Declaration

I certify that this work has not been accepted in substance for any degree, and is not concurrently submitted for any degree other than that of Doctor of Philosophy (PhD) of the Sudan University of Science and Technology. I also declare that this work is the result of my own investigation except where otherwise stated.

Mohamed Elgamri Atta Elmanan (PhD Candidate) ----------

Hassan Abdol Rahman Musnad (Supervisor) ----------

Acknowledgments

This work would not be possible without the help and support of many people and institutions.

I would like to thank my supervisor Prof. Hassan A. Musnad for his continuous help and scientific advises.

I would also like to thank the dean of the College of Forestry and Range Science, Sudan University, Dr. Abdel Hafeez A. M. Yeddi for his support and help during the study.

My thanks and gratitude goes also to Secretary of Scientific affairs and the College of Graduate Studies of the Sudan University of Science and Technology for their support and flexibility.

My thanks and appreciations to IFS for their great support and make available all the necessary equipments and financing the field trips.

My thanks and appreciations go to my colleagues Dr. Abdelaziz Karamala and Dr Mohamed A. Dosogi for their continuous encouragement and scientific advice.

Thanks to Dr. Amnah Hamid head of remote sensing authority and Dr. Al Tayiab Ganawa for providing me with training in GIS and remote sensing.

My thanks to Siddig Elbushra and his colleagues in the training unit of the Ministry of Higher Education and Scientific Research for their help during preparation to travel to USA.

My gratitude to Anwar Abdol Hamid, the director of Forests National Corporation in the White Nile state and to Abdel Aziz Sid Ahmed the director of Ed Diuem Forests Circle for their support and hospitality.

My thanks and gratitude to the team helped to collect the field data, in particular Albalah, Abotalib, Hamid and Hassan Altom.

For their help and encouragement my thanks and appreciations go to the dear colleagues of Soba Dr. Tagelsir Elnaim, Dr. Ali Khalid, Dr. Ahmed Eldouma, Dr. Farah Yousif, Dr. Mohamed Osman Ibenof, Dr. Ibrahim Albaher Dr. Abdol Elhay Elmadina, Dr. Majeeda Ibrahim, Dr. Siddig Faris, Dr. Abdallah Elfeel, Dr. Nawal Khider, Dr. Amani Kobail, Dr. Yassir Yousif, Ustaz Abdolbasit Elhessain and Ustaz Mahgoup Sulieman.

My acknowledgement go to Germany to Prof, Johann Goldammer chair of the Global Fire Monitoring Centre and Mr. Gerd Wuesteney the former GTZ team leader at Jebel Marra Forest Circle for their support and encouragement.

Special acknowledgement to Prof. Chris Justice, the head of the geography Department at University of Maryland for his scientific advices, flexibility, support and encouragement.

Also in USA my gratitude and appreciations to Dr. Simon Trigg who was closely supervise my work in the University of Maryland.

My thanks and gratitude goes to Virginia for her first initiative to contact me from USA and also for her help and scientific advices.

My thanks and appreciations go to START organization for their financial support to accomplish my research work in USA.

My gratitude and appreciations go to Mohamed Ezeldeen Mirghani, Mohamed Yousif Lutfi, Mohamed Ahmed Yagoab and Elsadig for their help and hospitality during my stay in USA.

My gratitude is to wife Nadia Yousif For her patience and taking care of our kids.

Table of contents

Declaration		I
Acknowledgements		II
Table of contents		IV
Abstract		VIII
Arabic Abstract		X
List of tables		XI
List of figures		XII
List of maps		XIV
List of plates		XV
Chapter I		
Introduction		
1.1.	Global wildland fire issues	1
1.2.	The need to quantify fire	3
1.3.	Wildland fire in Africa	4
1.4.	Wildland fire in Sudan	5
1.5.	Research objective	7
1.4.1.	Remote sensing objectives	7
1.4.2.	Field-based objectives	7
1.5.	Hypothesis	7
Chapter II		
The Study Area		
2.1.	Location	8
2.2.	Climate	10
2.3.	Geology and Topography	11
2.4.	soils	12
2.5.	Vegetation	12
2.6.	Wildlife	15
2.7.	Socio-economic of Albaja	17
Chapter III		
Literature Review		
3.1.	Introduction	19
3.2.	Remote sensing	20
3.2.1.	Electromagnetic Radiation and its properties	21
3.2.2.	Digital remote sensing data	22
3.2.3.	Vegetation indices	23
3.2.3.1.	Normalized Difference Vegetation Index (NDVI)	23

3.2.4. Spectral reflectance of Earth surface materials 24
3.2.5. Remote sensing of wildland fires 26
3.2.6. Some remote sensing sensors 30
3.2.6.1. MODIS Satellite 30
3.2.6.2. NOAA-AVHRR 31
3.2.6.3. Landsat 32
3.3. Fire Regime Types 33
3.3.1. Fire-dependent Ecosystems 33
3.3.2. Fire-Sensitive Ecosystems 34
3.3.3. Fire-Independent Ecosystems 35
3.4. Wildland fire and biological diversity 35
3.5. Prescribed Fire 36
3.6. Wildland fire causes 38
3.7. Community-Based Fire Management (CBFiM) 39

Chapter IV
Materials and Methods

4.1. Burned area mapping methodology 41
4.2. Methodology used to estimate biomass 42
4.3. Vegetation assessment survey 44
4.4. Questionnaire and meetings 45
4.5. Computer and software 46

Chapter V
Results and Discussions

5.1. Wildfire regime in Albaja 47
5.1.1. Wildland fire history and mapping 47
5.1.2. Wildland fire extent 55
5.1.3. Fire season 57
5.1.4. Fire frequency 59
5.2. Impacts of wildland fire on vegetation 61
5.2.1. Trees 62
5.2.2. Shrubs 63
5.2.3. Grasses and herbs 68
5.3. Spatial configuration and quantity of biomass 75
5.4. Wildland fire causes 79
5.5. Damage caused by wildfire 81
5.6. Social survey 82
5.6.1. Education level 82

Chapter VI
Conclusions and Recommendations

6.1. Conclusions 84

6.2. Recommendations 85
References 86
Appendices

Abstract

Although wildland fire occurs on a large scale in Sudan, there is limited knowledge on its extent, seasonality and frequency. Consequently its impacts on the environment are not well understood. The overarching objective of this study is to contribute in finding and recommending measures leading to minimize the adverse impacts of wildland fire on the environment in Sudan. This objective is investigated in the Albaja region of Sudan, which is chosen as a demonstration area representative of Sudan's marginal grassland. To address the objective in Albaja, the study integrates both biophysical and social survey data collected in the field with remote sensing data from the MODIS (MOderate Resolution Imaging Spectroradiometer) sensor. MODIS remote sensing data is analysed for the 2000-2005 period to discover Albaja's fire regime (extent, seasonality and frequency of burn). This new, satellite-derived information on burning in Albaja is then used to assess the effectiveness of the local fire management system that is currently applied to control wildland fires. The impacts of wildland fire frequency on trees, shrubs and grasses is then investigated by analyzing the satellite-derived fire data in conjunction with data collected in a vegetation cover survey carried out in Albaja in 2005. The study also combines MODIS vegetation index data with field measurements of herbaceous biomass in order to produce a spatially explicit map of end-of-wet-season biomass across the study area. Finally, a questionnaire survey with local farmers and nomads is used to investigate the different causes of wildland fire. The investigation reveals that on average 40% of the Albaja study area burns every year. It also reveals that the currently applied fire management activities do not control wildland fires and makes

recommendations to make these activities more effective. The study also concludes that the repeated wildland fires are negatively affecting the existence of the most valuable trees, shrubs and grasses, which subsequently reduces the range carrying capacity of Albaja and hence increase the poverty of the local people and the nomads. The study also finds that the spatial configuration and quantity of biomass become predictable at the end of the wet season by correlating field measurement of aboveground dry biomass with time-integrated vegetation index values obtained from MODIS vegetation indices product. Field-calibrated remote sensing data therefore provides a new, practical basis to prioritize the construction of fire lines to begin in areas with high biomass that are at most risk of fire spreading out of control. The social survey finds that the main causes of fire are Careless cooking, Charcoal production and Poachers. The combined results highlight the importance of fire as a process that affects not only the biophysical environment but also exerts direct control on people's livelihoods.

Arabic Abstract

List of Tables

Table 2.1	trees species recorded in Albaja area
Table 2.2	grasses and herbs species recorded in Albaja area
Table 2.3	Tribes in Albaja area
Table 5.1	Area burned and total rainfall in each year
Table 5.2	Starting and ending date of wildland fire in Albaja
Table 5.3	Burned area/Ha for each number of times burn category
Table 5.4	Average number/Ha and dispersion of Marakh and Ushar
Table 5.5	Average number of species in Hectares per number of times burn category
Table 5.6	Average vegetation cover and frequency of each species
Table 5.7	Average vegetation cover per number of times burn
Table 5.8	Average frequency per number of times burn
Table 5.9	Dominancy ranks per number of times burn
Table 5.10	Area burned in different range of the dry biomass in the year 2005
Table 5.11	Percent of education level for each group of the respondents

List of Figures

Figure 3.1 Electromagnetic Radiation
Figure 3.2 Each pixel in the image represents digital number
Figure 3.3 Spectral reflectance of water, soil and vegetation
Figure 5.1 Burned area/Year
Figure 5.2 Total rainfall/Year
Figure 5.3 Burned area in the year 2000/Month
Figure 5.4 Burned area in the year 2001/Month
Figure 5.5 Burned area in the year 2002/Month
Figure 5.6 Burned area in the year 2003/Month
Figure 5.7 Burned area in the year 2004/Month
Figure 5.8 Burned area in the year 2005/Month
Figure 5.9 Correlating burned area with total rainfall/Year
Figure 5.10 Correlating Burned area in each year with the burned area in the previous year
Figure 5.11 Burned area in the years 2000 – 2005/Month
Figure 5.12 Burned area/number of times burn
Figure 5.13 Average number of bushes per Ha/number of times burn
Figure 5.14 Average vegetation cover of some grasses/number of times burn
Figure 5.15 Average vegetation cover of some grasses/number of times burn
Figure 5.16 Average frequency of some grasses/number of times burn
Figure 5.17 Average frequency of some grasses/number of times burn
Figure 5.18 Correlating dry biomass with time integrated EVI
Figure 5.19 Correlating dry biomass with time integrated MSAVI2
Figure 5.20 Correlating dry biomass with time integrated NDVI

List of Maps

Map (2.1) White Nile State
Map (2.2) MODIS Image include Albaja
Map (5.1) Burned area in 2000
Map (5.2) Burned area in 2001
Map (5.3) Burned area in 2002
Map (5.4) Burned area in 2003
Map (5.5) Burned area in 2004
Map (5.6) Burned area in 2005
Map (5.7) Number of times burn
Map (5.8) Sample plots over number of times burn map
Map (5.9) End-of-wet season standing dry biomass

List of Plates

Plate (2.1) Jebel El Shwaih
Plate (2.2) Vegetation covers of Albaja
Plate (2.3) *Acacia raddiana* trees existing in areas less vulnerable to wildland fire
Plate (2.4) Many species of birds existing in Albaja
Plate (5.1) Narrow firebreaks constructed in Albaja
Plate (5.2) The valuable *Acacia raddiana* tree provides shade and fodder for the animals
Plate (5.3) *Leptadenia pyrotechnica* provides only little shade and it is browsed by animals
Plate (5.4) *Calotropis procera* is an indicator of land degradation
Plate (5.5) Cooking fire set by nomads can escape out of control
Plate (5.6) Charcoal production is one of the activities that can cause wildland fire

List of Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
BIRD	
CBFiM	Community-Based Fire Management
CO_2	Carbon dioxide
DVI	Difference Vegetation Index
EM	Electro-Magnetic
EMR	Electromagnetic Radiation
ESA	European Space Agency
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
FNC	Forests National Corporation
GIS	Geographical Information System
GOFC/GOLD	Global Observation for Forest and Land Cover Dynamics
GPS	Global Positioning System
JMFC	Jebel Marra Forests Circle
LMIR	Long Mid InfraRed
LNIR	Long Near InfraRed
LP DAAC	Land Processing Distributed Active Archive Centre
MODIS	MODerate-resolution Imaging Spectrometer
MODIS	MODerate-resolution Imaging Spectrometer
MSAVI	Modified Soil Adjusted Vegetation Index
MSAVI-2	Modified Soil Adjusted Vegetation Index 2
MVI	Modified Vegetation Index
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NERC	Natural Environment Research Council
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
RPA	Range and Pasture Administration
SAFNet	South African Fire Network
SMIR	Short Mid InfraRed
SMIR	Short Mid InfraRed
SNIR	Short Near InfraRed
SPOT	Systeme Probatoire d'Observation de la Terre
UNEP	United Nations Environment Programme
USD	United States Dollar

USDA