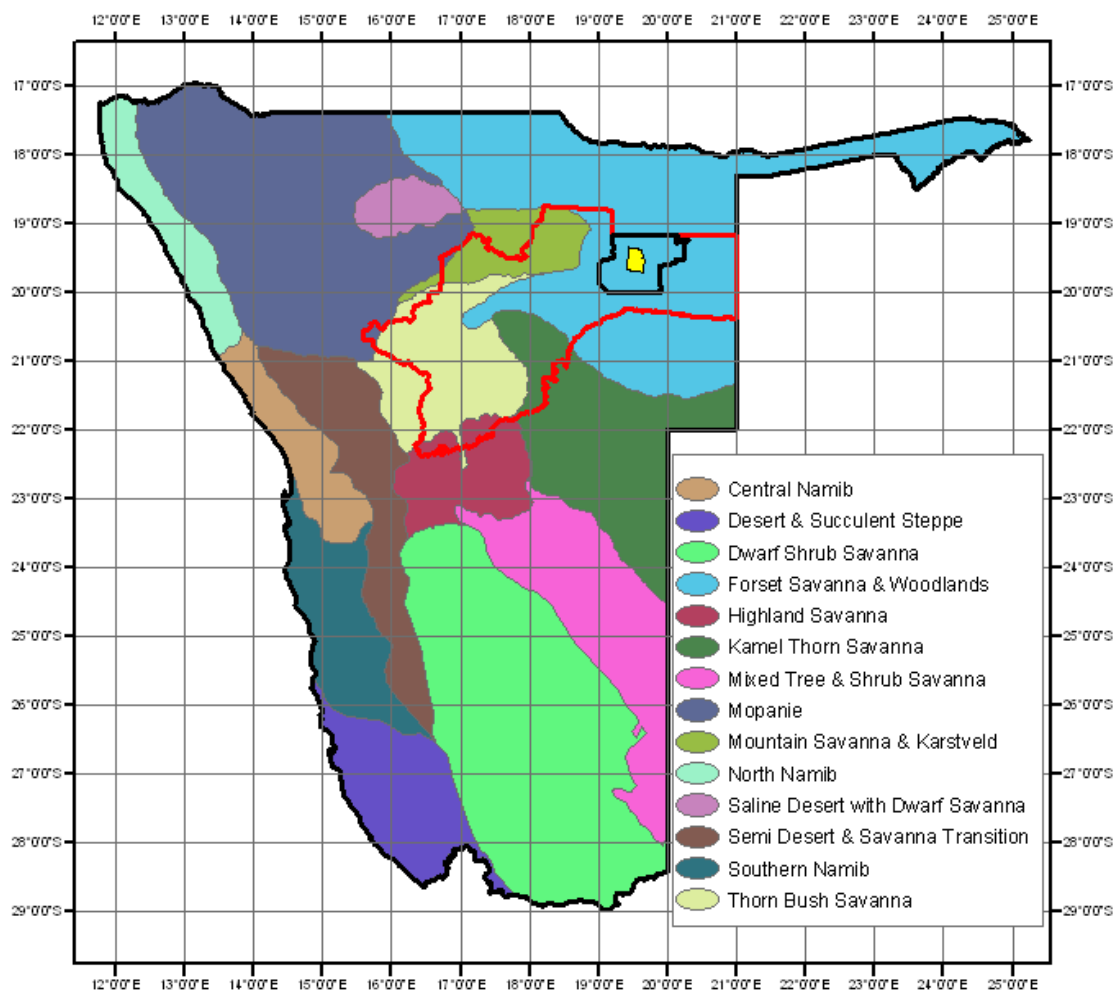


Figure 3. Location of the AOI (M’Kata community forest in yellow) in the Otjozondjupa Region (red border). The AOI can also be found in the centre of the forest savanna and woodland zone (light blue) in the general vegetation map of Namibia, after Giess (1977). Source: Atlas of Namibia 2003.

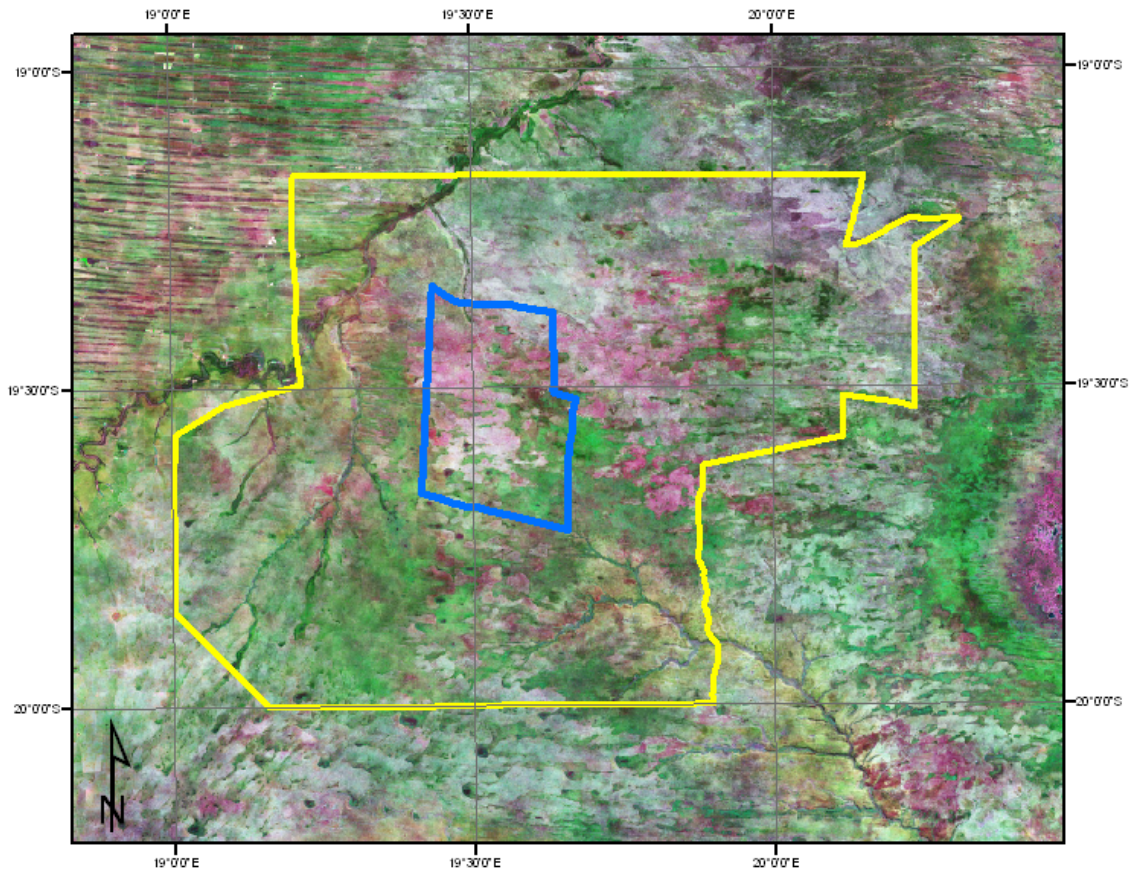


Figure 4. False colour composite (bands 7, 4 and 2), a subset of two Landsat 7 images acquired by the satellite in April 2000 (see chapter 3.6.2 and 4.2.2). The blue outlined polygon indicates the M’Kata community forest in the centre of the N#a-Jaqna conservancy (yellow line). The Omatako omuramba can easily be identified as a dark irregular band in the north-western corner of the image while the Daneib omuramba follows a south-eastern course.

### 3.1.2 Terrain, Soils and Drainage pattern

The project area has a reputation of being a rather flat landscape. The altitude range between 1 150 m - 1 250 m and the landform type is commonly regarded as a plain. Other less common landform elements are small pans, seasonally waterlogged depressions, which might support small-scale grass- and sedgelands, as well as dunes and dune valleys. There are no active dunes present today, but only old overgrown, remnant ones that were formed long ago. Their more or less west-eastern orientation was determined by the direction of winds during those times.

The lithology can be characterized as unconsolidated eolian and is mostly made up of Kalahari sands and calcrete. The sands have generally low water retention and low levels of nutrients. A distinction can be made between the red sands and the

whitish calcareous sands. The red material is probably the older sand. White and grey sands are most likely the younger redistributed sands that have not yet been coated with iron oxide. The recent drainage pattern follows no preferred orientation, but fossil drainage lines from Pleistocene times (Shaw & Thomas 1996; Deacon & Lancaster 1988), the so-called omiramba have a distinct course. The first is the Omatako omuramba with a northeast course towards the Okavango River. The second, the Daneib omuramba consists of all the other smaller drainage lines, which flow eastwards into Botswana. The soil in the omiramba tends to be more clayey than the surrounding sands and some parts are seasonally waterlogged after good rains.

### **3.1.3 Climate** (a rather personal account)

The region's climate can be distinguished into summer and winter months. Most rains fall during summer when moist, subtropical air moves southwards from the tropical zones. The winter climate, by contrast, is dominated by high-pressure systems or anti-cyclones, which circulate dry air over the region.

The beginning of the year, in January and February, is midsummer and fairly hot with maximum temperatures between 35–40°C and average minima around 20°C. On a typical day the sky will start blue and by early afternoon clouds will appear. In the late afternoon there can be torrential rain and even hail on some days. Such storms are spectacular but by the early evening the sky will usually begin to clear again. The frequency of the rains decreases, and they cease around March or April. From then the heat is waning and the land gradually cools and dries out. In May the nights quickly become cooler, accentuating the temperature difference between the bright, hot days and the clear nights. By June the nights are getting cold, approaching freezing in the valleys. Clouds will be a rare sight for the next few months. July and August are winter, when the maximum temperatures are between 20–25°C and the minima are between 0–10°C. Humidity is between 10–20%. Most broad-leaved trees have shed their leaves. In the next three months the local people start to burn huge areas and the veld fires will damage most of the woody vegetation. In September everything is dry and clear and it starts getting hot sometimes. Most acacias and some broad-leaved trees are flowering or start to flower. All through October the heat mounts, and by

November it can be very hot during the day (35°C). However, the humidity is still exceedingly low (between 20–30%), so even the high temperatures feel quite pleasant. Everything is still dry, and the vegetation – most trees are already fruiting – awaiting the rains. Though the clouds often build up in the afternoon, they won't usually deliver until at least December. When and if the rains do arrive, they are a huge relief, dropping the temperatures at a stroke, clearing the air and reviving everything.

### **3.1.4 Land Cover**

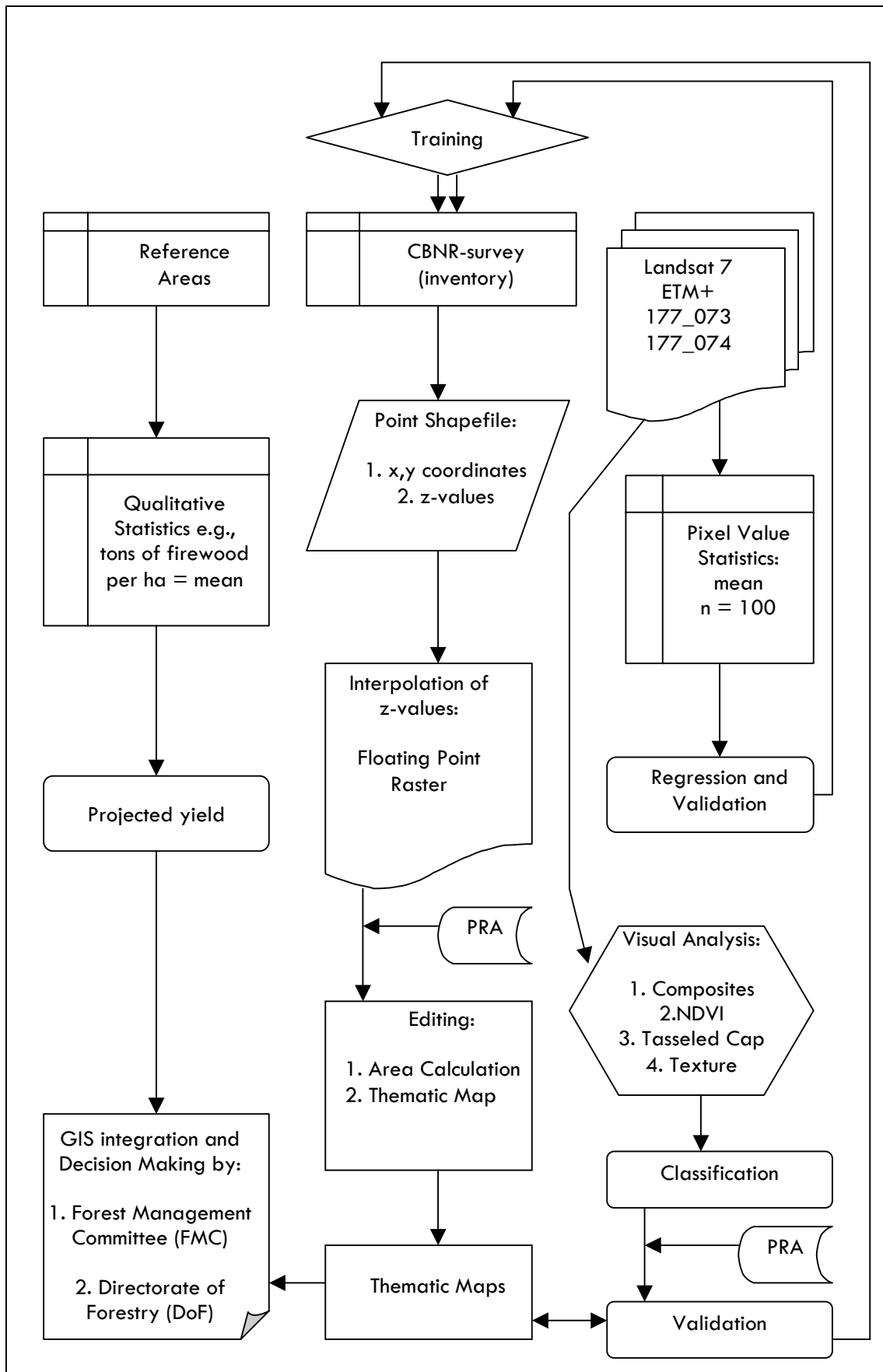
Most of the study area can be described as savanna. There is, however, no generally accepted definition of the term savanna. Due to the utilisation of different criteria, such as physiognomy, flora and environmental conditions, the term describes various forms of vegetation. I am following Maria A. Beebe's definition. She uses the term savanna "... to include all ecosystems in which C4 grasses potentially dominate the herbaceous stratum and where woody plants, usually fire-tolerant, vary in density from widely scattered individuals to a closed woodland broken now and again by drainage-line grasslands." (Kehl 2005).

In the study area savannas thus defined range from almost closed woodlands to sparse grasslands with scattered thorn bushes, i.e. forming small to large scale vegetation mosaics separated by subtle soil and micro-climatic changes. Human activities have been an important determinant of the woodland vegetation in the study area. People are the main igniters of fires, and probably have been for millennia. Further, most of the valuable timber species in the woodlands have been heavily logged in the past four to three decades and in the whole constituency increasing grazing pressure has been recorded as cattle replace migratory wildlife, following the introduction of fences and boreholes.

## **3.2 Workflow**

The following flowchart (Figure 5) illustrates the workflow and methodological concepts for data collection, processing and integration of the results into a GIS.

Figure 5. Workflow and methodological concepts of the study

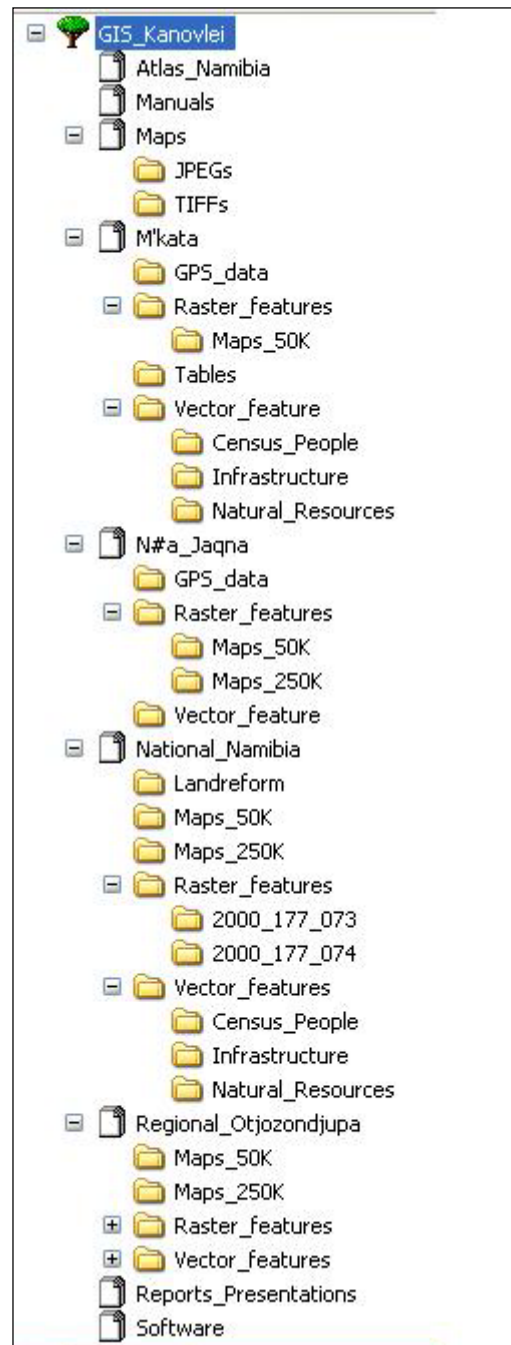


### 3.3 Preparations and Preliminary Assessments

#### 3.3.1 GIS Database Establishment

Geographic information systems are an information technology with the capacity to store, analyse, and display both spatial and non-spatial data (Parker 1988). According to the present technical specifications of the project it was decided to go without related database but to develop only an uncomplicated directory structure (Figure 6) for appropriate data storage. The advantages of related databases, for example constructed with MS ACCESS, might not be experienced at this stage, since the amount of the present descriptive data has been gathered sufficient in three attribute tables (ground truth data, reference area data and survey data). However, the index and a series of fields in the table allow to establish a relationships with other tables if in the future further different attribute tables need to be introduced.

Figure 6. The structure of the GIS\_Kanovlei directory - Kanovlei is the name of the forestry station - is kept simple and with only three levels straightforward.



##### 3.3.1.1 Projection System of the GIS

One of the key aspects when working with a GIS is the correct data indexation. Firstly, the cartographic base and the reference system used have to be clear. The base cartography used for this study has been a topographic map series at a scale of 1:250.000 and 1:50.000 and processed satellite images. The Namibian Map System

normally comprises two projections for either a countrywide (1:1.000.000) or sheet wise (1:50.000, 1:250.000) display.

The sheet wise series (250k and 50k) are classified according to the following projection system:

Projection: LO Gauss Conformal

Spheroid: Bessel 1841 (Schwarzeck Datum)

Central Meridian: 13,15,17,19 and 21 E of Greenwich

Reference Latitude: 22 S

While the projection system used in the 1:1.000:000 cartography is the following:

Projection: Albers Equal Area Conic

Spheroid: Bessel 1841 (Schwarzeck Datum)

Central Meridian: 17 E of Greenwich

Reference Latitude: 22 S

Unfortunately, there appears still to be confusion on the exact datum used for digitised data. It is possible that conversions took place between the Schwarzeck datum and the more conventional WGS 84 datum in most of the available digitised data in Namibia. Some software converts data back to WGS 84 by default and this is not always realized. However, the two scenes used for this study were georeferenced using the WGS 84 datum and Geodetic (latitude/longitude) projection (see chapter 3.6.1). The same datum was used to obtain GPS data in the field (coordinates in decimal degrees, map units in meters)(see datasheet in Appendix 1).

### **3.3.2 Schedule of the study**

The study was conducted within 16 weeks, between the 11.07.2005 and the 30.10.2005. Altogether 136 man-days have been used, including 25 days for preparation and training (18.4 %), 50 days of fieldwork (37.5 %), 32 days for analysing data (32.5) and 18 days for writing (13.2 %) (see project schedule matrix in Appendix 1).



### 3.3.3 Vegetation Type and Canopy Cover Classification

The classification and coding used in this study do not necessarily match with ecological land types. The identification of vegetation type and canopy cover classes should rather be considered as the authors attempt to implement and compromise a classification structure in the context of management and utilisation of the AOI. The classification and codes should later be used for vegetation type and canopy cover determination (z-values) in the monitoring prototype (see chapter 3.4) and as criteria for satellite image classification (see chapter 3.6.3).

Most vegetation types in savanna habitats are seasonal in the sense of canopy development of trees and shrubs and the growth and senescence of lower vegetation strata. Land cover terminology should therefore recognize vegetation seasonality (Dale 1999). Thus, the vegetation type classes used for this study indicate physiognomic categories and focus on predominant species without precluding the residence of others. Canopy cover classes should represent the different levels of screening sunlight from the ground and hence, the potential intensity of absorption in the red and blue segments of the visible spectrum and green reflectance. The following codes are used in this study:

Table 1. Vegetation Type Classes

Code	Description
W	Broad leaved, deciduous woodland
A	Fine-leaved evergreen/semi-deciduous woodland
S	Mixed Scrubland
- Additional land types with little or no cover in the AOI -	
G	Grassland
D	Disturbed lands
B	Bare ground
U	Unclassified

Table 2. Canopy Cover Classes

Code	Description
v	very open (<10%)
o	open (10-40%)
m	medium (40-70%)
d	dense (>70%)

Table 3. Dominant or characteristic (key) tree species

Code	Scientific	English	Vernacular (!Kung)
Ae	<i>Acacia erioloba</i>	Camel-thorn	!ai
Ax	<i>Acacia spp.</i> <sup>2</sup>	Acacias	
Bu	<i>Burkea africana</i>	Sandveld Seringa	!gu
Lo	<i>Philenoptera nelsii</i> <sup>3</sup>	Apple-leaf	
Pt	<i>Pterocarpus angolensis</i>	Kiaat or Dolf	n#hang
Ts	<i>Terminalia sericea</i>	Silver cluster-leaf	tsao

### 3.3.3.1 Description of Vegetation Type Classes

#### Broad-leafed, deciduous woodland

Broad-leafed refers to the leaves or leaflets of the dominant woody species being larger than about 20 mm (major axis). Deciduous means that the majority (> 70%) of all tree and shrub leaves are lost for at least three months. Woodlands have a tree cover greater than 10%. *Burkea africana* (Sandveld Seringa) and *Pterocarpus angolensis* (Kiaat or Dolf) are the key tree species<sup>4</sup> on unconsolidated, deep and sandy soils. These trees are usually between 10 and 20 m tall and often grow single and widely spaced. Usually, they branch some distance above the ground. Grasses generally dominate the herbaceous stratum and the shrub layer can be quite diverse in this ecotone.

Code example: Wm\_Bu-Pt

Broad-leaved deciduous woodland, medium canopy cover (40-70%), characteristic woody species *Burkea africana* and *Pterocarpus angolensis*.

#### Fine-leaved evergreen/semi-deciduous woodland

Leaves, or more precise the pinnule of the dominant fine-leafed woody species are smaller than 20 mm, and usually less than 2 mm wide. Evergreen means that more than 70% of tree leaves are retained year round, and semi-deciduous is in between

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<sup>2</sup> e.g. *A. ataxacantha*, *A. fleckii*, *A. hebeclada*, *A. luederitzii* and *A. mellifera*.

<sup>3</sup> Syn = *Lonchocarpus nelsii*

<sup>4</sup> Less common tree species are Mangetti trees (*Schinziophyton rautanenii*), which could replace *Burkea africana* on top of the dunes and form together with *Pterocarpus angolensis* the characteristic tree species in this habitat. However, this ecotone is less common in the study area.

evergreen and deciduous. The characteristic element is *A. erioloba*, a tree with a typical umbrella-shaped crown usually between 10 and 25 m tall. Other Acacia species are frequent as well but rather multi-stemmed shrubs or small trees. Some broad-leaved, semi-deciduous tree and shrub species (e.g., *Philenoptera nelsii*, *Terminalia sericea* and *Combretum* species) are also widespread woody elements in this structure and can in some parts exceed the land cover of the acacias. Fine-leaved evergreen/semi-deciduous woodland is most common along the fossil drainage lines (omiramba), i.e. on more clayey than on deep sandy soils.

Code example: Ad\_Ae-Lo

Fine-leaved evergreen/semi-deciduous woodland, dense canopy cover (> 70%), characteristic woody species *Acacia erioloba* and *Lonchocarpus nelsii*.

### **Mixed Scrublands**

Mixed Scrublands are defined as having few tree species larger than 5 m and a tree canopy cover of less than 10%, while the cover of short (< 3 meter), multi-stemmed woody plants (shrubs) occupy more than 10% of the area. Common species are *Acacia mellifera*, *Bauhinia petersiana*, *Combretum collinum*, *C. hereroense*, *C. zeyheri*, *Grewia flava*, *G. flavescens*, *Ochna pulcha*, but the key and most abundant species is usually *Terminalia sericea*.

Code example: So\_Ts

Scrubland, open canopy cover (10-40%), characteristic woody species *Terminalia sericea*.

### **3.3.3.2 Vegetation type sub-classes and their ID's**

Each of the above vegetation type classes can be further differentiated due to their different composition and differences in their canopy cover. All relevant sub-classes, which could occur in the AOI have been given an ID (Table 4) for simplification and classification purposes.

Table 4. Vegetation type sub-classes (codes: W, A, S and D), canopy cover classes (codes: d, m and o) and their identification numbers (ID)

Broad-leaved, deciduous woodland						
<b>Code</b>	Wd_Bu-Pt	Wm_Bu-Pt	Wo_Bu-Pt	Wd_Bu-Ts	Wm_Bu-Ts	Wo_Bu-Ts
<b>ID</b>	101	102	103	104	105	106
<b>Code</b>	Wd_Bu-Lo	Wm_Bu-Lo	Wo_Bu-Lo	Wd_Pt-Bu	Wm_Pt-Bu	Wo_Pt-Bu
<b>ID</b>	107	108	109	110	111	112
<b>Code</b>	Wd_Pt-Ts	Wm_Pt-Ts	Wo_Pt-Ts	Wd_Pt-Lo	Wm_Pt-Lo	Wo_Pt-Lo
<b>ID</b>	113	114	115	116	117	118
<b>Code</b>	Wd_Lo-Bu	Wm_Lo-Bu	Wo_Lo-Bu	Wd_Pt-Lo	Wm_Pt-Lo	Wo_Pt-Lo
<b>ID</b>	119	120	121	122	123	124
<b>Code</b>	Wd_Pt-Ae	Wm_Pt-Ae	Wo_Pt-Ae			
<b>ID</b>	125	126	127			
Fine-leaved evergreen/semi-deciduous woodland						
<b>Code</b>	Ad_Ae-Lo	Am_Ae-Lo	Ao_Ae-Lo	Ad_Ae-Lo	Am_Ae-Lo	Ao_Ae-Lo
<b>ID</b>	201	202	203	204	205	206
<b>Code</b>	Ad_Ae-Lo	Am_Ae-Lo	Ao_Ae-Lo			
<b>ID</b>	207	208	209			
Mixed scrubland						
<b>Code</b>	Sd_Ts-Bu	Sm_Ts-Bu	So_Ts-Bu	Sd_Ts-Pt	Sm_Ts-Pt	So_Ts-Pt
<b>ID</b>	301	302	303	304	305	306
<b>Code</b>	Sd_Ts-Lo	Sm_Ts-Lo	So_Ts-Lo	Sd_Ts-Ae	Sm_Ts-Ae	So_Ts-Ae
<b>ID</b>	307	308	309	310	311	312
<b>Code</b>	Sd_Lo-Ts	Sm_Lo-Ts	So_Lo-Ts			
<b>ID</b>	313	314	315			
Disturbed land						
<b>Code</b>	Dd_Ts	Dm_Ts	Do_Ts			
<b>ID</b>	401	402	403			

### 3.3.3.3 Land types with little or no tree and shrub cover

#### Disturbed lands

Thickets of so-called intruder bush species e.g., *Dichrostachys cinerea* and *Acacia mellifera*, or old and abandoned millet fields with *Terminalia sericea* and/or *Dicrostachys cinerea* and/or *Acacia mellifera* are classified as disturbed land.

Code example: Dd\_Ts

Disturbed land, dense canopy cover (< 70%), characteristic woody species *Terminalia sericea*.

#### Bare ground

An area is classified as bare if the ground cover of all three strata (trees, shrubs and grasses) is together less than 10%. This is sometimes the case along gravel roads, in

former quarries where surface material has been removed for road building activities, after intensive bush fires or along the slopes of some dunes and in dry pans.

Code example: Bv\_Ts, very open canopy cover (< 10%), characteristic woody species *Terminalia sericea*.

### **Agriculture or Grassland**

Classified by having a tree or shrub cover of less than 10% in millet (mahangu) fields or in open grassland (most common grass species are *Stipagrostis uniplumis*, *S. ciliaris*, *Eragrostis lehmaniana* and *Schmidtia kalahariensis*). The extent of this ecotone is very small in the study area and it has therefore been neglected during the surveys.

Code example: Gv\_Ae

Grassland, very open canopy cover (< 10%), characteristic woody species *A. erioloba*.

### **3.3.4 Ground Surveys**

The above presented vegetation types are based on a series of ground surveys (Figure 7) carried out by two community members and the author in August 2005. We took coordinate readings with a GPS device<sup>5</sup> approximately every 100 meters along each line transect. GPS data were stored as waypoints and recorded in a data sheet (Appendix 2). We recorded at each point the following data: key tree or shrub species, estimation of canopy cover and regeneration rate, dead wood availability and evidence of human activity (burning, farming, wood extraction). We also took pictures to document the different vegetation types. The surveys provided indications for further rapid eco-assessments (see next chapter) and training sites for supervised classification. Coordinate reading and data recording have been performed:

1. along gravel roads (40 km)
2. along bush tracks (46 km).<sup>6</sup>

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<sup>5</sup> Throughout this study two different GPS receiver types have been used: two GARMIN etrex Legend and one MobileMapper from Thales.

<sup>6</sup> The circumference of the community forest is over 125 km but some 40 km along the SW-corner have not been demarcated with cut-lines due to accessibility.

3. along two line transects in the centre of the forest, each one stretching about 5.5 km. One line is following a N-S route while the other stays in a right angle to the first one in E-W direction. Further, two line transects cross-cutting the northern omiramba in W – E direction, each one is around 2 km long.



Figure 7. Location of the different line transects in the AOI. Line transects following gravel roads are indicated in Green (40 km) and bush tracks in Red (46 km). The two 5.5 km transects in the forest centre and two smaller ones (2 km) crossing a small omuramba from West to East in the North of the community forest are indicated in Blue.

### 3.3.5 Reference Areas for Firewood

The reason to set up reference areas for certain timber and non-timber products e.g., firewood, Kiaat logs, grazing or veldkost was to establish a representative factor for a given area (tons/ha). This factor should be used to calculate the total expected yield for

a certain timber and non-timber product in the different classified zones (see chapter 4.1.1). Nonetheless, during the course of the study the set up of reference areas has been focused on Camel-thorn firewood availability. The following methodological details focus therefore on firewood assessment sites only, while the evaluation in the other assessment sites for timber and non-timber products have not been completed yet.

### 3.3.5.1 Camel-thorn firewood availability

Reference areas have been selected to calculate a projected yield for the AOI. The evaluation plots were based on ground survey results, local knowledge and information from satellite imagery. Altogether fourteen evaluation plots, eight plots representing class 1 (low availability) and 6 plots representing class 2 areas (medium availability), have been established in two different areas to calculate the potential amounts of firewood availability. All plots have been demarcated together with members of the proposed firewood harvester teams using a GPS device. The area of each plot is 25 ha (500 x 500 meters).

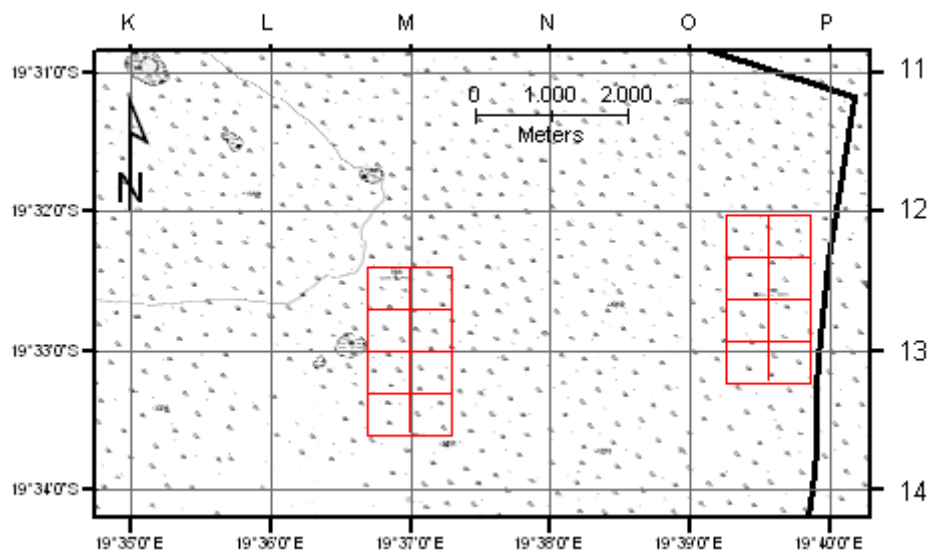


Figure 8. Location of the firewood evaluation plots (red border).

The author had to choose such relatively large areas due to unreliable results obtained during previous trials with areas extending only between 1000 m<sup>2</sup> and 1 ha. During the course of the study 25 ha plots could not be established to represent class 3 (high

availability area) appropriately. However, sites, which are locally regarded as high availability areas, are relatively uncommon in the AOI. It was therefore planned to use a factor slightly higher than the one established for class 2 (see chapter 4.1.1).

### **3.3.5.2 Trial harvesting scheme**

Its was planned to verify the projected yield calculations with a trial harvesting scheme in an area large enough to represent a realistic firewood availability situation in the AOI. Unfortunately, large scale operations include demanding logistics and labour (far over 100 people have been involved). Therefore, the results of the trial harvesting scheme were only towards the end of the study available.

## **3.4 Development of a monitoring prototype**

In July 2005 the author encouraged community members of M’Kata, in particular the Forest Management Committee (FMC) members, to develop a user-friendly woodland evaluation tool, which is simple, rapid, inexpensive, robust and concurrent with the woodland management objectives - monitoring prototype, so to speak. It was hoped that this approach would result in an inventory and monitoring tool useful for local planning of various timber and non-timber products in the community forest. As a result, the CFNEN monitoring book<sup>7</sup> has been developed as the major component for the Community Based Natural Resource (CBNR) assessment. It is designed in A5 format for better handling and is at present equipped with ten different maps and four different data sheets. Trained young community members – the honorary foresters or M’Kata monitoring team– use the monitoring book to collect various vegetation and environmental data at specific sample locations, which they approached usually on a horse or on foot using a GPS device (Figure 9).

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<sup>7</sup> Community members have developed the CFNEN monitoring book together with the author in an evolutionary process and decided which data should be collected. The author only advised and facilitated the process and the design of the system.



The maps have been produced only for monitoring purposes and are based on four scanned 1:50.000 topographic map sheets (i.e. TIFF images of the 1919AD, 1919BC, 1919CB and 1919DA map sheets, Source: MLRR, Surveyor General 1977 based on air photography from 1973) and x,y coordinates collected with a GPS device. The first map in the monitoring book has a scale of 1:300.000 and provides an overview of the whole AOI (Appendix 3). The map is also used to indicate all routes during the whole assessments. Nine other more detailed maps have a scale of 1:100.000 and were used to approach the sample locations for the daily routine. The sample plot locations are based on a '1-minute' grid with an additional index. Thus, resource assessments were systematically collected only at sample plots, which are determined by the x, y coordinates of the '1-minute' grid (e.g. plot C19 has the coordinates E 19° 27' 00" / S - 19° 39' 00" and plot C20 the coordinates E 19° 27' 00" / S -19°40' 00"). Altogether 298 sample locations were established in the community forest. Shortest distance from one point to another is approximately 1.833 km (00° 01' 00" or one minute) at this location.

At present, the CFNEN monitoring book uses four data sheets in different colours. The data sheets should document silvicultural features and distribution and density of selected timber and non-timber products. These features and attributes should later be used as z-values for an interpolation (see chapter 3.5 and 4.1.2). The first data sheet incorporates information about five major tree species. Key informants supplied the vernacular names of the species and indigenous knowledge. Codes are used for vegetation type determination, canopy cover and regeneration rate (see chapter 3.3.3). On the three other data sheets the monitoring team collect additional information about dry wood, veldkost and thatching grass availability. Notes on the physical environment included land form and veld fire situation (Appendix 4).

All data collected by the monitoring team are approximations by rule of thumb applied on an area with a radius of 50 m. To train the monitoring team how to estimate the values for canopy cover in the field (high (>70 %), medium (70 - 40 %) and low (40 – 10 %)) caused quite some difficulties because of the very rough guesses. Up to now, only value determination for dead wood availability have been linked to measurements in particular evaluation plots.



Figure 9. Trained community members usually approach the assessment points on a horse. They take coordinate readings with a GPS device and use the CFNEN monitoring book for recording.

### 3.5 Processing of CBNR-Inventory Data

The collected vegetation and environmental data were further analysed in DBF tables, using standard spreadsheets and GIS applications e.g., MS-Excel 2000 and ArcGis 8.3<sup>8</sup>.

#### 3.5.1 Transfer of collected data

**APPLICATION:** MS Excel (MS Office 2000)

**AIM:** to tabulate, convert and analyse the collected vegetation and environmental data in a DBF table (dBase IV or \*.dbf).

This table should later define a layer, for example a point feature class, and ought to be editable to alter the layer. Hence, the table must maintain certain features in the required dBase file format.

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<sup>8</sup> It is intended, that most calculations and some more simplified area interpolations can also be done by hand. A PC definitely facilitates the work if a trained personnel is available but it is not an absolute necessity.

**RESULT:** a DBF table, which contains geographic locations in the form of x, y coordinates in decimal degrees and z-values (silvicultural features and attributes for selected timber and non-timber products, see Figure 10).

ID	INDEX	X_COORD	Y_COORD	TREE1	TREE2	TREE3	TREE4	TREE5	COVER_PT	COVER_BU	COVER_LO	COVER_AE	COVER_TS	COVER	REGEN_PT
1	A11	19.4166666666667	-19.5166666700000	BU	PT	TS	LO	0	1	2	1	0	1	1.00	1
2	A12	19.4166666666667	-19.5333333300000	BU	PT	TS	0	0	1	2	0	0	1	0.80	1
3	A13	19.4166666666667	-19.5500000000000	TS	BU	PT	0	0	1	1	0	0	2	0.80	1
4	A14	19.4166666666667	-19.5666666700000	BU	PT	0	0	0	1	2	0	0	0	0.60	1
5	A15	19.4166666666667	-19.5833333300000	TS	LO	0	0	0	0	0	1	0	2	0.60	0
6	A16	19.4166666666667	-19.6000000000000	BU	TS	PT	0	0	1	1	0	0	1	0.60	1
7	A17	19.4166666666667	-19.6166666700000	PT	BU	0	0	0	1	1	0	0	0	0.40	1
8	A18	19.4166666666667	-19.6333333300000	TS	LO	AE	0	0	0	0	1	1	2	0.80	0
9	A19	19.4166666666667	-19.6500000000000	BU	LO	TS	0	0	0	1	1	0	1	0.60	0
10	A20	19.4166666666667	-19.6666666700000	BU	PT	0	0	0	1	2	0	0	0	0.60	1
11	B1	19.4333333333333	-19.3500000000000	BU	TS	PT	0	0	1	2	0	0	1	0.80	1
12	B2	19.4333333333333	-19.3666666700000	PT	BU	TS	0	0	1	1	0	0	1	0.60	1

Left part of the table

REGEN_BU	REGEN_LO	REGEN_AE	REGEN_TS	DEAD_PT	DEAD_AE	VELDKOST	GRAZING	THACHING	FIRE	AREA_TYP	MAPNAME	CODE	VEGID	DATE	SURVEYOR
1	1	0	1	1	0	1	1	1	0	P	1919AD	Wld_BU-PT	101	8-Oct-2005	E_Sagaria
1	0	0	1	1	0	1	1	1	0	P	1919AD	Wld_BU-PT	101	7-Oct-2005	E_Sagaria
1	0	0	2	1	0	1	1	1	0	P	1919AD	Sd_TS-BU	301	7-Oct-2005	E_Sagaria
2	0	0	0	1	0	1	1	1	0	P	1919AD	Wlm_BU-PT	102	7-Oct-2005	E_Sagaria
0	1	0	2	0	0	1	1	1	0	P	1919AD	Sm_TS-LO	308	7-Oct-2005	E_Sagaria
1	0	0	2	1	0	2	1	1	0	P	1919AD	Wlm_BU-PT	102	7-Oct-2005	E_Sagaria
1	0	0	0	1	0	1	1	1	0	P	1919AD	Wlo_BU-PT	103	30-Sep-2005	E_Sagaria
0	1	1	2	0	1	2	1	1	0	P	1919AD	Sd_TS-BU	301	30-Sep-2005	E_Sagaria
1	1	0	1	0	0	1	1	1	0	P	1919AD	Sm_TS-BU	302	30-Sep-2005	E_Sagaria
1	0	0	0	1	0	1	1	1	0	P	1919AD	Wlm_BU-PT	102	30-Sep-2005	E_Sagaria
1	0	0	1	1	0	1	2	1	2	P	1919AD	Wld_BU-PT	101	30-Sep-2005	E_Sagaria
2	0	0	1	1	0	1	2	1	2	P	1919AD	Wlm_PT-BU	111	30-Sep-2005	E_Sagaria

Right part of the table

Figure 10. A dBase IV table is used to list and process the collected vegetation and environmental data.

### 3.5.2 Add the DBF table to a map

**APPLICATION:** ArcMap (ArcGIS 8.3)

**AIM:** add a DBF table with x,y coordinates to a map.

**APPROACH:** Tools | Add XY Data

If other datasets and/or layers have been already added to the map the x,y coordinates will be automatically transformed to match the coordinate system of the data frame.

**RESULT:** a XY-data layer (\*.Events) with the appropriate GCS.

### 3.5.3 Creating point features from coordinate values

**APPLICATION:** ArcMap (ArcGIS 8.3).

**AIM:** create a point features class (shapefile).

**APPROACH:** Right-click the XY-dataset (\*.Events) in the ToC | Data | Export Data

**RESULT:** a new and editable point data source (Shapefile Feature Class, Geometry Type: Point) created in the appropriate location. Once the data have been added to a map, the layer behaves like other point feature layers.

### 3.5.4 Surface generation

Surface interpolators create a continuous surface from sampled point values. The interpolated surfaces should represent the distribution of the different z-values and might later allow area calculation in ha for the different attributes (see 3.5.5). Surface generation functions make predictions for all locations in a raster dataset and are based on a basic principle of geography: localities close to one another are more alike than the one more apart (Tobler's law, the statistical relationship among the measured points). There are a variety of ways to derive a prediction for each location; each method (e.g., Inverse Distance Weighted, Spline and Kriging) is referred to as a model. Below is a brief description of the Spline and Kriging method:

"Spline estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. Conceptually, it is like bending a sheet of rubber to pass through the points while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for gently varying surfaces such as elevation, water table heights, or pollution concentrations. ... The Regularized [Spline, the author] method creates a smooth, gradually changing surface with values that may lie outside the sample data range. ... For Regularized, Weight defines the weight of the third derivatives of the surface in the curvature minimization expression. The higher the Weight, the smoother the surface. ... The typical values that may be used are 0, .001, .01, .1, and .5. ... Number of points identifies the number of points used in the calculation of each interpolated cell. The more input points you specify, the more each cell is influenced by distant points and the smoother the surface is." (Help Content of ArcGis 8.3).

“The Kriging method assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. ... This function is most appropriate for spatially correlated distance or directional bias in the data, which is often the case in soil science or plant community mapping.”(Help Content of ArcGIS 8.3).

**APPLICATION:** ArcMap (ArcGIS 8.3) | Extension: Spatial Analyst.

**AIM:** to create a continuous surface (raster dataset) from sampled point values which represent Z value fields from the layer’s Attribute Table, for example the field DEAD\_AE, which represent the estimated values for firewood availability in the different assessment sites.

**APPROACH:** 1. Spatial Analyst | Interpolate to Raster | Spline | choose input points and Z value field e.g., the field DEAD\_AE from the DBF table to calculate a raster surface for firewood availability | Spline type = Regularized | Weight = 0.1 | Number of points = 8 | Cell Size = 0.001 and/or 0.0003.

2. Spatial Analyst | Reclassify via the Reclassify dialog box allows to modify the calculated values to a common scale and save the changes to a new output raster.

**RESULT:** reclassified images representing different z-value fields in a floating-point grid.<sup>9</sup>

### 3.5.5 Editing, area calculation and production of thematic maps

The area (e.g. in ha) of the interpolated surfaces must be determined for computation of the expected yields of the different timber and non-timber products. The new vector

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<sup>9</sup> For this thesis surface interpolations were only be done for a particular timber product (firewood, z-value field: DEAD\_AE) and range of vegetation types (z-value field: VegID). Other reclassified raster datasets based on z-values for tree cover, regeneration, grazing, veldkost etc. will be produced by demand or as soon as the results from the appropriate reference plots are made available.

data can further be used to create thematic maps consisting of lines and polygons, which are easier to understand and to work with.

**APPLICATION:** ArcMap (ArcGIS 8.3) | Editor and ArcCatalog.

**AIM:** to edit the outlines of the reclassified raster datasets in such a way that the area for the new created polygons, which for example could represent the different sites of each firewood availability class, will be automatically calculated and included in the Attribute Table of a new Shapefile.

**APPROACH:** 1. Editor Toolbar | Start Editing | Create new feature with the sketch tool in a new polygon layer (a Shapefile copy of the AOI outline) | Save Edits | Stop Editing.

2. ArcCatalog | File | New | Personal Geodatabase | Import | Shapefile to Geodatabase.

3. ArcMap | Add Data | Add the new edited Shapefile from the new Personal Geodatabase | Open Attribute Table

The advantage: Shape\_Length and Shape\_Area of all new created polygons will be automatically calculated and included in the Attribute Table.

**RESULT:** a new reclassified image representing the different Z value fields in a floating-point grid.

Hardcopies of the inventory-based images and thematic maps were taken back to the community for re-evaluation. For further information please see chapter 3.7 and 3.8.

### **3.6 Processing of Satellite Imagery**

Every natural and synthetic object on the earth's surface and near surface reflects and emits EMR (Figure 11) over a range of wavelengths in its own characteristic way according to its chemical composition and physical state. Remote sensing depends on diagnostic spectral response pattern of features and their different conditions with enough variation to allow for individual identification. Using remote sensing data, vegetation can be distinguished from most other (mainly inorganic) materials by virtue of its absorption in the red and blue segments of the visible spectrum, its higher green reflectance and, especially, its very strong reflectance in the near IR. Further, different

types of vegetation might show distinctive variability from one another owing to such parameters as leaf shape and size, overall plant shape, water content, and associated background e.g., soil types and spacing of the plants.

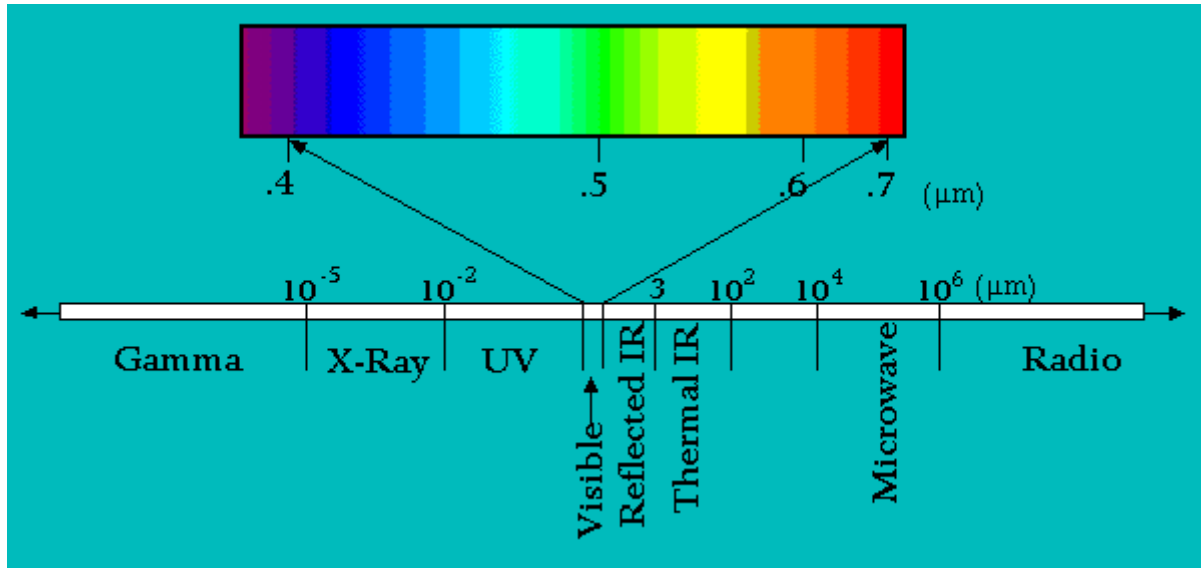


Figure 11. Principal division of the electromagnetic spectrum with focus on the visual range

Absorption centred at about 0.65 μm (visible red) by chlorophyll pigment in green-leaf chloroplasts that reside in the outer or Palisade leaf, and to a similar extent in the blue (0.45 μm). There is also strong reflectance between 0.7 and 1.0 μm (near IR) in the spongy mesophyll cells located in the interior or back of a leaf, within which light reflects mainly at cell wall/air space interfaces, much of which emerges as strong reflection rays. The intensity of this reflectance is commonly greater than from most inorganic materials, so vegetation appears bright in the near IR wavelengths. These properties of vegetation account for their tonal signatures on multispectral images: darker tones in the blue and, especially red, bands, somewhat lighter in the green band, and notably light in the near IR bands (Anonymous 2005).

### 3.6.1 Motive, Sensor Use and Specifications

The motive to use and process data from satellite imagery for this study was twofold:

1. Qualitative analysis

Different images e.g., true and false colour composites, could provide the basis for visual analysis and classification of land cover in the AOI. Temporal analysis could assist in the classification process too.

## 2. Qualitative analysis

Spectral analysis of satellite imagery could provide a reference data set for comparison and validation with the CBNR-survey results.

Subsequently, cloud-free and georeferenced Landsat imagery data from September 2004 (dry season) and April 2005 (rainy season) with full wavebands have been ordered at the South African Imagery Acquisition Centre (SAC) via the DoF/MAWF. The data, unfortunately, have not been arrived in time and only two appropriate Landsat 7 scenes from April 2000 were available in the MAWF (Table 4). However, both scenes were already rectified by the supplier (WGS 84 and Geodetic latitude - longitude projection) and had all wavebands available. Although the temporal distance to the study is more than five years the author had no other chance but to use the two scenes.

Table 5. List of Landsat ETM+ images used in this study

Path/Row	Sensor	Date	Levels of correction
177/73	ETM	24.04.2000	1G
177/74	ETM	24.04.2000	1G

The Enhanced Thematic Mapper Plus (ETM+) is a multispectral scanning radiometer that is carried on board the Landsat 7 satellite (USGS 2005). The sensor has provided nearly continuous acquisitions since July 1999, with a 16-day repeat cycle (temporal resolution).<sup>10</sup> The ETM+ instrument provides image data from eight spectral bands (spectral resolution). The spatial resolution is 30-metereters for the visible and near infrared (bands 1-5 and 7). Resolution for the panchromatic (band 8) is 15-metereters, and the thermal IR (band 6) is 60 meters (spatial resolution). The approximate scene size (sensor swarth width) is 170 x 185 km (observation extent).

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<sup>10</sup> An instrument malfunction occurred on May 31, 2003, with the result that all Landsat 7 scenes acquired since July 14, 2003 are only available in "SLC-off" mode.



Table 6. Spectral resolution of TM and ETM+ (spectral bandwidths in  $\mu\text{m}$ )

Sensor	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8
TM	0.45 – 0.52	0.52 - 0.60	0.63 - 0.69	0.76 - 0.90	1.55 - 1.75	10.4 - 12.5	2.08 - 2.35	N/A
ETM+	0.45 – 0.52	0.53 - 0.61	0.63 - 0.69	0.78 - 0.90	1.55 - 1.75	10.4 - 12.5	2.09 - 2.35	.52 - .90

### 3.6.2 Data Preparation and Enhancement

While the northern part of the project area is located in scene 177\_73, the southern part is located in scene 177\_74 (Namibia Landsat 7 Coverage) (Figure 12). To make the raw data more interpretable general data preparation and enhancement is applied to both scenes. The objective is to produce mosaicked, multi-layer (bands 7, 5, 4, 3, 2 and 1) subsets with 15-meter (pan-sharpened with band 8) and 30-meter resolution and M'Kata community forest as the AOI in its centre.

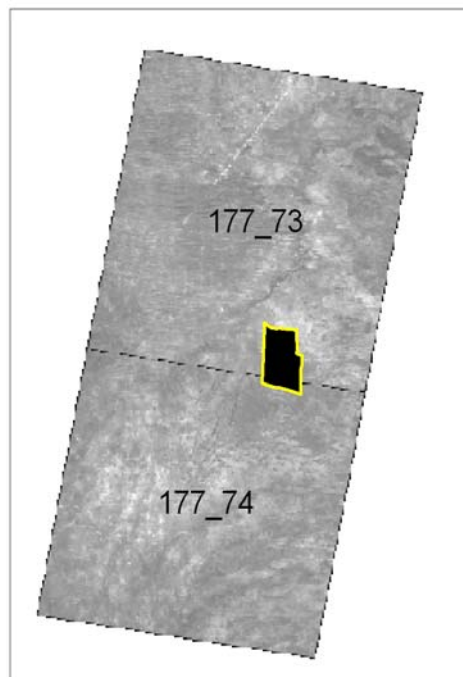


Figure 12. Location of M'Kata community forest in the Landsat 7 scene 177\_073 and 177\_074 of the Namibia Landsat 7 Coverage (band 2, 30-meter spatial resolution Image).

To produce such composites ERDAS IMAGINE 8.6 has been as the appropriate IP application because it offers various options and approaches, which differ considerably in their need of time and system resources. For this study the following sequence was used to make image raw data more interpretable:

### **3.6.2.1. Create new multi-layer Images for True and False Colour Composites**

Multispectral remote sensing data are often displayed as near infrared false colour composites, in which the near infrared band is displayed as the red colour layer, the red band is displayed as the green colour layer, and the green band is displayed as the blue colour layer. TM/ETM channel combinations 4/3/2 and 4/5/2 or 7/4/2 and 7/5/4 are usually regarded as good combinations for enhancing vegetation.

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to create from each scene a new multi-layer (multispectral) image with the bands 7, 5, 4, 3, 2 and 1 (spatial resolution/pixel size = 30m).

**APPROACH:** via Data Preparation | Subset or Image Interpreter | Utilities | Subset

**RESULT:** two multi-spectral images (e.g., ETM24042000\_177\_073\_754321 and ETM24042000\_177\_074\_754321)

### **3.6.2.2. Subset creation (with M'Kata community forest as the AOI)**

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to create from each new multi-layer image a subset (e.g. via inquire box) with M'Kata community forest as the area of interest (AOI).

**APPROACH:** via Data Preparation | Subset

**RESULT:** two multispectral subsets (e.g., ETM24042000\_Mkata\_073\_754321 and ETM24042000\_Mkata\_754321)

### **3.6.2.3. Fusing multispectral and panchromatic data (Resolution merge)**

Higher resolution imagery is generally single band (for example Landsat panchromatic 15-meter data, band 8), while multispectral imagery generally has the lower resolutions (for example Landsat 30-meter data, bands 7, 5, 4, 3, 2 and 1). Resolution Merge techniques can combine multispectral data with high-resolution imagery and produce high resolution, multispectral imagery. This improves the interpretability of the data by having high-resolution multispectral information.

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to create from the two subsets and the AOI of the panchromatic band new integrated images of higher spatial resolutions (15-meter pixel size instead of 30-meter).

**APPROACH:** Image Interpreter | Spatial Enhancement | Resolution Merge (Figure 13)

In our case the original scene radiometry (colour balance, overall scene luminance) of the input multispectral image should be maintained as closely as possible in the output file. The 'Principal Component' method is therefore probably the best choice of the three methods offered by ERDAS IMAGINE 8.6. This method scales the high resolution data set to the same data range as the intensity component (PC 1, with for instance 8-bit) with the result, that the band histograms of the output file closely resemble those of the input multispectral image (Erdas Field Guide 2002).

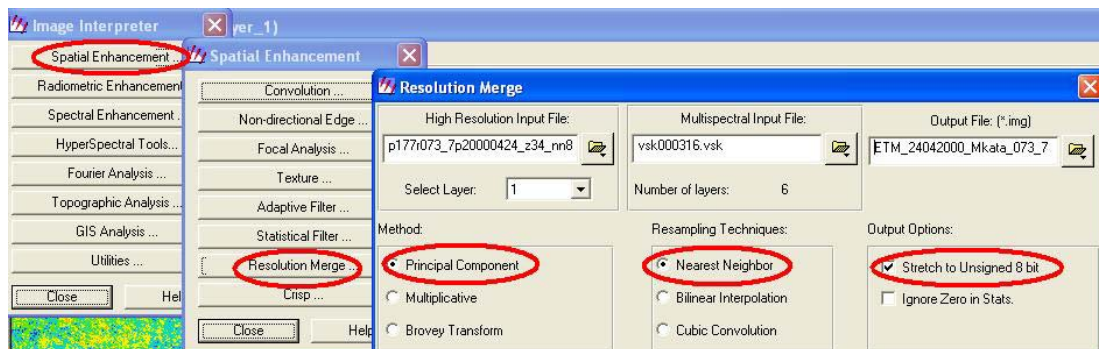


Figure 13. Approach and adjustments placed in the ERDAS IMAGINE 8.6 Resolution Merge menu.

Nearest Neighbor Resampling Technique uses the value of the closest pixel to assign it to the output pixel without averaging them as the other methods (bilinear interpolation and cubic convolution) do. The extremes and subtleties of the data values are therefore not lost. This is an important consideration when discriminating between vegetation types. The Nearest Neighbor method is suitable for use before classification (Erdas Field Guide 2002).

**RESULT:** two multispectral pan-sharpened subsets (e.g., ETM24042000\_Mkata\_073\_754321pan)

#### 3.6.2.4. Mosaic Subsets

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to join the two subsets together (either the two 30-meter or the two 15-meter subsets). The input images contain map and projection information and have the same number of layers.

**APPROACH:** 1. Select Layer To Add | Raster Options | Display as True Colour, Fit to Frame and Background Transparent | File | select the two appropriate subsets | Multiple | Multiple Images in Virtual Mosaic.

2. Raster | Mosaic Image | Edit | Image Matching | Colour Balancing | Automatic Colour Balancing and Matching Method | Overlap Areas

3. Edit | Overlap Functions | Average

4. Process | Run Mosaic.

**RESULT:** two joined multi-spectral images of 30-meter and 15-meter resolution focusing on the AOI (e.g. ETM24042000\_Mkata\_754321 or ETM24042000\_Mkata\_754321pan)

#### 3.6.2.5. Spectral Enhancement via Vegetation indexes

Vegetation indexes (VIs), usually based upon brightness values, attempt to measure biomass or vegetation vigour. A simple form of VI is a ratio between two digital values from separate spectral bands. For green vegetation, the rationing strategy can be especially effective because of the inverse relationship between vegetation brightness in the visible red and the near IR. Healthy vegetation reflects strongly in the near IR portion of the spectrum while absorbing strongly in the visible red. The most commonly used index is the Normalized Difference Vegetation Index (NDVI)<sup>11</sup> and defined by the following general equation:  $NDVI = (NearIR - VISRed) / (NearIR + VISRed)$  (Erdas Field Guide 2002).

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<sup>11</sup> The red and near infrared bands that are commonly used for the NDVI calculation are: AVHRR: band 1 for red, and band 2 for near IR. Landsat MSS: band 2 for red, band 4 or band 3 for near IR. Landsat TM: band 3 for red, band 4 for near IR.

Calculating the ratio of the visible red and near IR reflected back up to the sensor yields a number from minus one (-1) to plus one (+1). An NDVI value of zero means no green vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. Clouds, water, and snow yield negative values due to larger visible red reflectance than near IR. The NDVI values for rock and bare soil are near zero due to their similar reflectance in both bands. Therefore, in a NDVI image the lighter tones are associated with dense coverage of healthy vegetation. For unhealthy or stressed vegetation the ratios are lower than for healthy green vegetation. Thus, a NDVI image could significantly enhance the discrimination of vegetation from other surface cover types (Campbell 2002).

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to produce from each multi-spectral 30-meter and 15-meter resolution image a NDVI image.

**APPROACH:** Image Interpreter | Spectral Enhancement... | Indexes...

**RESULT:** two NDVI images with 30-meter and 15-meter resolution (e.g. ETM24042000\_Mkata\_ndvi or ETM24042000\_Mkata\_ndvi\_pan)

### 3.6.2.6. Spectral Enhancement via Tasseled Cap transformation

The Tasseled Cap<sup>12</sup> or TC transformation offers a way to optimise data viewing for vegetation studies. Full explanation of the basic TC concept and its characteristics was provided in Kauth & Thomas (1976) and Crist & Cicone (1984). Although defined initially by Kauth & Thomas for Landsat 2 MSS data for crop development, subsequent research has extended the concept to the six non-thermal bands of TM 4 and 5 (Crist & Cicone 1984) and further to TM 7 (Huang et al. 2003). There are three data structure axes that define the vegetation information content (Erdas Field Guide 2002):

#### 1. BRIGHTNESS

A weighted sum of all bands, defined in the direction of the principal variation in soil reflectance.

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<sup>12</sup> A plot of data for an entire growing season has a distinctive shape similar to that of a tasseled (Santa Claus-type) cap provides the basis for the name Kauth & Thomas gave to their technique.

## 2. GREENNESS

Orthogonal to brightness, a contrast between the near IR and visible bands.

Strongly related to the amount of green vegetation in the scene.

## 3. WETNESS

Relates to canopy and soil moisture.

The Tasseled Cap transformation for Landsat TM and ETM+ data can be performed using the following formula (Huang 2003)<sup>13</sup>:

Index	Band 1 +/- Band 2 +/- Band 3 +/- Band 4 +/- Band 5 +/- Band 7
Brightness	= 0.3561 + 0.3972 + 0.3904 + 0.6966 + 0.2286 + 0.1596
Greenness	= -0.3344 - 0.3544 - 0.4556 + 0.6966 - 0.0242 - 0.2630
Wetness	= 0.2626 + 0.2141 + 0.0926 + 0.0656 - 0.7629 - 0.5388

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to perform a Tasseled Cap transformation from the 7/4/2 multispectral 30-meter image.

**APPROACH:** Image Interpreter | Spectral Enhancement... | Tasseled Cap...

**RESULT:** two TC images with 30-meter and 15-meter resolution (e.g. ETM24042000\_Mkata\_TC)

### 3.6.2.7. Spatial Enhancement via Texture

As an enhancement, texture is particularly applicable to radar data, although it may be applied to any type of data (Erdas Field Guide 2002). Texture is an important operation in IP and if the predominant vegetation type classes prefer specific topographic sites separation might be easier with texture images and could aid in the classification process. Therefore, texture images have been prepared from 30-meter composites using 3 x 3 windows.

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to experiment if a texture image can aid the classification process.

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<sup>13</sup> The formula used in ERDAS IMAGINE 8.6 for TC transformation is based on Landsat 4 and 5 features and uses different factors for the three data structure axes.

**APPROACH:** Image Interpreter | Spatial Enhancement... | Texture...

**RESULT:** two texture images with 30-meter (e.g. ETM24042000\_Mkata\_Texture)

### 3.6.3 Qualitative Analysis: Image Segmentation / Classification

Multispectral image classification can be performed by an automated process called unsupervised classification in which pixels are sorted into a finite number of individual classes based on their data values e.g., brightness and/or by a supervised classification which is more controlled by an analyst instructing the application to recognise pattern based on similar spectral signatures in the data.

Due to similarity of spectrum characteristics in most vegetation type classes unsupervised classification alone has limited ability in accurately classifying vegetation. Thus, for this study a hybrid technique was used to organise the land cover in appropriate vegetation type classes. First an unsupervised classification of a specified number of natural clusters, then a supervised classification to combine or separate out appropriate categories. The ground survey samples and the CBNR inventory provided the training sites for a supervised classification of the AOI.

Often, a trial-and-error approach with different composites and VIs is needed to produce the most appropriate classification results. The first step of the hybrid method, the unsupervised classification, was therefore carried out on different composites and indexes simultaneously.

#### 3.6.3.1. Unsupervised Classification

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to produce a first thematic land categorisation for various multi-spectral and enhanced images.

**APPROACH:** via Data Preparation | Unsupervised Classification or Classifier | Unsupervised Classification

ERDAS IMAGINE uses the ISODATA algorithm to perform an unsupervised classification. ISODATA stands for "Iterative Self-Organizing Data Analysis Technique." It is iterative in that it repeatedly performs an entire classification

(outputting a thematic raster layer) and recalculates statistics. "Self-Organizing" refers to the way in which it locates the clusters that are inherent in the data.

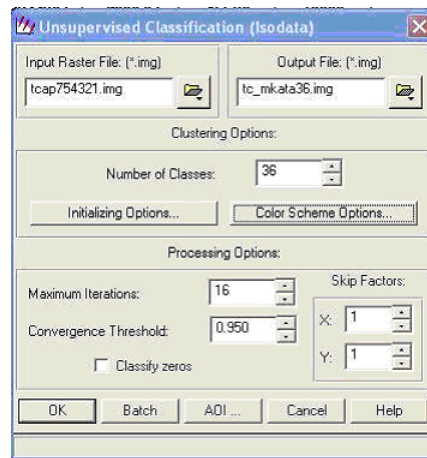


Figure 14. Setting used for a unsupervised classifications with 36 classes

The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means and each time the clustering repeats the means of these clusters are shifted. The new cluster means are used for the next iteration (Erdas Field Guide 2002). The ISODATA utility repeats the clustering of the image until either:

1. a maximum number of iterations has been performed, or
2. a maximum percentage of unchanged pixels (convergence threshold) has been reached between two iterations.

The output file will have a grey scale colour scheme if the initial cluster means are arbitrary. If the initial cluster means are from an existing signature set, then the output file will use the colours of this signature set.

**RESULT:** a first thematic categorisation (Output Cluster Layer) based on 36 classes and a Signature Set (\*.sig) for each classified image.

### 3.6.3.2. Supervised Classification

Due to the results of the first image segmentation process a supervised classification has been performed with the Tasseled-Cap image only. During the supervised classification process each pixel will be sorted into a class which has the nearest



spectral property with the pixel. Therefore, appropriate object classes and representative areas (training sites) for each desired class must be defined, i.e. selected sites with known land cover are used as training templates<sup>14</sup>. These training samples were used to define supervised spectral signatures for various vegetation types. Correct and representative ground truth information is critical to this process. A flowchart of the classification process, combining the use of supervised spectral signatures, NDVI and texture analysis (Figure 20) should comment and illustrate the approach used in this study. Explanation of workflow step:

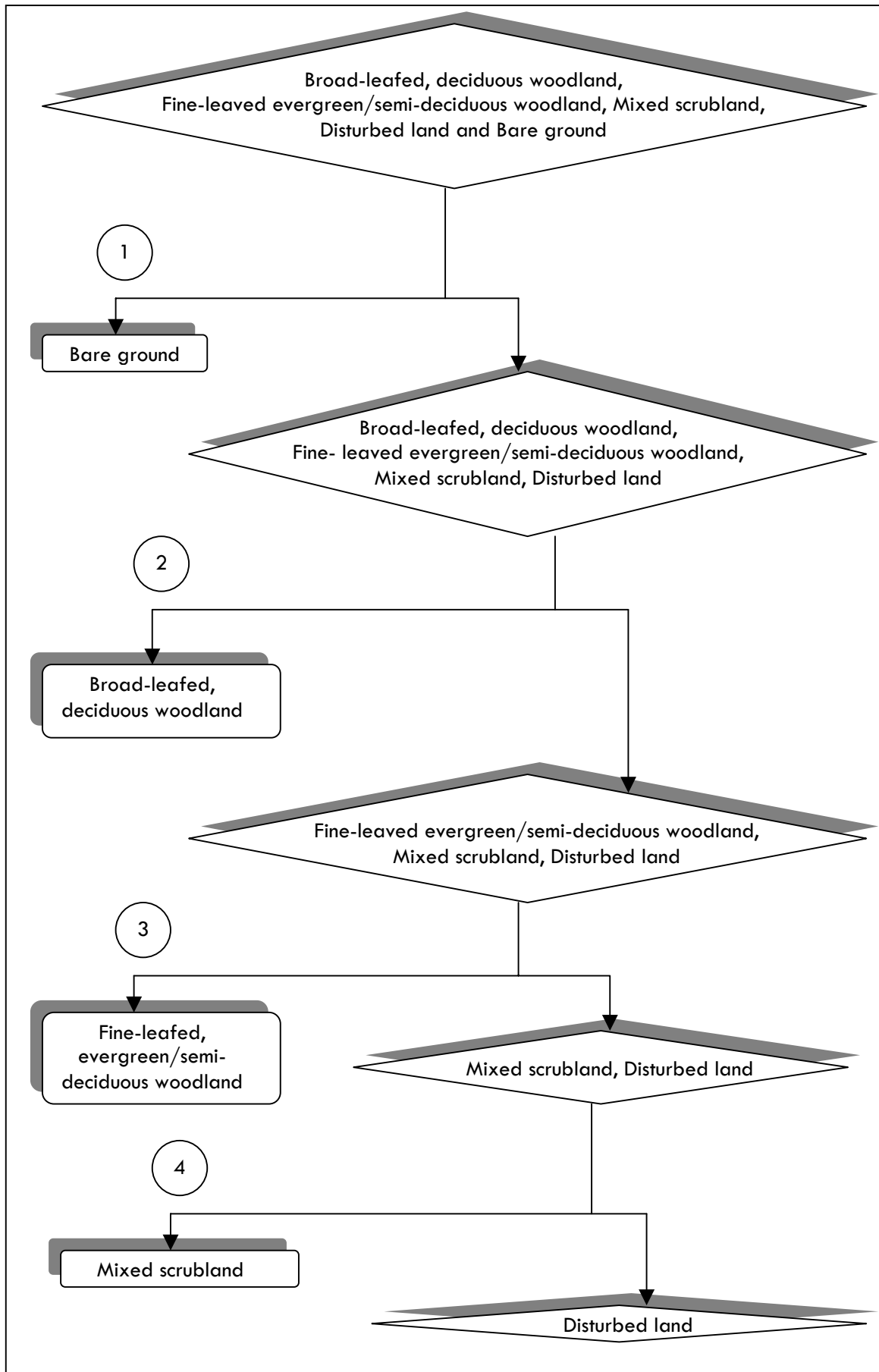
1. Very sparsely vegetated land and bare ground was very uncommon in the AOI but could be determined by its high spectral reflectance and low NDVI values.
2. Broad-leaved deciduous woodland is classified by its specific reflectance and location.
3. Most fine-leaved evergreen woodland/semi-deciduous woodland could be identified by its low reflectance in the visible bands and the highest NDVI of all land covers. However, some scrublands with a high quantity of fine-leaved evergreen shrubs or small tree species, usually Acacias, could not spectrally distinguished from evergreen woodland. The differentiation between the two vegetation types must therefore be regarded as incomplete especially since, significant texture differences between the two classes also failed to appear.

Similar to step 3 the classification of the remaining two types, mixed scrubland and disturbed land must be regarded as incomplete.

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<sup>14</sup> A training sample is a set of pixel selected to represent a potential class and to generate a parametric signature. A training site is the geographical area in the image.

1. Figure 15. Workflow during classification of vegetation types



Additionally, some areas with a relative small extent could be classified as agriculture or grassland with very few trees (Code Gv).

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to assign corresponding classes to groups with homogeneous characteristics, i.e. discriminating multiple vegetation types from each other within the image.

**APPROACH:** The supervised classification has been carried out for each vegetation type class according to the following sequence:

1. Spectral signature appraisal in training sites with the Spectral Profile Tool.

2. Confine and masking of appropriate areas for creation of training samples:

AOI | Tools | Create Polygon AOI | Classification | Signature Editor | Create new Signatures from AOI

3. Verification of new created signatures according to ETM+ specifications:

Signature Editor | Display Mean Plot Window | Signature Mean Plot Chart

Signature Editor | Histogram

Signature Editor | Selection of one class | View | Image Alarm

4. Further verification and separating of classes via Feature Space Layer. The

Advantage: nonparametric signatures allow inspecting and comparing the shape of the spectral plot as well as the distance between signatures in measurement space:

Signature Editor | Feature | Create

Signature Editor | Feature | Masking | Objects | Annotation Layer

4. Recoding:

Interpreter | Image Interpreter | GIS Analysis | Recode

5. Overlay with index and texture:

Some vegetation types, however were confusing to be classified because of their similarity of spectrum characteristics. Therefore, to a certain degree the NDVI and the texture image have been used as additional information sources for discrimination and it was found that e.g., continuous edges (edge lines) could be additional tools, especially to discriminate mixed scrubland from disturbed land.

**RESULT:** a thematic raster layer and optionally a distance file (for post-classification thresholding).

### **3.6.4 Quantitative Analysis: Canopy cover vs average NDVI pixel values**

Spectral analysis of satellite imagery could provide a reference data set for assessment and validation of the results of the CBNR-inventory, i.e. the canopy cover data need to be significantly correlated to the corresponding average NDVI pixel values. Regression analysis was used to test this requirement.

#### **3.6.4.1 Area determination of spectral sample data**

**APPLICATION:** ArcMap (ArcGIS 8.3)

**AIM:** to generate polygons (buffer) around the x,y coordinates of the sample locations.

**APPROACH:** A circular buffer with a 100-meter radius around the central position of each inventory sample location (e.g., the x,y coordinates of sample location C 10, C11 etc.) should represent the corresponding pixel values of the NDVI image:

Tools | Buffer Wizard | Features of layer 'Inventur2005' | Distance 100 Meters | Save Buffers in a new layer (Polygon Shapefile)

**RESULT:** Buffer polygons for import to ERDAS IMAGINE 8.6.

#### **3.6.4.2 Average pixel value extraction**

**APPLICATION:** ERDAS IMAGINE 8.6

**AIM:** to generate in a 100-meter radius around the sample locations the average NDVI pixel values.

**APPROACH:** The resulting polygons were imported into ERDAS IMAGINE 8.6 and the mean of all NDVI pixel values falling within a 100 m radius of the central location of the sample locations was used for zonal statistics. This ensures that the majority of the pixel values corresponding with the field samples areas are represented in the analysis: Interpreter | GIS Analysis | Zonal Attributes | Save Zonal Statistics to Polygon Attributes | Input Vector (Buffer) and Raster (NDVI) layer | Zonal functions: Max, Min, Mean, Range and SD

**RESULT:** average pixel values and other relevant parameter are saved in the buffer polygon Attribute table.

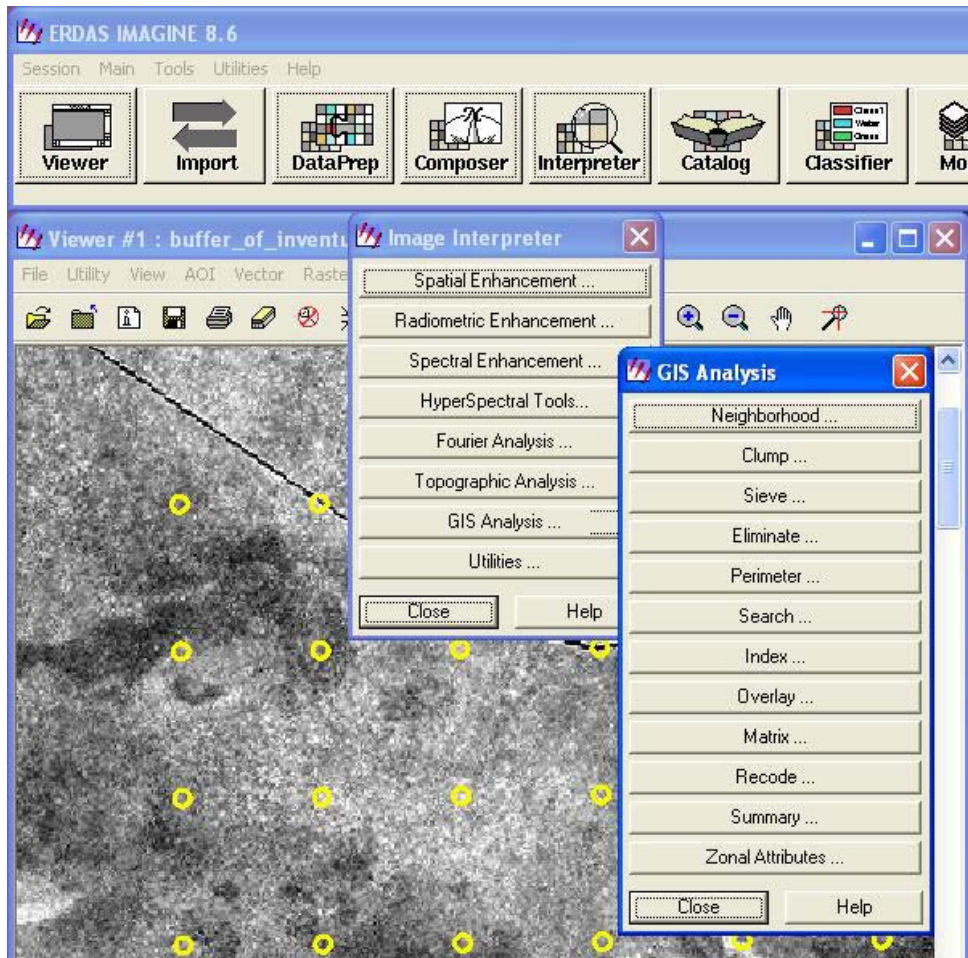


Figure 16. Erdas Image 8.6 allows to obtain the mean of all pixel values falling within a given radius of an imported buffer polygon via Zonal Attributes.

### 3.6.4.3 Creating a new DBF table

**APPLICATION:** ArcMap (ArcGIS 8.3)

**AIM:** to create a new DBF table for export in MS Excel

**APPROACH:** Right-click the buffer shapefile in the ToC | Attribute Table | Export

**RESULT:** a new DBF table with the average NDVI pixel values and other statistical parameters (Max, Min, Mean, Range and SD) for each sample location.

#### 3.6.4.4 Regression analysis

**APPLICATION:** MS-Excel (statistical functions from the Analysis ToolPak)

**AIM:** Computation of regression analysis parameters to test for a possible correlation between the estimated canopy cover data and corresponding average NDVI pixel values.

**APPROACH:** MS-Excel | Tools | Analysis ToolPak | Regression

**RESULT:** Statistic of Regression and Plot with trend line.



Figure 17. Monitoring team members discussing the assessment results and produced image maps with other community members and combine them with additional information or adjustments.

### 3.7 Participatory Rural Appraisal (PRA)

Hardcopies of the resulting classified image and the inventory-based images (thematic maps) were taken back to the community for discussions on woodland management issues, with emphasis on resource availability in different seasons. Additionally, discussing these image maps identified eco-sociological norms and rules.

**AIM:** to re-evaluate and to modify the preliminary image maps and suggested harvest rates per area with all relevant community stakeholders.

**APPROACH:** PRA and open-ended discussions on local management and resource availability.

**RESULTS:** additional information with emphasis on resource availability in the different areas and seasons.

### 3.8 Editing (see also 3.5.5)

When all people appeared satisfied with the resulting classification and inventory images, on-screen digitising (editing) was used to simplify the classified image and the inventory based raster images (Figure 19). Thematic maps consisting of lines and polygons are easier to understand and to work with.

**APPLICATION:** ArcMap (ArcGIS 8.3) | Editor and ArcCatalog

**AIM:** to edit the outlines of the classified raster image in such a way that the area for the new created polygons, which represent the different vegetation types, will be automatically calculated and included in the Attribute Table of a new shapefile. The new vector data can be used to create thematic maps consisting of lines and polygons which are easier to understand and to work with.

**APPROACH:** Editor Toolbar | Start Editing | Create new feature with the sketch tool in a new polygon layer (a Shapefile copy of the AOI outline) | Save Edits | Stop Editing.

ArcCatalog | File | New | Personal Geodatabase | Import | Shapefile to Geodatabase  
ArcMap | Add Data | Add the new edited Shapefile from the new Personal Geodatabase | Open Attribute Table | The advantage: Shape\_Length and Shape\_Area of all new created polygons will be automatically calculated and included in the Attribute Table.

**RESULTS:** simplified thematic maps indicating the different vegetation types and the area (ha) for each shape (polygon) in the Attribute Table.

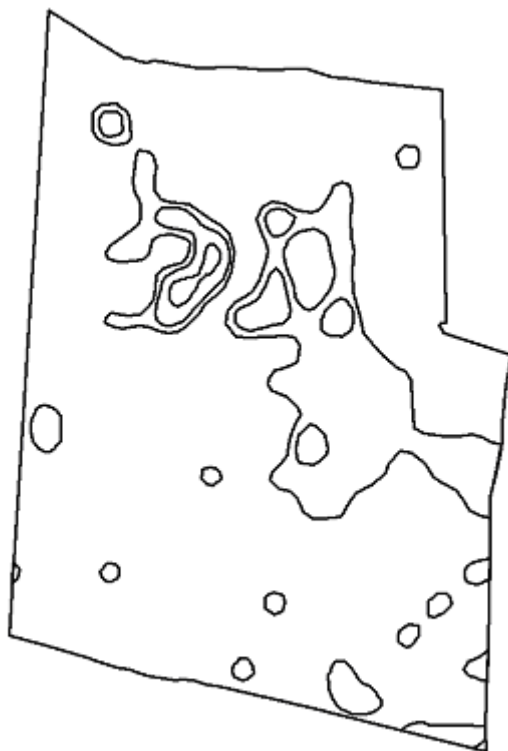


Figure 18. After editing the outlines of the reclassified raster dataset and saving the results in a new geodatabase the area (ha) of the different zones will be calculated automatically.

### 3.9 GIS

The simplified images were incorporated in the GIS according to the determined directory structure (see chapter 3.3.1), allowing easy an access and overlays with other information.



## 4. Results and Discussion

### 4.1 Reference plots and projected yield for firewood

The following results focus on firewood availability only, since other timber and non-timber assessments in the reference plots have not been completed yet.

#### 4.1.1 Firewood availability in the Camel-thorn evaluation plots

The results of the yield in each evaluation plot can be found in Table 6 and 7 followed by calculation of relevant statistical values. Since the standard deviation<sup>15</sup> and the confidence interval<sup>16</sup> for both average values are acceptable, the mean ( $\mu_x$ ) for class 1 (0.015 tons/ha) and class 2 (0.026 tons/ha) will be used as the factor for calculation of firewood availability (see chapter 4.1.3 and Table 9). Since no reference area could be established in the zone with high availability of firewood (class 3) a factor slightly higher than the mean for class 2 will be used for calculations (i.e. factor used for class 3 sites = 0.027 tons/ha).

Table 7. Firewood availability for class 1 (low amount of firewood available).

Plot	tons/plot	tons/ha
1-1	0.32	0.0128
1-2	0.28	0.0112
1-3	0.35	0.014
1-4	0.39	0.0156
1-5	0.25	0.01
1-6	0.42	0.0168
1-7	0.51	0.0204
1-8	0.48	0.0192
median	0.37	0.0148
<b>mean</b>	<b>0.375</b>	<b>0.015</b>
SD	0.0085	0.0034
Co	0.0599	0.0024
1.Q	0.31	0.0124
2.Q	0.37	0.0148
3.Q	0.435	0.0174

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<sup>15</sup> The standard deviation is a measure of how widely values are dispersed from the average value (the mean).

<sup>16</sup> The confidence interval is a range on either side of a sample mean.

Table 8. **Firewood availability for class 2** (medium amount of firewood available).

<b>Plot</b>	<b>tons/plot</b>	<b>tons/ha</b>
2-1	0.65	0.0128
2-2	0.79	0.0112
2-3	0.45	0.014
2-4	0.82	0.0156
2-5	0.61	0.01
2-6	0.58	0.0168
xm	0.63	0.0252
<b>mean</b>	<b>0.65</b>	<b>0.026</b>
SD	0.1258	0.005
Co	0.0872	0.0034
1.Q	0.59	0.0235
2.Q	0.63	0.0252
3.Q	0.755	0.0302

#### 4.1.2 Surface creation and Editing

Interpolation of the appropriate z-values, in this case the field DEAD\_AE, with the Regularized Spline method and reclassification, resulted in a continuous surface based on the sampled point z-values (Appendix 5). As anticipated the surface is smooth and changes only gradually between the different availability classes. Provided that the estimations of the survey are accurate enough to represent the situation in the field the interpolation seems to correspond with the more or less even distribution of this particular timber resource.

A new vector layer (Figure 19) has been created via editing to work out the area (e.g. in ha) of the interpolated surfaces. The area values are utilized for computation of the expected firewood yield.

#### 4.1.3 Projected firewood yield

The area values (ha) of the different firewood availability classes, respectively sites have been multiplied with the appropriate factor for each class followed by computation of the total expected yield (Table 9), which also represents the basis for maximal harvest suggestions in case M'Kata community wants to use this resource commercially.

Table 9. Computation of firewood availability and projected yield.

Area_ID	Availability_Class	ha	Factor (µx)	Tons
2	1	403,6	0,015	6,054
3	2	151,3	0,026	3,630
4	3	315,1	0,027	9,767
5	2	1420,9	0,026	34,102
7	2	180,0	0,026	4,321
8	2	590,9	0,026	14,183
9	2	288,4	0,026	6,922
10	1	120,5	0,015	1,807
11	2	297,6	0,026	7,142
12	1	153,4	0,015	2,301
13	1	127,4	0,015	1,911
14	1	112,7	0,015	1,691
15	1	137,3	0,015	2,059
16	1	101,9	0,015	1,529
17	1	554,9	0,015	8,323
18	1	389,6	0,015	5,844
19	1	107,9	0,015	1,619
20	1	81,0	0,015	1,216
21	1	27,2	0,015	0,409
22	1	346,8	0,015	5,202
23	1	3135,1	0,015	47,0270
24	1	84,3	0,015	1,264
25	1	10468,1	0,015	157,021
<b>SUM</b>		<b>19596,0</b>		<b>325,344</b>

Overall, the preliminary results suggest particular collection sites for firewood, different harvesting values for each site and a total yield, which should not exceed 325 tons for M’Kata community forest.

#### 4.1.4 Trial Harvesting Scheme

Large scale harvesting operations confirmed that the calculated figures offer a fair indication which amounts of firewood can be expected in the AOI. Over 100 people collected firewood in a demarcated area covering almost 7000 ha in the eastern parts of the AOI (Figure 20). Within this area was a 4275 ha class 1 zone. Theoretically, the area should provide 64.12 tons (4275 ha \* 0.015 tons) of firewood while the harvest resulted in over 72 tons, 12.5 % more than expected. The difference between the calculated yield and the real amount can be tolerated and confirms that the calculations can be regarded as rather conservative.

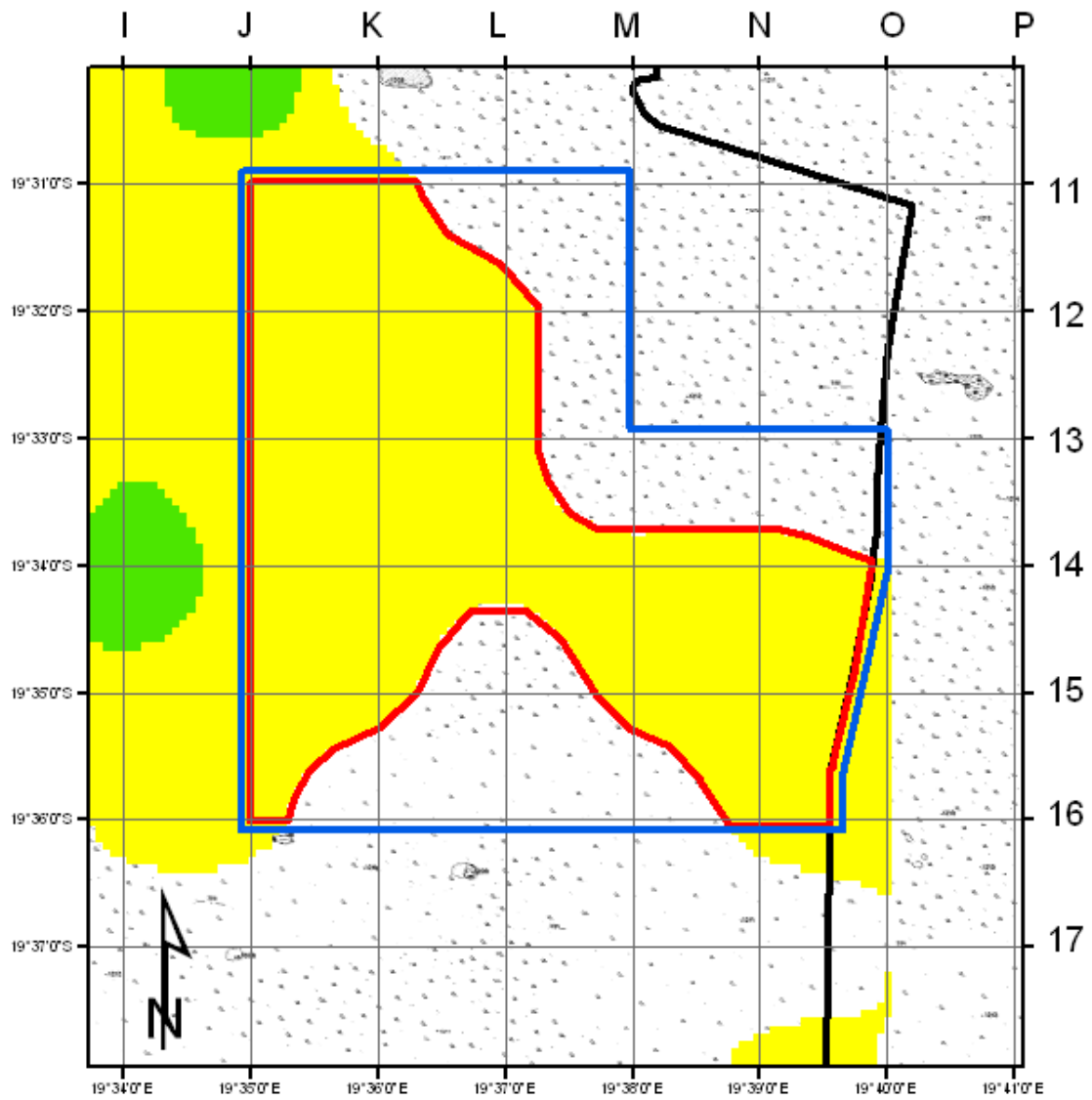


Figure 19. A demarcated area (blue border) with almost 7000 ha in the eastern parts of the AOI contains an area with 4275 ha (red border). The 4274 ha have been determined as a class 1 zone (yellow area). Theoretically, the area should provide 64.12 tons ( $4275 \text{ ha} \times 0.015 \text{ tons}$ ) of firewood while the harvest resulted in over 72 tons, 12.5 % more than expected.



## **4.2 Results from imagery data preparation and enhancement**

### **4.2.1 Visual analysis of True and False Colour Composite**

#### **4.2.1.1 True Colour Composite (30-meter resolution)**

The true colour composite (Appendix 6) provides a good impression of the land cover in the AOI. Healthy green vegetation in fine-leaved evergreen/semi-deciduous woodland or mixed scrublands appears dark to medium green, which is mostly the case in the eastern and south-eastern part of the AOI. Areas with a low cover of green vegetation appear in different shades of blue-green, blue and violet. This is most probably thinly covered broad-leaved, deciduous woodland. Yellowed vegetation or very sparsely covered land appears in light colours e.g. in the whole lower central part of the AOI. However, some zones in this image could not without doubt correlated with the vegetation type classes e.g. areas with a sierra or brown shade.

#### **4.2.1.2 False Colour Composites (30-meter resolution)**

Interpretation of false colour composite requires some practice since, at least for the human eye, colours are allocated in an unusual way (Appendix 6). The 4/3/2 composite for example conveys information comparable to colour infrared photographs and green vegetation appears in different shades of red while areas with decadent vegetation or sparsely covered land appears green to blue-green. Healthy green vegetation appears in a 7/4/2 composite (RGB, middle IR band 7 = R, near IR band 4 = G and visible green band 2 = B) bright green. Yellowed vegetation or sparsely covered land appears pink to magenta. Land with very little vegetation cover or bare soil appears in shades of light brown, grey and yellow to white. Between the different false colour composites the author prefers this band combination because the different vegetation categories or the state of deciduous woodland or scrubland can be a little bit better discriminated compared to the true colour or the 4/3/2 composite. This is probably due to the fact that the combination of middle and near IR reflectance of the living plant canopies can be better differentiated from the visible reflectance of the plant canopies.

#### **4.2.1.3 False Colour Composites (15-meter resolution)**

The two previous 30-meter resolution false colour composites illustrate the detail available before the resolution merge. It was expected, that compared to the 30-meter resolution false colour composites the 15-meter image would provide a far clearer differentiation between the vegetation type classes due to a clearer rendition of the vegetated surfaces. However, this 15-meter resolution image gave the impression that it might not significantly aid in the differentiating of the different vegetation type classes. Hence, to save time and system resources, it was decided not to use this image for further processing but the 30-meter resolution.

#### **4.2.1.4 Spectral Enhancement - NDVI**

As anticipated, the inverse relationship between vegetation brightness in the visible red and the near IR yielded good results for the AOI. The lighter tones in the NDVI image (Appendix 6) can be associated with dense coverage of healthy green vegetation while the ratios for less green vegetated areas are lower and these sites appear consequently darker. The rationing strategy of the NDVI could almost certainly aid to discriminate the different vegetation type classes during the classification process.

#### **4.2.1.5 Spectral Enhancement - Tasseled Cap**

A spectral enhanced Tasseled Cap image with a 4/3/2 band combination is shown in Appendix 6. Compared to its false colour parent image (30-meter resolution) the TC image provides an improved differentiation between the different vegetation types and it was decided to use this image together with the 30-meter false colour composites for unsupervised classification.

#### **4.2.1.6 Spatial Enhancement - Texture**

Apart from a better detection of the millet fields in the eastern part of the AOI, the course of the gravel roads and a few structures in the southwest of the area the texture image (Appendix 6) could not add so much information for the visual interpretation.

## **4.3 Results from Image Classification**

### **4.3.1 Unsupervised Classification**

The first step of the hybrid method, the unsupervised classification, was carried out on different false colour composites and the TC image simultaneously. The TC produced during this trial-and-error approach the most appropriate classification results and the image with 36 classes is shown in Appendix 7.

### **4.3.2 Supervised Classification**

The supervised classification has been performed with the Tasseled-Cap image resulted in a rather generalized categorization, i.e. only three vegetation type classes (broad-leaved deciduous woodland, fine-leaved evergreen/semi-deciduous woodland, and mixed scrubland) could be differentiated. Attempts to further refine the classification into sub-classes based on vegetation canopy was only possible for this three vegetation types due to similarity of spectrum characteristics in zones with more heterogeneous stands – the mixed pixel problem. A new vector layer representing the extent of the nine different classes (three vegetation types, each class with three canopy cover values) has been created from the classified image (Table 10 and Appendix 7).

Using a combination of supervised and unsupervised methods based on Landsat 7 images for cost effective mapping of remote areas is a common venture (Fox, et al. 2002). However, correct and representative ground truth information is critical for the classification process, in particular if classification is based on spectral analysis alone. At present, the author does not exactly know to what extent the quality of the ground truth data contributed to imperfect classification but suspect that the quality of the ground truth data was too inferior.

The monitoring team consisted of young community members, between 19 and 22 years, who attended only one five days course and just got some additional on-the-job training. Far superior ground truth information can be expected from more professional survey teams following a more strict data collection protocol. Further training could be preformed in reference areas where the canopy cover could be determined with a densiometer and a Bitterlich relascope (Verlinden & Laamanen



2002). This approach would allow the comparison of results obtained by estimating canopy cover with results obtained by determining with some more sophisticated equipment.

Table 10. The extent of three different vegetation type classes determined after classification of a Tasseled Cap image.

<b>Vegetation type</b>	<b>Code</b>	<b>area (ha)</b>	<b>% of the total area</b>
Deciduous woodland Dense canopy cover	Wd	6352	7.32
Deciduous woodland Medium canopy cover	Wm	16544	19.06
Deciduous woodland Low canopy cover	Wo	19564	22.55
<i>Sub-Total</i>		42460	48.93
Evergreen woodland Dense canopy cover	Ad	3772	4.54
Evergreen woodland Medium canopy cover	Am	5558	6.41
Evergreen woodland Low canopy cover	Ao	5633	6.51
<i>Sub-Total</i>		14963	17.26
Mixed scrubland Dense canopy cover	Sd	5584	6.43
Mixed scrubland Medium canopy cover	Sm	12988	14.96
Mixed scrubland Low canopy cover	So	10745	12.39
<i>Sub-Total</i>		29317	33.79
Agriculture/Grassland Very low canopy cover	Gv	263	0.003
<b>Grand Total</b>		<b>86764</b>	<b>100</b>

It is an indispensable step to use training sites in supervised classification, but it requires substantial human operations. Such substantial human operations make training data selection a time-consuming and laborious processing. This is especially exasperating; if spectral signatures repeatedly fail to discriminate between specific vegetation types, i.e. when two or more types and/or stages, have very similar spectral signatures. This was frequently the case for zones with fine-leaved evergreen/semi-deciduous woodland and mixed scrubland.

It would have been a big advantage for the study to perform a temporal analysis with time corresponding images to detect differences between broad-leaved deciduous woodland, fine-leaved evergreen/semi-deciduous woodland and mixed

scrubland. Particularly, deciduous woodland types could have been easier identified because of its big annual NDVI difference, while fine-leaved evergreen woodland would maintain a high NDVI average during the dry season. But unfortunately the required scenes were not available and as a result, generalization of the classification was essential.

## 4.4 Raster comparison

### 4.4.1 Qualitative results

Although, a certain degree of conformity cannot be neglected, the differences between the distribution and extent of three major vegetation types appear to be substantial in the three different generated maps (image classification and Spline and Kriging interpolation) (Table 11 and Appendix 5 and 7). The results of the Spline method seem too smooth and the differentiation between the different classes appears generally too persuasive. In comparison with the classification results Spline overestimated the extent of evergreen woodland and underestimated deciduous woodlands. Kriging overestimated the extent of evergreen woodland even more but and underestimated the amount of deciduous woodlands as well compared to the classification. To summarize: based on the rough z-value grid, both interpolations display the distribution of the three vegetation types quite unrealistic and deviate significant from the results of the classification.

Table 11. Comparison between the extents of three different vegetation types determined with three different methods (classification of a Tasseled Cap image and interpolation with Spline and Kriging).

Vegetation type	Classification % of the total area	Spline % of the total area	Kriging % of the total area
Deciduous woodland	48.93	36.71	43.84
Evergreen woodland	17.24	28.93	33.61
Mixed scrubland	33.79	34.34	22.54

#### 4.4.2 Quantitative Results (linear regression analysis)

Testing for correlation between estimated canopy cover and NDVI gave the following results:

Table 12. Regression analysis parameter

<b>Linear Fit</b>	$y = a + b * x$
<b>Input y range</b>	average NDVI pixel values
<b>Input x range</b>	canopy cover values
<b>Standard Error (SE)</b>	19.072
<b>Correlation Coefficient (R)</b>	0.047
<b>Coefficient of Determination (R<sup>2</sup>)</b>	0.002
<b>Adjusted R<sup>2</sup> (R<sup>2</sup><sub>adj.</sub>)</b>	0.001
<b>Sample size (n)</b>	289
<b>Degrees of Freedom (df)</b>	1
<b>Results of F-test (F)</b>	0.643

The correlation between the average pixel values and estimated canopy cover was  $R = 0.047$  ( $R^2 = 0.002$ ,  $R^2_{adj.} = 0.001$ ), i.e. the correlation is not significant at all. The relationship between the estimated and measured cover is shown in Figure 20. Since the different estimated canopy cover classes have a very similar distribution along the measured pixel values, it is obvious that not even a trend could be determined.

As pointed out in chapter 4.3.2 and 4.4.1 the quality of the survey data as well as the time difference between survey and date of image recording must be regarded as limiting factors for a perfect correlation. However, that the correlation would turn out as bad as this was not expected and gives a strong indication to improve on training in reference areas to determine canopy cover on a more precise level.

Two further technical or methodological questions remain using the buffer polygon NDVI pixel extraction approach and determination of the mean. The NDVI is often used and its correlation to green biomass is unquestionably (Campbell 2002). Green vegetation in arid and semi-arid areas however, could exhibit varying response curves in different climatic zones across all waveband and the NDVI might be therefore not always be a reliable representation for green vegetation (Ringrose et al. 1994). Rules for pixel inclusion within polygons in ERDAS IMAGINE 8.6 could not be quantified. When rasterizing a polygon for subsetting an image, extracting a training signature, calculating image statistics etc., the application must determine whether to

include partial pixels<sup>17</sup> within the polygon. Unfortunately, it remains unclear at what intersection level e.g., 20 %, 50 % or 70 % of the pixel area, can a single pixel be considered to fall within that polygon boundary? For this study is therefore just assumed, that all pixel falling within polygon boundary are included in the zonal statistics as well as 50 % of the pixel intersecting with the polygon.

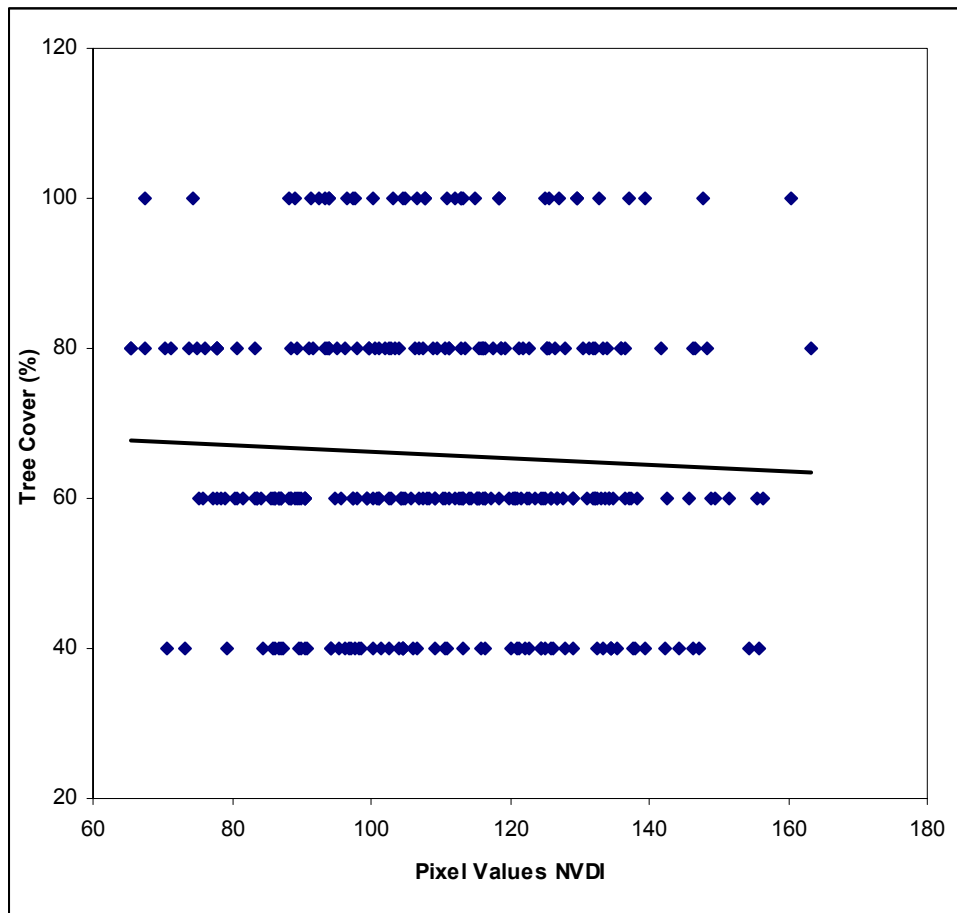


Figure 20. Relationship between estimated canopy cover and mean NDVI pixel values.

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<sup>17</sup> A partial pixel is one that is not fully contained within the selected region, in this case the buffer polygons boundary.

## 5. Conclusions

Most users of collective resources are trapped in a commons dilemma, unable to create solutions. The 'tragedy of the commons' is a concept first described by Hardin (1968), which holds that users of a public resource will demand an increasing share of the common good to the detriment and eventual loss of the resource. Ostrom (1990) revised the 'tragedy of the commons' and points out that some social groups have struggled successfully against threats of resource degradation by developing and maintaining self-governing institutions and local resource evaluation tools.

In Namibia most of the savanna woodlands are located in the north-central and north-eastern parts of the country. These areas were estimated to have comprised 12.4 million ha in 1995, which is 15 per cent of the total land area. During the period 1990 - 1995, the estimated annual loss of forest cover was 42 000 ha, the annual rate of deforestation being 0.3 per cent (FAO 1997). The loss of woody vegetation cover and the consequent environment and socio-economic problems are severe, especially in the north-central regions of Namibia.

Community forests in Namibia differ not only concerning spatial expansion or membership, also their development potential is very different indeed. The state through the Minister of Agriculture, Water and Forestry transfers property rights over natural resources to the local inhabitants of the community forests. Legally the model implies that resources are used collectively and administered through a representative body, the so-called forest management committee (FMC). Consequently, a forest management committee for M'Kata community forest has been established together with a monitoring prototype as a start-up approach designed as an adaptive tool to determine resource availability at grassroots level. It was hoped that this approach would result in participatory assessments useful for local evaluation in the community forest. Based on comprehensible data collection the FMC could re-evaluate and adapt the harvest rates for certain resources – an important condition to tackle successfully the possible dilemma of collective resources.

The monitoring prototype is management orientated and will not generate a comprehensive biodiversity database but attempts to meet the needs of the forest users and resource managers. The collected and processed data form the basis for the

definition of the annual yield or respectively, the harvesting permits for the community. In the near future four new community forests, neighboring M’Kata, with a total area of over 250.000 ha will hopefully submit their applications for formal approval. Therefore, the need to offer the new communities a reliable tool for woodland assessments is vital.

There are multiple advantages of community based monitoring systems. With total costs of less than 10 NAD<sup>18</sup> per km<sup>2</sup> the system is rather low-priced. Second, the system is community and management orientated and the closer management is to the ecosystem, the greater the responsibility, accountability and local participation (Feuerriegel & Nuding 2003).

Table 13. **Costs and delivery times**<sup>19</sup>

<b>Operation</b>	<b>Costs (Euro/km<sup>2</sup> and NAD/km<sup>2</sup>)</b>	<b>Time (months)</b>
Purchase of satellite images	0,05 or 0.35	1 to 5
Image processing and interpretation	0.2 or 1.4	0.5
Field survey	0.3 or 2.1	1
Data analysis	0.4 or 2.8	1
Map production	0.2 or 1.4	0.5
Appraisal and report writing	0.2 or 1.4	0.5
<b>Total</b>	<b>1.35 or 9.45</b>	<b>4.5 to 8.5</b>

Initial work indicated the importance of vegetation seasonality and vegetation structure characteristics for forest type classification (Dale 1999). Remote sensing techniques have been available for several years and are regarded as an advantageous technology for vegetation assessment and classification (Campbell 2002). The choice to use satellite imagery for this study was clear because successful classification of satellite images can be an additional test for the internal consistency of the monitoring prototype.

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<sup>18</sup> Average exchange rate (2005) NAD : EURO = 7 : 1 or 1 NAD = 0.14 EURO

<sup>19</sup> The evaluation of costs and delivery times is based on the actual time and costs that were necessary for this study to achieve the results. Labour costs depend on the size of the grid and the resulting numbers of assess points used for a particular area. However, delivery time of satellite imagery should be reduced in an operational status for several reasons, e.g. direct order at the SAC and not via DoF/MAWF. Image processing, data analysis and ground surveys were time-consuming in the starting phase and might be limited later to analyses and updating. Additional cost may arise for equipment e.g., GPS devises, horses and camping gear, and development of a related database. Since the

Inconsistent survey methodologies would provide incomprehensible or unreliable results, which was the case for determination of vegetation type distribution and extent as well as for determining of canopy cover. All survey results were rapid eco-assessments (rule of thumb) and the monitoring team believed that their survey results were good approximations. How accurate or rather how inaccurate some of the guesses really were has been demonstrated. The training and didactic material to illustrate and determine for example canopy cover values were obviously inadequate and insufficient. Additional training in reference areas, where at least some silvicultural parameters have been determined with scientific equipment is regarded as indispensable. Grid reduction e.g., from a '1-minute grid' to a '30-second grid', and subsequently a substantial increase in sample locations could also be an important measure to improve the quality of data collection.

The considerable time difference of more than five years between the surveys and the age of satellite images was without doubt a further limiting factor. There are however, clear indications that up-to-date data will be made available for the project for more appropriate analysis. The surveys and the satellite data should be able to produce results with a resolution of approximately 1 ha. Thematic maps with a scale of 1:200.000 to 1:100.000 could be produced from this data, which seems to be sufficient for most inventories in the region, in particular for dead wood resources, which have a more or less homogenous distribution in their resource areas.

Apart from data collection the second challenge on the community level is to develop appropriate means of data processing and interpretation by members of the FMC. It is very important that FMC members start to do some calculations by their own and do simplified area interpolations by hand. Time is not regarded as a big issue in the community and a simple calculator, a table and a chair could facilitate most of the work. Production of own charts and simplified maps would definitely improve ownership attitude and responsibility - both important requirements to tackle successfully the possible dilemma of collective resources.

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study was regarded as a pilot project construction of database was reduced to a simple directory structure, but once the system is applied on more regional level database construction becomes inevitable.

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## Appendices 1 - 7



# Appendix 1

Figure A-1.1 Project Schedule Matrix: Integration of geo-information technologies and indigenous knowledge structures – K. Feuerriegel

No.	Activities	11.07.W28	18.07.W29	25.07.W30	01.08.W31	08.08.W32	15.08.W33	22.08.W34	29.08.W35	05.09.W36	12.09.W37	19.09.W38	26.09.W39	03.10.W40	10.10.W41	17.10.W42	24.10.W43
1.	MSc-Concept	■ ■	■														
1.1	Obtaining Literature	■	■														
1.2	Thesis writing			■	■				■	■		■			■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■
1.3	Proof reading		■													■	■
1.4	Sending Thesis to UNIGIS Salzburg																■
2.	Obtaining Digitised Data		■					■ ■									
3.	Ground Truth Concept	■	■ ■	■ ■													
3.1	Ground Truth Implementation					■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■									
3.2	Data Transfer (DBF Table)																
4.	Reference Area Concept	■	■ ■	■ ■													
4.1	Reference Area Implementation					■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■									
4.2	Data Transfer (DBF Table)													■			
5.	Training Concept		■ ■	■ ■													
5.1	Monitoring Book Concept		■ ■														
5.2	Monitoring Book Implementation			■ ■													
5.3	Training Implementation				■ ■ ■ ■												
5.4	Trial Survey and Evaluation					■ ■ ■ ■	■ ■ ■ ■										
5.5	Survey Implementation							■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■ ■				■ ■		
5.6	Data Transfer (DBF Table)							■ ■				■ ■ ■ ■					
6.	Enhancement Satellite Imagery							■ ■ ■	■ ■								
6.1	Classification								■ ■ ■ ■				■				
6.2	Determination Mean NDVI Values												■	■			
7.	Point Feature and Surface Generation												■	■			
7.1	Area Determination (Editing)												■ ■	■ ■			
8.	Projected Yield vs Trial Harvest														■	■	
8.1	Classification vs Interpolation of Vegetation Types														■	■	
8.2	NDVI vs Vegetation Cover														■	■	

The activities 1. to 8.2 have been carried out by the FMC members: Mr. Josef Kahimbi and Mr. John Nehemina ■, the Monitoring team members: Mr. Ruben Gabriel and Mr. Erastus Sagaria ■, Mrs. I. Boesche ■ and Mr. K. Feuerriegel ■. Each of the coloured squares (■, ■, ■ and ■) correspond to one working day. ■ together 25 days, ■ together 28 days, ■ = 3 days and ■ = 80 days (Total = 136 days).



# Appendix 3

## Route Map - M'Kata Community Forest



Scale 1:300,000 - WGS 1984 - Note: This map should only be used for indicating your route during reporting!

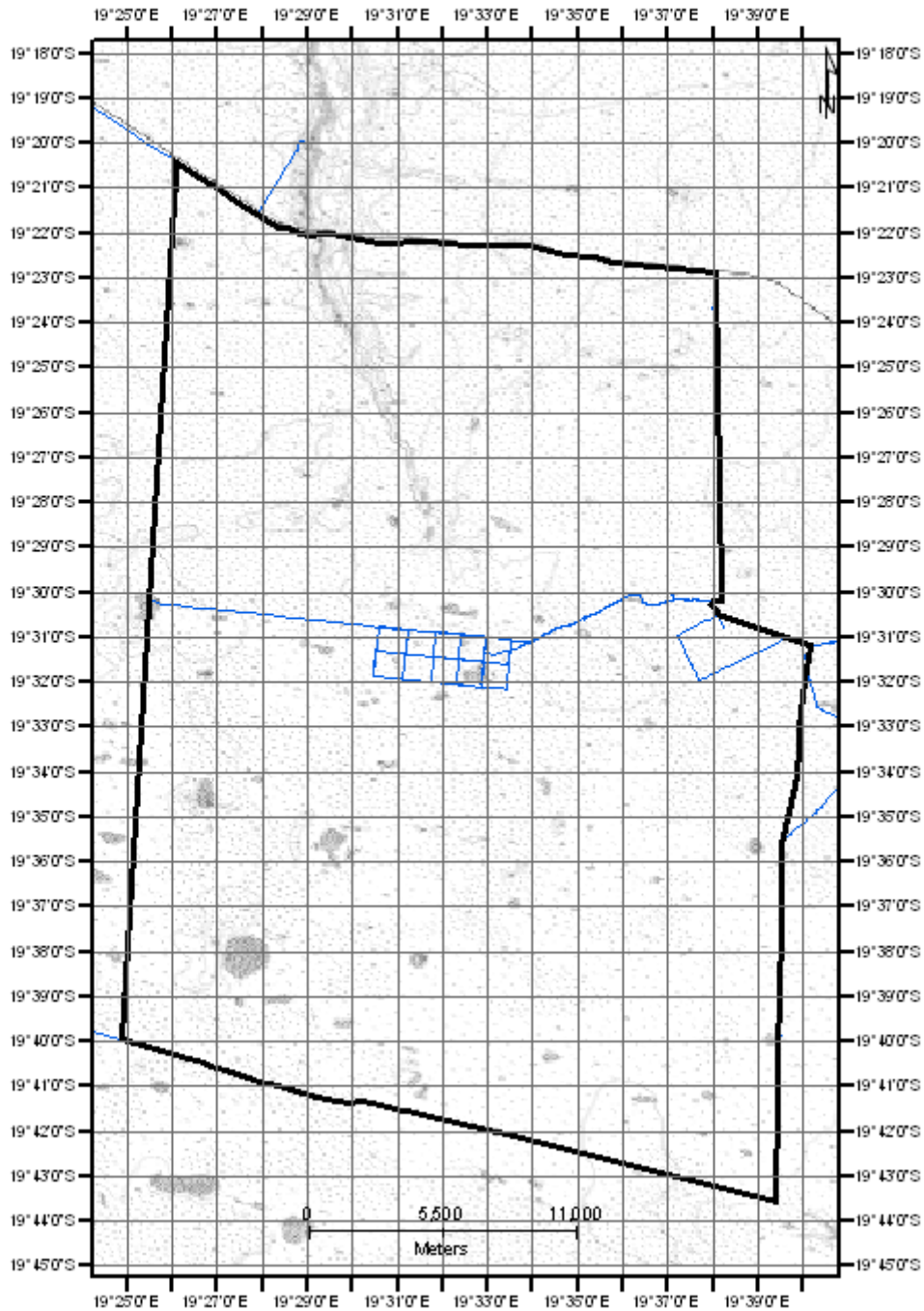


Figure A-3.1 The Monitoring Book's route map (1:300,000), 1-minute grid and additional index.

# Map 1 - M'Kata Community Forest

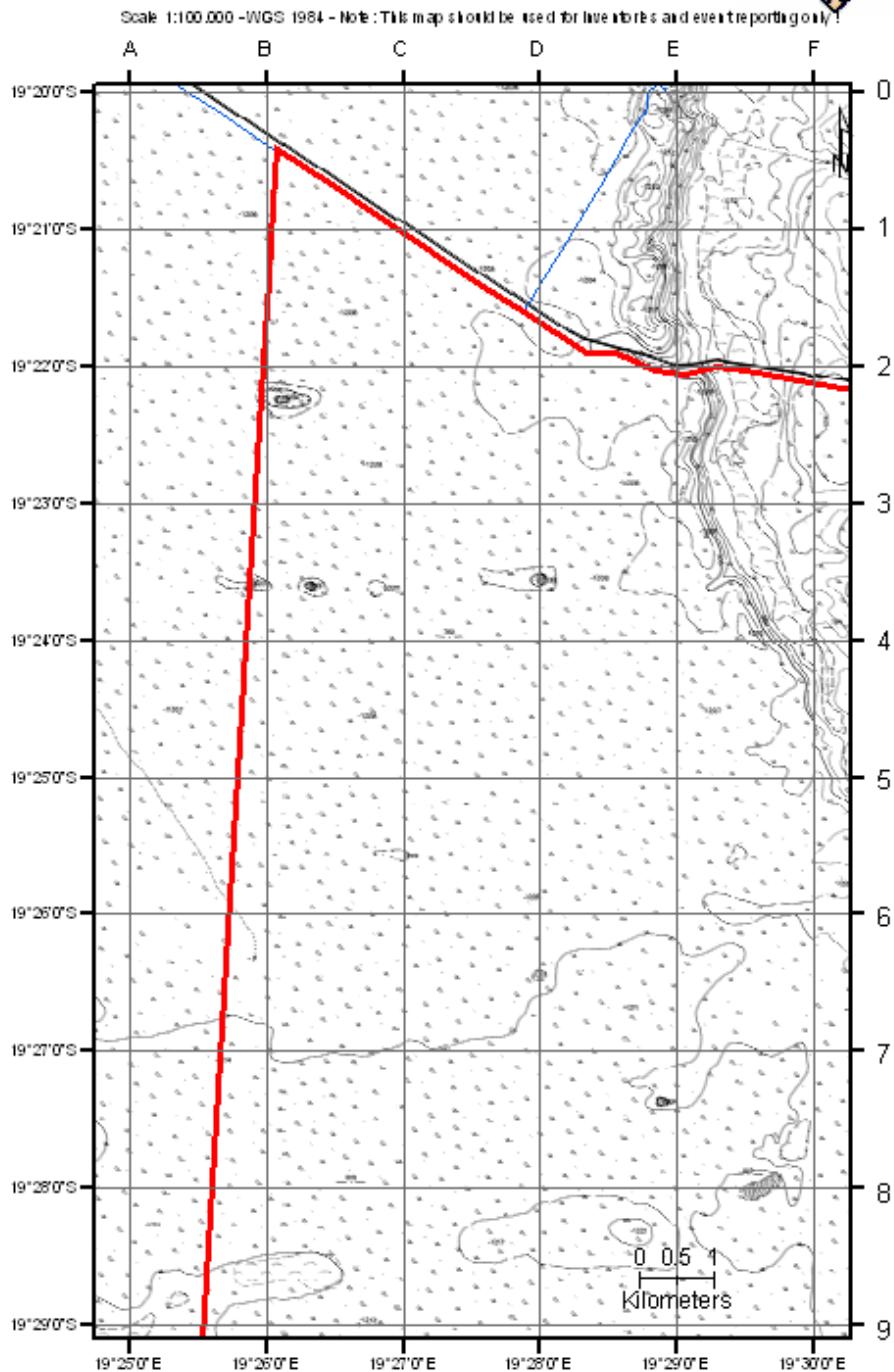


Figure A-3.2 The Monitoring Book's orientation map No. 1 (1:100,000) with 1-minute grid and index.

# Appendix 4

Figure A-4.1. Inventory Rules (Monitoring Book)

## Inventory Rules

1. Never work alone when riding a horse. There must be always two honorary foresters working together in the community forest.
2. The monitoring book is always by its master, the honorary forester.
3. In case of important events (fire, illegal activities, problems with the horses etc.) the honorary forester informs the FMC at the same day.
4. The honorary forester receives every month a new monitoring book and the current one must be handed over to the FMC.
5. Forms and maps have to be filled according to the monitoring rules:
  - Use only the appropriate keys to report.
  - Do not invent information (no data are also valuable information).
6. Before every patrol the honorary forester makes sure that the GPS receiver has the following settings: Main Menu > Setup > Units > Position Format: hddd.ddddd ° > Map Datum: WGS84 > Distance/Speed: Metric > Elevation: Metric
7. Do not hesitate to ask the FMC or the CFNEN adviser if you have questions related to the monitoring system.



Figure A-4.1 Fact sheet examples from the Monitoring Book for z-value assessment.

### Fact Sheet Trees - Forest Inventory M’Kata

Key: H = high , M = medium, L = low

Waypoint	Trees	T_Cover	T_Regeneration
	Pt Bu Lo Ae Ts	H, M, L	H, M, L

### Fact Sheet Drywood - Forest Inventory M’Kata

Key: H = high , M = medium, L = low

Waypoint	Dry wood Planks (Pt)	Dry Firewood (Ae)
	H, M, L	H, M, L

### Fact Sheet Fire and Area - Forest Inventory M’Kata

Key for Fire: 0 = this year, 1 = last year, 2 = two or more years ago

Key for Area: D = Dune, O = Omiramba, P = Plain

Waypoint	Fire: 0, 1, 2	Area: D, O, P

### Fact Sheet Veld Kost, Grazing and Thatching Grass

Key: H = high , M = medium, L = low

Waypoint	Veld kost: H, M, L	Grazing: H, M, L	Thatching: H, M, L

## Appendix 5

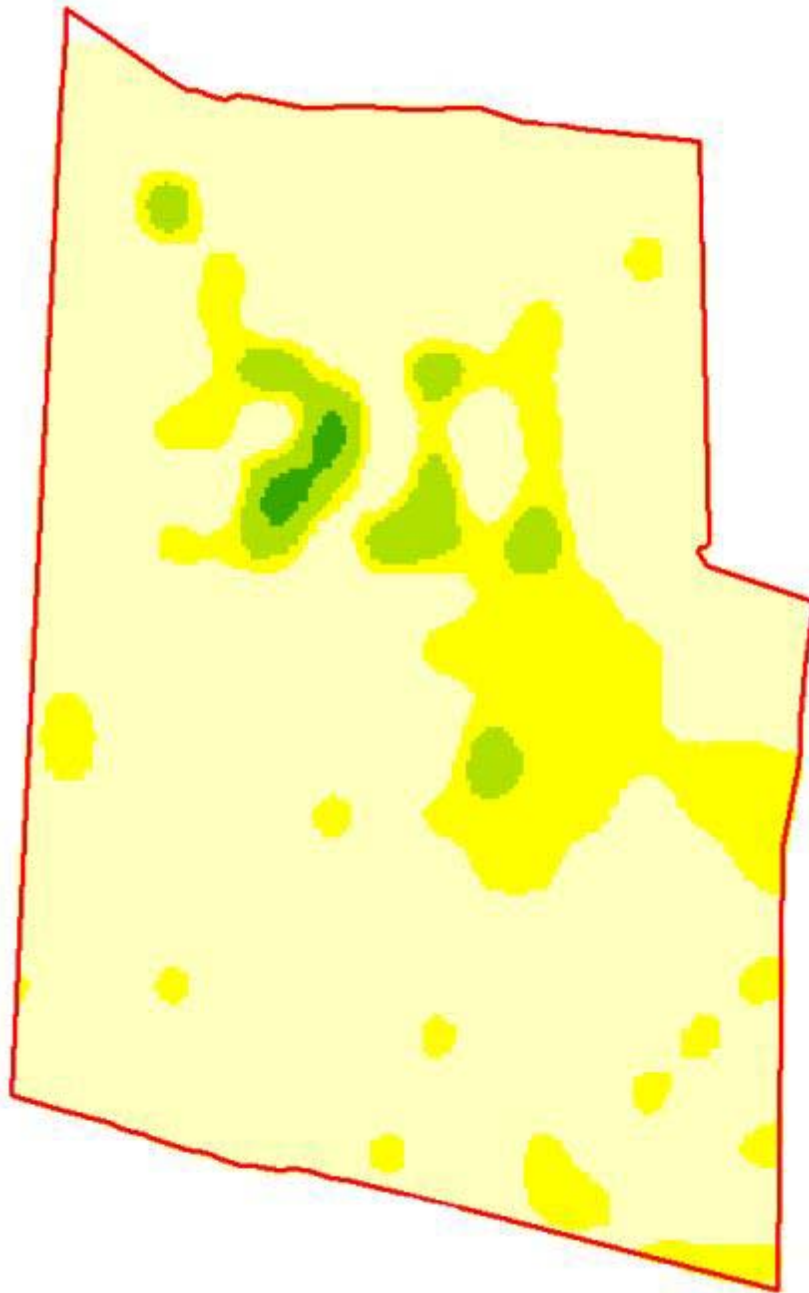


Figure A-5.1 A reclassified raster dataset representing the three different firewood availability classes after interpolation with the Spline method. The dark green area represents a zone with high availability of firewood (class 3 = 0.027 tons/ha), green areas symbolize class 2 with a mean of 0.026 tons/ha and yellow areas stand for class 1 with 0.015 ton/ha.

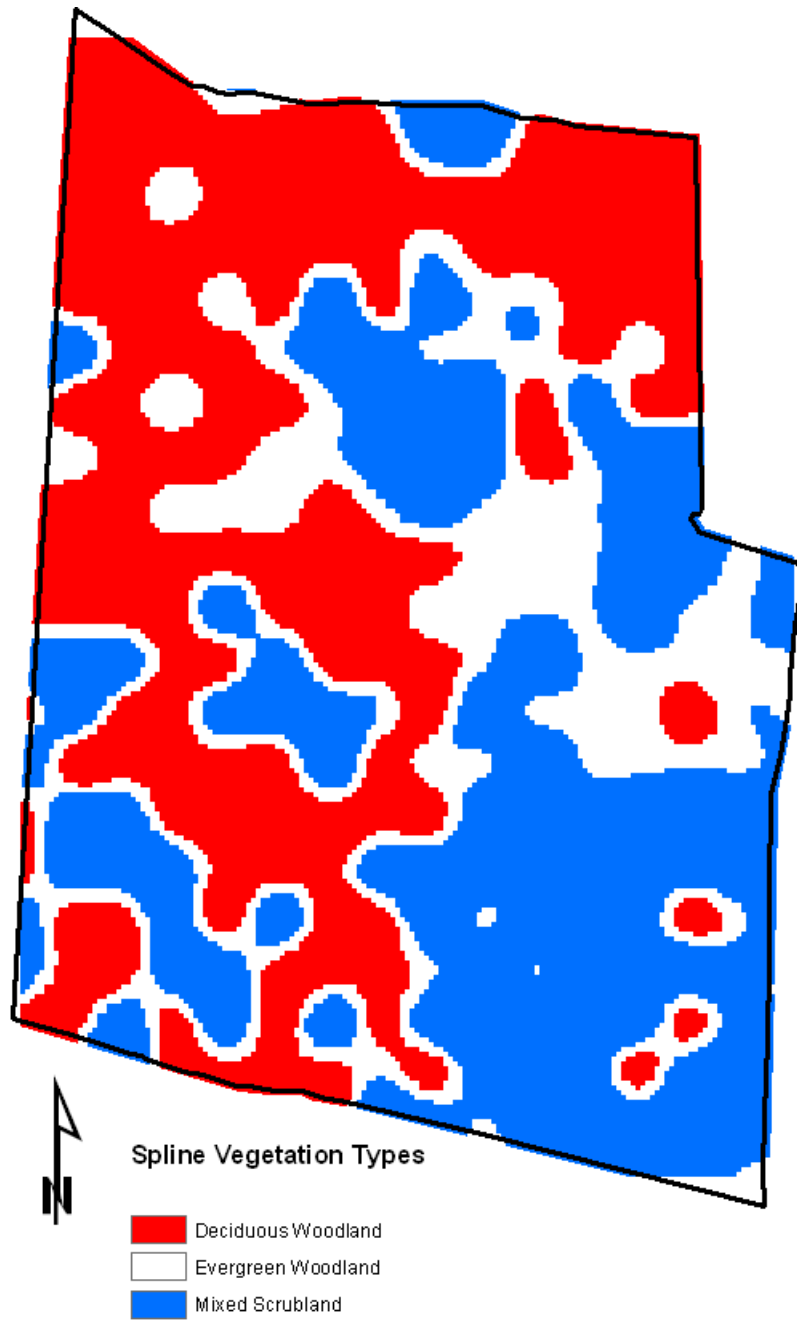


Figure A-5.2 A reclassified raster dataset representing the interpolation results (Spline method) of three different vegetation types. The red area represents deciduous woodland (31856 ha, 36.7 % of the area), white areas symbolize evergreen woodland (25106 ha, 28.9 % of the area) and mixed scrublands are in blue (29801 ha, 34.3 % of the area).

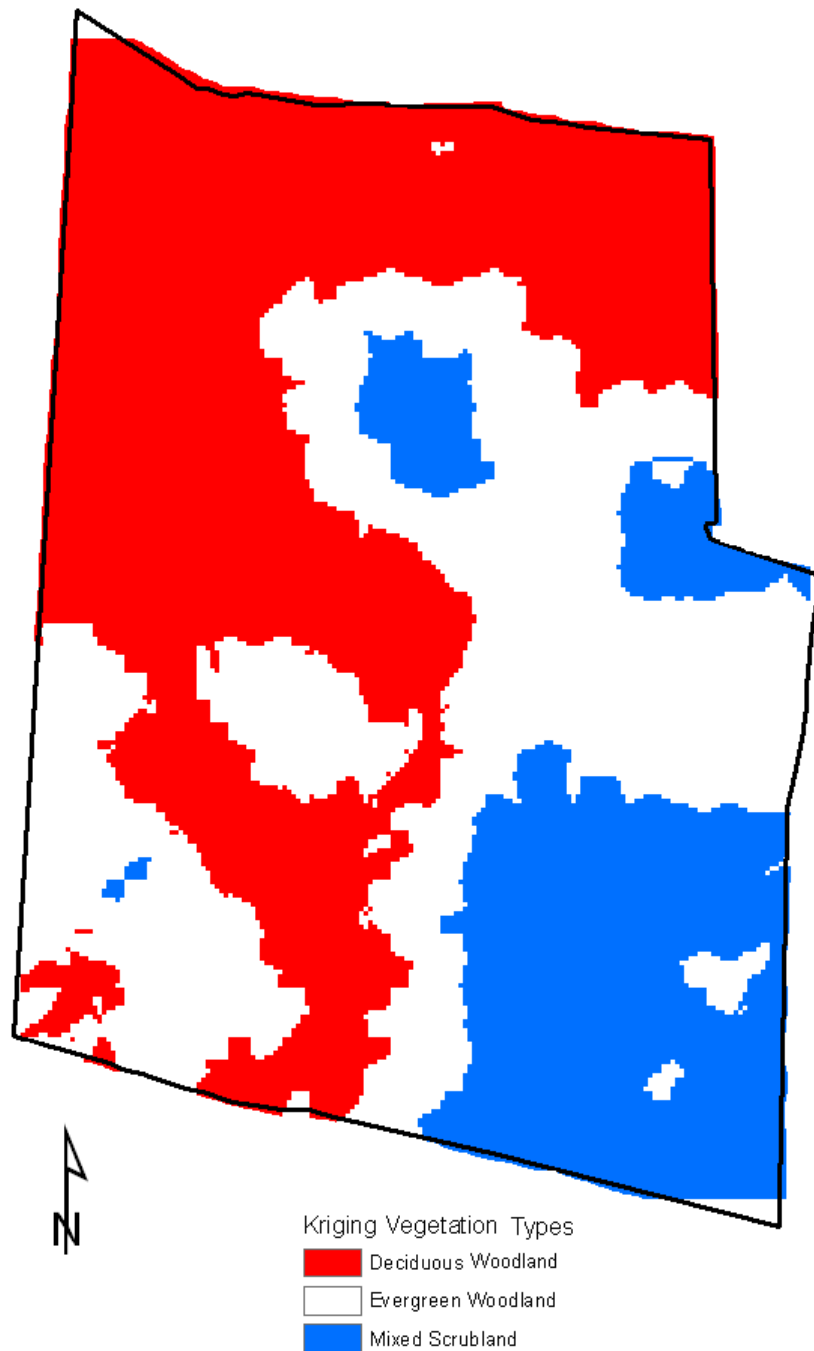


Figure A-5.3 A reclassified raster dataset representing the interpolation results (Kriging method) of three different vegetation types. The red area represents deciduous woodland (38038 ha, 43.8 % of the area), white areas symbolize evergreen woodland (29164 ha, 33.6 % of the area) and mixed scrublands are in blue (19563 ha, 22.5 % of the area).

## Appendix 6

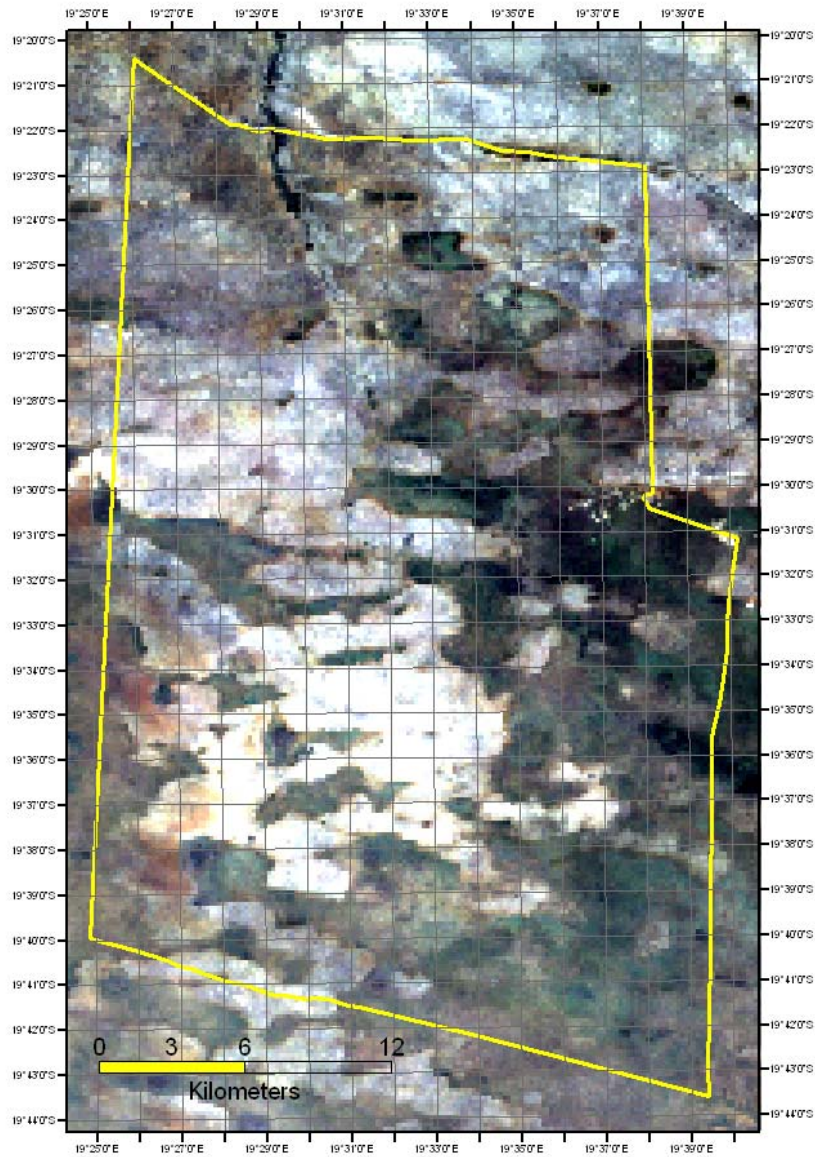


Figure A-6.1 The AOI in a multispectral, true colour composite (Landsat 7) where Band 3, 2 and 1 have been assigned to red, green and blue, respectively RGB.

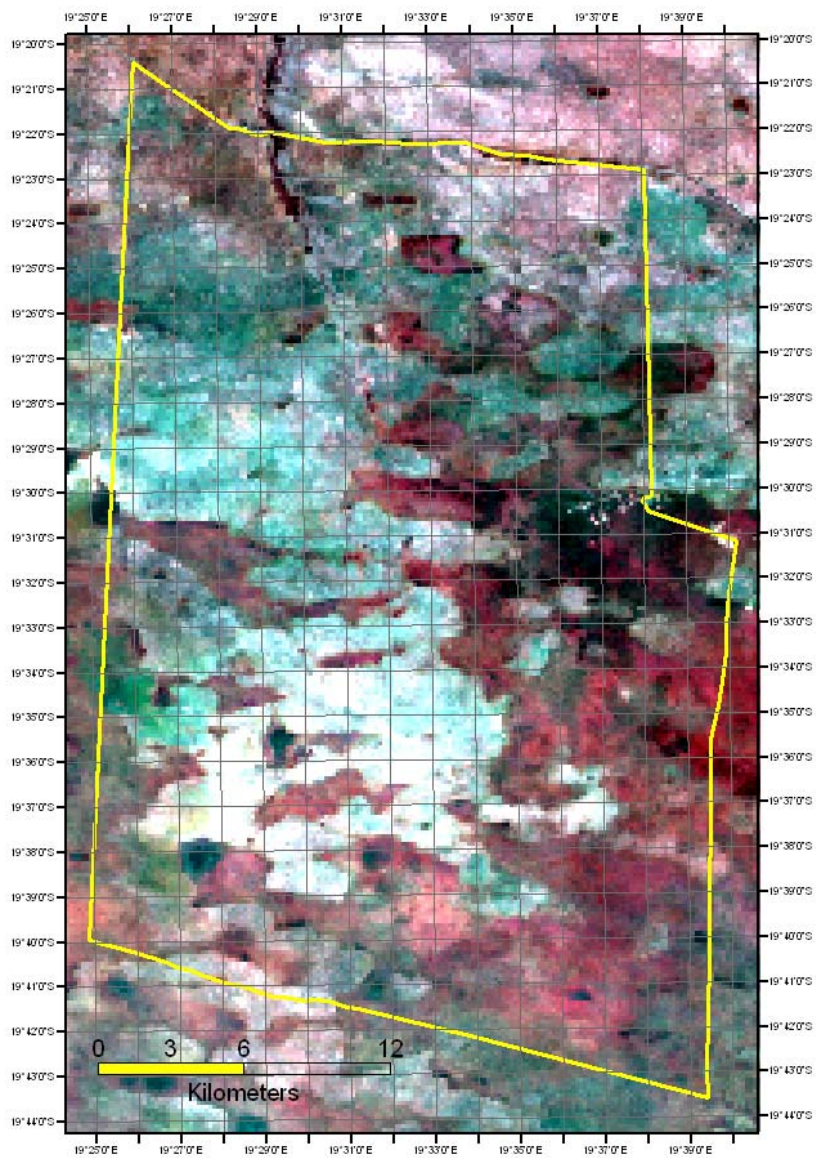


Figure A-6.2 The AOI in a false colour composite with 4/3/2 ETM+ Band combinations assigned to RGB.



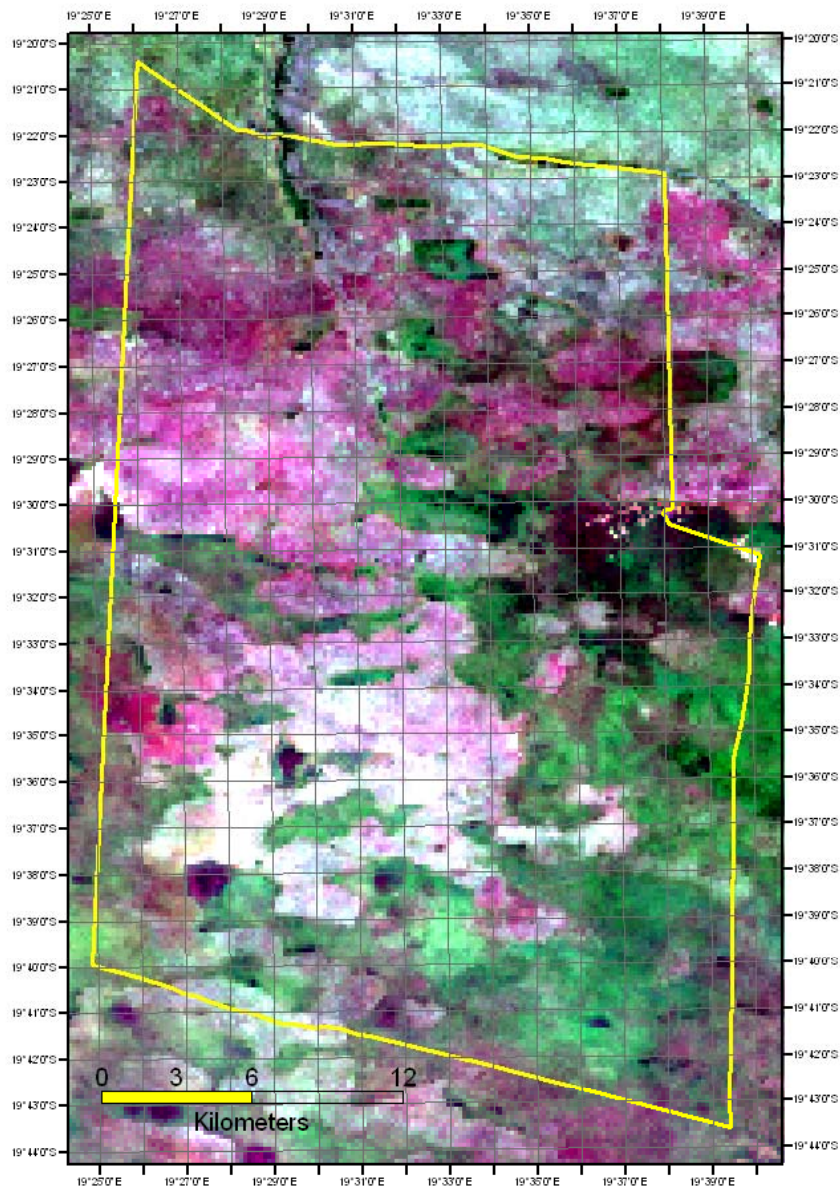


Figure A-6.3 The AOI in a false colour composite with 7/4/2 ETM+ Band combinations assigned to RGB.

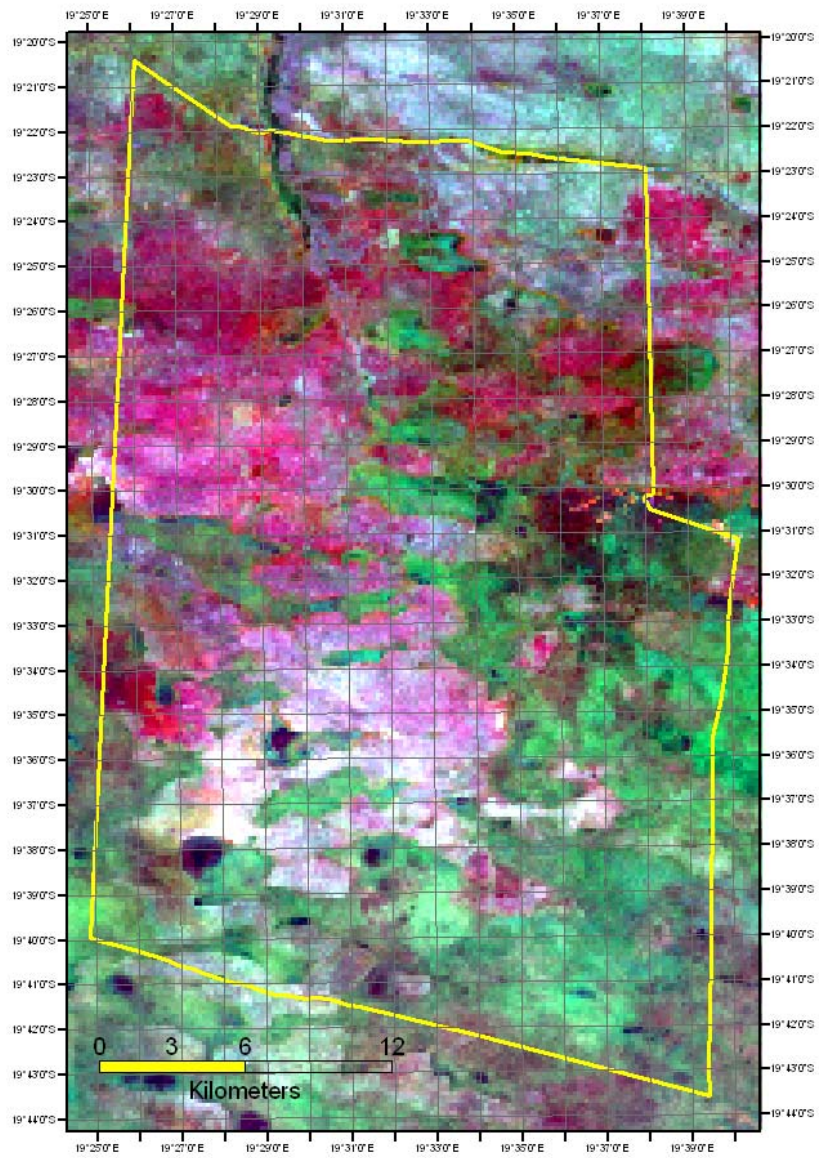


Figure A-6.4 The AOI in a 7/4/2 multispectral, pan-sharpened composite rendering visible and very near IR reflectance at 15-meters ground resolution.



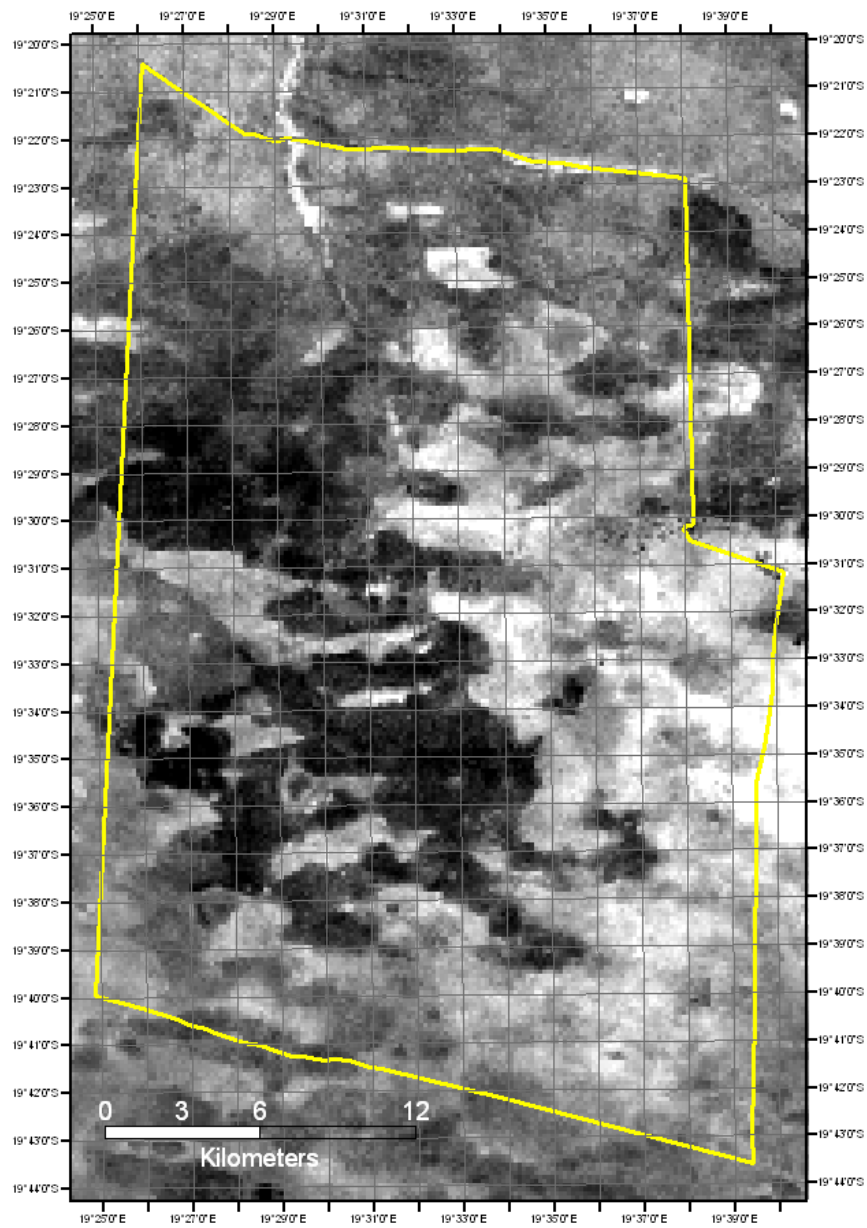


Figure A-6.5 NDVI image derived from 7-4-2 multispectral image (30-meter resolution)

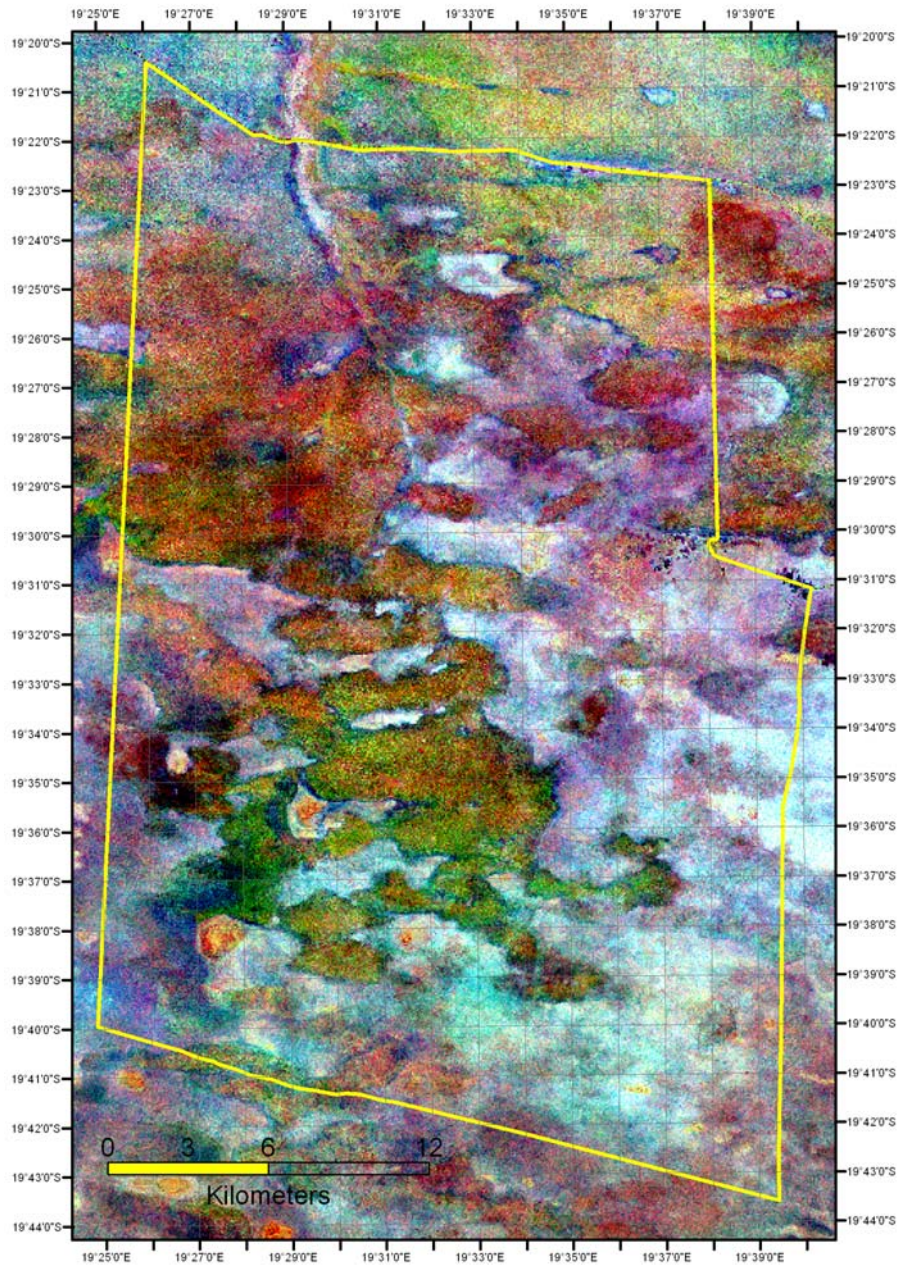


Figure A-6.6 Tasseled Cap transformation derived from 4-3-2 multispectral image (30-meter resolution).



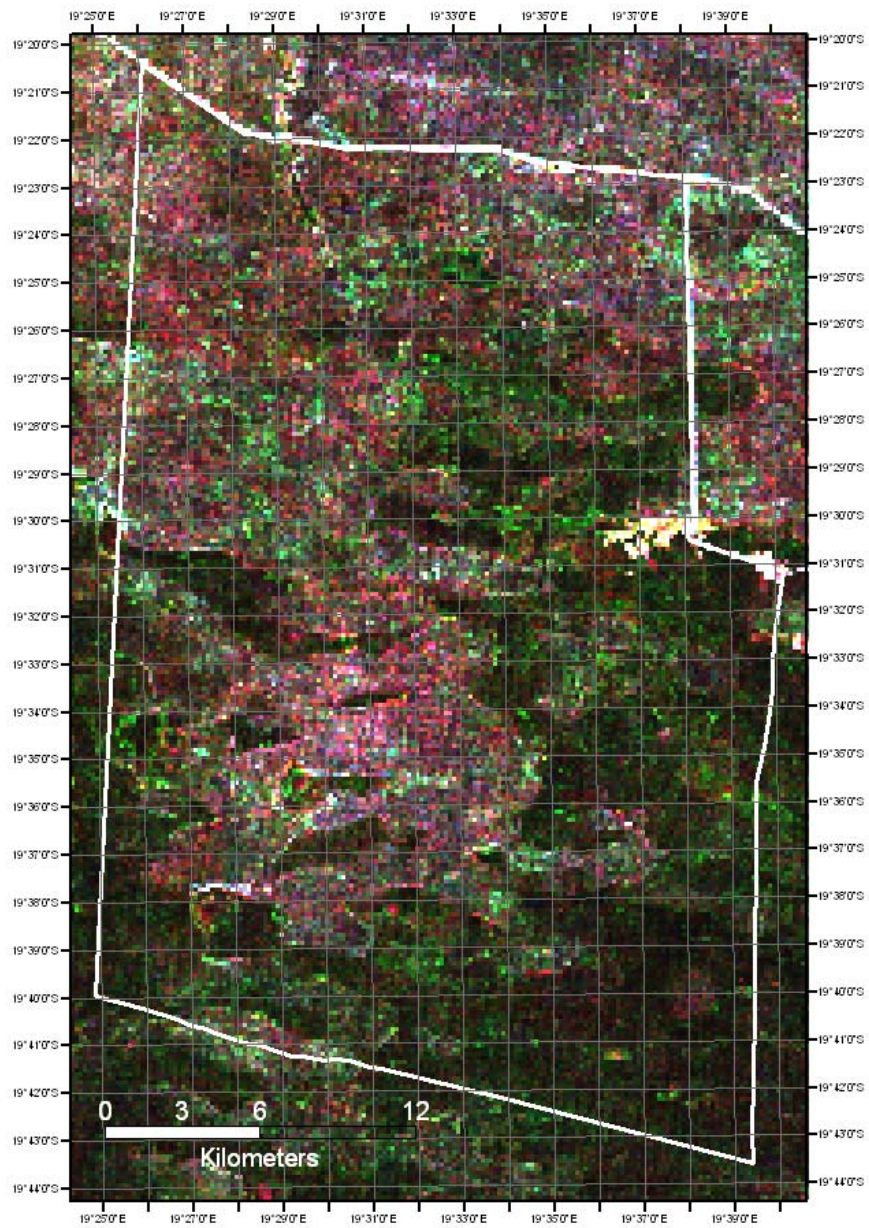


Figure A-6.7 Texture image.

# Appendix 7

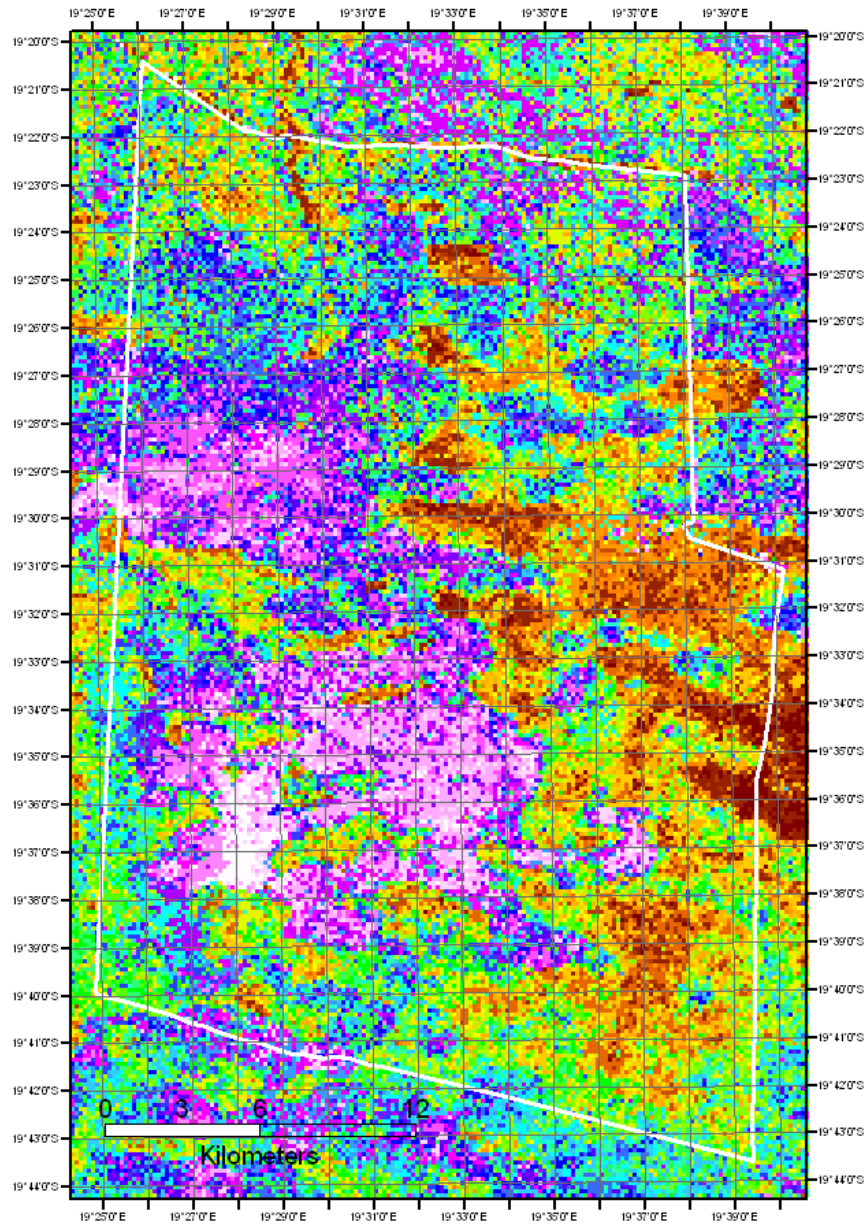


Figure A-7.1. Result of unsupervised classification with 36 classes.

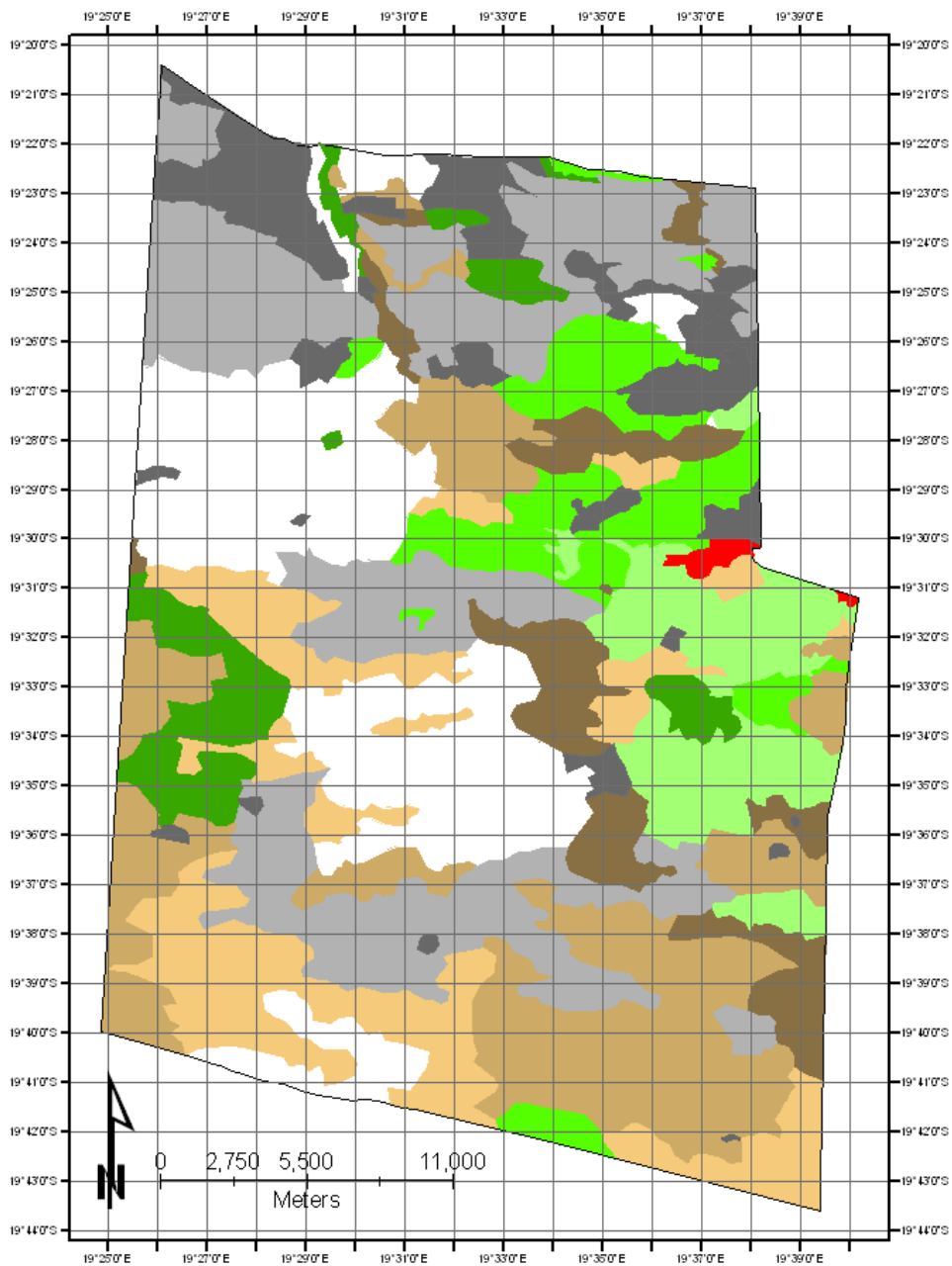


Figure A-7.2 Results of the supervised classification (9 classes) after editing. The distribution and extent of three different vegetation types and three canopy cover values are symbolize in shades of grey (deciduous woodland, 42460 ha, 48.95 % of the area), grey (evergreen woodland, 14963 ha, 17.25 % of the area) and brown (mixed scrubland 29317 ha, 33.79 % of the area). The small red area are representing sites for agriculture (millet fields with 263 ha).

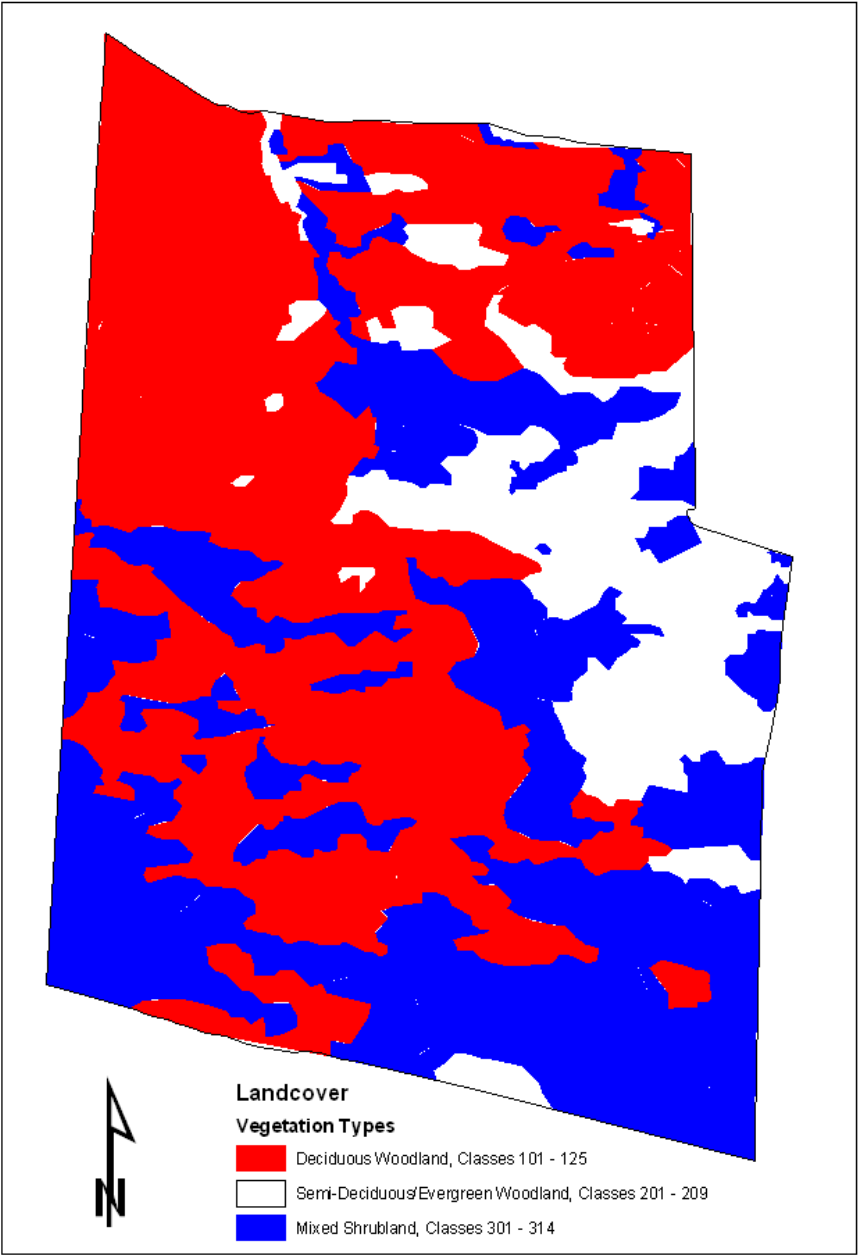


Figure A-7.3 Merged results of the supervised classification (3 classes).

# Erklärung

Ich versichere, diese Master Thesis ohne fremde Hilfe und ohne Verwendung anderer als der angeführten Quellen angefertigt zu haben, und dass die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen hat. Alle Ausführungen der Arbeit die wörtlich oder sinngemäß übernommen wurden sind entsprechend gekennzeichnet.

Datum 30.10.2005

eigenhändige Unterschrift:

(Karsten Feuerriegel)