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Editor
Prof. Dr.habil. Elmar Csaplovics
Research Group Remote Sensing
Department of Geosciences
Technische Universität Dresden
Helmholtzstraße 10
D-01062 Dresden
Tel. +49 351 463-33372
Fax +49 351 463-37266
E-Mail: elmar.csaplovics@tu-dresden.de
Homepage: https://tu-dresden.de/bu/umwelt/geo/ipf/fern

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Assessing, monitoring and mapping forest resources in the Blue Nile region of Sudan using an object-based imageanalysis approach

Mustafa Mahmoud El-Abbas

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Submitted by

MSc. Mustafa Mahmoud El-Abbas,

born on April 6, 1977 in Khartoum

Academic Supervisors

Prof. Dr.habil. Elmar Csaplovics
Institute of Photogrammetry and Remote Sensing, TU Dresden

Prof. Dr. Elnour Abdalla Elsiddig
Faculty of Forestry, Department of Forest Management , University of Khartoum

Dr. habil. Hannelore Kusserow
Institute o1 Geographical Sciences, FU Berlin

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Editorial

> Nothing is more pleasant than the country around Sennaar, in the end of August and beginning of September […]; instead of that barren, bare waste, which it appeared on our arrival in May (1772, editor's note), the corn now sprung up, and covered the ground, made the whole this immense plain appear a level, green land, interspersed with great lakes of water and ornamented at certain intervals with groups of villages, the conical tops of the houses presenting, at a distance, the appearance of small encampments. Through this immense, extensive plain, winds the Nile, a delightful river there, above a mile broad, full to the very brim, but never overflowing. Every where on these banks are seen numerous herds of the most beautiful cattle of various kinds, the tribute recently extorted from the Arabs, who, freed from all their vexations, return home with the remainder of their flocks in peace, at as great a distance from the town, country, and their oppressors, as they possibly can.
>
> Bruce of Kinnaird J (1791) Travels to discover the sources of the Nile, in the years 1768, 1769, 1770, 1771, 1772, and 1773, in six volumes, vol V, ch IX, p 231f

Sub-Saharan semi-arid regions suffer from increasing local impact on vegetation canopies in terms of overgrazing by herds and flocks, overexploitation of soils by rainfed agriculture neglecting fallow cycles and fuelwood consumption as well as illegal timber extraction. Subregional to local variations in extent and severity of impact are due to varying patterns of socio-economic and socio-political pressure on the local people and are furthermore driven by gradients of migration of people displaced from their homelands due to ethnical and economic reasons. Mapping state and changes of land use and land cover is often focusing on monitoring and analysing the effects of long-term to medium-term climatic variations towards their impact on specific eco-climatic zones. This approach is more and more blamed for its neglect of regional and subregional variations of drought phenomena via arguing that the whole mechanism is much more complex in terms of causes and reasons of land cover changes. Local to regional patterns of land use land cover change have to be assessed and analysed much more intensively. Besides parameters of climatic change such as variations in periodicity and decline of amount of rainfall, increasing impact of strong winds and of temperature variations, spatio-temporal information on regional and local land use and land cover change as a mirror of anthropozooic impact has to be collected in a much more holistic way. It is obvious that the latter is responsible for severe land degradation, thus creating a circulus vitiosus which more and more deteriorates the livelihood of indigenous people. Local patterns of vegetation status and change are to be assessed in high spatio-temporal resolution in order to get a better idea about the interrelated effects of human impact on land degradation, deterioration of livelihood and subsequent abandonment of the land. Remote sensing of the environment by (very) high resolution spaceborne imagery provides the perfect tool and methodological background for collecting, maintaining, analysing and visualising spatio-temporal data which are capable to describe land use and land cover change in different scales both quantitatively as well as qualitatively.

Semi-arid regions of sub-Saharan Africa differ significantly in terms of their environment, their equipment with natural resources and their socio-political condition. Availability of water throughout the year is an advantage which attracts both displaced as well as migrating people and their herds and flocks. Conflicts with regard to rights of water and land use between local and migrating people are inevitable. Thus besides eco-climatic conditions the far more significant driving force of land degradation is resulting from socio-economic and socio-political instabilities, which change both in time (from seasonal to multi-annual) as well as in space (from the water hole level to the local land management level).

It is self-evident that especially the riverine environments along the large rivers crossing the sub-Saharan drylands are and have been the focal points of settlement and land exploitation, the Nile and Niger rivers being both the most significant ancient as well as recent representatives. The kingdom and town of Sennar came into power after the invasion of the Funj people from nowadays southern Sudan (Sudd) at the beginning of the 16th century. It found its peak during the 17^{th} century when territorial expansion reached its apogee by extending the territory as far as to Southern Kordofan in the west and Dongola in the north. The Funj Sultanate of Sennar (Sinnar) lasted till 1821 when Turkish influence which grew since the late 18^{th} century culminated in a peaceful invasion. After the resignation of the last king the territory was assimilated into the Ottoman Egypt. The old capital of Sennar extended approximately 20km north-northwest from the new town. A milestone in rural development driven by colonial policies was the establishment of the Sennar dam in 1925 by the English colonial administration, aiming at fostering irrigation agriculture (dominantly cotton, then more and more replaced by wheat) in the Gezira scheme (founded 1911) bordering Sennar State in the northwest. Till a few years ago the town of Sinja was the capital of Sennar State, but Sennar itself was always and is still the largest town in terms of the number of inhabitants. Population has multiplied by five from 1973 to 2007, thus proving significant migration. Reasons are closely related to socio-political threats such as the Ethiopian-Eritrean and the South Sudan conflicts, associated with socio-economic pressure due to overexploitation of resources caused by accumulation of different, often controversial demands on land use. Severe impacts are driven by an ongoing trend towards mechanised farming based on rainfed agriculture which threatens sensible soil strata and leads to degradation and subsequent decline of crop yields. At the same time riverine forests along the Blue Nile are affected by often illegal fuelwood and timber extraction as well as grazing activities. The monitoring and assessment of forest resources along the Blue Nile is a matter of highest priority under the tasks of the Sudanese Forest National Cooperation (FNC). The multitude and heterogeneity of socio-ecological and socio-economic driving factors of soil and vegetation degradation calls for a sound and reliable methodology of spatio-temporal monitoring of patterns of land use and land cover changes as well as a subsequent critical analysis of parameters of efficiency and integrability of spaceborne remote sensing for management and planning of protective and restorative measures of policies of forest management and forest conservation. Mustafa El-Abbas focuses on that issue by implementing multi-source and multi-resolution operational earth observation via (very) high resolution imagery of Terra Aster and RapidEye sensor systems and by analysing the potential of object-based image analysis for multi-scale monitoring from the level of categorical land use land cover classes to the level of forest structural attributes such as average stand height and especially forest stand volume.

Mustafa El-Abbas provides an extensive and at the same time in-depth research into the innovative assessment and evaluation of up-to-date imagery and image analysis for forest management purposes in the semi-arid environment of forests along the Blue Nile. It is obvious that Mustafa El-Abbas is perfectly capable to accumulate, condense and extend as well as to apply a wealth of target-oriented knowledge of the local and regional characteristics of land cover and land use change in the Blue Nile region in general and of forest cover change and forest structure on the stand level with specific regard to pure riverine *Acacia nilotica* stands in particular.

> Balboch is on the eastern bank of the Nile, not a quarter of a mile from the ford below. The river here runs north and south; towards the sides it is shallow, but deep in the middle of the current, and in this part it is much infested with crocodiles, Sennaar is two miles and a half S.S.W. of it. We heard the evening drum very distinctly […]
>
> Bruce of Kinnaird J (1791) Travels …, vol V, ch VII, p 177

> The banks of the Nile about Sennaar resemble the pleasantest parts of Holland in the summer season; but soon after, when the rains cease, and the sun exerts its utmost influence, the dora [millet] begins to ripen, the leaves to turn yellow and to rot, the lakes to putrify, smell, and be full of vermin, all this beauty suddenly disappears.
>
> Bruce of Kinnaird J (1791) Travels …, vol V, ch IX, p 232

The overall scientific value and reliability of the research presented by Mustafa Elabbas is evident. It is challenging to realise that based on the well-structured, detailed and in-depth work of Mustafa El-Abbas a clear perspective for a multi-level regionalisation of multi-sensor and multi-resolution earth observation data analysis for purposes of forest management from the categorical land use land cover level to the local forest stand level is made possible. The presented performance of operational satellite imagery of very high (geometric) resolution and of object-based image analysis for monitoring and assessment of forest canopy characteristics in different scales is providing a promising baseline for a significant improvement of forest management issues in drylands of semi-arid sub-Saharan Africa, where accessibility of terrain is limited and dynamics of change both resulting from migration gradients as well as from subsequent anthropozooic impact on natural resources, especially on ligneous layers of vegetation, are highly frequent. The research of Mustafa El-Abbas contributes significantly to a better understanding of causes and reasons of degradation of forest canopies in semi-arid environments at a regional to local scale. The complexity of driving factors of forest degradation along the Blue Nile valley has strong spatio-temporal characteristics. It is evident that impacts are driven by complex factors which are connected in a multifold thematic network of interrelations of both economic as well as political and ecological, climatic, geomorphological and biogeographical parameters. Mustafa El-Abbas provides an important and innovative contribution to an improvement of the monitoring of forest cover and forest use at the multi-scale and multi-temporal level which represents a cornerstone for establishing a sound forest management in the Blue Nile region of the Sudan and beyond.

Dresden, April 2017

Elmar Csaplovics

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Mustafa El-Abbas

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Acronyms and abbreviations

AI	Artificial Intelligence
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
DBH	Diameter at Breast Height
DN	Digital number
EO	Earth Observing
ERSDAC	Japan's Earth Remote Sensing Data Analysis Center
FAO	Food and Agriculture Organization
FNC	Sudan’s Forest National Corporation
FRA	Forest Resource Assessment
FSO	Feature Space Optimization
GCP	Ground Control Point
GEOBIA	Geographic Object-Based Image Analysis
GIS	Geographic Information System
GLCM	Gray-level Co-occurrence Matrix
GPS	Global Positioning System
ha	Hectare
LU/LC	land use/land cover
METI	Japan’s Ministry of Economy, Trade and Industry
ML	Maximum Likelihood
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
NN	Nearest Neighbour
OBIA	Object Based Image Analysis
OLV	Object Layer Value
PCA	Principal Component Analysis
PPS	Population Proportional to Size
R	Coefficient of determination
RB	Rule Based
RMSE	Residual Mean Square Error
SPSS	Statistical Package for the Social Sciences

SWIR	Short Wave Infrared
TIR	Thermal Infrared
TM	Thematic Mapper
TTA	Training and Test Area Mask
UNCD	United Nations Capital Development Fund
USGS	United States Geological Survey
UTM	Universal Transverse Mercator projection
VNIR	Visible and Near-Infrare

ABSTRACT

Following the hierarchical nature of forest resource management, the present work focuses on the natural forest cover at various abstraction levels of details, i.e. categorical land use/land cover (LU/LC) level and a continuous empirical estimation of local operational level. As no single sensor presently covers absolutely all the requirements of the entire levels of forest resource assessment, multisource imagery (i.e. RapidEye, TERRA ASTER and LANDSAT TM), in addition to other data and knowledge have been examined. To deal with this structure, an object-based image analysis (OBIA) approach has been assessed in the destabilized Blue Nile region of Sudan as a potential solution to gather the required information for future forest planning and decision making. Moreover, the spatial heterogeneity as well as the rapid changes observed in the region motivates the inspection for more efficient, flexible and accurate methods to update the desired information.

An OBIA approach has been proposed as an alternative analysis framework that can mitigate the deficiency associated with the pixel-based approach. In this sense, the study examines the most popular pixel-based maximum likelihood classifier, as an example of the behavior of spectral classifier toward respective data and regional specifics. In contrast, the OBIA approach analyzes remotely sensed data by incorporating expert analyst knowledge and complimentary ancillary data in a way that somehow simulates human intelligence for image interpretation based on the real-world representation of the features. As the segment is the basic processing unit, various combinations of segmentation criteria were tested to separate similar spectral values into groups of relatively homogeneous pixels. At the categorical subtraction level, rules were developed and optimum features were extracted for each particular class. Two methods were allocated (i.e. Rule Based (RB) and Nearest Neighbour (NN) Classifier) to assign segmented objects to their corresponding classes.

Moreover, the study attempts to answer the questions whether OBIA is inherently more precise at fine spatial resolution than at coarser resolution, and how both pixel-based and OBIA approaches can be compared regarding relative accuracy in function of spatial resolution. As anticipated, this work emphasizes that the OBIA approach is can be proposed as an advanced solution particulary for high resolution imagery, since the accuracies were improved at the different scales applied compare with those of pixel-based approach. Meanwhile, the results achieved by the two approaches are consistently high at a finer RapidEye spatial resolution, and much significantly enhanced with OBIA.

Since the change in LU/LC is rapid and the region is heterogeneous as well as the data vary regarding the date of acquisition and data source, this motivated the implementation of post-classification change detection rather than radiometric transformation methods. Based on thematic LU/LC maps, series of optimized algorithms have been developed to depict the dynamics in LU/LC entities. Therefore, detailed change "from-to" information classes as well as changes statistics were produced. Furthermore, the produced change maps were assessed, which reveals that the accuracy of the change maps is consistently high.

Aggregated to the community-level, social survey of household data provides a comprehensive perspective additionally to EO data. The predetermined hot spots of degraded and successfully recovered areas were investigated. Thus, the study utilized a well-designed questionnaire to address the factors affecting land-cover dynamics and the possible solutions based on local community's perception.

At the operational structural forest stand level, the rationale for incorporating these analyses are to offer a semi-automatic OBIA metrics estimates from which forest attribute is acquired through automated segmentation algorithms at the level of delineated tree crowns or clusters of crowns. Correlation and regression analyses were applied to identify the relations between a wide range of spectral and textural metrics and the field derived forest attributes. The acquired results from the OBIA framework reveal strong relationships and precise estimates. Furthermore, the best fitted models were cross-validated with an independent set of field samples, which revealed a high degree of precision. An important question is how the spatial resolution and spectral range used affect the quality of the developed model this was also discussed based on the different sensors examined.

To conclude, the study reveals that the OBIA has proven capability as an efficient and accurate approach for gaining knowledge about the land features, whether at the operational forest structural attributes or categorical LU/LC level. Moreover, the methodological framework exhibits a potential solution to attain precise facts and figures about the change dynamics and its driving forces.

Kurzfassung

Da das Waldressourcenmanagement hierarchisch strukturiert ist, beschäftigt sich die vorliegende Arbeit mit der natürlichen Waldbedeckung auf verschiedenen Abstraktionsebenen, das heißt insbesondere mit der Ebene der kategorischen Landnutzung / Landbedeckung (LU/LC) sowie mit der kontinuierlichen empirischen Abschätzung auf lokaler operativer Ebene. Da zurzeit kein Sensor die Anforderungen aller Ebenen der Bewertung von Waldressourcen und von Multisource-Bildmaterialien (d.h. RapidEye, TERRA ASTER und LANDSAT TM) erfüllen kann, wurden zusätzlich andere Formen von Daten und Wissen untersucht und in die Arbeit mit eingebracht. Es wurde eine objekt-basierte Bildanalyse (OBIA) in einer destabilisierten Region des Blauen Nils im Sudan eingesetzt, um nach möglichen Lösungen zu suchen, erforderliche Informationen für die zukünftigen Waldplanung und die Entscheidungsfindung zu sammeln. Außerdem wurden die räumliche Heterogenität, sowie die sehr schnellen Änderungen in der Region untersucht. Dies motiviert nach effizienteren, flexibleren und genaueren Methoden zu suchen, um die gewünschten aktuellen Informationen zu erhalten.

Das Konzept von OBIA wurde als Substitution-Analyse-Rahmen vorgeschlagen, um die Mängel vom früheren pixel-basierten Konzept abzumildern. In diesem Sinne untersucht die Studie die beliebtesten Maximum-Likelihood-Klassifikatoren des pixel-basierten Konzeptes als Beispiel für das Verhalten der spektralen Klassifikatoren in dem jeweiligen Datenbereich und der Region. Im Gegensatz dazu analysiert OBIA Fernerkundungsdaten durch den Einbau von Wissen des Analytikers sowie kostenlose Zusatzdaten in einer Art und Weise, die menschliche Intelligenz für die Bildinterpretation als eine reale Darstellung der Funktion simuliert. Als ein Segment einer Basisverarbeitungseinheit wurden verschiedene Kombinationen von Segmentierungskriterien getestet um ähnliche spektrale Werte in Gruppen von relativ homogenen Pixeln zu trennen. An der kategorische Subtraktionsebene wurden Regeln entwickelt und optimale Eigenschaften für jede besondere Klasse extrahiert. Zwei Verfahren (Rule Based (RB) und Nearest Neighbour (NN) Classifier) wurden zugeteilt um die segmentierten Objekte der entsprechenden Klasse zuzuweisen.

Außerdem versucht die Studie die Fragen zu beantworten, ob OBIA in feiner räumlicher Auflösung grundsätzlich genauer ist als eine gröbere Auflösung, und wie beide, das pixel-basierte und das OBIA Konzept sich in einer relativen Genauigkeit als eine Funktion der räumlichen Auflösung vergleichen lassen. Diese Arbeit zeigt insbesondere, dass das OBIA Konzept eine fortschrittliche Lösung für die Bildanalyse ist, da die Genauigkeiten - an den verschiedenen Skalen angewandt - im Vergleich mit denen der Pixel-basierten Konzept verbessert wurden. Unterdessen waren die berichteten Ergebnisse der feineren räumlichen Auflösung nicht nur für die beiden Ansätze konsequent hoch, sondern durch das OBIA Konzept deutlich verbessert.

Die schnellen Veränderungen und die Heterogenität der Region sowie die unterschiedliche Datenherkunft haben dazu geführt, dass die Umsetzung von Post-Klassifizierungs- Änderungserkennung besser geeignet ist als radiometrische Transformationsmethoden. Basierend auf thematische LU/LC Karten wurden Serien von optimierten Algorithmen entwickelt, um die Dynamik in LU/LC Einheiten darzustellen. Deshalb wurden für Detailänderung "von-bis"-Informationsklassen sowie

Veränderungsstatistiken erstellt. Ferner wurden die erzeugten Änderungskarten bewertet, was zeigte, dass die Genauigkeit der Änderungskarten konstant hoch ist.

Aggregiert auf die Gemeinde-Ebene bieten Sozialerhebungen der Haushaltsdaten eine umfassende zusätzliche Sichtweise auf die Fernerkundungsdaten. Die vorher festgelegten degradierten und erfolgreich wiederhergestellten Hot Spots wurden untersucht. Die Studie verwendet einen gut gestalteten Fragebogen um Faktoren die die Dynamik der Änderung der Landbedeckung und mögliche Lösungen, die auf der Wahrnehmung der Gemeinden basieren, anzusprechen.

Auf der Ebene des operativen strukturellen Waldbestandes wird die Begründung für die Einbeziehung dieser Analysen angegeben um semi-automatische OBIA Metriken zu schätzen, die aus dem Wald-Attribut durch automatisierte Segmentierungsalgorithmen in den Baumkronen abgegrenzt oder Cluster von Kronen Ebenen erworben wird. Korrelations- und Regressionsanalysen wurden angewandt, um die Beziehungen zwischen einer Vielzahl von spektralen und strukturellen Metriken und den aus den Untersuchungsgebieten abgeleiteten Waldattributen zu identifizieren. Die Ergebnisse des OBIA Rahmens zeigen starke Beziehungen und präzise Schätzungen. Die besten Modelle waren mit einem unabhängigen Satz von kreuz-validierten Feldproben ausgestattet, welche hohe Genauigkeiten ergaben. Eine wichtige Frage ist, wie die räumliche Auflösung und die verwendete Bandbreite die Qualität der entwickelten Modelle auch auf der Grundlage der verschiedenen untersuchten Sensoren beeinflussen.

Schließlich zeigt die Studie, dass OBIA in der Lage ist, als ein effizienter und genauer Ansatz Kenntnisse über die Landfunktionen zu erlangen, sei es bei operativen Attributen der Waldstruktur oder auch auf der kategorischen LU/LC Ebene. Außerdem zeigt der methodischen Rahmen eine mögliche Lösung um präzise Fakten und Zahlen über die Veränderungsdynamik und ihre Antriebskräfte zu ermitteln.

1 Introduction

1.1 Background and motivation

1.1.1 Overview

Forests are crucial to human survival and well-being. Therefore, human needs and sustainable development are the main perceptions directing forest sector development. These two principles are hardly interrelated for the attainment of balance between community's rising demands for forest good and services, and the conservation and development of forest resources. These concepts have been expressed in forest management by sustainability, which was defined by UNCD (1992) as "*Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations*".

The rural areas of Sudan, as well as much of its urban areas, rely on forests. Blue Nile region constitutes an important area of forest resources in the Sudan, where the forests play a significant roles in the economy through provision of a variety of goods and services. They are mainly source of sawn timber, fuel wood, charcoal, and construction materials from local to national levels, in addition to many other non-wood forest products as a main source of income and livelihood for the rural poor people (Deafalla, 2012). In spite of the fact that dry-land forests are not well-known for their export-oriented timber production; Sudan is a major producer of Gum Arabic for decades, producing more than 80% of the world market (Abdelgalil, 2005). Moreover, forests provide a variety range of environmental services (e.g. protection against desert creep, agricultural land deterioration, protection of the rivers and their tributaries against erosion, soil amelioration, wildlife sanctuaries, etc.), and are as well important for cultural and religious heritage and traditional practices.

There are several challenges the forest sector in the Sudan is facing which imposes the needs for well-designed information systems and management plans. One of these challenges are changes in land use/land cover (LU/LC) particularly due to deforestation and land degradation. In spite of LU/LC and its dynamics serves as one of the major input criteria for sustainable development programs, currently, unregistered land covers almost about 85 to 90% of the land area in Sudan, while the remaining part is a private ownership, which is restricted to the registered rights offered before the implementation of the Unregistered Land Act in 1970. Before that time, the majority of the area was forest and grassland, which used communally for pasture and traditional farming under customary land laws (Agrawal, 2007). In this form of use, the right to cultivate an area of newly opened land became vested to the farmer who cleared it for use. This condition no longer exists, when the government disregarded the land used by customary laws, which were unregistered lands, forest and waste lands which the government managed. Subsequently, large areas were leased to individuals to be used for mechanized rain-fed agriculture, while majorities, whom used the land in the past for traditional farming, were not allowed to use the land. Since then, most of the natural land cover was dramatically destroyed as the issued act greatly influenced the exploitation of the land during the past decades (Elsiddig, 2004). Accordingly, as an absence of effective land-use plans are clear, an accurate, cost-effective and up to date knowledge about LU/LC patterns, in terms of their distribution, magnitude, and changing proportions, are highly demanded by legislators, planners, and local to national officials to construct better land use policy.

1.1.2 Deforestation and land degradation

The international concern about forest cover changes is motivated not only by the irretrievable imbalance in the natural environment, but also from the perspective that it is a destructive process in which the economic feasibility is lower than the environmental losses. Deforestation is a complex ecological and socio-economic process caused by a number of anthropogenic and natural factors. In present, global land cover is altered principally by people and their direct activities such as agricultural expansion, fuel wood collection, forest harvesting, mismanagement, urban and suburban construction and development (Myers, 1994). In Sudan, unsustainable wood harvesting and uncontrolled expansion of mechanized rain-fed agriculture inside forest land as well as a growing pressure on lands used for shifting cultivation has led to large-scale deforestation and land degradation. These changes in natural resources have gained attention as a result of the potential effects on climate change and subsequent desertification, erosion, increased run-off and flooding, increasing CO^2 emissions, climatological effects and biodiversity loss, in addition to other indirect impact such as migration and poverty (Mas, 1999; Williams, 2006).

As deforestation and land degradation are dynamic, interactive processes that grown and vary over time and place, the quantification and specifying the location of these dynamics remain an important aspect for such deteriorating regions. It is fundamental in forest management for the control of natural forest cover changes to identify the trends, rate, magnitude, and to specify the locations of these changes to find out how and why they developed (naturally or as a result of anthropogenic interventions) and to understand the specific driving forces, toward the best solutions to sustain our resources.

Based on the previous inventories conducted in order to study the extent, composition and changes of forest resources in Sudan, either partially conducted or are incomplete, it has been clearly observed that there an obvious change in the forest cover in the Sudan, and is evidently research has proven for declining forest resources and warned of expected bad consequences (e.g. FAO and FNC, 1998; Dawelbait *et al.*, 2006; FNC, 2007). Abdelgalil (2005) estimated the total decline in forest cover proceeds at a variable annual rate between 1-5% standing in an average rate for the past decade of -3% in the Sudan. A huge gap between afforestation and deforestation was also shown, which is expected to stand at 1:32 respectively. The most recent report available for the extrapolation of forests resources provided by FRA (2010), states that the forest area declined from 76.4 million ha in 1990 to 69.9 million ha in 2010, with an annual decline rate of -0.9% (table 1.1).

Table 1-1: Old united Sudan forest cover, source FRA 2010

Type of land/water	**Area (000 ha)**			
	1990	**2000**	**2005**	**2010**
Forest	76 381	70 491	70 220	69 949
Other wooded land	58 082	54 153	52 188	50 224
Other land	103 137	112 956	115 192	117 427
Inland water bodies	12 981	12 981	12 981	12 981
Total area	**250 581**	**250 581**	**250 581**	**250 581**
Forest area %	32.1	29.7	29.6	29.4
Annual deforestation rate	-959 -1.4%	-589 -0.8%	-589 -0.8%	-542 -0.7%

From the above mentioned statistics it has been clearly observed that the natural forests are being dramatically destroyed at an alarming rate threatening most of the local communities who rely almost totally on forests for their everyday life and income generation. Despite the importance of forests from one side, and the massive changes from the other side, Sudan has never conducted a complete national forest inventory. AFRICOVER was the only consistent formulated project to meet the demand of homogeneous database for African countries based on remotely sensed data and visual interpretation, which has been operational in the period 1995-2002 and was intended to cover ten countries. A local operational level there are the regular inventories of forest reserves as a basis for management plans, which are conducted utilizing conventional terrestrial sampling technique. The current status of natural forest cover can only be extrapolated from these uncertain surveys, as well as those made by FRA through FAO projects (1990, 2000, 2005 and 2010).

1.1.3 Remote sensing and forest resource assessment

As described above, typical updating of the LU/LC is still mainly based on costly and time consuming terrestrial sampling technique and visual and manual interpretation of remote sensing data as performed once for the part of the country in the 1990s by the AFRICOVER project, dealing with land cover at small scale, disregarding the operational at local scale level.

The challenge of image-based digital change analysis is the ability of the existing systems to automatically or semi-automatically determine, within specific time intervals whether there is change or not, and to locate the spatial distribution and the extent of the change as well as to quantify the trend and magnitude of the dynamics more or less precisely (Hall and Hay, 2003; Zhou *et al*., 2008). The synthesis information needed for LU/LC change analysis is diverse. Although LU/LC changes can be monitored by conventional terrestrial inventories and surveys, space- and air-borne remote sensing facilitates a cost-effective way for detecting change, as it can explicitly reveal spatial patterns of LU/LC change over a large geographic area in a recurrent and consistent way (Zhou *et al*., 2008). Thus, remote sensing provides a valuable contribution to document LU/LC changes at local, regional and global scales since the 1970s (Lambin *et al*., 2003), as well as the potential capability for the identification of driving forces responsible for such changes.

Despite the importance of LU/LC change detection as an environmental variable which supports environmental planning, resources management, and public policy decision making, the scarcity of information about LU/LC and its dynamics is clear. Meanwhile, remotely sensed data are inherently suited to provide an accurate, cost-effective and up to date source of information about LU/LC and its dynamics. Therefore, this paucity is particularly related to the scarcity of efficient and accurate LU/LC information extraction methods (Foody, 2002; Estes and Mooneyhan, 1994). From the above mentioned perspective, it appears that an innovative approach for the interpretation of increasing availablility of advanced remotely sensed data to provide valuable spatial information on change (Lu *et al*., 2004; Rogan and Chen, 2004), and ultimately, this information into usable knowledge, is the highest priority for remote sensing applications (Franklin, 2001). Moreover, the development of the applications and interpretation approaches should follow the acceleration of advanced technologies and data available.

There are various tasks that can be accomplished in the visual interpretation that is performed manually by a human interpreter. Previous researchers such as Campbell (2002) and Lillesand *et a*l. (2008) have sorted these tasks into classification “assigning objects, features, or areas to classes based on their appearance on the image”, detection “determining the presence or absence of a feature”, recognition “assigning an object or feature to a general class or category”, identification “specifying the identity of an object with enough confidence to assign it to a very specific class”, enumeration “listing or counting discrete items visible on an image”, measurement “dealing with objects and features measurement in terms of distance, height, volume or area, etc.”, and delineation “drawing boundaries around distinct regions of the image characterized by specific tones or textures”. Despite its diverse applications and precision, it is tedious and time consuming. Therefore, powerful line of thought in remote sensing is to develop interpretation approaches toward the automation of image interpretation process in a way that imitates human intelligence (Curran, 1985). Hence, many researchers (as e.g. Hay and Castilla, 2008; Lang, 2008; Blaschke, 2010) focused on a form of remote sensing known as an object-based image analysis (OBIA), that is methods and tools that adequately replicate human interpretation of remotely sensed data in automated/semi-automated ways. Recently, OBIA techniques have gained a lot of attention as an alternative analysis framework that can mitigate the weaknesses associated with the past dominant pixel based approach. It is based on the assumption that image objects offer features at hierarchical spatial levels, and exploit image information more intelligently for mapping LU/LC, as it is much closer to real-world features than discrete pixels (Gamanya *et al*., 2007).

As a result of the hierarchical nature of forest planning, LU/LC mapping has to be structured with certain amounts of detail at certain abstraction levels. Single-level approaches may be insufficient (Csaplovics, 1992), while a hierarchical approach is likely to be a more efficient way of producing adequate results at different levels of details. In the perspective of remote sensing as a primary data source to fully understand, monitor, model and manage the interactions between different levels, three elements are needed (Hay *et al*, 2003):

- Remote sensing data contain sufficient details to identify surface features in a hierarchical manner;

- Methods and theories provide a capability to discover pattern components, real-word features at their respective scale of representation;
- Respective features can be connected in an appropriate hierarchical structure.

Therefore, an OBIA approach might provide a methodological framework of computer-based analysis for complex environment, possibly in a multi-level object hierarchy, based on spectral, spatial and structural information available on objects (Benz *et al.*, 2004; Lang, 2008).

Based on the previously mentioned background, the present study attempts to automate the interpretation process with its broad perspective (i.e. classification, measurement, enumeration, delineation, recognition, and identification) at various hierarchical levels of details. More specifically, rules to identify and classify real-world features at different abstraction levels of detail on the basis of human knowledge and data available, as well as models at the operational level to be used and generalized for the estimation of *Acacia nilotica* forest stand parameters will be developed. Criteria for the validation of the above mentioned methods will be based on thematic quantitative site-specific and non-site-specific measures as well as model validation based on an independent set of field survey data, respectively. As a special task of classification, object-based post classification change detection, which is crucial issue in the updating of the information for sustainable management, was also examined.

From the above mentioned perspective, pertinent research questions to be tackled by this research are:

- Could an OBIA approach provide advances in mapping and monitoring patterns of LU/LC using optical multispectral imagery?
- Could the study develop an accurate model at the operational level based on the extracted information from the object(s) values of remotely sensed data to predict *Acacia nilotica* forest stand parameters?
- Is OBIA inherently more precise at finer than at coarser spatial resolution? How do both pixel-based and OBIA approaches perform in the relative accuracy as a function of spatial resolution?
- Could the proposed approach to detect precisely the spatial distribution of hot spots of degraded and successfully recovered areas?
- What is the rate and magnitude of forest cover change in the region during the period of study?
- What are the driving forces of forest cover changes?
- What are the possible solutions that may stimulate the restoration of degraded areas?

1.2 Research hypotheses

1. OBIA approach provides accurate and precise results for mapping, monitoring and modeling forest cover at various abstraction levels of details.

- The forest cover of the study area has been significantly changed (deforested and reforested) during the period of the study.

- Deforestation is caused mainly by human factors (land clearance for mechanized agriculture, firewood, charcoal making and grazing in relation to population growth and poverty), meanwhile the stable and on the way to recover areas are often as a result of specific methods of land management.

1.3 Objectives

On the basis of lack in knowledge and weaknesses in method previously mentioned, the research aimed to develop and assess OBIA as an effective tool for providing an accurate and up-to-date information at different levels, which support decision making, planning and sound management of forests on a sustainable basis.

More specifically, the aims of the study are:

1. To develop and evaluate an OBIA segmentation and classification approach for mapping natural forest cover of a wide area of the Blue Nile region based on optical multispectral imagery.

This objective will be achieved by hierarchical LU/LC classification. Object based image analysis approach will be performed using optical multispectral satellite imagery and *eCognition* software. Nine LU/LC classes needed to be identified, i.e. agriculture (rain-fed), bare-land, crop-land, dense-forest, scattered-forest, grassland, orchard, settlements and water body. Different segmentation strategies will be applied based on the OBIA paradigm that might be effective to separate similar spectral values into a basic of unclassified image objects in groups of relatively homogeneous pixels, based on shape and compactness criterion at different scales. There are mainly two methods which will be examined (rule-based (RB) and nearest neighbor (NN) classifiers) to assign segmented objects to their corresponding class. The final results are shown in maps and figures (chapter 4).

2. To assess the OBIA approach versus the traditional per-pixel approach utilizing two different spatial resolutions.

A well-known maximum likelihood (ML) classification algorithm in pixel based approach will be applied to examine if the spectral properties of the discrete pixels alone can be used to discriminate between classes effectively. By a combination of remotely sensed data (i.e. Aster and RapidEye) and the field survey data, the nine respective LU/LC classes are distinguished. Training samples representing the typical spectral patterns for each LU/LC class will be defined. Then the quality of the results will be assessed by an independent set of test samples (chapter 4). In order to assess the quality of the results obtained by the object based approach, the same set of testing samples which have been used to assess the above mentioned approach have to be introduced to the OBIA approach to generate Training and Test Area (TTA) Masks. Therefore, the classification results as well as the validation statistics are shown and compared.

3. To determine the magnitude and patterns of temporal LU/LC change.

This objective will be achieved by utilizing three consecutive optical multispectral images, two LANDSAT TM images of 1990 and 1999 as well as TERRA ASTER image of 2009 to evaluate forest cover dynamics during the period 1990 to 2009 (chapter 5). The method adopted in this research consists of a cross operation of classified images of different dates, which utilize the overlaying images for comparison towards change detection. A new layer of segments will be created represent the change areas as well as the overlapping areas of each pair of classified images. The proposed results might contain change "from-to" information classes. Moreover, the developed approach might allow the operator to effectively know the spatial pattern of change, the trend and magnitude of the dynamics of change which have occurred for each of the classified LU/LC classes. Subsequently, the change maps resulting from cross operation will be validated.

4. To identify key factors responsible for changes that may provide recommendations to formulate a recovery plan to restore deforested areas.

This objective will be achieved based on socio–economic data in form of social survey of households combined with spatiotemporal object based image analysis. Aggregated to the community-level, social survey of household data provides a comprehensive perspective to the Earth Observation (EO) data for a predetermined hot spots of degraded and successfully recovered areas. Thus, the study will utilize social survey of household through a well-designed questionnaire based on multi-choice and open ended questions in order to address the factors affecting land cover dynamics based on the perception of local communities. Population Proportional to Size (PPS) sampling technique has been applied to collect 120 questionnaires distributed on selected villages from the study area. These data are coded, interred and analyzed using the Statistical Package for the Social Sciences (SPSS) software.

5. To develop a model based on remotely sensed data to estimate *Acacia nilotica* pure stand structural attributes.

This objective will be achieved by an interactive processing of Aster and RapidEye imagery extracted metrics against forest inventory parameters at plot-level. Initially the image has to be segmented to achieve meaningful preliminary units. The following steps allow for the prediction of structural attributes of *Acacia nilotica* pure stands. Subsequently, two main sets of analyses will be undertaken. Firstly, based on the computed object features, the association between various image metrics and forest structural characteristics using Pearson's correlation coefficient will be addressed. Secondly focus will be laid upon the higher correlated forest attribute to develop a model by analyzing their relationship with the extracted image metrics using regression models. The selected models will be validated by randomly selected field survey data. In the final stage, the validated model will be used to produce the quantitative forest structure map.

6. To develop future forest planning in the study area by providing tools that facilitate forest management on a sustainable basis.

This objective will be achieved by providing recommendations for the legislators, planners, and local to national officials based on the potentiality of the expected output to be integrated in the future forest planning and decision making (chapter 8).

2 Study area

2.1 Overview

This chapter provides a short description of the study area, which demonstrates the general characteristics of the Blue Nile region in means of its geographic location, climate, topography and vegetation cover, in addition to specific characteristics of the selected sites for the proposed study.

2.2 Introduction to the study area

2.2.1 General description

Sinnar state is one of the 16 states of the Republic of Sudan (figure 2.1). It has an area of 1.084.600 hectares, an estimated population of 1,270,500 capita according to the 2008 census, and is growing at the rate of 2.6% per annum. By projection, the present population was 1,402,000 capita. Sinnar is the capital of the Sinnar State. Another significant town is Sinja, which was the capital of the state till a few years ago. The main economic activity is cultivation within the irrigated schemes besides seasonal rained-fed agriculture. The state is located in the central-east of Sudan. It lies between latitude 12.5 – 14.7° N and longitude 32.9 – 35.4° E, it shares its borders with the Gezira State in the North, White Nile and South Sudan in the west, Gadarif State in the east and Blue Nile State in the South. The most important feature in the state is a Blue Nile valley (Arabic = Bahr Azraq), were the main forests, residential areas and horticultural land lie on the river banks along the basin from south-east to north-west.

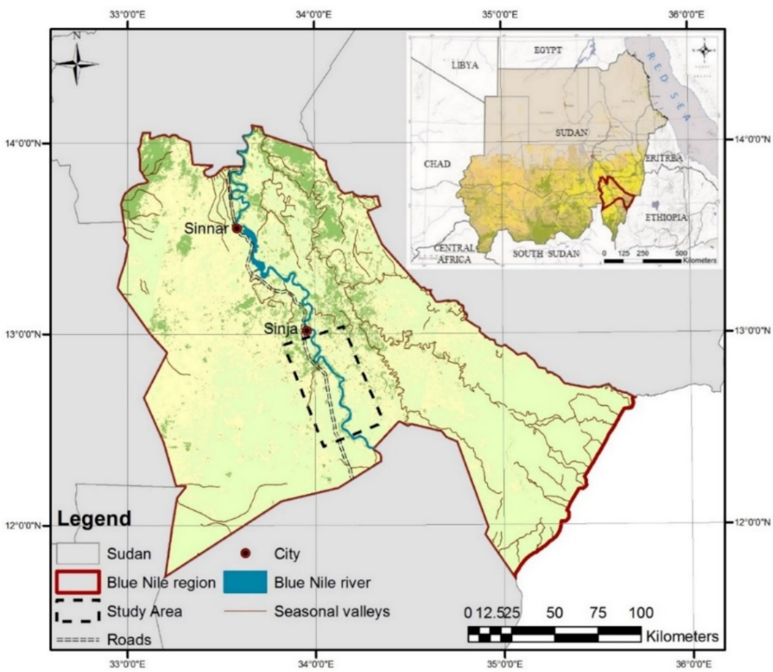

Figure 2-1: Location of the study area (developed by the author)

2.2.2 Vegetation

The most accurate and widely used classification of the vegetation cover of the Sudan was made by Harrison and Jackson (1958), while the general description of the ecological zones consists of; desert, semi desert, low rainfall savannah woodland, high rainfall savannah woodland, flooded areas and mountain vegetation. Sinnar State lies in the zone of a low rainfall woodland savannah. Accordingly the main vegetation communities of the study area are described as follow:

Bush land

I) *Acacia mellifera* and *Cadaba rotundifolia* often with association of mixed areas of *Cadaba rotundifolia* and *Boscia senegalensis*. The bushes and small trees of *Acacia mellifera* and the associated woody species range from 2 to 4 m height. Woody vegetation is generally open with scrubby patches and more or less extensive thickets separated by stretches of short grasses. The common grasses are *Tetrapogon spathaceus*, *Sehima ischaemoides* and *Beckeropsis nubica*. *Acacia mellifera* may be locally absent. In this case *Cadaba rotundifolia* bush land or open grassland, composed mainly of the annuals *Cymbopogon nervatus* and *Sorghum purpureosericeum*, ranging from 0.6 to 0.9 m height, or on low-lying soils, of the perennial *Ischaemum afrum*, are found.

II) *Acacia nubica* bush land, often found with scattered *Calotropis procera*, distributed around the residential areas on upper part of *Blue Nile* valley (*Karab*). This form normally grows on clay plain soils. The bushy *Acacia nubica* stands raise 1.2 to 1.5 m height and the canopies frequently are closed gives a continuous low thicket. Its distribution seems clearly associated with disturbance, particularly with livestock movements.

III) Riverain thickets and bush land, mainly found along the bank of the Blue Nile, which occurs commonly on dark gray-brown sandy loams of the erosion slope (*Karab*) area close to the river. The species related to this area are *Ziziphus sp.*, *Cordia spp.*, *Cadaba rotundifolia*, *Crateva adansonii*, *Salvadora persica*, *Maytenus sp.*, *Piliostigma reticulatum*, *Grewia villosa*, *Balanites aegyptiaca*, *Boscia senegalensis*, *Maerua angolensis*, *Tamarindus indica*, *Ficus sp.* and *Gardenia sp.*

Woodland

I) This class of wood land is light and open, the dominant species is *Acacia senegal*. The trees are tapped extensively for gum (Gum Arabic) by the local people. The trees are 4-6m high, casting a tenuous shade, and are spaced 6-10m. The under storey of this class is similar to that of the above mentioned. This occurrence of *A. senegal* wood land has been noticed by Smith (1949) but is not recorded by Harrison and Jackson (1958).

II) The main species of this community are *Acacia seyal*, *Acacia fistula* and *Balanites aegyptiaca*, representing a wood land with areas of tall annual open grass land. This community was distributed mainly in the south of the state. It is wood land or sometimes wooded grass land (Gillman 1949) about 6-10m high with an understory of tall annual grasses ranging from 2 to 3 m height. This class found in the association of annual grasses include the tall (1-3 m) species *Sorghum purpureosericeum*, *Hyparrhenia confinis*, *Sorghum spp.*, *Cymbopogon nervatus*, *Rottboellia exalatata*, *Barchiaria obtusiflora* and, in more dense wood land, *Beckeropsis nubica* and *Sehima ischaemoides*.

III) Broad-leaved deciduous woodland, being the characteristic vegetation on rocky hills and also occurs on the clay plain soils in the more southerly parts of the state, generally in areas where the slope of the terrain is more obvious than in the *Acacia seyal*, *Acacia fistiula* and *Balanites aegyptiaca* woodland. It may also occur in patches of more permeable (*Fuda*) soils in the *Acacia*- tall grass area.

Grassland

I) Wide shallow depressions of grey clay soil, annually flooded during the rainy season, consist mainly of open grassland of *B. obtusiflora* associated with the herbs *Ipomoea repens*, *Caperonia serrata*, *Cyperus spp.*, and the grasses *Eriochloa nubica*, *Panicum porphyrrhizos*, *Echinocloa colonum*, *Cloris gayana* and *Cynodon dactylon*.

Forest

I) *Acacia nilotica* forest. Single storey pure stands of *Acacia nilotica* about 15-20 m high, lie in seasonally flooded basins along the bank of the river and are sometimes found on similar flooded areas, such as drainage channels (*Khours*) and shallow surface catchment areas (*Hafirs*), on the clay plain inland from the Blue Nile. These forests, many of which are managed or regulated by the Forest National Corporation (FNC) for conservation objectives are as well of considerable economic importance as they provide hard wood round logs and sawn timbers.

2.2.3 Climate

The climate of the region is tropical and continental. The year is sharply divided between a very humid, rainy summer and autumn season and the intense dry winter and spring season. The winter months of December and January are relatively cold, with the average of 16º c to 35° c. while March to November are potentially very hot (20° c- 41° c) except in so far as the temperatures are reduced by evaporation in the rainy season (figure 2.2).

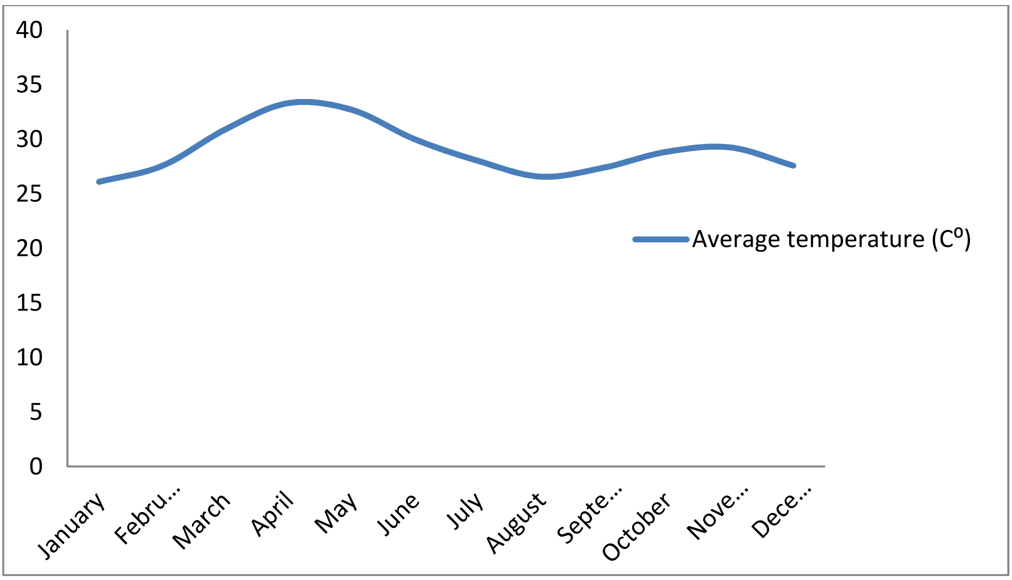

Figure 2-2: *The average temperature during the year in the study area (source; NCDC)*

The rainfall in the region comes as a result of the South Atlantic and Congo air masses, with little or no Indian Ocean influence. The study area lies in the zone in which rainfall increases to the south-east. The annual precipitation varies between 300mm to 500mm (figure 2.3) occurring between June to October and much heavily in August (figure 2.4).

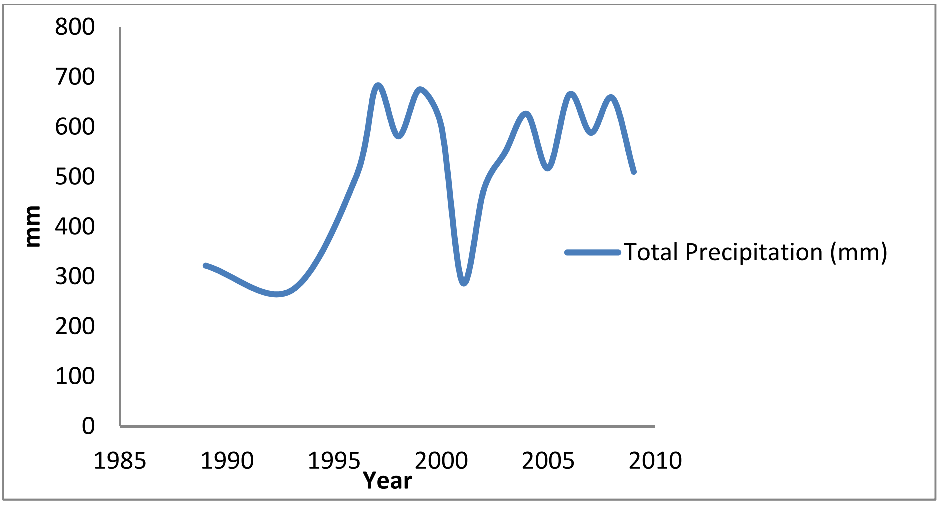

Figure 2-3: Rainfall pattern during two past decades in the study area (source; NCDC)

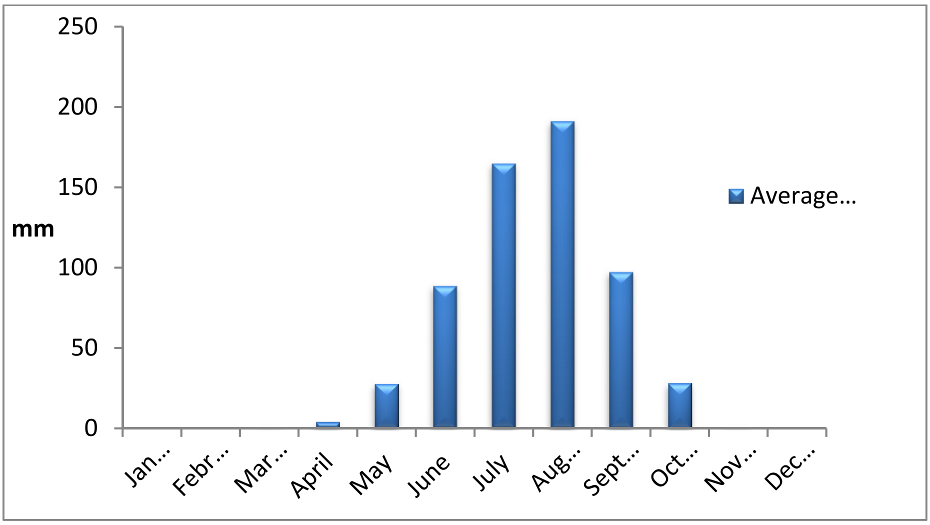

Figure 2-4: The average precipitation rate during the year in the study area (source; NCDC)

1.1.1. Topography and soil

The topography of the area is generally flat with some scattered mountain, of an altitude ranging from 1300 to 1500 feet above mean sea level.

The soil characteristics of the area in general are clays, alkaline dark coloured, which swells and sticky when it is wet, while it become cracks when it is dry. An exception was found in the slope (*Karab*) of the narrow eroded part of the Blue Nile River where the soils are sandy loams and clays, as well as permeable, fertile, sand-silt mixture (*Gerif*) in the nearest part along the banks of the Blue Nile valley.

2.3 Test sites

2.3.1 LU/LC level

The selected site, shown in figure 2.1 (site A), covers about 96.121 hectares, representing approximately 9 percent of the total area of the state, and is located in the centre of the state. This area covers most features in the state, which consist of; forests, horticultural land and settlements which lie near the bank of the Blue Nile River. Most of the entire area is grass land and rain-fed agriculture but it was dominated by natural forests till a few decades ago (figure 2.5).

 Land clearance for mechanized farming.	 Rainfed agriculture (fallow).
 *Acacia nilotica* pure stand (*Alambwa* forest).	 Scattered trees and shrubs (dry season).
 Flooded stand at the river bank during the rainy season.	 Uncultivated abandoned agricultural land dominated by grasses (dry season).

Figure 2-5: Some of the main features observed in the study area (photography taken by the Author)

Many existing approaches of land cover extraction are based on spectral properties. The selected site contains a large amount of entities that cannot be easily distinguished based on spectral properties. For instance, the main materials of buildings used are straw, wooden material and mud in addition to a large amount of trees grown in the settlements patches, which makes it difficult to separate them from other categories when using approaches based on pixel spectral value. Hence, the selected site provides a good opportunity to assess whether the proposed OBIA land cover mapping approach is more effective than other per pixel approaches such as the maximum likelihood algorithm.

2.3.2 Forest stand level

The second test site is *Alambwa* reserved forest, with an area of about 210 hectares (figures 2.1). The dominant species is *Acacia nilotica* "*Sunt*" trees, managed by FNC for thirty years sawn timber production. This forest stands like several other valuable neighbour stands distributed along with the Blue Nile valley, are affected by several factors like illegal cutting, expansion of horticultural land inside the forest area and by pathogen forest dieback. This dynamic situation needs up-to date and cost-saving methods to collect accurate information for reasonable management system. In this research EO data was used to evaluate the effectiveness of OBIA for forest stand parameters estimation, and assess the result versus collected field inventory data. A detailed description is given in section 4.3.6.

3 Theoretical background

3.1 Overview

This part provides a background to the foremost theoretical and methodological contributions that correspond to the field of object based image analysis and its applications at different levels, i.e. small scale analysis of LU/LC pattern as well as forest structural attributes at stand level. Specific concern will be laid upon the focus on dry land forests of Sudan (i.e. Blue Nile region) and its dynamics based on the OBIA. The review focuses on topics that are of most significant for the study and within the sphere of responsibility of the sited authors.

3.2 Introduction

Remote sensing can be defined as studying an object without making any real contact with the object. More precisely, *"...remote sensing in the most generally accepted meaning refers to instrument-based techniques employed in the acquisition and measurement of spatially organized (most commonly, geographically distributed) data/information on some property(ies) (spectral; spatial; physical) of an array of target points (pixels) within the sensed scene that correspond to features, objects, and materials, doing this by applying one or more recording devices not in physical, intimate contact with the item(s) under surveillance (thus at a finite distance from the observed target, in which the spatial arrangement is preserved); techniques involve amassing knowledge pertinent to the sensed scene (target) by utilizing electromagnetic radiation, force fields, or acoustic energy sensed by recording cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, sound detectors, seismographs, magnetometers, gravimeters, scintillometers, and other instruments"* (Short, 2009).

This is a comprehensive definition of remote sensing in broad perspective. However, in this study remote sensing refers to imaging objects on the earth surface with the use of passive optical multi-spectral sensors (i.e. LANDSAT TM, TERRA ASTER and RapidEye). This study exclusively deals with the electromagnetic range of visible, near infrared and shortwave infrared radiation. Meanwhile, the object based image analysis approach was introduced as a main processing method for the interpretation of natural features in the study area.

Previously image analysis techniques were solely based on pixel level which explores the spectral differences of various features of interest to be extracted as thematic information pixel per pixel. Due to complexity and spectral similarity in semi-arid areas, land cover mapping with remotely sensed data encounters serious problems when applying methods based on spectral information and ignoring spatial information. To overcome the failings of conventional pixel-based classification approach at facilitating precise LU/LC classification, researchers adopted a new method of remote sensing image analysis known as OBIA (Benz *et al.* 2004). Based on the assumption that the scene is composed of different sized real-world entities, and that a single resolution might not be appropriate to discriminate all classes within the image, OBIA was proposed to be an advanced solution to solve the issue (Gamanya *et al.*, 2007). The advantage of using OBIA is the capability to define rules for image object identification at various