

**MAPPING OF WOODY VEGETATION IN ARID ZONES:
a multi-sensor analysis.**

A case study in the Serowe area, Botswana.

By

Andrés Hernández Riquene

February, 2002

**MAPPING OF WOODY VEGETATION IN ARID ZONES:
a multi-sensor analysis.**

A case study in the Serowe area, Botswana.

By

Andrés Hernández Riquene

February, 2002

MSc Thesis

Forestry for Sustainable Development



Forest Science Division

**INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH
OBSERVATION, ENSCHEDE, THE NETHERLANDS**

**MAPPING OF WOODY VEGETATION IN ARID ZONES:
a multi-sensor analysis.**

A case study in the Serowe area, Botswana.

by

Andrés Hernández Riquene

Thesis submitted to the International Institute for Geo-Information Science and Earth Observation in partial fulfillment of the requirements for the degree of Master of Science in Forestry for Sustainable Development.

Degree Assessment Board

Prof. Dr. Ir. A. de Gier

Chairman and Head of Forest Science Division

Prof. Dr. Ir. R. de Wulf

(External Examiner)

Dr. Y. A. Hussin

(Student Advisor)

Ir. M. F. Gelens

(First supervisor/FSD)

Ir. L. M. van Leeuwen

(Second Supervisor/FSD)

Dr. M. Lubczynski

(Second Supervisor and External Member ITC)

Supervisors

Ir. M. F. Gelens

(First supervisor/FSD)

Ir. E. Keizer

(Second Supervisor/FSD)

Ir. L. M. van Leeuwen

(Second Supervisor/FSD)

Dr. M. Lubczynski

(Second Supervisor)



Forest Science Division

**INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND
EARTH OBSERVATION, ENSCHEDE, THE NETHERLANDS**

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

ABSTRACT

Botswana woody vegetation presents large spatial and temporal variability. Elevation, soil type and texture, and groundwater depth gradients are some of factors influencing this variation. The vegetation distribution analysis in the area is a challenge because changes in vegetation cover and structure can have impact on the groundwater recharge. The main objective of this study was to identify and map the different woody vegetation cover types in the Serowe area using LANDSAT TM, ASTER and IKONOS satellite data, based on floristic and structure approaches. Besides, their relationships with a selected number of environmental factors were analyzed.

Vegetation mapping was mainly done using Landsat TM, ASTER and IKONOS images from year 2001. First of all, based on Landsat TM 2000 images and supervised classification a preliminary vegetation map was obtained because images from year 2001 were not available. Three sub-areas (10x10 km) representative of major landscape types (sandveld, escarpment and hardveld) were evaluated where vegetation cover characteristics, environmental data and other plot information were collected using stratified random sampling design. Relevés were clustered following two approaches: floristic (using TWINSpan software) and Structure (using a system proposed by the Kenyan Soil Survey), and then Landsat TM, ASTER and IKONOS images were classified based on these two approaches. Comparison between approaches in each sensor and between sensors was done using confusion matrix, kappa statistic and 'Z' test. Besides, CANOCO software was used to find relationships between sensor bands and crown cover by means of Detrended Canonical Correspondence Analysis (DCCA) and between environmental variables and crown cover by means of Canonical Correspondence Analysis (CCA).

Results suggest the presence of 4-plant communities in the place, grouped using floristic approach and 10 classes following and structure approach. Moreover, Landsat TM and ASTER sensors were feasible for vegetation mapping using this two approaches being floristic approach the best in ASTER and there was not significant difference when comparing Landsat approaches. However, ASTER sensor was better than Landsat TM using floristic and structure approaches at 95% confidence interval when comparing them. Landsat TM5, TM7, TM3 bands and ASTER AB4, AB3, AB5 were found adequate to vegetation classification in arid regions. On the other hand, soils types and soil texture gradients are strongly related to vegetation distribution and water table depth and elevation gradients had less effect on it.

Landsat result suggested that this sensor is suitable for bushy areas discrimination and for ASTER the result indicated that it was suitable when mapping wooded areas. The understory brightness due to dry vegetation (no chlorophyll), strong soil signal of brighter soils, absorption power of black soils and also to the darkening effect produced by vegetation cover introduce noise in vegetation classification.

The two sensors were significantly different at 95% confidence interval using floristic and structure approach. These results showed that use of ASTER satellite data gives more reliable vegetation maps than Landsat TM satellite data. On the other hand, soils types and soil texture gradients were found governing the vegetation distribution in the zone.

ACKNOWLEDGEMENTS

I would like to thank and express my sincere gratitude to the Government of The Netherlands for the award of a fellowship. Besides, I am thankful to the officials in the Forestry Research Institute and Ministry of Agriculture of Cuba for nominating me and supporting me to pursue this course.

I am very grateful to my first supervisor Ir. M. F. Gelens for his guidance, valuable suggestions and critical comments and for making me aware of the purpose and structure of a logic research. Thanks to my second supervisors Ir. E. Keizer, Ir. L. M. van Leeuwen and Dr. M. Lubczynski, who gave me very useful suggestions and new ideas during the course of this work.

Special thanks to Dr. Iris van Duren who gave me ideas and suggestions, helping me to find the better way to survey and analyze the vegetation of my study area.

Thanks to Dr. J. de Leeuw and Ir. Jelle G. Ferwerda for helping me with Canonical Correspondence Analysis and Detrended Correspondence Analysis based on CANOCO software and thanks to Mrs. Wietske Bijker for teaching me how to work with TWINSpan software.

I am thanking also my classmates, Ana Tan Sotomayor, Alejandra Fregoso Domingues, Robert Aguma, Mohan Prasad Poudel and Padam Prasad Dahal, who gave support in my research and many times helped me to clarify doubts.

I am grateful to the staff members of the Forest Science Division Prof. Dr. Ir. A. de Gier, Dr. Y. A. Hussin, Dr. M. J. C. Weir, MSc. R. Albricht and Dr. D. G. Rossiter from Soil Science Division for the support and trust provided by them.

I want to express my gratitude to the group of officers and workers of the Botswana Geological Survey Department, especially Mr. Obed Obakeng and Mr. N. Ramotsoko for the assistance during the fieldwork time. A very especial thanks goes to “The professor” Mr. David, who helped me a lot with the identification of the very complicated Setswana names of the Botswana flora. I would like to say thanks to the people from the Botswana National Meteorological Services, especially to Miss Penny Mmamodise Lesolle who helped me to get valuable information. Thanks to Dr. M.P. Setshogo, lecturer of Biological Sciences Department of Botswana University, who kindly helped me to find the scientific names to some plant species.

Finally, my special and very warm thanks go to my sweet wife, Liliana Caballero, for being patient during these 10 months of my studies, when far away.

TABLE OF CONTENTS

ABSTRACT.....	i
ACKNOWLEDGEMENTS.....	ii
TABLE OF CONTENTS.....	iii
LIST OF FIGURES.....	vi
LIST OF TABLES.....	vii
LIST OF APPENDICES.....	viii
LIST OF PHOTOS.....	viii
ABBREVIATIONS.....	ix
1. INTRODUCTION.....	1
1.1 GENERAL INTRODUCTION.....	1
1.1.1 Vegetation and water.....	1
1.1.2 The arid and semiarid zones.....	1
1.1.3 Characteristics of savannas areas.....	2
1.2 VEGETATION MAPPING AND FACTORS INFLUENCING VEGETATION DISTRIBUTION.....	3
1.2.1 Vegetation mapping. An overview.....	3
1.2.2 Main factors influencing the vegetation distribution.....	5
1.2.2.1 Vegetation and Climate.....	6
1.2.2.2 Vegetation and Soil.....	6
1.2.2.3 Vegetation and Groundwater.....	6
1.2.2.4 Vegetation and Man’s Cultural Practices.....	7
1.3 PROBLEM STATEMENT.....	8
1.4 OBJECTIVES.....	9
1.4.1 Main objective:.....	9
1.4.2 Specific objectives:.....	10
1.5 HYPOTESIS.....	10
1.6 RESEARCH QUESTIONS.....	10
1.7 RESEARCH APPROACH.....	11
2. REVIEW OF EXISTING AND GENERALLY APPLIED METHODS.....	12
2.1 VEGETATION MAPPING PROCESS.....	12
2.1.1 Project Planning.....	12
2.1.2 Field Methods.....	12
2.1.3 Data Management And Analysis For Vegetation Mapping.....	12
2.1.4 Needed Materials In The Vegetation Mapping Process.....	13
2.2 USED METHODS IN THE VEGETATION PATTERN MAPPING.....	13
2.2.1 Used Method For Vegetation Mapping In Arid And Semiarid Zones.....	13
2.3 SENSORS AND PLATFORMS MORE SUITABLE IN THE VEGETATION MAPPING PROCESS.....	14
2.4 THE MINIMUM MAPPING UNIT (MMU) ACCORDING TO THE VEGETATION MAPPING OBJECTIVE.....	16
2.5 DETAIL LEVEL IN THE VEGETATION MAPPING PROCESS.....	17

3.	<u>MATERIALS AND METHODS.....</u>	18
3.1	STUDY AREA DESCRIPTION	18
3.1.1	Location.....	18
3.1.2	Topography	18
3.1.3	Soils.....	19
3.1.4	Climate	20
3.1.5	Vegetation	20
3.2	MATERIALS.....	20
3.2.1	Satellite Images	20
3.2.2	Aerial Photographs.....	20
3.2.3	Topographic Maps.....	21
3.2.4	Global Positioning Systems (GPS)	21
3.3	METHODS	21
3.3.1	Pre-fieldwork Stage (Data Preparation)	21
3.3.1.1	Geometric Correction.....	21
3.3.1.2	Image classification.....	22
3.3.1.3	Preparation of the sub-study areas	22
3.3.1.4	Sampling Design for Data Collection	23
3.3.2	Field Check & Sampling Stage (Data Collection)	24
3.3.2.1	Sample Plot Surveying and Ground Truthing	24
3.3.3	Post-Field Stage (Data Processing and Analysis)	24
3.3.3.1	Image Processing.....	24
3.3.3.2	Data Processing	25
3.3.3.2.1	Classification system according to floristic composition.....	25
3.3.3.2.2	Classification system according to vegetation structure	25
3.3.3.3	Image Classification.....	26
3.3.3.4	Evaluation of the classification results.....	27
3.3.3.4.1	The Confusion Matrix	27
3.3.3.4.2	Kappa Statistic.....	27
3.3.3.5	Gradient analysis	28
3.3.3.5.1	Environmental variables.....	29
4.	<u>RESULTS.....</u>	31
4.1	GENERAL OBSERVATIONS RELATED TO THE THREE MAJOR LANDSCAPES TYPES PRESENT IN THE STUDY AREA.....	31
4.2	VEGETATION CLUSTERING ACCORDING TO FLORISTIC COMPOSITION	31
4.3	VEGETATION CLUSTERING ACCORDING TO STRUCTURE.....	33
4.4	CLASSIFICATION OF LANDSAT TM IMAGE	34
4.4.1	Use of floristic approach	34
4.4.2	Use of structure approach.....	36
4.5	CLASSIFICATION OF ASTER IMAGE	37
4.5.1	Use of floristic approach	37
4.5.2	Use of structure approach.....	39
4.6	CLASSIFICATION OF IKONOS IMAGES.....	40
4.6.1	Use of floristic approach	40
4.6.2	Use of structure approach.....	40

4.7	ACCURACY EVALUATION.....	42
4.7.1	Using Floristic approach	42
4.7.1.1	Confusion Matrix and Kappa Statistic for vegetation map based on Landsat TM	42
4.7.1.2	Confusion Matrix and Kappa Statistic for ASTER vegetation map	45
4.7.2	Using Structure approach.....	46
4.7.2.1	Confusion Matrix and Kappa Statistic for Landsat TM vegetation map	46
4.7.2.2	Confusion Matrix and Kappa Statistic for ASTER vegetation map	47
4.7.3	Comparison among the different Error Matrices according to the classification approach and the sensor.....	49
4.7.3.1	Comparison according to classification approach.....	49
4.7.3.1.1	Error Matrices from Landsat TM vegetation maps.....	49
4.7.3.1.2	Error Matrices from ASTER vegetation maps.....	50
4.7.3.1.3	Comparison between sensors according to floristic approach	50
4.7.3.1.4	Comparison between sensors according to structure approach.....	51
4.8	RELATIONSHIP BETWEEN VEGETATION, ENVIRONMENTAL FACTORS AND SENSOR BANDS.....	51
4.8.1	Indirect gradient analysis for species coverage (using DCA).....	51
4.8.2	Direct gradient analysis (using CCA and DCCA)	52
4.8.2.1	Relationship between vegetation distribution and environmental factors	52
4.8.2.2	Relationship between vegetation cover and sensor bands	55
4.8.2.2.1	Relationship between vegetation cover and Landsat TM bands.....	55
4.8.2.2.2	Relationship between vegetation cover and ASTER bands.....	57
5.	<u>DISCUSSION</u>	<u>60</u>
5.1	VEGETATION CLASSIFICATION USING LANDSAT TM IMAGE	60
5.2	VEGETATION CLASSIFICATION USING ASTER IMAGE	60
5.3	VEGETATION CLASSIFICATION USING IKONOS IMAGE.....	61
5.4	COMPARISON BETWEEN SENSORS ACCORDING TO CLASSIFICATION APPROACH	61
5.5	DIRECT GRADIENT ANALYSIS (using DCCA and CCA).....	61
5.5.1	Relationship between vegetation distribution and sensors bands (using DCCA). 61	
5.5.1.1	Relationship between vegetation cover and TM bands.....	62
5.5.1.2	Relationship between vegetation cover and ASTER bands.....	63
5.5.2	Relationship between vegetation cover and environmental factors (using CCA) 63	
6.	<u>CONCLUSIONS AND RECOMMENDATIONS</u>	<u>65</u>
6.1	CONCLUSIONS	65
6.2	RECOMMENDATIONS.....	66
7.	<u>REFERENCES.....</u>	<u>67</u>

LIST OF FIGURES

<i>Figure 1-1 Flowchart showing the procedure to achieve the suitable sensor for land cover mapping in the area.....</i>	<i>11</i>
<i>Figure 3-1 Botswana country map showing the Serowe study area.....</i>	<i>18</i>
<i>Figure 3-2 Serowe area geological cross section.....</i>	<i>19</i>
<i>Figure 3-3 Map showing the area covered by the different landscape types found in Serowe region.</i>	<i>22</i>
<i>Figure 3-4 Sampling plot distribution in each stratum.</i>	<i>23</i>
<i>Figure 3-5 Distribution of the four additional points.....</i>	<i>23</i>
<i>Figure 3-6 Classification of the structure of the woody vegetation.....</i>	<i>26</i>
<i>Figure 3-7 Procedure followed to reach the statistical correlation between the different environmental variables, and vegetation data.....</i>	<i>29</i>
<i>Figure 3-8 Approaches to ordination in plant ecology. (a) Indirect ordination; (b) Direct ordination; (c) Summarization of environmental variation. Source: Kent, M.; Coker, P. (1992).....</i>	<i>30</i>
<i>Figure 4-1 Divisive classification of the 53 relevés into 4 main plant communities using TWINSPLAN. Numbers in the bottom represent the TWINSPLAN runs. Numbers in the dendrogram indicate the total number of relevés used in each run. Numbers in each community box indicate the number of classified relevés.</i>	<i>33</i>
<i>Figure 4-2 Plant Community Map of Serowe area derived from Landsat TM satellite image (bands 4,3,2 false color composite) based on floristic composition.</i>	<i>35</i>
<i>Figure 4-3 Vegetation Map of Serowe area derived from Landsat TM satellite image (bands 4,3,2 false color composite) based on vegetation structure.....</i>	<i>36</i>
<i>Figure 4-4 Plant Community Map of Serowe area derived from ASTER satellite image (bands 3,2,1 false color composite) based on floristic composition.....</i>	<i>38</i>
<i>Figure 4-5 Vegetation Map of Serowe area derived from ASTER satellite image (bands 3,2,1 false color composite) based on vegetation structure.</i>	<i>39</i>
<i>Figure 4-6 Vegetation Map of Serowe area based on IKONOS satellite image (bands 4,3,2 false color composite) using the structure of the vegetation.</i>	<i>41</i>
<i>Figure 4-7 DCA ordination diagram for the species composition in the Serowe region.</i>	<i>52</i>
<i>Figure 4-8 Ordination diagram based on CCA for species data of Serowe region.</i>	<i>53</i>
<i>Figure 4-9 Ordination diagram based on CCA for sites data of Serowe region.....</i>	<i>54</i>
<i>Figure 4-10 Percent of explained variance of floristic cover data by each environmental variable influencing in Serowe region.....</i>	<i>54</i>
<i>Figure 4-11 Relationship between Water table depth and Altitude for Serowe region.....</i>	<i>55</i>
<i>Figure 4-12 Ordination diagram based on DCCA showing the relationship among Landsat TM bands and species data of Serowe region.</i>	<i>56</i>
<i>Figure 4-13 Ordination diagram based on DCCA showing the relationship among Landsat TM bands and sites of Serowe region.....</i>	<i>56</i>
<i>Figure 4-14 Variance or spread of species scores explained by each of the Landsat TM bands of Serowe region vegetation.</i>	<i>57</i>
<i>Figure 4-15 Ordination diagram based on DCCA showing the relationship among ASTER bands and species data of Serowe region.</i>	<i>58</i>
<i>Figure 4-16 Ordination diagram based on DCCA showing the relationship among ASTER bands and sites of Serowe region.....</i>	<i>58</i>
<i>Figure 4-17 Variance or spread of species scores explained by each of the ASTER bands of Serowe region vegetation.</i>	<i>59</i>

LIST OF TABLES

<i>Table 3-1 Soils unit more frequents in the study area (Source: Obakeng, 2000).....</i>	<i>19</i>
<i>Table 3-2 Number of plots planned in pre-fieldwork stage and checked in the fieldwork stage.....</i>	<i>23</i>
<i>Table 4-1 Species-by-site output table used by TWINSpan to cluster the relevés.....</i>	<i>32</i>
<i>Table 4-2 Percent of relevés clustered in each class.....</i>	<i>34</i>
<i>Table 4-3 Cover percent of each plant community and their distribution in the different landscapes types found when using Landsat TM image and the floristic approach.....</i>	<i>35</i>
<i>Table 4-4 Cover percent of each class and their distribution in the different landscapes types found when using Landsat TM images and the vegetation structure approach.....</i>	<i>37</i>
<i>Table 4-5 Cover percent of each plant community and their distribution in the different landscapes types found when using ASTER images and the floristic approach.....</i>	<i>38</i>
<i>Table 4-6 Cover percent of each vegetation class and their distribution in the different landscapes types found when using ASTER images and the structure approach.....</i>	<i>40</i>
<i>Table 4-7 Cover percent of each vegetation class and their distribution in the different landscapes types found when using IKONOS images and the structure approach.....</i>	<i>41</i>
<i>Table 4-8 Confusion Matrix for Landsat TM Vegetation Community Map (VCM).....</i>	<i>42</i>
<i>Table 4-9 Proportion of each class used in the calculation of Var(K) for Landsat TM VCM.....</i>	<i>43</i>
<i>Table 4-10 Confusion Matrix for ASTER Vegetation Community Map (VCM).....</i>	<i>45</i>
<i>Table 4-11 Proportion of each class used in the calculation of Var(K) for ASTER VCM.....</i>	<i>45</i>
<i>Table 4-12 Confusion Matrix for Landsat TM following a Structural Vegetation Classification (SVC).....</i>	<i>46</i>
<i>Table 4-13 Proportion of each class used in the calculation of Var(K) for Landsat TM following SVC.....</i>	<i>47</i>
<i>Table 4-14 Confusion Matrix for ASTER following a Structural Vegetation Classification (SVC).....</i>	<i>48</i>
<i>Table 4-15 Proportion of each class used in the calculation of Var(K) for ASTER following SVC.....</i>	<i>48</i>
<i>Table 4-16 Comparative matrix for the use of both approach in Landsat TM.....</i>	<i>49</i>
<i>Table 4-17 Comparative matrix for the use of both approach in ASTER.....</i>	<i>50</i>
<i>Table 4-18 Sensors comparative matrix according to the use of floristic approach.....</i>	<i>50</i>
<i>Table 4-19 Sensors comparative matrix according to the use of structure approach.....</i>	<i>51</i>

LIST OF APPENDICES

<i>Appendix 1 Overview of the Vegetation Mapping Process.....</i>	<i>72</i>
<i>Appendix 2 Soil environmental variables tested in the gradient analysis.</i>	<i>73</i>
<i>Appendix 3 Species common name, scientific name and code how used in the ordination diagrams.....</i>	<i>73</i>
<i>Appendix 4 Matrix of correlation coefficients for species data and environmental variables in the Serowe Region.....</i>	<i>74</i>
<i>Appendix 5 Matrix of correlation coefficients showing the relationship between species data and Landsat TM images in the Serowe Region</i>	<i>75</i>
<i>Appendix 6 Matrix of correlation coefficients showing the relationship between species data and ASTER images in the Serowe Region.....</i>	<i>76</i>

LIST OF PHOTOS

<i>Photo 1 Open vegetation growing in the Sandveld area.</i>	<i>77</i>
<i>Photo 2 Cows getting shadow under an Acacia fleckii (Mohahu) tree in Sandveld area.</i>	<i>77</i>
<i>Photo 3 Vegetation growing close to the escarpment edge. A leafless tree of Ricinodendrum rutananii (Mokongwa) can be observed in the background of the picture.</i>	<i>78</i>
<i>Photo 4 Thick vegetation mainly of Acacia trees growing on a dry riverbed.</i>	<i>78</i>
<i>Photo 5 Acacia karroo (Mooka) and Acacia tortilis (Mosu) trees growing on dark soils in the hardveld area.....</i>	<i>79</i>
<i>Photo 6 Cattle post in the Hardveld area close to the riverbed area.</i>	<i>79</i>

ABBREVIATIONS

ABI	ASTER Band 1
ASTER	Advanced Spaceborne Thermal Emission and Reflection
AVHRR	Advanced Very High Resolution Radiometer
CANOCO	CANOnical Community Ordination
CCA	Canonical Correspondence Analysis
CEC	Commonwealth of the European Communities
DCA	Detrended Canonical Analysis
DCCA	Detrended Canonical Correspondence Analysis
DN	Digital Number
ERS SAR	European Remote Sensing Synthetic Aperture Radar
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information Systems
GPS	Global positioning System
IFOV	Instantaneous Field Of View
LAI	Leaf Area Index
Landsat MSS	Landsat MultiSpectral Scanner
Landsat TM	Landsat Thematic Mapper
LIDAR	LIGHT Detection And Ranging
MMU	Minimum Mapping Unit
NDVI	Normalized Difference Vegetation Index
NIR	Near InfraRed
PCA	Principal Component Analysis
RADAR	RADio Detection And Ranging
SECWMB	South East Catchment Water Management Board
SPOT	Satellite Probatori D'Observation de la Terre
SVC	Structural Vegetation Classification
TM1	Landsat TM band 1
TWINSpan	Two Way Indicator Species Analysis
USGS	United Stated Geological Survey
VCM	Vegetation Community Map
VIF	Variance Inflation Factor

1. INTRODUCTION

1.1 GENERAL INTRODUCTION

1.1.1 Vegetation and water

Vegetation is one of the main components of the hydrological cycle, notably during the transpiration process when plants transpire the water through the leaves and also through evaporation of water intercepted by leaves when the rains occur. Vegetation has important ecological effects beyond their influence on the hydrology of both ground and surface water, and on soils. (Higgins, 2000).

The vegetation is a fundamental factor that contributes to the variation on the water table both through recharge and discharge. The rainfall interception by the plant canopies depends mainly on the size, distribution and orientation of the leaves, its surface characteristics and the roughness of the bark.

Retained water will either evaporate or reach the soil by stem flow or through the litter. The amount of water that evaporates depends on the relationship between the interception capacity of the vegetation and the rainfall amount and the intensity and the evaporative capacity of the air after the rainfall.

In general the interception will be highest for species with dense canopies, rough bark and deep litter layers in areas with low intensity summer rainfall (LeMaitre *et al.*, 2000).

The irrational use of this natural resource (vegetation), changes the hydrological cycle and produce adverse effects. Sometimes, these are irreversible when non-sustainable vegetation management is carried out in fragile ecosystems (Rossouw, 1997).

1.1.2 The arid and semiarid zones

Arid environments are extremely diverse in terms of their landforms, soils, fauna, flora, water balances, and human activities. Because of this diversity, no practical definition of arid environments can be derived. However, the one binding element to all arid regions is aridity. Aridity results from the presence of dry, descending air. Therefore, aridity is found mostly in places where anticyclonic conditions are persistent (FAO, 1989).

Vegetation of arid and semiarid ecosystems is often characterized by tree-shrub-grass savannas and woodlands. With increasing aridity the density of trees decreases and thorny, xerophile and drought resistant species gain in importance (CEC *et al.*, 1986). In these zones the paucity of vegetation cover and the lack of moisture produce weathering, erosion and soil processes that differ markedly from those in other environments (Drysdale, 2000). Within it many vegetation types that are characteristic of savanna vegetation can be found.

1.1.3 Characteristics of savannas areas

An extensive cover of grasses with scattered or small groves of trees characterizes savanna vegetation. Plants in the savanna have adapted to the long dry season in a number of ways. Many grasses and trees of the savanna flourish during the brief wet season and then go into a state of dormancy. Grasses turn brown and trees lose their leaves to reduce the loss of water by transpiration (Ritter, 2001). These plant adaptations are a result of the rainfall variations in these areas.

Climate in savannas areas is typified by hot temperatures up to 47°C and high potential evaporation of up to 4000mm per year. Low annual rainfall 0-600mm (Kingsford, 1997) and a positive water regime (precipitation greatest than evapotranspiration) during the rainy season, and a negative one during the dry season (Mistry, 2000) also characterize these zones. Climate variations between seasons have influence on the process of soil formation. Here, rainfall together with the temperature plays a fundamental roll in the process of decomposition till organic matter formation.

Soils in this zone are formed over time as climate and vegetation act on parent rock material (Favreau *et al.*, 2001). Significant leaching of nutrients and intensive weathering of minerals characterize these soils, although these two activities are slowed with decreasing rainfall. Natural fertility (which largely depends upon the organic matter content of the topsoil) is often low (FAO, 1989). Besides, these soils are poorly developed structurally, resulting in limited water-holding capacity. This soil characteristic is decisive for the water acquisition by plant superficial root, which cannot reach the deeper groundwater.

Water availability is increased by the groundwater recharge, which in semi-arid areas is highly variable (Favreau *et al.*, 2001). This groundwater recharge is dependent on rainfall and has a direct influence on the elevation of the water table that is largely dependent on it. On the other hand, declining water tables are often associated with increasing groundwater salinity as saline groundwater is mobilized (SECWMB, 2000).

Throughout the savanna zones clear skies and high levels of solar radiation favor photosynthesis, plant growth and biomass yields. The limiting factors are those imposed by unfavorable soil water balance or water deficit caused by drought and by inadequate or excessive drainage (Cole, 1986). The action of these factor and also climate, soil characteristics and human pressure are the most important ones, which have influence on savanna vegetation distribution.

In savanna biomes, biological processes as moisture and plant available moisture are limited, and rainfall is inherently variable and unpredictable. The biotic system (plants, animals) is therefore driven by infrequent rainfall events, which vary in space and time. Many forest types occur in areas of relative low mean annual precipitation and consequently experience regular periods of stress due to the soil water deficits, especially during the rainless season (Dye, 1996). These biological processes not only affect plant and animals, but are also a major limitation for people who live in or around savannas areas. Many

of these communities rely on subsistence agriculture or pastoralism. Productivity of crops and pastures is therefore governed by uneven and often unpredictable nature of rainfall distributions (Cole, 1986).

The strong drought that affects these areas increases scarcity of resources (for people) and therefore the human pressure. The effects can be clearly observed in the clearance of woodlands for cultivation, timber extraction for construction, the search for firewood, cultivation along rivers and streams, and overgrazing (Mazambani, 1997), which reduce the capacity of the system to withstand the erosive forces of wind, and to a lesser extent water (Ritter, 2001). All these human actions contribute to accelerate environmental degradation and the destruction of the ecological balance in the place.

Savannas areas are widespread through some African countries. Botswana, one of them, at present most of its land cover is classified as savannas. The population growth, joined to agriculture and pastureland needs, has led to land degradation, that is, transformation of natural vegetation cover mainly in grasslands, and also bare-land because overexploitation of agriculture land mainly. In Serowe, which is one of its districts, these problems are affecting the vegetation areas in the place, contributing to its gradual changes.

The vegetation mapping and also the study of the impacts produced by some factors affecting these areas are very important starting point to analyze the vegetation distribution in the place.

1.2 VEGETATION MAPPING AND FACTORS INFLUENCING VEGETATION DISTRIBUTION

1.2.1 Vegetation mapping. An overview

The primary goal of vegetation mapping is to classify existing natural and semi-natural vegetation of terrestrial ecosystems within different landscapes.

Vegetation mapping has been developed as a function of demand for obtaining more detailed map about species habitat distribution, community mapping and in general vegetation resources mapping.

The availability of sensors capable of recording images in a suitable spectral and spatial resolution is being used as an important tool in this process. These satellite images can be used to delineate a variety of vegetation types based upon species and/or structure. Further, the use of multi-spectral data with supervised and unsupervised classification can be applied to delineate certain features of interest (such as man-made forest plantations, natural forests, etc), thus aiding to the mapping process.

Satellite images are very important for instance for monitoring desertification (Tripathy & Ghosh, 1996), forest fragmentation (Diaz, 2000; Caballero, 2001) vegetation health and density as well as monitoring landform processes (Jacobberger & Hooper, 1991) and ecological zoning among others. Finding the appropriate method, image, sensors and mapping unit and detail level, constitute an important step in the mapping process. It will lead to achieve better results.

Chapter 1. Introduction.

The vegetation mapping can be carried out with different objectives. The main purpose among others could be:

- Vegetation mapping to produce vegetation cover map at different levels of detail,
- Vegetation mapping for assessing biodiversity, and
- Vegetation mapping to detect changes over time

The vegetation mapping with the objective of producing forest cover maps has been done in many parts of the world. Different methodologies, which include different classification methods, have been used.

The vegetation mapping requires an appropriate selection of the information source origin to use, that is, adequate sensor type and spectral and spatial resolution. Keeping in mind this, in tropical areas the capability of data coming from optical sensors and radars has been investigated by many authors (Trisurat *et al.*, 2000; Apan, 1997). In arid regions the use of optical sensor has been used with more success because in these regions cloud coverage are less than in tropical areas.

For vegetation mapping for assessing biodiversity using remote sensing the existing studies carried out with the objective of evaluate the species distribution patterns can be essentially categorized into three types (Nagendra, 2001):

- The first involves direct mapping of individual plants or associations of a single species in relative large, spatially continuous units that can be distinguished using the remote sensor.
- The second involves habitat mapping using remotely sensed data, and predictions of species distribution based on habitat requirements.
- Finally, establishment of direct relationship between spectral radiance values recorded from remote sensors and species distribution pattern recorded from field observation.

With regard to first technique it can be stated that mapping individual trees using high spatial resolution data poses problems not encountered when mapping associations or habitat patches. Pixels covering different components of the tree can be extremely variable in intensities. This makes the spectral signature of a species of tree difficult to define. Besides, using low spatial resolution data has the problem that individual trees cannot be discriminated. Only spatially contiguous associations of individuals belonging to single species, whether sufficiently large compared to remote sensor spatial resolution, can be discriminated. Using this methodology a fast vegetation assessment can be done. Besides it is not detailed but can be very cheap.

Regarding to the second technique many studies has been carried out for modeling the distribution patterns and abundance of single species from remote sensing, but fewer studies has been carried out to correlate the distribution of sets of species, or communities, with habitats maps derived from remote sensing.

In the last technique, the spectral reflectance values have been widely used to determine the species distribution in a given place. In a study carried out by Lewis (1994) a clustering of different plants species had been done taking into account its ground cover percentage obtaining seven groups. After that, a new clustering was done using the spectral reflectance of these plants and six groups were identified. The two classification schemes were significantly corresponding ($P < 0.005$). This suggests that it might be possible to derive a direct relationship between the vegetation and the spectral reflectance data. This could be used in turn to extrapolate to other landscapes.

Since this result was obtained after having carried out a species clustering using other factors, the authors noticed that this result had been influenced by the specie information. In places where the vegetation is more diverse these results could vary due to the influence of the different spectral reflectance.

The different studies explained before gives an idea about the importance of vegetation mapping with the objective of predicting vegetation change under the effect of particular factors. Without a doubt, vegetation is one of the most sensitive indicators for environmental change. The behavior of vegetation change reveals the interconnection between nature and climate on Earth. Aside from the expected seasonal variations, it reveals how human activities, such as deforestation and urbanization, are having a profound effect on ecosystem characteristics.

1.2.2 Main factors influencing the vegetation distribution

Vegetation is one of the main landscape components. When an ecologist observes the vegetation formations that can appear in an area, the first things that he can detect are the plant communities that will be growing together in certain localization. The reason for those plants to grow together in a particular environment is usually because they have similar requirements.

The influence of certain factors on the vegetation will determine the abundance of species in the place. This abundance, besides being influenced by the environmental factors, can also be conditioned by the characteristics of each species, which allow them to grow in certain environment.

Not all the plant species that have characteristics to grow in a certain place grow with the same power. In order to form groups of plants with the same quantity of individuals within the communities, competition arises in the area for the space, which is related to the reproduction rate of each plant species. It determines that some species are excluded toward the most inhospitable places inside the area.

Many factors have influence in the vegetation pattern. It can be related to physiographic (elevation, aspect, slope), geomorphology (land form), climatic (radiation, light, temperature, precipitation), edaphic (soil type and texture, structure, organic matter and moisture content), and ground water level, mainly. Besides, man's cultural practices also have an impact in the vegetation distribution.

1.2.2.1 Vegetation and Climate

The physical environment of the savanna land is rarified by seasonal variation but predictable rainfall regime, which provide moisture during the period most favorable for plant growth. Areas of low annual rainfall may still receive heavy individual storms causing flood and erosion (Hudson, 1987). This climate feature distinguishes the savanna environment from that of tropical forest. Drought is one of the more important phenomena in representing the climate variations. Investigations suggest that drought is reinforced by changes in vegetation and soil (Charney, 1975; Walker & Rowntree, 1976), which may be caused either by previous drought or by the influence of man (CEC *et al.*, 1986).

In Africa savannas most of the species show a precise response to climatic conditions. The deep rooting tree and shrub species, able to draw groundwater, respond to rising temperatures and increasing atmospheric humidity. September onwards, many trees and shrubs flower and grow new leaf before rains. They include most of the *Acacia* species, *Albizia anthelmentica* and *Rhigozum brevispinosum*. These carry their leaves into the dry season and shed them only after the first frost, which exert a grater influence than drought on the seasonal rhythm (Cole, 1986).

1.2.2.2 Vegetation and Soil

Some of the soils common in semi-arid areas are particularly vulnerable, either because they have poor resistance to erosion (high erodibility), or because of their chemical and physical properties (Hudson, 1987). Soils of strongly contrasting color, profile characteristics, texture, and moisture, holding capacity and base status occur within the savanna zones (Cole, 1986). The distribution of plant species in savanna areas is influenced by soil moisture conditions. Plants develop root system, which enables them to penetrate into shallow or deep soil layers and to tap groundwater to avoid the desiccation (Leistener, 1967) and also to utilize the moisture held in the surface soils after rains (Cole, 1986).

1.2.2.3 Vegetation and Groundwater

Researchers have been developing works focusing on the understanding of the relationship between vegetation and groundwater. Two fundamental aspects to analyze how groundwater resources and their utilization are affected by or have an effect on vegetation are considered:

- The effects of vegetation on groundwater recharge and extraction of groundwater by vegetation.
- The effects that abstraction of groundwater may have on vegetation communities (or, to put it more broadly, terrestrial habitats) the character of which is determined to some extent by groundwater.

The two aspects cannot be completely separated. For example the extraction of water from the soil profile by roots reduces water flux to groundwater. The ability of vegetation to tap groundwater (i.e. from the saturated zone) depends on the depth to the water table, the penetrability of the profile and the inherent ability of the plant species to develop deep root systems. Plants also extract water from unsaturated zone,

increasing the availability of water storage capacity of the profile and thus also reducing recharge (Scott & LeMaitre, 1998) if the groundwater table is shallow, vegetation can directly draw water from the saturated zone and thus reduces the amount of effective groundwater recharge (Lubczynski, 2000) (LeMaitre *et al.*, 2000).

Manipulation of vegetation cover by altering density or species changes water-use, infiltration and soil evaporation and thus ultimately influences the amounts and patterns of surface runoff and ground water recharge (Scott & LeMaitre, 1998).

In contrast to that, water table depletion could also has a strong negative impact on vegetation distribution. A study carried out in a semi-arid region of Spain demonstrated the influence of the groundwater extraction on the vegetation changes. The investigation was carried out to local scale, at a study level of plant communities. Aerial photographs of different years were digitized and vegetation cover maps were obtained. The minimum-mapping unit in this case, was of 0.25 ha. An overlap of the different maps obtained on the different dates was done. It was concluded that there was a tendency to the emergence of xerophytic vegetation due to the decrease of the water availability in the area. As main reasons to this change, the water extraction for the urban and tourist supply were identified (Muñoz-Reinoso, 2001).

1.2.2.4 Vegetation and Man's Cultural Practices

Man influences the vegetation by cutting trees for house-building, fencing and fuel, by using fire for hunting and stimulating new grass growth for domestic stock and by clearing land for cultivation. Cattle ranching activities also constitute another impact of man's activities en savannas woodland (Moleele, 1998). The increase of cattle densities grazing in savanna areas contributes to the impoverishment of these zones (Perkins & Thomas, 1993). The fuelwood harvesting from the savannas is the principal energy source in most of southern African households (Mistry, 2000) affecting many vegetation types. The cutting of *Combretum imberbe*, *Acacia giraffae*, *A. tortilis subsp. heteracantha* for fence poles and of *Terminalia sericea* in the Botswana Ghanzi area, has reduced the number of trees in some areas. Today cutting is restricted to woodland areas, trees are valued as shade for cattle and only dead wood is used for fuelwood (Cole, 1986). Little arable land for too many people results in permanent deforestation. Some problems resulting from deforestation are the disappearance of woodland areas, loss of biodiversity and loss of protection to the soil (Mazambani, 1997).

The inappropriate land use practices in arid zones, which contribute to decline in the amount and quality of the biological productivity whether or not in conjunction with natural extremes events, accelerate the desertification process.

1.3 PROBLEM STATEMENT

The progressive reduction of vegetation cover is one of the major problems that Botswana faces. The forest cover estimated for year 2000 oscillated around 12 million ha, with an annual loss around 9% among years 1990 and 2000 (FAO, ND).

This country is moderately forested with around 25 percent forest cover and an additional 20 percent of its terrain classified as wooded land where closed forests are rare and occur only in riparian strips, particularly in the Okavango swamps (FAO, ND). It is a semi-arid country with no perennial river network and with a climate characterized by cycle droughts (Chilume, 2001).

Botswana woody vegetation has large spatial and temporal variability due to land use, fire and rainfall. Other factor like soil type and groundwater also contribute to this variability. Woody vegetation is a source of browse for cattle and biomass energy for 80% of the population in the country (Kgathi, et. al, 1994) cited in (Dube, 1998).

The rangeland resources, which comprise natural vegetation cover of broadleaf and *Acacia* tree and shrub savanna, with mixed species herbaceous layer (Ringrose *et al.*, 1990) are often used on a communal basis by livestock (Cattle) and smallstock (sheep and goats). Rangeland products such as fuelwood and thatching grass are also increasingly harvested to fulfill basic human needs. This combined effect of heavy grazing, browsing, and human use has led locally to range degradation (Ringrose *et al.*, 1999).

Serowe is the capital of central district. The population growth, which is approximately 3% and the immigration in this zone, has led to vegetation cover decrease due to fuelwood collection. Others population needs like drinking water (for people and animals), breaking up new land for grazing (cattle ranching) as well as sustenance agriculture has brought vegetation depletion in the remnant areas.

The large pressure by humans and animals had led to land degradation as a result of overgrazing, lowering of groundwater and extensive fire. Overgrazing is causing deterioration in the grass cover favoring encroachment of others plant species, which are spread over in communal rangelands (Moleele, 1998), (Moleele & Perkins, 1998), mainly in the dry season when the volume of grass decrease. Reduction of water table level is an effect mainly of drilling more and more boreholes to pump water for animals and human consumption. Besides, extensive droughts and water loss by tree leaves transpiration contributes to this decrease as well. Fire is frequently used in hunting activities and for clearing land for sustenance agriculture, thus destroying many savanna areas. These impacts of human activities affect those vegetation cover types that are soil moisture dependent and very susceptible to these changes.

The incidence of these factors has contributed to decrease of the reserves of groundwater in the region, which is considered a very important resource, which is used mainly as drinking water. This water scarcity effect has influence on the vegetation in the area as the groundwater level decreases. Studies have

shown that a very narrow relationship exists between vegetation and groundwater table depth fluctuation (Timmermans & Meijerink, 1999; Cantero *et al.*, 1998; Scott & LeMaitre, 1998).

The analysis of vegetation distribution in this district area is important because changes in vegetation cover and structure can have a significant impact on the groundwater recharge by altering components of the hydrological cycle such as interception and transpiration.

Considering everything above, vegetation maps as detailed as possible are needed to determine accurately the vegetation composition in the zone and extrapolate this to comparable areas. Besides, these vegetation maps could be a very important data source to upscale the transpiration models that are being obtained for the different plant species in the same area.

The preparation of accurate maps leads to the need of using adequate data from sensors and platforms with regard to spatial and spectral resolution fitting to the requirement of the study. Up to now most of the studies towards analysis of vegetation have been founded on the use of Landsat TM (30m spatial resolution and 7 bands), Landsat MSS (80m spatial resolution and 5 bands) and SPOT_HRV (20m resolution and 4 bands) as main sources of satellite image data. Some studies using Landsat MSS satellite data have found that, it has not been possible to monitor the woody vegetation monitoring with the required accuracy.

Nowadays, new sensors are being developed producing higher resolution data like IKONOS (1m panchromatic (nominal at <26deg off nadir) 4m multispectral (nominal at <26deg off nadir)) (SIE, 2000) and ASTER (15 bands, VNIR 15m spatial resolution, SWIR 30m spatial resolution and TIR 90m spatial resolution). These permit a better discrimination of the object on the ground.

In order to find a more feasible way to obtain more accurate vegetation maps the present research is undertaken. For this a multi-sensor analysis to reach the most appropriate one in the process of vegetation mapping will be done. These vegetation maps also will be used to analyze the vegetation distribution in the area related to the impacts of certain environmental factors like: soil, topography, and water table depth data on this type of biome. Also it will be an input in a transpiration study, which is being carried out at the same time in other research to upscale the transpiration model to the complete vegetation types in the study zone. In this step Geographic Information Systems (GIS) will be used as an important tool in the analysis. The obtained result will give the possibility to the decision maker to understand the environmental conditions related to vegetation and to take the correct measures against degradation.

1.4 OBJECTIVES

1.4.1 Main objective:

To develop a methodology to identify and map the different woody vegetation cover types in the Serowe area and to analyze their relationship with a selected number of environmental factors.

1.4.2 Specific objectives:

1. To classify the woody vegetation cover types in the Serowe area according to:
 - Species composition (at plant community level), and
 - Structure.
2. To determine the more suitable sensor (LANDSAT TM, ASTER and IKONOS) for mapping the woody vegetation cover types in the Serowe area using the two different classification systems mentioned above.
3. To analyze the relationship between woody vegetation distribution in the Serowe and the environmental factors topography (elevation), groundwater table depth, soil types and soil texture.

1.5 HYPOTESIS

1. It is possible to map the vegetation cover in the Serowe region according to species composition (at plant community level) and structure with the same degree of accuracy.
2. The results in terms of precision/accuracy of the vegetation maps obtained using LANDSAT TM, ASTER and IKONOS satellite images when using the classification systems mentioned above does not shows any difference.
3. The correlation between bands and vegetation distribution is better shown when using bands from the visible part of electromagnetic spectrum.
4. The vegetation distribution in the Serowe region does not have any relationship with environmental variables such as topography (elevation), groundwater table depth, soil type or soil texture.

1.6 RESEARCH QUESTIONS

1. How can the woody vegetation in the Serowe area be classified based on:
 - Species composition?
 - Structure?
2. Do LANDSAT TM, IKONOS and ASTER satellite image data give similar or different result in terms of precision/accuracy when used for woody vegetation cover type mapping in the Serowe area using the two classification systems mentioned above?
3. Based on the answer to the above, which combination of sensor (and possibly even more specifically: sensor bands) and classification system gives the best result?
4. Is woody vegetation distribution in the Serowe area related to topography (elevation), depth of groundwater table, soil type and soil texture or not?

1.7 RESEARCH APPROACH

Research approach (or conceptual framework, as it is also called) is an important part of any research, which has the objective to serve as a guide for reaching successfully fulfillment of the work. Figure 1-1 summarizes the whole spatial analysis process for reaching the objective of determining the more suitable sensor and platform as well as the classification approach.

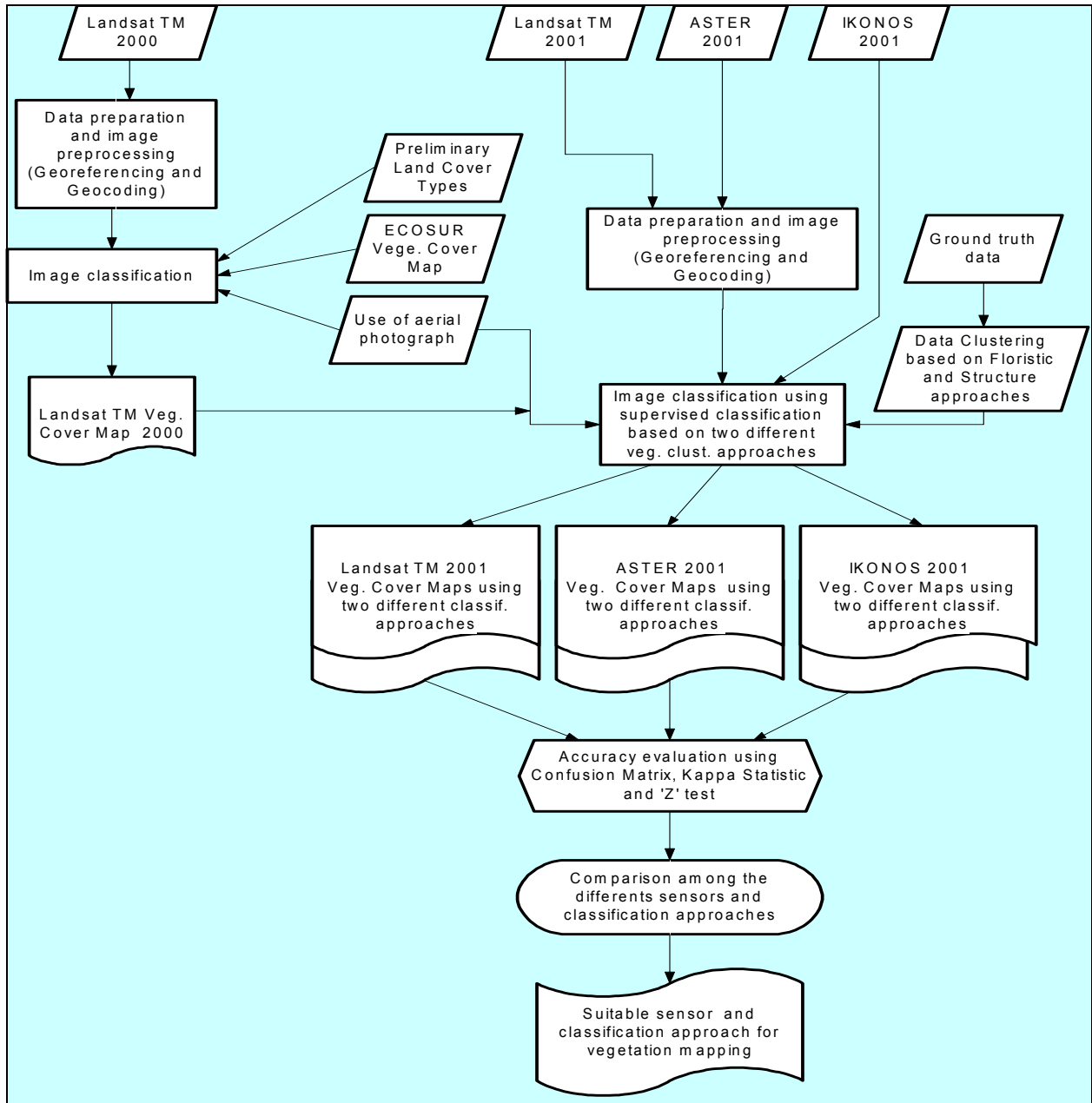


Figure 1-1 Flowchart showing the procedure to achieve the suitable sensor for land cover mapping in the area.

2. REVIEW OF EXISTING AND GENERALLY APPLIED METHODS

2.1 VEGETATION MAPPING PROCESS

The Vegetation Mapping Process entails the evaluation of existing data and information, the collection of new field data, the analysis and interpretation of the data, and the creation and evaluation of the vegetation maps. Next a brief process explanation is given (USGS, 1994). The appendix 1 shows an overview of the vegetation mapping process.

2.1.1 Project Planning

In preparation for implementation of this process, there is a preliminary review of the size and accessibility of the area, along with an evaluation of the availability of useful data.

The initial site visit provides the opportunity to further evaluate the information on the area and interact with experts who can assist in the mapping process. Preliminary field reconnaissance trip(s) commence at this time to initiate the classification, photointerpretation/image classification and mapping team(s) to the relationship between the vegetation and imagery. Simultaneously, a better understanding is developed about the key biophysical variables, management concerns, accessibility issues, ownership patterns, and the boundaries of the mapping program on the area.

2.1.2 Field Methods

Here the vegetation is sampled to identify and to characterize the full representation of all vegetation types across the area and to identify the photographic/image signatures that are associated with each type. The samples chosen to characterize the full variation of vegetation types are determined through stratification approach selected, which ensure a broad approach to sampling that should portray the fullest possible range of representative variation of all vegetation types across the area. The number of sample points for each vegetation type depends on the amount of information that has already been gathered about the vegetation type, the inherent variability of the vegetation type, the area covered, the time for fieldwork implementation and the complexity of the environment.

2.1.3 Data Management And Analysis For Vegetation Mapping

The field-collected plot data are entered and managed in standardized relational database management systems that have the capability to retrieve the data by the user. The plot data are analyzed to illustrate floristic patterns and to relate these patterns to key environmental variables. The result of this process is a list of all of the vegetation types found on the area. Each community occurring in the area is thoroughly described based on the data collected on the area and the information available for the community from others classification. Vegetation field keys are produced using the biological and environmental characteristics of the community.

Photointerpretation/image interpretation keys also are developed which link the patterns identified on imagery to the vegetation types. To accomplish this, the photo-interpreters review the characteristics of the signatures (texture, tone, color, etc.) to identify which characteristics are diagnostic of the vegetation types. The signatures initially identified on the imagery are then documented to provide a guide for interpreting and mapping vegetation from the aerial photography and satellite image. The step list include:

2.1.4 Needed Materials In The Vegetation Mapping Process.

The vegetation mapping involves many materials, which are needed through the whole process. The utilization of these materials by the surveyor depends mainly of his training level that permits him to use them. Besides, it also depends of the acquisition power of the enterprise where he works.

2.2 USED METHODS IN THE VEGETATION PATTERN MAPPING

This section discusses several methods for mapping vegetation patterns. These methods include (1) combining existing vegetation maps for local, regional or global coverage, (2) visual photointerpretation of satellite and photographic images, (3) digital classification of satellite data, and (4) combination of the three previous methods. This hybrid approach, which is the standard for future programs, draws on the strengths of all 3 methods, and facilitates consistency in boundary location that is needed for edge-matching maps.

The vegetation mapping methods are very related with the methodologies followed in the execution of the different investigations. These methods are executed according to the scale, which the work is wanted and the level of information that it is wanted to reach. Not all yield the same results when they are applied in different areas. It is related mainly to the sensor resolution (spectral, spatial) that is used and also to the incidence of environmental factors. For this reason we can observe that the use of the vegetation mapping methods keeps a narrow relationship with the area where research is carried out, either in the tropical areas or arid areas.

2.2.1 Used Method For Vegetation Mapping In Arid And Semiarid Zones.

Modeling the spectral response of vegetation has been attempted by a number of authors. Mapping vegetation in an arid environment should have advantages over a similar task in a tropical or temperate environment. The vegetation is characteristically sparse of low densities exhibiting wide spatial and temporal variations and fairly uniform in shape. A common geometric shape (e.g. spheres or cones) can be assumed. Due to single plants on a soil background, multiple scattering between different canopy layers can be ignored.

Making an analysis of methodologies used in some research we can note that they are used according to the vegetation mapping objectives. In a research carried out by Muñoz-Reinoso (2001) in Spain with the

purpose of analyzing the vegetation cover changes visual photointerpretation of aerial photographs (AP)(Method 2) was used. Overlaying of the different map obtained by means of the photointerpretation was applied. The selection of aerial photos was justified here because the study was at communities. On the other hand, McGwire *et al.*, (2000) in an arid region of California used in his analysis digital classification of the narrow spectral resolution images (Method 3) using different classifiers with the purpose to identify the best one to quantify vegetation cover.

In other research also done in California arid zone, with the objective to delineate environmental mapping units were used (Method 1 and 2). In this case maps already existent were combined and also screen digitizing of a scanned MSS paper image was carried out (Blanco, 1994).

If we analyze these three methods, it can be noticed that the use of aerial photographs is very important when detailed analysis of the vegetation is required.

2.3 SENSORS AND PLATFORMS MORE SUITABLE IN THE VEGETATION MAPPING PROCESS

More or less thirty years ago "remote sensing" was associated almost exclusively with aerial photography. In the present time, aerial photographs continuously used as an important tool in vegetation cover mapping to local scale (Muñoz-Reinoso, 2001). With the technological development new remote sensing sensors have been launched to cover different applications.

Multispectral sensors, which acquire digital information simultaneously in multiple windows, commonly called bands, of the electromagnetic spectrum are now flown on both space-based and airborne platforms. Some airborne sensors acquire data simultaneously in more than 200 spectrally narrow bands, resulting in what is called "hyper-spectral remote sensing." This kind of sensor has been satisfactorily used in California to study vegetation cover in arid zones (McGwire *et al.*, 2000). According to the way in which these sensors record the information they have been called either passive or active sensors.

Passive sensors measure either solar energy reflected by objects on the earth or infrared energy emitted by the objects themselves. In the visible portion of the spectrum, they acquire useful data only during clear daylight conditions.

The development of airborne and space-based RADAR has provided a totally new capability for mapping in a day-night, all-weather environment. RADAR is active sensor, which provides its own energy to illuminate the earth. It acquires information in the longer wavelength microwave portion of the spectrum where clouds and rainfall are penetrated. The information contained in RADAR data is inherently different from that in optical data. While multispectral and hyper-spectral sensors measure primarily chemistry-based responses, data from RADAR sensors can be used to infer structural properties of the surface and vegetation (size, shape, and roughness) and physical parameters (moisture content and

salinity). Under the right conditions, RADAR data can also be used to map topography and surface displacements. This is referred to as SAR interferometry.

The ERS-1 SAR data has been used in Papua New Guinea to discriminate forest from non-forest, which looks promising. Also here it was found that band C radar data in general makes it difficult to differentiate the forest from non-forest unless significant difference exists in the plant canopy (Conway, 1997).

Most recently laser altimeters or light detection and ranging (LIDAR) systems have evolved, which are active optical sensors that generate energy using lasers. This type of sensor has been used to map the vegetation cover. In forest area this sensor develops a profile of the forest canopy, which is used to determine the forest tree height and also from the understory. The basis of LIDAR sensing is simple. As an active sensor, LIDAR can be flown at night, but unlike SAR, it is unable to penetrate clouds.

Platforms such as the Advanced Very High Resolution Radiometer (AVHRR) have proved efficient at mapping vegetation at global and continental scales (Lambin, 1997; Muchoney *et al.*, 2000) (Tucker *et al.*, 1985). The AVHRR, which is a National Oceanic and Atmospheric Administration (NOAA) satellite, provides pixel resolutions of one and four km. For continental mapping of vegetation, NOAA data has been used to calculate the Global (or Green) Vegetation Index (GVI). The GVI, with its 4 km pixels, can be applied to forest ecosystem modeling and atmospheric emissions of vegetation at a global scale (Gaston *et al.*, 1997). Besides linear mixtures applied to time series of this satellite have been used for vegetation differentiation based on plant phenology (Zhu, 2001).

Higher resolution multi-spectral imagery available from platforms such as Landsat Thematic Mapper (TM) (30 m pixels), and Satellite Pour l' Observation de la Terre (SPOT) (20 m pixels) have been investigated for larger scale data sets (Gjertsen, 1993; Peterson *et al.*, 1987; Luman & Ji, 1995). Also, Landsat TM has been used for local and province scale studies (Trisurat *et al.*, 2000; Apan, 1997). Vegetation mapping with SPOT data is generally improved over mapping performed using TM data, particularly where heterogeneous areas of vegetation are found, or where outlying pockets of vegetation exist (Gjertsen, 1993). All of these platforms exhibit improved results when compared to AVHRR data.

Nowadays, the launching of new satellite like ASTER (15m Visible-NIR, 30m SWIR and 90 TIR spatial resolution) and also the use of IKONOS (1m spatial resolution) contribute to improve the quality and accuracy of the information contents in the vegetation map because of its finer spatial resolution. But, it also would be good to consider the acquisition cost of satellite imagery. Some times free satellite images data like ASTER can give good or better result as more expensive satellite data from Landsat TM and IKONOS.

While there is no single ideal sensor for all applications, when used in combination, these new remote sensing technologies potentially allow substantial improvements in vegetation/land cover mapping and monitoring. These sensors provide new capabilities for acquiring high-resolution digital remotely sensed

data. Information can then be rapidly processed, quantitatively analyzed, and disseminated to support long-term strategic planning by state and local governments, as well as monitoring changes through time and responding to periodic hazards

2.4 THE MINIMUM MAPPING UNIT (MMU) ACCORDING TO THE VEGETATION MAPPING OBJECTIVE

The selection of the correct MMU is one of the main steps to achieve the required detail level in the vegetation mapping. For vegetation classification, the unit of observation is typically the "stand," defined as a relatively homogeneous area with respect to species composition, structure, and function.

It has been suggested that spatial resolution should be less than half the size of the target feature measured in its smallest dimension. Therefore, the MMU for the vegetation inventory should not be equal to spatial resolution of the sensor.

For example, increasing the MMU to a value twice the sensor's spatial resolution would result in a higher degree of generalization and many narrowly banded vegetation features that are biologically important are not considered because they fall below the MMU. Selecting a finer sensor spatial resolution would result in much larger datasets, increased processing time, and increased data management costs. It has been said that the selection of the correct MMU would avoid to mix and confusing between single classes and classes (Berry & Ritter, 1995).

Spatial scale of data (sensor resolution, MMU, data aggregation methods) and the specificity of classification schemes influence the accuracy and interpretability of results (Snetsinger & Ventura, 2001).

If the data are captured by satellite based remote sensing instruments the resolution of the data is determined by the height of the orbit and optics of the instrument. This is referred to as the spatial resolution of the sensor, the pixel size or the instantaneous field of view. Some sensors that provide multi-spectral data suitable for generating land cover data are the Landsat MSS with a spatial resolution of 79 x 79 m, the TM at 30 x 30 m, SPOT HRV (XS) at 20 x 20 m, and Indian LISS 1-3 (72 x 72 m; 36.25 x 36.25 m; 23.5 x 23.5 m, respectively). The minimum mapping unit is directly related to the sampling rate. In other words, the smallest pixel size available for land cover mapping would be 20 x 20 meters. Since the smallest feature that can be mapped should have a width of two of these cells then the minimum mapping unit would be an area of 1600 square meters (40m x 40m) Therefore, in any land cover classification system based on remotely sensed data the original pixel size will determine the size of the features that can be mapped (Cowen *et al.*, 1998).

Perhaps the most important decision regarding the mapping will be the determination of the appropriate level of resolution. In other words, the smallest feature which can be represented on a map. This is directly related to the mapped scale or the source material, or the type of sensor being used.

For example, AP in Spain has been used for vegetation mapping at local level with the objective of detecting change in plant communities using for that 0.25 ha as a MMU (Muñoz-Reinoso, 2001). Also with the same objective but changing the mapping scale to global using NOAA-AVHRR the MMU used has been 162 km² (Lambin, 1997). This comparison confirms the statement above exposed.

2.5 DETAIL LEVEL IN THE VEGETATION MAPPING PROCESS

The level of detail is dependent on many factors: the objectives of mapping, the information need, the spatial and radiometric resolutions of the sensor, the environmental condition of the target area, the analytical techniques to be applied, and others (Apan, 1997).

The detail level is very related with the MMU and the scale. The use of satellite images to show global and local patterns depends on the scale of the image. Thus, changing the scale changes the patterns of reality, which has obvious implications for understanding the dynamics of any environmental system (Marceau & Hay, 1999).

There is no rule to select the proper scale, but there are hierarchical levels that might help in the decision of picking an appropriate scale. The coarser the scale, the higher is the level. Lower levels tend to provide data for testing a hypothesis whereas higher levels display broad patterns and processes (Grunner, 1999). Generally, the larger the ecological scale becomes, the fewer detail is available.

The scale of remotely sensed data for vegetation mapping is important because using a large pixel size may not be suitable for mixed species and cover. Factors such as the optical properties of vegetation have been investigated, and the effect of scale on NDVI and LAI has been shown to change accuracy of final maps (Sandison, 1999).

Some studies have noted the difficulty to separate the spectral values of tropical vegetation types. For example, a study with the objective of tropical forest rehabilitation using Landsat TM showed that species level or detail forest type differentiation was not permissible given the environmental condition, vegetation properties and the sensor capabilities (Apan, 1997). Also it has been found that the differentiation of different forest types using ERS-1 SAR data was in general difficult in Papua New Guinea (Conway, 1997).

All previously said confirm that to obtain a desirable detail level it is important to choose first a good scale to reach the objective. But the choice of an appropriate scale depends on three main factors: the output information desired about the ground scene, the methods used to extract the information from the imagery, and the spatial structure of the scene itself (Marceau & Hay, 1999).

3. MATERIALS AND METHODS

3.1 STUDY AREA DESCRIPTION

3.1.1 Location

Serowe study area is located in the Central District, about 275 km NE of Gaborone, which is the capital of Botswana. Coordinates related to this zone are 26°07' 37" E (western limit), 26° 54' 10" E (eastern limit), and 22°14' 10" S (northern limit), 22°30' 33" S (southern limit). The figure 3-1 shows the study area location in the Botswana country map.

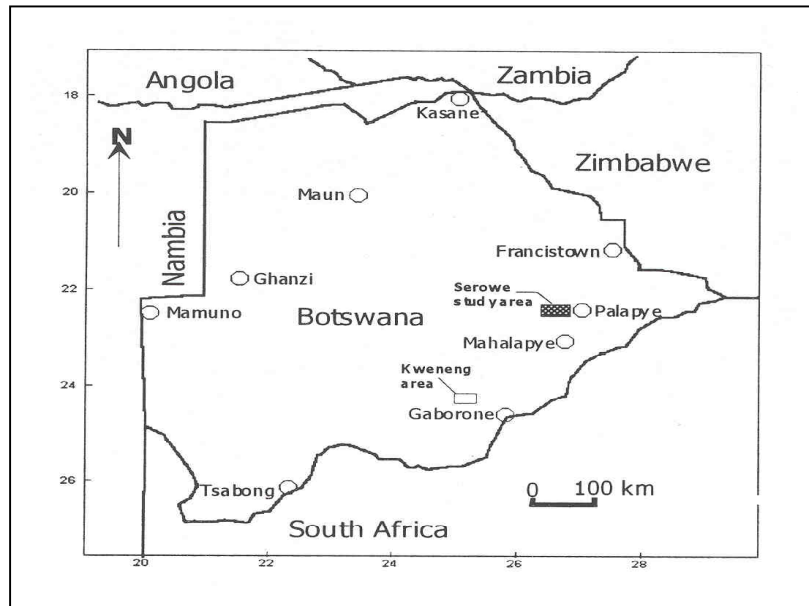


Figure 3-1 Botswana country map showing the Serowe study area.

3.1.2 Topography

Topography is gentle, and varies from 1060 meters above sea level (m.a.s.l) to approximately 1240 m.a.s.l. It is characterized to be lower in the east and southeast of the region, and the highest in the vicinity of the escarpment edge. From here the average slope is 5% and it gradually decreases to less than 1% towards the east and southeast. This escarpment, a major topographic feature in the country, marks the eastern limits of Kalahari sands. It trends approximately NNE-SSW (Figure 3-2).

Along the escarpment significant outcrops of Stormberg basalt occur, with more isolated outcrops of both basalt and Ntane Sandstone common to the east (Wellfield, 2000).

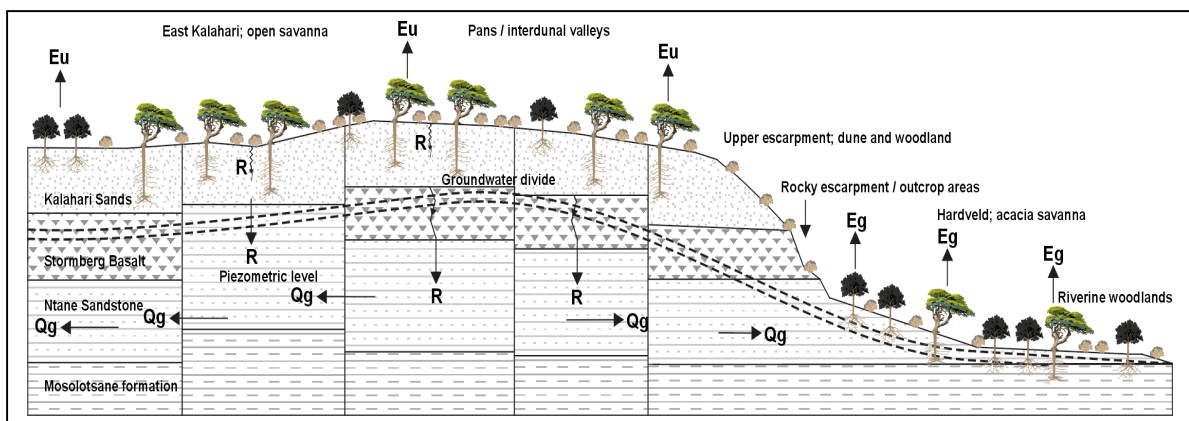


Figure 3-2 Serowe area geological cross section.

3.1.3 Soils

Soils units, which can be found in that region, are related to arenosols, regosols, lixisols, luvisols and vertisols. Arenosols are the most common soil units in the study area. It has low moisture retention capacity than the other soil units (Table 3-1).

Table 3-1 Soils unit more frequents in the study area (Source: Obakeng, 2000)

Soil units	General description
Arenosols	Soil excessively well drained, and have low water retention capacity. Fine sands are predominant (>75%) with minor clay or silt (<5%).
Regosols	Well drained to moderately well drained, but less drained than Arenosols. It is sandy loams to clay loams, with minor coarse sand.
Lixisols	Soils well drained. The sand content is about 20%, and high clay content (usually >20%).
Luvisols	Soils well drained. It consists of nearly equal proportions of coarse and fine sand. The sand content is about 20% to 30% with high clay content (usually >20% as a lixisols).
Vertisols	This soil unit is poor to perfectly drained. Soils are predominantly clays and fine silt. The clay content is generally in excess of 50%.

3.1.4 Climate

Climate is characterized as semi-arid, with a mean annual rainfall of 447 mm, cool dry winters, and hot moist summers. Rainfall occurs mainly in summer followed by a dry winter season. Summer season stretches from October to April, coinciding with the rainfall period, which has a peak occurring in January. High intensity, short duration and highly localized rain showers characterize this rainfall. The winter season involved the remaining months completing the year period beginning in May and finalizing in September (Tyson, 1986) (Obakeng, 2000).

3.1.5 Vegetation

Main vegetation type is the Northern Kalahari Tree and Bush Savanna type. Trees are mostly of *Grewia* and *Acacia* species, which are characterized by the marked tendency to occur in cluster, and are normally accompanied by a variety of grass species such as the ones belonging to the genera *Aristida* and *Eragrostis*. Vegetation communities are determined by location on either sandveld or hardveld areas. Dense vegetation is found within and along river courses. This suggests that the vegetation density could be governed by the availability of water, which may be partly controlled by topography and geomorphology (Obakeng, 2000).

3.2 MATERIALS

3.2.1 Satellite Images

The images used in this research come from Landsat TM, ASTER and IKONOS. The Landsat TM images were collected on August 11, 2000 and October 1, 2001, which have a spatial resolution of 30m. These images have a spectral response of 7 bands with three of these bands located in the visible part of electromagnetic spectrum and the others in the near, middle and thermal infrared part. In the case of ASTER image it were collected on August 23, 2001 with a spectral response of 14 bands and one band in the NIR backward. The spatial resolution of these bands is 15m in the visible and NIR, 30m in the SWIR and 90m in the TIR. In IKONOS case the image was collected on December 1, 2001 with a spectral response of 5 bands. The spatial resolution of this sensor is 1-meter Panchromatic, 1-meter Pan-sharpened Multispectral and 4-meter resolution Multispectral bands. From the Landsat TM and ASTER scenes, sub-scenes containing 3465 columns and 1467 rows covering the study area were cut out for the study. The entire IKONOS image covering an area of 10 by 10 kilometers was used as it is.

3.2.2 Aerial Photographs

The aerial photographs used are from 1988 (scale 1:50000). The aerial photographs were used for helping in the process of land cover classification on the Landsat TM 2000. These were also useful for the image classification process of the of Landsat TM, ASTER and IKONOS 2001 image.

3.2.3 Topographic Maps

The topographic maps used in the vegetation survey were the sheets No 2226 B3, 2226 B1, 2226 A2 and 2226 A4 (scale 1: 50 000), which covered half of the study area. The others topo-sheet were not available. Department of Survey and Lands of the republic of Botswana published these ones in 1983. The main uses of these maps were coordinates verification, location of the principal and secondary roads to reach the study area and location of the sample plots for survey.

3.2.4 Global Positioning Systems (GPS)

A Garmin 12XL GPS receiver was used for recording all the coordinates of the different ground points. Just before surveying the sample plots the reading accuracy of it was tested and reading error accurately calculated.

3.3 METHODS

3.3.1 Pre-fieldwork Stage (Data Preparation)

Pre-fieldwork is a fundamental step before the field survey. In this stage the available information about the study area was compiled. The images were pre-processed and pre-classified. Besides an appropriate sampling design for the distribution of the samples plot was developed.

3.3.1.1 Geometric Correction

Raw digital images usually contain geometric distortions so significant that they cannot be used as maps. The sources of these distortions range from variations in the altitude, and velocity of the sensor and platform, to factors such as panoramic distortion, earth curvature, relief displacement, and nonlinearities in the sweep of a sensor's Instantaneous Field Of View (IFOV). The intent of geometric correction is to compensate for the distortion introduced by these factors so that the corrected image will have the geometric integrity of a map (Lillesand & Kiefer, 1994).

The image supplier corrects some of these distortions and the other ones can be corrected in the geo-referencing process from the images to maps, which already exist, or using images that have been previously geo-referenced.

In this step the image geometric characteristics were analysed. It was done with the objective of avoiding error introduction in the process. A selection of the appropriate band combinations to be used in the classification process as well as the image transformation method was selected. To fulfill this stage, a Landsat TM image from August 2000 was georeferenced and geocoded. After that, the information related to the different ground features in the image was analysed.

3.3.1.2 Image classification

On the Landsat TM image previously geocoded it was applied a supervised classification in order to identify as much as possible the different land cover classes on the place. The image transformation method used was Principal Component Analysis (PCA). Besides, aerial photographs and ECOSUR vegetation map were available in this stage. In case of the latter, it was used as reference map for helping to identify in the Landsat TM 2000 image the different vegetation classes already identified by them. The final result was a map representing the more important cover classes on the place. In this step it was not possible to use the Landsat TM, ASTER and IKONOS image from the year 2001 because these were not available in this time.

3.3.1.3 Preparation of the sub-study areas

Because the whole study-area was too big to cover completely within the period of time scheduled for surveying, it was decided to select three sub-areas representative of the three major landscape types found in the study-area (sandveld, escarpment and hardveld) (figure 3-3). The selected sub-areas covered 10x10 km each.

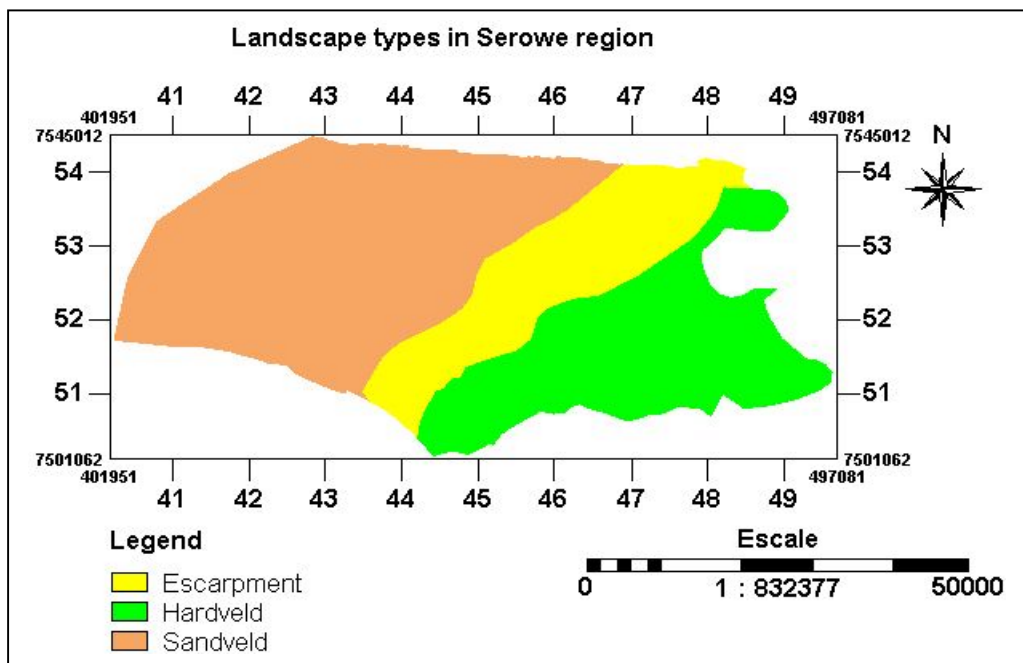


Figure 3-3 Map showing the area covered by the different landscape types found in Serowe region.

3.3.1.4 Sampling Design for Data Collection

Within each sub-area stratified random sampling was applied (Kent & Coker, 1992) (DeGier, 1998), the strata being the woody vegetation cover classes identified on the Landsat 2000 image. Allocation of sample points to the different strata was random and their number proportional to the size of the areas covered by the strata (Figure 3-4).

Taking the above-mentioned sample points as centres, four additional sample points were generated, 500 m away from the centre point and in the directions North, East, South and West (Figure 3-5). Because of time constraints eventually only two sample points of each cluster of five were surveyed: the “centre” point and one of the “outer” points. The latter was randomly selected.

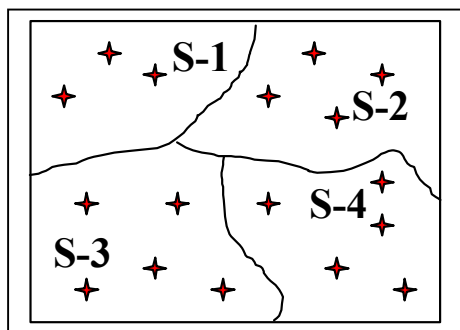


Figure 3-4 Sampling plot distribution in each stratum.

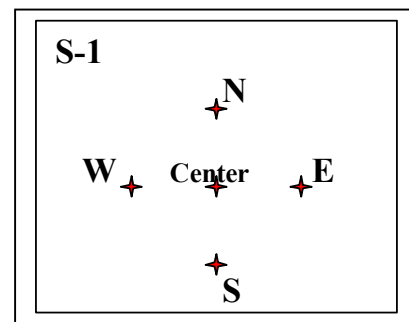


Figure 3-5 Distribution of the four additional points.

However, contingency points were also taken in case some points became inaccessible or the selected sample covers before the fixed time. The table 3-2 shows the number of plots per landscape type, which were planned in this stage and the real amount that were surveyed in the data collection stage.

Table 3-2 Number of plots planned in pre-fieldwork stage and checked in the fieldwork stage.

Vegetation Class	Sandveld	Escarpment	Hardveld	Plan	Survey
Agriculture	0	4	12	16	8
Bare Soil	0	4	0	4	2
Escarpment Vegetation	0	12	0	12	6
Hardveld Woodland	0	8	4	12	6
Hardveld woodland savanna	0	0	8	8	4
Open savanna	12	4	4	20	10
Open savanna-shrubs	8	0	0	8	4
Open savanna-trees	12	12	16	40	20
Outcrop Area	0	4	4	8	4
Water Body	0	0	4	4	2
Total of Plots				132	66

3.3.2 Field Check & Sampling Stage (Data Collection)

The field check-up and sampling are one of the main phases in the project execution. In this stage the Pre-field stage developed plan was carried out.

3.3.2.1 Sample Plot Surveying and Ground Truthing

After the GPS was correctly set up the coordinates of the selected points were entered in the receiver. Maps together with GPS were used then to navigate to the nearest road. Then using GPS the plot center was located. After the plot center was marked tree measurements were then taken on an area that correspondent to a 12.62 m circular plot (500m²). It was chosen because of its simplicity and easy alignment. These plots were corrected on the area whether any variation in slope on the terrain was observed.

Tally sheets, which had been prepared in advance, were used to record plot parameters on it. Plot information like slope, plot ID, radius, land cover, sample plot altitude (m.a.s.l), was filled in the tally sheet first. Then, other information related to vegetation cover characteristics as determination of species per strata, height, DBH, crown diameter (of tree, bush and shrub), and soil type were recorded. Top of the tree was taken for its height at the right angle to the leaning side of the tree while dbh was taken above 1.3m for trees higher than 4m. Finally general remarks about the plot were recorded describing the condition of the plot. For instance, if there was human interference, animals grazing, fire, etc. In this stage also ancillary data about water table depth, climate and livestock was collected.

3.3.3 Post-Field Stage (Data Processing and Analysis)

3.3.3.1 Image Processing

For completing this task, the Landsat TM 2000 image preprocessed in the data preparation stage was taken as the master image for georeferencing the other ones (LANDSAT TM and ASTER 2001). IKONOS images were already geo-referenced. Using Tie points geo-reference and a first order (affine) polynomial transformation, points were collected to assign coordinates to the different pixels in the images. These selected points were enough so that the residuals and the root mean square error gave a sufficiently small positional error. In this way, images from Landsat TM and ASTER from year 2001 were georeferenced.

After having completed the georeferencing process, a re-sampling was carried out. In this step the image geometric distortions were corrected and the pixels in the slave image were adapted to the master image pixels. In this way the image was north oriented and ready to be used. It was applied to the Landsat TM 2001. In case of ASTER 2001 image a new georeference was created with the objective of maintaining the same pixel size as the original image. As a result of the transformation geocoded images were obtained.

These free of geometric distortions and correctly prepared images were used in this stage for the final processing. When trying to do the image classification it was noted that proper separation of the different vegetation cover classes on the place was difficult. To overcome this problem the selection and application of an image enhancement technique to the images was carried out. A linear stretching technique with the objective of re-distributing the digital number values of the input images over a wider range of values was applied. With this operation it was possible to obtain a better contrast in the images when these were displayed, and also a better class separation. This technique permitted to recognize and to classify the pixels on the base of their digital signatures.

3.3.3.2 Data Processing

The collected data in the field were used to classify the different sets of images using two different vegetation classification systems: according to floristic composition and vegetation structure.

3.3.3.2.1 Classification system according to floristic composition

In the first method the information in the relevé sheets collected in the different landscape types were clustered using TWINSpan software with regard to species and cover of these in each plot. Clustering permitted to identify as accurately as possible the different plant communities.

TWINSpan is a Two Way Indicator Species Analysis. This software not only classifies the sites, but also constructs an ordered two-way table from a sites-by-species matrix. The ordination of the samples in this program is done by the method of correspondence analysis and division of the first ordination axis at its center of gravity (the centroid). Two groups are formed, one negative (left hand) and other positive (right hand). It uses for the sample classification an algorithm of reciprocal averaging to arrange the data in the two-way table.

3.3.3.2.2 Classification system according to vegetation structure

The relevés also were clustered taking into account the crown cover by trees, bushes and shrubs in the area. It was done with the objective to classify the vegetation according to its structure. The structure classification used here follows the system proposed by the Kenyan Soil Survey and explained by Van-Wijngaarden (1985).

In this classification the vegetation was classified in four main layers. These layers were:

- Tree layer; dominated by single or multi-stemmed trees more than 6m high,
- High shrub layer; dominated by single or multi-stemmed trees or shrubs which have a large part of the crown at a high of more than 2m, but are in general less than 6m,
- Low shrub layer; dominated in general by multi-stemmed shrubs with most of their crowns less than 2m high, and

- Herb layer; dominated by annual and perennial herbs, including grasses,

This structure classification is based on the cover percentage by trees and shrubs only, which can be presented in a two-dimensional graph (figure 3-6). In this classification the tree and high shrub layer are combined because their functions are comparable: providing shade and wind protection and food for only elephants and giraffes (Van-Wijngaarden, 1985).

In this research, the vegetation cover was recorded in a slightly different way as compared to the above. Three main layers were recorded:

- Tree layer; dominated by trees more than 4m high,
- High Shrub layer, dominated by plant with more than 2m high and less than 4m, and
- Low Shrub layer; dominated by plants with crowns less than 2m.

In this case the upper boundary for the High Shrub layer changed. It was brought in line with the classification used in the survey carried by the ECOSURV project in the same area. (ECOSURV, 1998). Even so, it was still possible to use the diagram shown in figure 3-6 because for the vegetation classification Tree and High Shrub layer were grouped together. Low Shrub layer was used as it was.

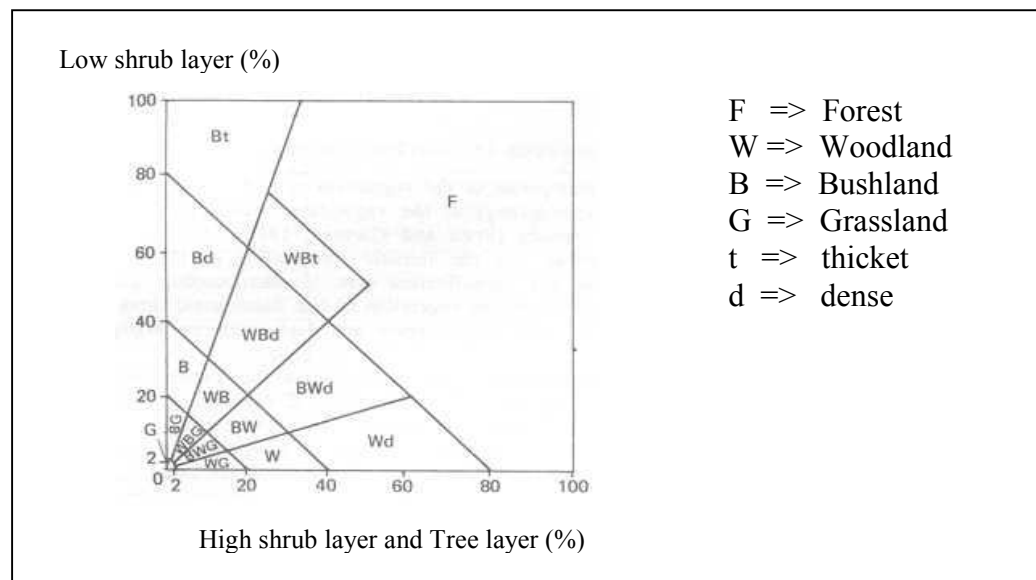


Figure 3-6 Classification of the structure of the woody vegetation

3.3.3.3 Image Classification

After the plant communities, and the different structure classes were identified these were used in the classification of LANDSAT TM, ASTER and IKONOS images from year 2001. The band combinations,

chosen for classifying the different set of images were the following. In case of LANDSAT TM, ASTER and IKONOS bands 4,3,2 (NIR, Red and Green respectively) were used for the classification purpose. In ASTER images band 4, which was used, corresponded to the NIR nadir.

This digital image classification was done using supervised classification taking into account the two relevés clustering criteria as explained, obtaining one classified map based on the plant communities occurring in the place and other based on the vegetation structure in each data set. The latest one was independent to the type of plant growing in each plot.

3.3.3.4 Evaluation of the classification results

After having carried out the image reclassification and selected and identified the samples as true pixels, the classification accuracy was quantified for each vegetation cover map using a Confusion Matrix and Kappa Statistic.

3.3.3.4.1 The Confusion Matrix

A Confusion Matrix, which is a broadly used technique, was used to compare a sample of true pixels for each vegetation cover class already obtained in the fieldwork and the classified pixels in the image on the base of a pixel-by-pixel comparison. This permits to analyze how accurate the different maps were when comparing with the ground truth data. Five types of information were then analyzed. They were: accuracy per class (ACC) (also referred also as User Accuracy); reliability per class (also referred also as Producer Accuracy); average accuracy; average reliability and overall accuracy.

3.3.3.4.2 Kappa Statistic

The Kappa Statistic is another method to assess accuracy. It represents the degree of agreement between the classified image (based on Plant Communities or Vegetation Structure) and the ground truth data. It indicates how the classification differs from random classification of the reference data (Lillesand, 1994). Values of Kappa range from 0 (no association, that is any agreement between the map and the ground truth equals chance agreement) through to 1 (full association, that is perfect agreement between map and ground truth). Less than chance agreement leads to negative values of kappa. (Skidmore, 1999)

The Kappa factor is given by the formula (Banko, 1998):

$$Kappa (\hat{K}) = \frac{Po - Pe}{1 - Pe}$$

Where:

Po → Proportion of units (map and ground truth) that agree,

Pe → Proportion of units expected to agree by chance.

The values of the parameters P_o and P_e can be calculated with the following formula (Banko, 1998):

$$P_o = \frac{\sum X_{ii}}{N}; \quad \text{Where: } X_{ii} \text{ is total units (map and ground truth) that agree, and } N \text{ total of sample pixels}$$

$$P_e = \frac{\sum X_{i+} * X_{+i}}{N^2}; \quad \text{Where: } X_{i+} \text{ and } X_{+i} \text{ are the marginal totals of row } i \text{ and column } i \text{ respectively.}$$

N^2 is total of sample pixels at power two.

Once Kappa is calculated for each matrix a test for significance (the so-called ‘Z’ test) can be performed for each matrix to determine if the agreement between the classification and the reference data is significantly greater than zero. In other words, a test to see if the classification is significantly better than a random assignment of land cover categories to pixels. Here the null hypothesis is $K=0$. Before the test can be run, the variance of Kappa must be calculated.

The formula to calculate the Kappa variance is gives by Siegel & Castellan (1988):

$$Var(\hat{K}) = \frac{2}{Nk(k-1)} * \frac{Pe - (2k-3)(Pe)^2 + 2(k-2)\sum pj^3}{(1-Pe)^2}$$

$N \Rightarrow$ Number of classes to be compared

$k \Rightarrow$ Number of true classes

$pj^3 \Rightarrow$ Proportion of each class

With the variance value calculated, running of the ‘Z’ test can be continued. ‘Z’ can be calculated as follows (Siegel & Castellan, 1988):

$$Z = \frac{\hat{K}}{\sqrt{Var(\hat{K})}}$$

3.3.3.5 Gradient analysis

In order to investigate whether any (statistically significant) relationship exists between vegetation on the one hand and on the other hand (a) environmental variables and (b) band-specific spectral reflectance, an ordination method using direct and indirect gradient analysis was applied. This was done through Canonical Correspondence Analysis using CANOCO software.

3.3.3.5.1 Environmental variables

Four environmental variables were tested: ground water table depth, elevation, and soil type and soil texture (Figure 3-7). Because of their non-quantifiable character, soil type and soil texture were tested using dummy variables (Appendix 2). CANOCO allows testing statistically whether the occurrence of certain species (Appendix 3) is strongly/weakly related to certain (environmental) variables. In this process basically two types of analysis take place: Direct Gradient Analysis (DGA) and Indirect Gradient Analysis (IGA) (Figure 3-8).

In DGA two input matrices are used: a matrix in which environmental variables are plotted against sites and a matrix in which species are plotted against sites (using species cover percentage). Subsequently it is attempted to explain one (the species occurrence) with the other (the environmental data). In other words: the environmental data are used DIRECTLY to organize the information on the vegetation. In DGA use was made of Canonical Correspondence Analysis (CCA). In CCA the effect of a particular environmental variable is tested after elimination of possible effects of other (environmental) variables by specifying the latter as co-variables.

In IGA the species data (in the shape of a matrix in which species are plotted against sites (using species cover percentage)) are first organized in an ordination diagram (independently of the environmental data). The result of this is subsequently compared with the environmental data in order to detect possible environmental gradients explaining the variation in the species data. The environmental interpretation is thus INDIRECT. In IGA use was made of Detrended Canonical Analysis (DCA). DCA is based on reciprocal averaging.

In case of the relationship between digital value – species cover, Detrended Canonical Correspondence Analysis (DCCA) was used. In DCCA first “detrending” takes place using reciprocal averaging, which is followed by CCA. In DCCA each band is considered as an “environmental variable” and the same procedure as in CCA is applied.

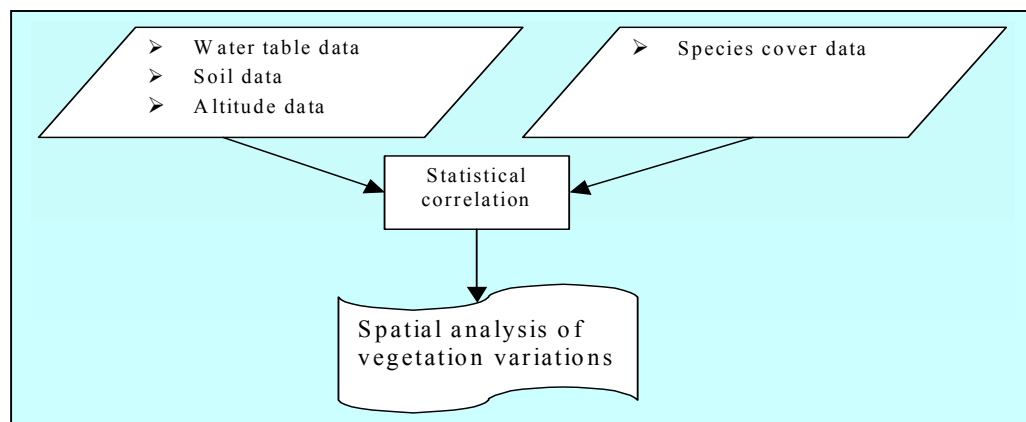


Figure 3-7 Procedure followed to reach the statistical correlation between the different environmental variables, and vegetation data.

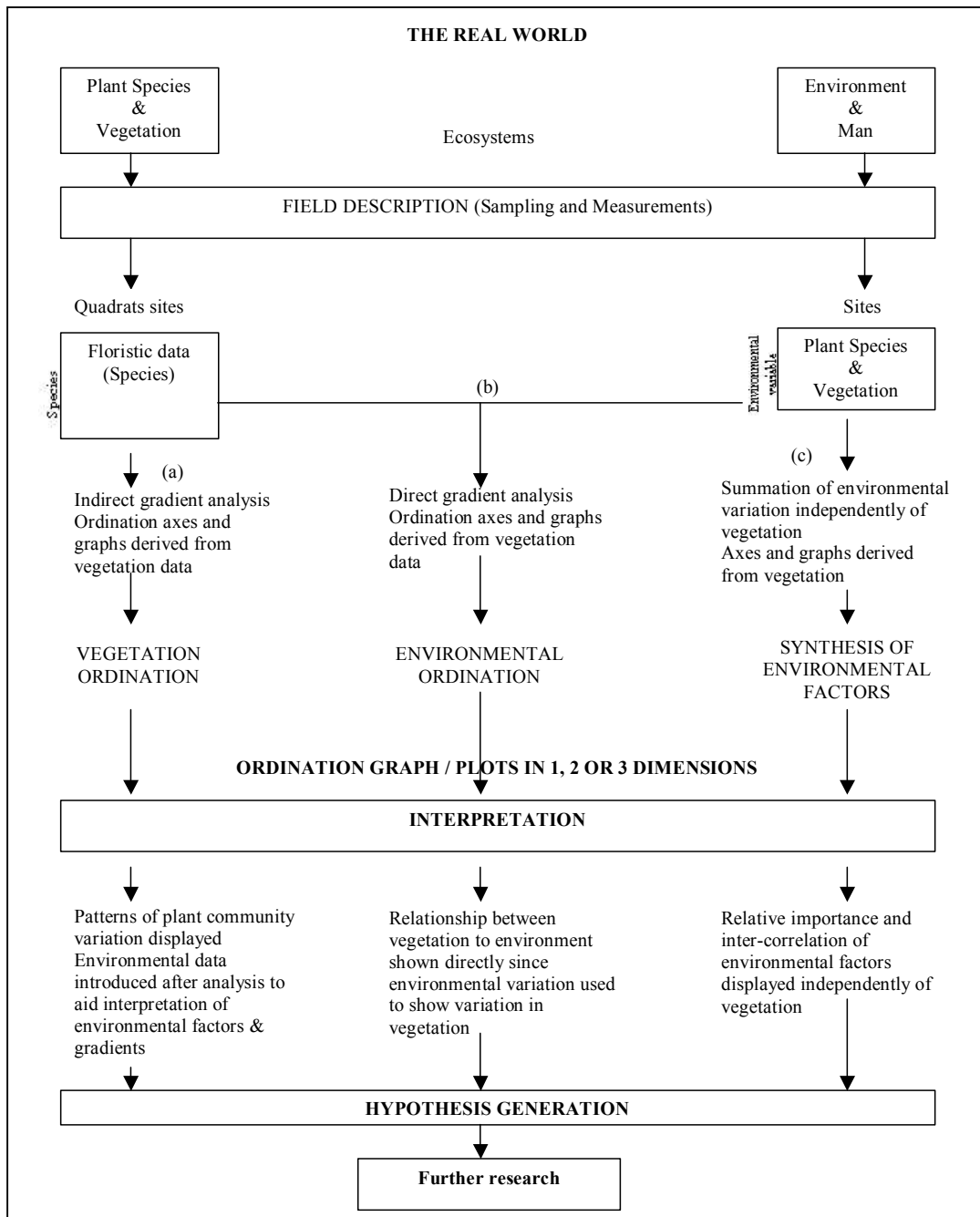


Figure 3-8 Approaches to ordination in plant ecology. (a) Indirect ordination; (b) Direct ordination; (c) Summarization of environmental variation. Source: Kent, M.; Coker, P. (1992).

a) Vegetation data are analyzed independently of environmental data and environmental data are introduced only after ordination diagram has been produced (vegetation ordination).
 (b) Vegetation data are ordinated by using environmental data (environmental ordination).
 (c) The variability of the environmental data is analyzed independently of the vegetation axes and graphs derived from vegetations).

4. RESULTS

4.1 GENERAL OBSERVATIONS RELATED TO THE THREE MAJOR LANDSCAPES TYPES PRESENT IN THE STUDY AREA

During a reconnaissance survey the following was observed in relation to the vegetation present in the three main landscapes in the area.

Sandveld: This area is quite homogeneous with regard to species composition. Species like *Terminalia sericea*, *Ochna pulchra* and *Boscia albitrunca* are strongly represented in this area. Vegetation is relatively open (Photo1) with occasionally denser patches of vegetation dominated by shrubs and bushes. Main use of this area is rangeland and hundreds of cows can be seen grazing freely (Photo 2).

Escarpment: In this landscape type the vegetation is more heterogeneous with regard to species composition and is taller than the vegetation found in the Sandveld. Especially close to the escarpment edge the vegetation is quite dense (Photo 3). Species like *Combretum apiculatum* and *Croton gratissimus* can frequently be found in this area. The species *Ricinodendrum rutananii* grows close to the escarpment edge.

Hardveld: This area is considered to be more fertile in comparison to the Sandveld. Vegetation growing in this landscape type is generally speaking taller than the vegetation found in the other two landscape types, especially so close to riverbeds where heights of about 16m are reached. Species like *Acacia karroo*, *Acacia tortilis* and *Acacia mellifera* are strongly represented in this area. (Photo 5). This area is also used for grazing (Photo 6).

4.2 VEGETATION CLUSTERING ACCORDING TO FLORISTIC COMPOSITION

As explained in chapter 3, the different relevés with the information collected in the field were processed using TWINSpan software. Using this package, the following 4 major plant communities were differentiated:

- *Acacia karroo* – *Acacia tortilis* – *Ziziphus mucronata*
- *Dicrostachys cinerea* – *Combretum apiculatum* – *Grewia bicolor*
- *Terminalia sericea* – *Grewia retinervis* – *Dichrostachys cinerea*
- *Grewia flava* – *Grewia retinervis* – *Acacia mellifera*

Table 4-1 shows the result of TWINSpan's clustering of different relevés based on species dominance. The "dendrogram", showing how the relevés were grouped into the different plant communities, is shown in Figure 4-1.

Table 4-1 Species-by-site output table used by TWINSpan to cluster the relevés.

```

3334444444 111111      1114 233  323512223424222353552
56734501293012345246786786191259029090158837478334126

 1 Lon nel 22-----51-----1-----2 00000
53 Bos alb ---215---214211-----1-----1----- 00000
17 Spp1 212---25-----11-----2----- 00001
19 Aca gal --5---46-----11----- 00001
35 Gre fla 66525658--3325-23--22221-----32---31---2--- 00001
10 Bau pet -----12-----2-----22-----1----- 000100
11 Aca eri 42-----1-----22----- 000100
29 Aca mel ---634587-----1----- 000100
48 Spp3 -51-----2----- 000100
 2 Sec lon -----2-----2----- 000101
 8 Ter ser ---4-23663565454555355223-14555554-6---2--- 000101
28 Bur afr -----2-----1-21--12--25-2311----- 000101
31 Och pul -----1122--1-4231-333-46354-5--1--2----- 000101
57 Com spp -----34-3-1-635453553522-----2----- 000101
 4 Ma y sp --1-----2-3--11-----3----- 00011
 9 Str coc -----1-----3-41---1--1--3----- 00011
13 Aca fle -----22-42-126-2---6625371---22---2----- 00011
56 Gre ret 52-5255753-21-32-35353445565534342---5--22----- 00011
26 Aca eru 336-----6-----37----- 00100
41 Pel afr ---7-----325---3---54----- 00100
 3 Mim zey -----3-----3----- 001010
 5 Com coll -----1----- 001010
 6 Com mol -----1----- 001010
 7 Lan sch -----4-----545----- 001010
12 Gre bic -----3-25352222122----- 001010
15 Dio lyc -----2----- 001010
21 Gre fla -----2-----22--66-55245-2-5-25----- 001010
25 Com edu -----1-535-----57----- 001010
27 Cas tran -----2-----3----- 001010
30 Ozo spp -----2-----21----- 001010
34 Xim caf ---1-----2----- 001010
39 Rot cap -----2----- 001010
44 Lip jav -----1---5----- 001010
46 Pap cap -----15----- 001010
49 Euc und1 -----3----- 001010
51 Van inf -----2----- 001010
52 Ole afr -----6----- 001010
54 Rhu lep 2-----32-----2----- 001010
55 Ter pri -----1----- 001010
16 Com api 11---25162-13--1-1-2--1-8--12---6227765757-3- 001011
24 Ric rut -----4-----6----- 001011
33 Cro gra -----7--1---221-----2-----2-6-2-7----- 001011
58 Sol spp -----1-----1-1-----1----- 001011
40 Dic cin 53---4463-5521-2255555655-1--51-5746676-7155745----- 0011
18 Com her 11-----225-----6-----5 01
23 Aca nig -----2---2-167-----1 01
50 Euc und2 -----12-----2-1-2--1-4-----1 01
22 Aca tor -----4-----5 100
36 Ehr spp -----1-----1-1-----11-1--- 100
42 Bol spe -----2-----2----- 100
14 Asp afr -----1-----1--- 1010
43 Aca tor -----241-----31267- 10110
32 Aca kar -----1-----12-2--756552 10111
37 Aca caf -----3----- 10111
45 Euc div -----3----- 10111
47 Ole afr -----6----- 10111
20 Ziz muc 52-3-257--2-2-----5-----32-3--5271 11

00000000000000000000000000000000000000000000000000001111111
000000000000000000000000000000000000000000000000000001111111111111111000001
000000000011111111111111111111111111111110000000000000111001111
00011111110000000000000000000000000000000000000000000111111100001111111
  00011101111111111111111111110000111  00000011  0000011
 0000000111111111  000011
    
```

The process of plant community identification constituted of 3 divisions. In a first division, 2 groups were separated. A first group with 6 relevés belonging to the *Acacia karroo*_ *Acacia tortilis*_ *Ziziphus mucronata* plant community, and a second one with the remainder of the relevés. In a second division the remaining relevés were divided again in two groups, separating 14 relevés that corresponded with the plant community *Dichrostachys cinerea*_ *Combretum apiculatum*_ *Grewia bicolor*. In a third division it

was possible to identify two others plant communities corresponding to *Terminalia sericea*_ *Grewia retinervis*_ *Dichrostachys cinerea* (24 relevés) and *Grewia flava*_ *Grewia retinervis*_ *Acacia mellifera* (9 relevés) (Figure 4-1).

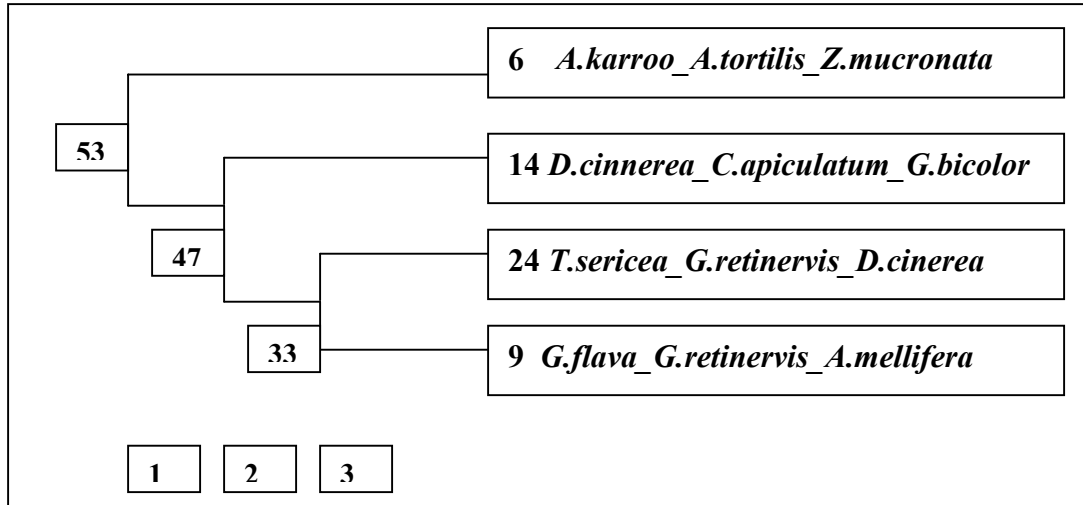


Figure 4-1 Divisive classification of the 53 relevés into 4 main plant communities using TWINSpan. Numbers in the bottom represent the TWINSpan runs. Numbers in the dendrogram indicate the total number of relevés used in each run. Numbers in each community box indicate the number of classified relevés.

When analyzing this dendrogram it can be observed that 11% of plots surveyed corresponded to the first plant community, 26% to the second, 45% to the third and 17% to the fourth plant community. This vegetation clustering was used as a basis to make a “plant community map” based on floristic composition for each of the landscapes present in the study area using the available images from the three types of sensors.

4.3 VEGETATION CLUSTERING ACCORDING TO STRUCTURE

Structure refers to the physical characteristics of vegetation, such as height, crown cover, and spacing between plants. It permits to group the vegetation in classes, which are known as “formations”. Taking into account this concept and using the system adopted by the Kenya Soil Survey (see chapter 3) the plots surveyed in the field were grouped into 10 main classes. These were:

Classes	Definition
B	Bushland
BG	Grassy Bushland

BW	Wooded Bushland
BWd	Dense Wooded Bushland
BWG	Grassy Wooded Bushland
F	Forest
W	Woodland
WB	Bushy Woodland
Wd	Dense Woodland
WG	Grassy Woodland

From Table 4-2 it can be observed that 45% of the sample plots was covered by Bushland of some kind and 42% by Woodland of some kind. The remaining sample plots were classified as Forest formation. This vegetation clustering was used as a basis to make a map based on vegetation structure for each of the landscapes present in the study area using the available images from the three types of sensors.

Table 4-2 Percent of relevés clustered in each class

Class	Relevés	%	Class	Relevés	%
B	2	4	W	7	13
BG	3	6	WB	1	2
BW	12	23	Wd	11	21
BWd	4	8	WG	3	6
BWG	2	4	Total	53	100
F	8	15			

4.4 CLASSIFICATION OF LANDSAT TM IMAGE

4.4.1 Use of floristic approach

Through classification of the Landsat TM image using NIR, Red and Green bands, the four plant communities identified with help of TWINSpan were mapped (Figure 4-2). The four plant communities were found to be present in each of the three landscapes types. The map shows that the plant community occurring most in the area is *T.sericea_G.retinervis_D.cinerea* with 59% of the area covered, followed by *G.flava_G.retinervis_A.mellifera* (20%) and *D.cinerea_C.apiculatum_G.bicolor* (12%). The plant community poorest in cover, with 5% of the area, is *A.karoo_A.tortilis_Z.mucronata*. In absolute terms (% of total study area) most of the *T.sericea_G.retinervis_D.cinerea* plant community can be found in the Sandveld area. Most of the *D.cinerea_C.apiculatum_G.bicolor* and *A.karoo_A.tortilis_Z.mucronata* plant communities, however, can be found in the Hardveld area, whereas the *G.flava_G.retinervis_A.mellifera* plant community was more or less equally represented in all three landscapes.

Chapter 4. Results

Analyzing the three landscapes, we can see that the Sandveld area is the most un-balanced in terms of occurrence of the different plant communities, with a very strong dominance by *T.sericea_G.retinervis_D.cinerea*. This dominance diminishes going towards the Escarpment and Hardveld areas, with in the latter area the *D.cinerea_C.apiculatum_G.bicolor* and *G.flava_G.retinervis_A.mellifera* plant communities becoming almost as dominant as *T.sericea_G.retinervis_D.cinerea* (Table 4-3).

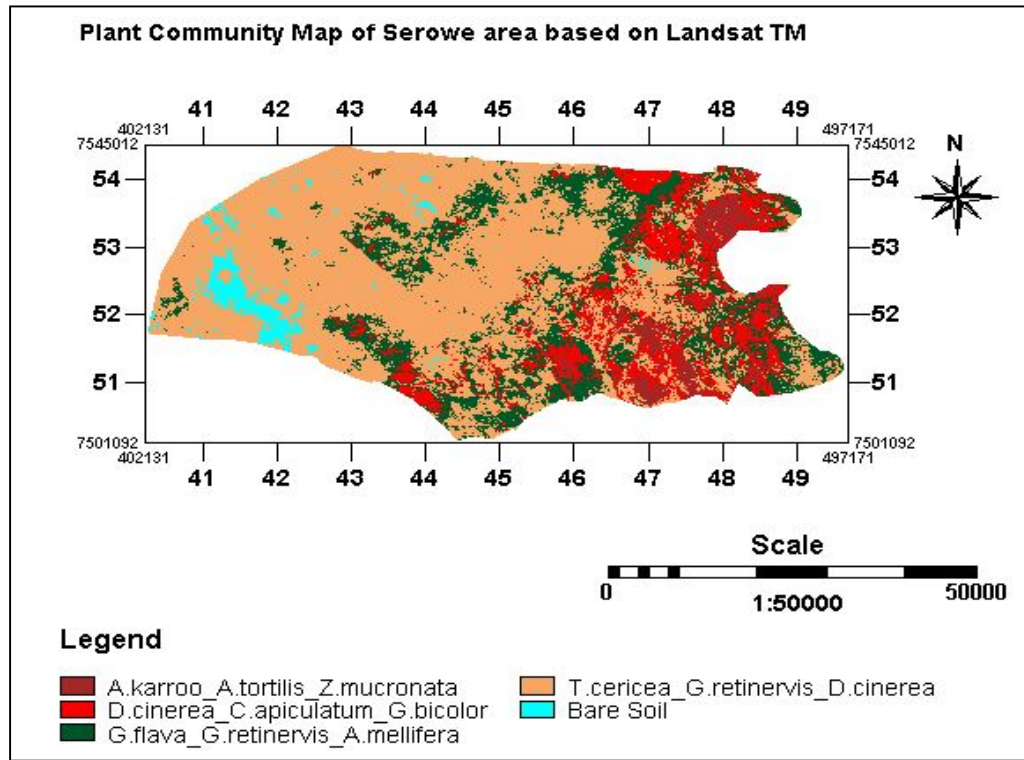


Figure 4-2 Plant Community Map of Serowe area derived from Landsat TM satellite image (bands 4,3,2 false color composite) based on floristic composition.

Table 4-3 Cover percent of each plant community and their distribution in the different landscapes types found when using Landsat TM image and the floristic approach.

Plant Community/Landscape	Sandveld	%	Escarpment	%	Hardveld	%	total
<i>T.sericea_G.retinervis_D.cinerea</i>	39.43	79.71	10.48	50.10	9.42	31.82	59.33
<i>D.cinerea_C.apiculatum_G.bicolor</i>	0.75	1.52	4.20	20.05	7.40	25.01	12.35
Bare Soil	2.90	5.86	0.12	0.58	0.01	0.02	3.03
<i>A.karoo_A.tortilis_Z.mucronata</i>	0.01	0.01	1.06	5.05	3.94	13.30	5.00
<i>G.flava_G.retinervis_A.mellifera</i>	6.38	12.90	5.07	24.23	8.84	29.85	20.29
Total	49.47	100.00	20.92	100.00	29.61	100.00	100.00

4.4.2 Use of structure approach

On the Landsat image it was only possible to distinguish six out of the 10 classes found during the field survey, namely: *Wooded Bushland*, *Grassy Bushland*, *Forest*, *Bushland*, *Dense Woodland* and *Woodland*. (Figure 4-3). Analyzing the map and Table 4-4, it can be observed that the study area is mainly covered by *Wooded Bushland* (49%). This vegetation cover is especially dominant in the Sandveld area of which it covers 69%. *Woodland* (18%) is the second most dominant vegetation cover in the study area. It is especially dominant in the Hardveld area of which it covers 31%. It is even more dominant here than *Wooded Bushland*. *Forest*, *Bushland* and *Dense Woodland* are almost equally represented in the study area covering approximately 10% of the total area each. *Grassy Bushland* is the vegetation type with the lowest cover (3%). It is basically only present in the Sandveld area. In general and in relative term (% of area covered by landscape type) one can observe a decrease of *Wooded Bushland* going from Sandveld to Hardveld and an opposite trend for *Woodland*, which increases going from Sandveld to Hardveld.

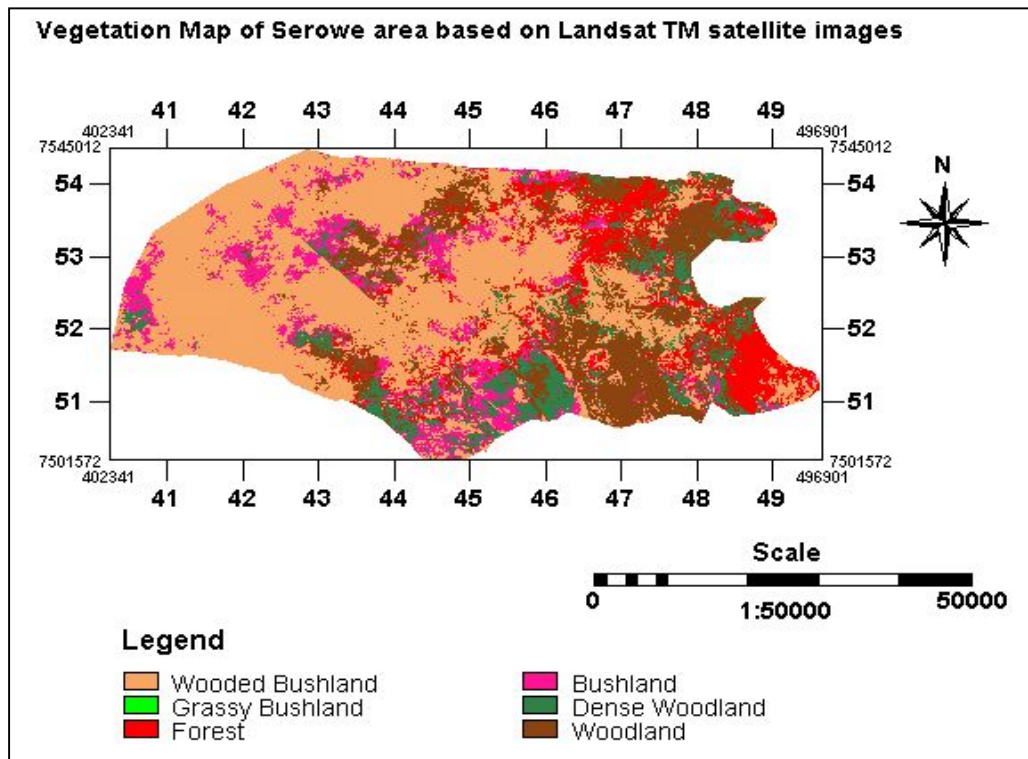


Figure 4-3 Vegetation Map of Serowe area derived from Landsat TM satellite image (bands 4,3,2 false color composite) based on vegetation structure.

Table 4-4 Cover percent of each class and their distribution in the different landscapes types found when using Landsat TM images and the vegetation structure approach.

Class/Landscape	Sandveld	%	Escarpment	%	Hardveld	%	total
Wooded Bushland	34.25	69.24	9.08	43.38	6.14	20.75	49.47
Grassy Bushland	0.03	0.06	0.00	0.00	0.00	0.00	0.03
Forest	1.68	3.40	4.12	19.67	5.25	17.72	11.05
Bushland	6.71	13.57	1.54	7.37	2.99	10.09	11.24
Dense Woodland	1.32	2.68	2.21	10.58	6.04	20.39	9.58
Woodland	5.47	11.05	3.98	19.00	9.19	31.04	18.64
Total	49.47	100.00	20.92	100.00	29.61	100.00	100.00

4.5 CLASSIFICATION OF ASTER IMAGE

4.5.1 Use of floristic approach

The vegetation map obtained using the ASTER image and using the floristic approach shows the same four plant communities that were identified in the Landsat TM image and previously clustered by TWINSpan (Figure 4-4).

Also here the plant community *T.sericea_G.retinervis_D.cinerea* turned out to be the most prominent with 59% of the total cover. About half the area of this plant community can be found in the Sandveld area, with the other half almost equally distributed over the Escarpment area and the Hardveld area. Contrary to the Landsat TM image, using the Aster image *A.karoo_A.tortilis_Z.mucronata* came out as the second most prominent plant community in the study area (with 20% of total cover). This plant community is well represented in the Escarpment area and the Hardveld area, but less pronounced in the Sandveld area. The other two plant communities occur in roughly equal measure, both covering approximately 9% of the total study area.

Analysis of the three landscapes shows that the Sandveld area is heavily dominated by the plant community of *T.sericea_G.retinervis_D.cinerea* (covering 84% of the area). Dominance of this plant community decreases going towards the Escarpment area and the Hardveld area. The latter two areas in this respect show a more mixed vegetation than the Sandveld area. The *G.flava_G.retinervis_A.mellifera* plant community is most prominently present in the Hardveld area (Table 4-5).

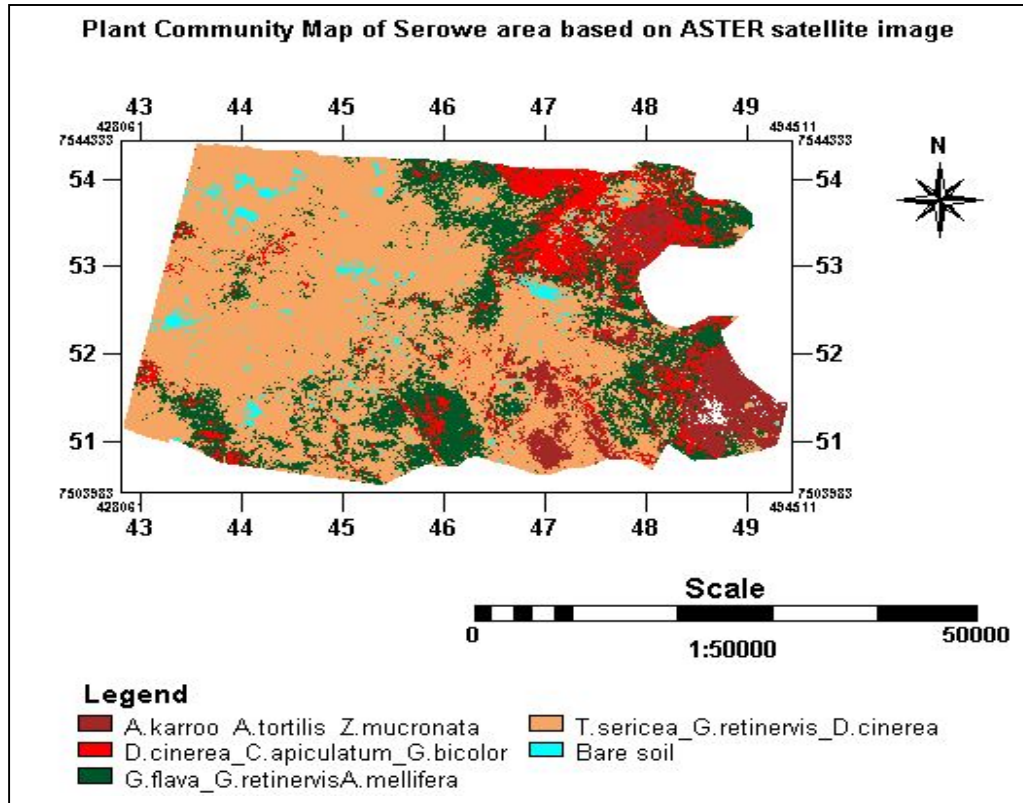


Figure 4-4 Plant Community Map of Serowe area derived from ASTER satellite image (bands 3,2,1 false color composite) based on floristic composition.

Table 4-5 Cover percent of each plant community and their distribution in the different landscapes types found when using ASTER images and the floristic approach.

Plant Community/Landscape	Sandveld	%	Escarpment	%	Hardveld	%	total
Bare Soil	1.11	3.34	0.82	2.85	0.22	0.57	2.15
T.sericea_G.retinerivis_D.cinerea	27.80	83.38	15.32	53.58	15.95	41.90	59.07
D.cinerea_C.apiculatum_G.bicolor	0.87	2.61	4.95	17.33	3.81	10.02	9.64
A.karroo_A.tortilis_Z.mucronata	3.48	10.43	6.30	22.04	10.80	28.37	20.58
G.flava_G.retinerivis_A.mellifera	0.08	0.24	1.20	4.20	7.28	19.14	8.57
Total	33.34	100.00	28.59	100.00	38.07	100.00	100.00

4.5.2 Use of structure approach

The use of the ASTER image with the structure approach resulted in a map with 6 classes: *Wooded Bushland*, *Dense Wooded Bushland*, *Forest*, *Dense Woodland*, *Woodland* and *Grassy Woodland* (Figure 4-5). *Wooded Bushland*, with 39% of the total area, is thereby the most prominent vegetation type in the study area, with most of it found in the Sandveld area, followed by the Escarpment area and the Hardveld area. *Dense Bushed Woodland* is the second largest vegetation type in the study area, covering 29% of the total cover and with approximately equal representation in the Sandveld and the Hardveld area and a somewhat smaller representation in the Escarpment area. The Escarpment area and the Hardveld area show a more mixed vegetation configuration than the Sandveld area. (Table 4-6).

Interesting to note here is that both with the Landsat TM image as well as the ASTER image six different vegetation classes are distinguished, but that these six classes are not the same. *Wooded Bushland*, *Forest*, *Dense Woodland* and *Woodland* can be distinguished on both images, whereas *Grassy Bushland* and *Bushland* are “exclusive” for the Landsat TM image and *Dense Wooded Bushland* and *Grassy Woodland* are “exclusive” for the ASTER image.

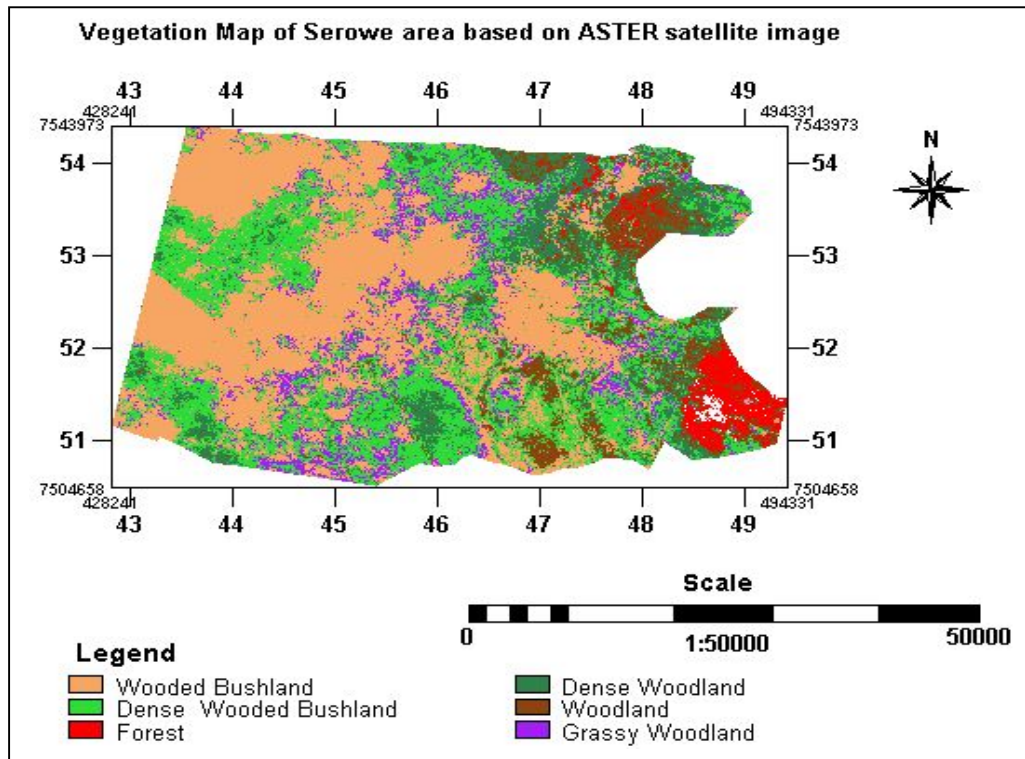


Figure 4-5 Vegetation Map of Serowe area derived from ASTER satellite image (bands 3,2,1 false color composite) based on vegetation structure.

Table 4-6 Cover percent of each vegetation class and their distribution in the different landscapes types found when using ASTER images and the structure approach.

Class/Landscape	Sandveld	%	Escarpment	%	Hardveld	%	total
Wooded Bushland	19.42	58.23	11.58	40.52	8.52	22.37	39.52
Dense Wooded Bushland	10.40	31.20	6.36	22.26	12.56	33.00	29.33
Forest	0.00	0.00	0.68	2.37	2.81	7.37	3.49
Dense Woodland	1.27	3.81	5.08	17.76	5.70	14.98	12.05
Woodland	0.12	0.36	1.45	5.06	4.73	12.42	6.30
Grassy Woodland	2.13	6.39	3.44	12.03	3.75	9.86	9.32
Total	33.34	100.00	28.59	100.00	38.07	100.00	100.00

4.6 CLASSIFICATION OF IKONOS IMAGES

4.6.1 Use of floristic approach

The IKONOS image only covered part of the study area (100 km²) located in the Sandveld region. In this case it was not possible to classify the images according to the floristic approach because all the relevés surveyed in this area were clustered in the same plant community when analyzing the data collected with regard to species composition.

4.6.2 Use of structure approach

The IKONOS image used in this study was not of the best quality with around 25 % cloud cover and haze. As a result of this almost all sample plots in this area were not or only poorly visible. It was therefore only possible to do a visual classification. As compared to the Landsat TM image and the ASTER image, it was only possible to identify 4 vegetation cover classes, plus “bare soil” as an additional class. Using the IKONOS image *Grassland* was differentiated as a new class. Other classes were: *Dense Bushland*, *Bushland* and *Woodland* (Figure 4-6).

From Table 4-7 it can be observed that the vegetation class, which is most present in the IKONOS study area is *Dense Bushland* with 47% of the total area, followed by *Bushland* with 41%.

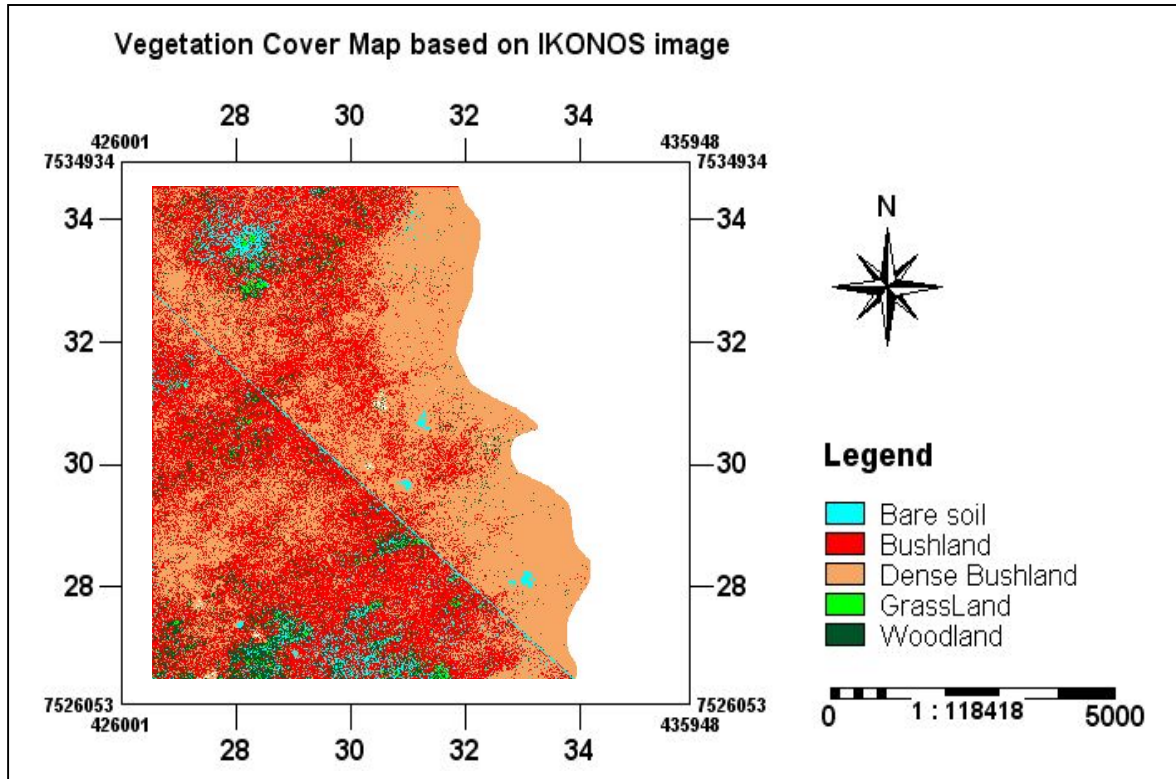


Figure 4-6 Vegetation Map of Serowe area based on IKONOS satellite image (bands 4,3,2 false color composite) using the structure of the vegetation.

Table 4-7 Cover percent of each vegetation class and their distribution in the different landscapes types found when using IKONOS images and the structure approach.

Class/Landscape	Sandveld
Bare soil	4.22
Bushland	41.36
Dense Bushland	46.72
GrassLand	1.01
Woodland	6.68
Total	100

4.7 ACCURACY EVALUATION.

An accuracy assessment was carried out to find out how reliable the classification of the different images into vegetation cover maps was. The results are shown below. In case of IKONOS, no accuracy assessment was done because visual interpretation was done with ground truth data of poor quality.

4.7.1 Using Floristic approach

4.7.1.1 Confusion Matrix and Kappa Statistic for vegetation map based on Landsat TM

Classes:

- A=> *T.sericea_G.retinervis_D.cinerea* plant community
- B=> *D.cinerea_C.apiculatum_G.bicolor* plant community
- C=> Bare Soil
- D=> *A.karoo_A.tortilis_Z.mucronata* plant community
- E=> *G.flava_G.retinervis_A.mellifera* plant community

Table 4-8 Confusion Matrix for Landsat TM Vegetation Community Map (VCM).

	A	B	C	D	E	UNC	ACC	Total
A	132	31	0	0	84	0	0.53	247
B	35	32	0	0	28	0	0.34	95
C	0	0	595	0	0	0	1	595
D	3	5	0	86	16	0	0.78	110
E	7	1	0	0	52	0	0.87	60
RELIABILITY	0.75	0.46	1	1	0.29			
Total	177	69	595	86	180			1107
Average Accuracy = 70.39 %								
Average Reliability = 69.97 %								
Overall Accuracy = 81.03 %								

With the above matrix as an example, the main calculations carried out to arrive at the accuracy evaluation are shown below.

Calculations:

Accuracy per class (AC):

$$AC \text{ (class A)} = (132/247)*100 = 53.4 \%$$

$$AC \text{ (class B)} = (32/95)*100 = 34.0 \%$$

Reliability per class (RE/CL):

$$RE/CL \text{ (class A)} = (132/177)*100 = 75\%$$

Overall Accuracy (OA):

$$OA = \frac{132 + 32 + 595 + 86 + 52}{1107} * 100 = 81\%$$

Analysis of the above confusion matrix shows that average reliability was 69.97%. Classes E (29%) and B (46%) were the ones worst classified in the process. It means that 71% and 54% of these classes respectively were omitted. Pixels wrongly classified in class E were instead classified as class A (46%), B (15%) and D (8%). Pixels wrongly classified in class B were instead mainly classified as class A (45%). The user accuracy was found to be slightly higher than the producer accuracy with 70.39%. Here the worst classified classes were A (0.53%) (34% was classified as class E and 12% as class B) and B (0.34%) (37% was classified as class A and 29% as class E) (Table 4-8). The overall accuracy of the classification process (correctly classified pixels) was 81% and agreement between classes oscillated around 0.7.

Subsequently the Kappa Statistic value (explained in chapter 3) was calculated. After that the ‘Z’ test was done using a 95% confidence level.

Table 4-9 Proportion of each class used in the calculation of Var(K) for Landsat TM VCM.

Proportion	A	B	C	D	E	Sum
P_j	0.1599	0.0623	0.5375	0.0777	0.1626	1.0000
P_j³	0.0041	0.0002	0.1553	0.0005	0.0043	0.1644

Proportion of correctly classified pixels (Po):

$$P_o = \frac{132 + 32 + 595 + 86 + 52}{1107} = 0.810298$$

Proportion of correctly classified pixels expected by chance (Pe):

$$P_e = \frac{(132 * 247) + (32 * 95) + (595 * 595) + (86 * 110) + (52 * 60)}{1107 * 1107} = 0.328246$$

Kappa Statistic:

$$K = \frac{0.810298 - 0.328246}{1 - 0.328246} = 0.717601$$

VARIANCE (VAR (K)):

$$Var(K) = \frac{2}{5 * 5(5-1)} * \frac{0.328246 - (2 * 5 - 3) / (0.328246)^2 + 2(5-2)0.1644}{(1 - 0.328246)^2}$$

$$Var(K) = 0.0248$$

'Z' test:

$$Z = \frac{0.717601}{\sqrt{0.024839}} = 4.5531$$

Summary:

Pe	0.3283
Po	0.8103
K	0.7176
Var(K)	0.0248
Z	4.5531

From the “standard normal probabilities” table (using Z=4.5531) it can be read that P<0.0004. Therefore the null hypothesis (Ho: K=0) is rejected: Kappa is not equal to 0. In other words: the results presented in the Confusion Matrix are significantly better than a random result (Z = 4.5531, P<0.0004).

4.7.1.2 Confusion Matrix and Kappa Statistic for ASTER vegetation map

Classes:

A=> Bare soil

B=> T.sericea_G.retinervis_D.cinerea plant community

C=> D.cinerea_C.apiculatum_G.bicolor plant community

D=> G.flava_G.retinervis_A.mellifera plant community

E=> A.karoo_A.tortilis_Z.mucronata plant community

Table 4-10 Confusion Matrix for ASTER Vegetation Community Map (VCM).

	A	B	C	D	E	UNC	ACC	Total
A	140	4	0	0	0	0	0.97	144
B	0	37	14	13	4	0	0.54	68
C	0	0	115	10	0	0	0.92	125
D	0	10	0	64	0	0	0.86	74
E	0	3	9	2	64	0	0.82	78
RELIABILITY	1	0.69	0.83	0.72	0.94			
Total	140	54	138	89	68			489

Average Accuracy = 82.43 %
 Average Reliability = 83.58 %
 Overall Accuracy = 85.89 %

Table 4-11 Proportion of each class used in the calculation of Var(K) for ASTER VCM.

Proportion	A	B	C	D	E	Sum
P _j	0.2863	0.1104	0.2822	0.1820	0.1391	1.0000
P _j ³	0.0235	0.0013	0.0225	0.0060	0.0027	0.0560

Summary

Pe	0.2215
Po	0.8589
K	0.8187
Var(K)	0.0047
Z	11.8993

Chapter 4. Results

When analyzing the confusion matrix for the ASTER-derived plant community map, it can be seen that average accuracy, average reliability and overall accuracy are all better than with Landsat TM. The class worst classified here is class B (69%). Pixels in this class wrongly classified were instead classified mainly as class D (18%).

Analyzing the average accuracy (82%) it was found that the major problem was also in class B (only 54% rightly classified). Here the wrongly classified pixels were mainly added to class C (20%) and D (19%) (Table 4-10). Kappa is almost 0.82 and the result of the Z test shows that the results presented in the confusion matrix are significantly better (using 95% confidence interval) than random results ($Z=11.8993$, $P<0.0004$).

4.7.2 Using Structure approach

4.7.2.1 Confusion Matrix and Kappa Statistic for Landsat TM vegetation map

Classes:

A=> Wooded Bushland

B=> Grassy Bushland

C=> Forest

D=> Bushland

E=> Dense Woodland

F=> Woodland

Table 4-12 Confusion Matrix for Landsat TM following a Structural Vegetation Classification (SVC).

	A	B	C	D	E	F	UNC	ACC	Total
A	35	4	2	5	0	6	0	0.67	52
B	0	9	1	9	0	6	0	0.36	25
C	0	0	33	0	3	1	0	0.89	37
D	0	0	0	18	0	0	0	1	18
E	0	0	2	0	36	1	0	0.92	39
F	1	0	0	0	9	52	0	0.84	62
RELIABILITY	0.97	0.69	0.87	0.56	0.75	0.79			
Total	36	13	38	32	48	66			233
Average Accuracy = 78.11 %									
Average Reliability = 77.22 %									
Overall Accuracy = 78.54 %									

Table 4-13 Proportion of each class used in the calculation of Var(K) for Landsat TM following SVC.

Proportion	A	B	C	D	E	F	Sum
P_j	0.1545	0.0558	0.1631	0.1373	0.2060	0.2833	1.0000
P_j^3	0.0037	0.0002	0.0043	0.0026	0.0087	0.0227	0.0423

Summary

Pe	0.1868
Po	0.7854
K	0.7361
Var(K)	0.0035
Z	12.3691

The classification of the vegetation using the structure approach and Landsat TM shows a low overall accuracy (78%). Average reliability was 77%. This was mainly caused by low accuracy in class D (56%). The misclassified pixels (44%) were mainly classified as class B (28%). Average accuracy was a little bit higher (78%) than average reliability. This was most heavily influenced by the accuracy in class B (36%). In this case the misclassified pixels were mainly related to class D (36%) and class F (24%) (Table 4-12). On the other hand, Kappa was good (0.73) and the Z test proved that the results in the error matrix were better than random results ($Z=12.3691$, $P<0.0004$).

4.7.2.2 Confusion Matrix and Kappa Statistic for ASTER vegetation map

Classes:

- A=> Wooded Bushland
- B=> Dense Wooded Bushland
- C=> Forest
- D=> Dense Woodland
- E=> Woodland
- F=> Grassy Woodland

Table 4-14 Confusion Matrix for ASTER following a Structural Vegetation Classification (SVC)

	A	B	C	D	E	F	UNC	ACC	Total
A	37	14	0	1	0	3	0	0.67	55
B	0	65	0	2	0	1	0	0.96	68
C	0	8	91	9	0	0	0	0.84	108
D	0	7	0	77	10	0	0	0.82	94
E	2	2	0	4	45	2	0	0.82	55
F	9	0	0	0	0	49	0	0.84	58
RELIABILITY	0.77	0.68	1	0.83	0.82	0.89			
Total	48	96	91	93	55	55			438

Average Accuracy = 82.56 %
Average Reliability = 83.08 %
Overall Accuracy = 83.11 %

Table 4-15 Proportion of each class used in the calculation of Var(K) for ASTER following SVC.

Proportion	A	B	C	D	E	F	Sum
P _j	0.1096	0.2192	0.2078	0.2123	0.1256	0.1256	1.0000
P _j ³	0.0013	0.0105	0.0090	0.0096	0.0020	0.0324	0.0324

Summary

Pe	0.1770
Po	0.8311
K	0.7947
Var(K)	0.0025
Z	15.8116

Using ASTER together with the structure approach gives a confusion matrix that shows a good overall accuracy (83%). Average reliability is also 83%, with the biggest error occurring with classification of class B (68%). Average accuracy was also high (82%). Here the largest proportion of misclassified pixels were found when classifying class A (67%) (Table 4-14). These results are also reflected in Kappa (0.79). Also the Z test shows that the error matrix data are adequate (Z=15.8116, P<0.0004).

4.7.3 Comparison among the different Error Matrices according to the classification approach and the sensor

After the different confusion matrices were obtained, a comparison between classification approaches and between sensors was carried out. In this stage also IKONOS data was not evaluated.

4.7.3.1 Comparison according to classification approach

4.7.3.1.1 Error Matrices from Landsat TM vegetation maps

Table 4-16 Comparative matrix for the use of both approach in Landsat TM.

Approach	Kappa	Variance	Z Statistic
Floristic	0.7176	0.0248	4.5531
Structure	0.7361	0.0035	12.3691
Comparison	Z Statistic	Result ^a	
Floristic vs. structure	-0.86	NS	

^a At the 95% confidence level
^b S = significant, NS = not significant

In the process of matrices comparison also a Z test was used to determine whether the results of the two error matrices were significantly different from each other. For this the following formula given by Skidmore (1999) was applied.

$$Z = \frac{K_{(flor)} - K_{(struct)}}{\sqrt{V_{(flor.)} - V_{(Struct)}}} = \frac{0.7176 - 0.7361}{\sqrt{0.0248 - 0.0035}} = \frac{-0.0185}{0.0213} = -0.86$$

The test shows that when using Landsat TM, the results obtained with the two approaches were not significantly different at 95% confidence level. The null hypothesis ($K_{(flor)} = K_{(struct.)}$) is accepted ($Z = -0.86$, $P > 0.05$) (Table 4-16). In this case the test result confirms that the obtained accuracy when doing vegetation mapping using structure and floristic approach using this sensor are quite similar.

4.7.3.1.2 Error Matrices from ASTER vegetation maps

Table 4-17 Comparative matrix for the use of both approach in ASTER.

Approach	Kappa	Variance	Z Statistic
Floristic	0.8187	0.0047	11.8993
Structure	0.7947	0.0025	15.8116
Comparison	Z Statistic	Result ^a	
Floristic vs. structure	10.9090	S	

^a At the 95% confidence level

$$Z = 10.9090$$

The results show that when using ASTER, the two approaches are significantly different in accuracy at 95% confidence level ($Z \sim 10.9090$, $P < 0.05$) (Table 4-17). It also demonstrates that with this sensor the floristic approach was better than the structure approach for vegetation mapping.

4.7.3.1.3 Comparison between sensors according to floristic approach

Table 4-18 Sensors comparative matrix according to the use of floristic approach.

Sensor	Kappa	Variance	Z Statistic
Landsat TM	0.7176	0.0248	4.5531
ASTER	0.8187	0.0047	15.8116
Comparison	Z Statistic	Result ^a	
Floristic approach	-5.0298	S	

^a At the 95% confidence level
^b S = significant, NS = not significant

$$Z = -5.0298$$

The results show that Landsat TM and ASTER show significantly different accuracies at 95% confidence level using the floristic approach ($Z \sim -5.0298$, $P < 0.05$) (Table 4-18). It reaffirms what already seems obvious when looking at the confusion matrix results. The ASTER vegetation community map was more accurate than the Landsat TM vegetation community map.

4.7.3.1.4 Comparison between sensors according to structure approach

Table 4-19 Sensors comparative matrix according to the use of structure approach.

Sensor	Kappa	Variance	Z Statistic
Landsat TM	0.7361	0.0035	12.3691
ASTER	0.7947	0.0025	15.8116
Comparison	Z Statistic	Result ^a	
Structure approach	-58.6000	S	

^a At the 95% confidence level
^b S = significant, NS = not significant

$Z = -58.6000$

The results show that Landsat TM and ASTER show significantly different accuracies at 95% confidence level using the structure approach ($Z \sim -58.6000$, $P < 0.05$) (Table 4-19). The comparative table shows that also using this type of approach the vegetation map based on the ASTER image classification is better than the one obtained using the Landsat TM image.

4.8 RELATIONSHIP BETWEEN VEGETATION, ENVIRONMENTAL FACTORS AND SENSOR BANDS

4.8.1 Indirect gradient analysis for species coverage (using DCA)

As a first step in Indirect Gradient Analysis (see chapter 3) the species data were organized in an ordination diagram (figure 4-7). Analyzing the diagram in a general way it can be noted that the first axis (the horizontal axis) shows 7 standard deviations. This means that the sites at opposite ends of the first axis have hardly any species in common, which means that there is likely to be a strong environmental gradient across the sites. The diagram also shows that the sample set was representative. The software-output also showed that the two first axes explain 92% of the species variance.

Groups of species at the extreme ends of both axes were further analyzed in an attempt to explain the species ordination diagram with environmental factors. From this analysis it seems that the patterns shown are related to the environmental variables soil type (correlated to the first axis) and soil texture

(correlated to the second axis). The pattern in the first axis, related to soil type, could be explained by the position of the species *A. karroo* and *A. tortilis* at the extreme right of the graph associated with S_Vre11 soil type and by *S. longepedunculata*, *A. fleckii* and *O. pulchra* at the left side of the graph associated with S_Aro21 soil type. The pattern in the second axis, related to soil texture, could be explained by the position of the species *A. mellifera* and *B. albitrunca* in the upper part of the diagram associated with sandy soil and *A. erubescens* and *L. javanica* in the lower part of the diagram associated with clayey soil. Taking the above into consideration, it was decided to use the uni-modal method CCA for further data analysis because a linear method would not be appropriate, because the data-set was too heterogeneous and deviated too much from the assumed model of linear response (Leps & Smilauer, 1999).

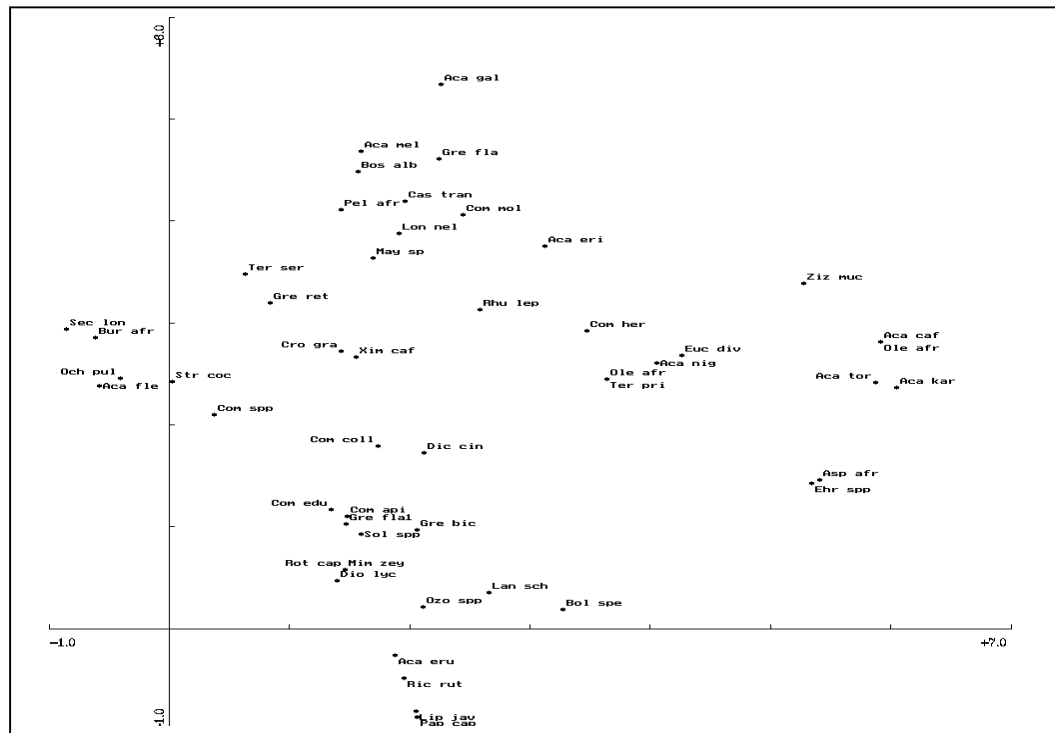


Figure 4-7 DCA ordination diagram for the species composition in the Serowe region.

4.8.2 Direct gradient analysis (using CCA and DCCA)

4.8.2.1 Relationship between vegetation distribution and environmental factors

Figures 4-8 and 4-9 show the relationships between the environmental variables and the species respectively the sites. The software-output (using “eigenvalues” to explain variance within an axis) indicated a reasonably good separation among the species and the sites along both axes (“eigenvalue” for axis 1=0.736; “eigenvalue” for axis 2=0.534).

Chapter 4. Results

The software-output also indicated that the first two axes explain 17.5% of the total variation (inertia) in the data set. It also indicated that correlations between the first species axis and the first environmental factor axis as well as between the second species axis and the second environmental factor axis were highly significant (0.9599 respectively 0.9231) (Appendix 4).

Analyzing (see Appendix 4) the first species axis, it could be observed that the highest correlation coefficient between the first species axis and an environmental variable was obtained by soil type S_Vre11 (0.6515) and the second highest correlation by soil texture type Sandy (-0.6330). With regard to the second species axis, it could be observed that soil types S_Rge31 (0.4743) and S_Arl30 (-0.4700) had the highest correlation coefficients.

The software-output shows that the fourteen variables (7 soil types, 5 soil texture types, groundwater table depth and elevation) included in the analysis explained 44% of the total variance in the floristic data. This means that the remaining 56% is explained by other environmental variables, which were not analyzed (measured) in this research. Soil type data explain 18% of the overall variation in the floristic data, whereas soil texture type explains 14% (figure 4-10). Groundwater table depth and elevation show a collinear pattern (figure 4-11). Together these two variables only explain 3% of overall variation in the floristic data.

The “Monte Carlo Permutation Test” was significant at $P < 0.05$ for the first axis. This result indicates that the result of the canonical ordination analysis could not be obtained by chance only.

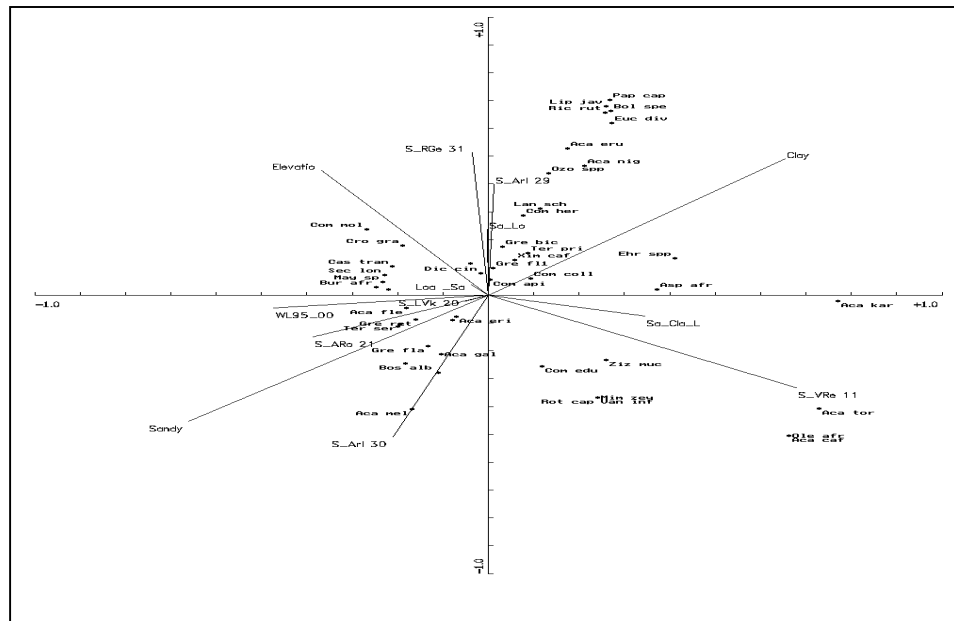


Figure 4-8 Ordination diagram based on CCA for species data of Serowe region.

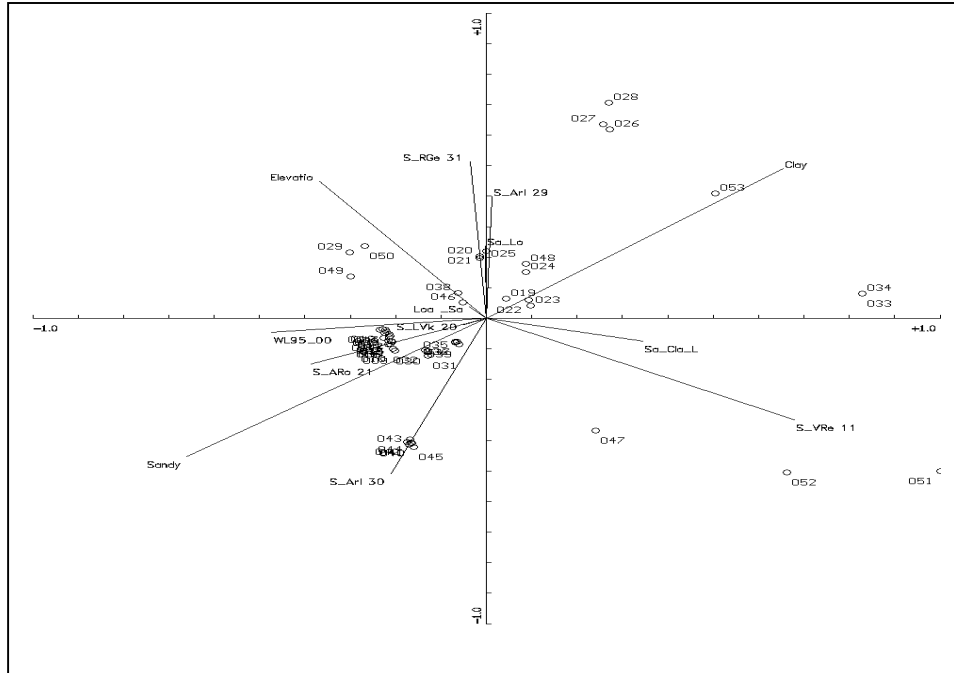


Figure 4-9 Ordination diagram based on CCA for sites data of Serowe region.

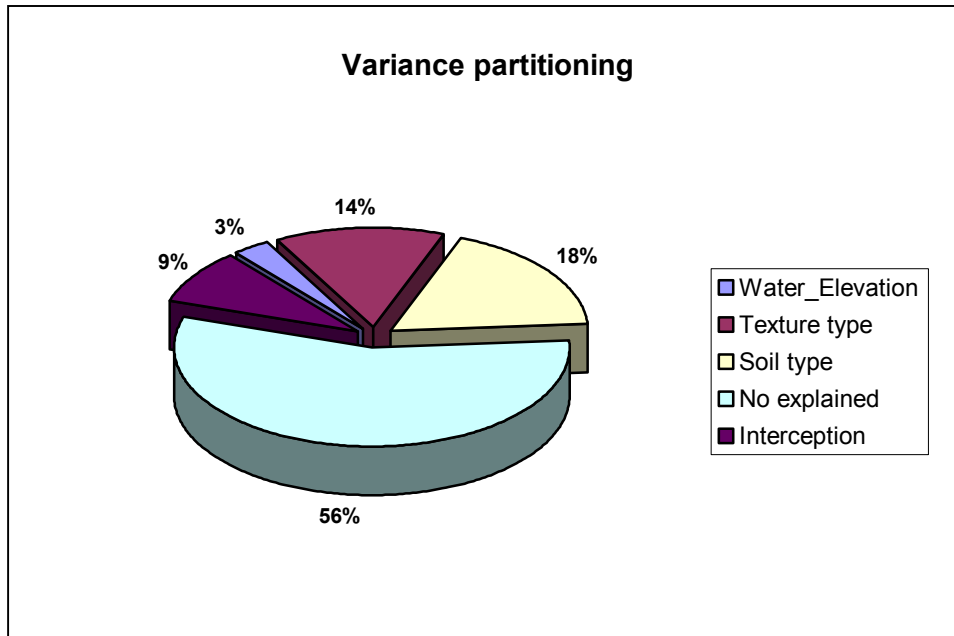


Figure 4-10 Percent of explained variance of floristic cover data by each environmental variable influencing in Serowe region.

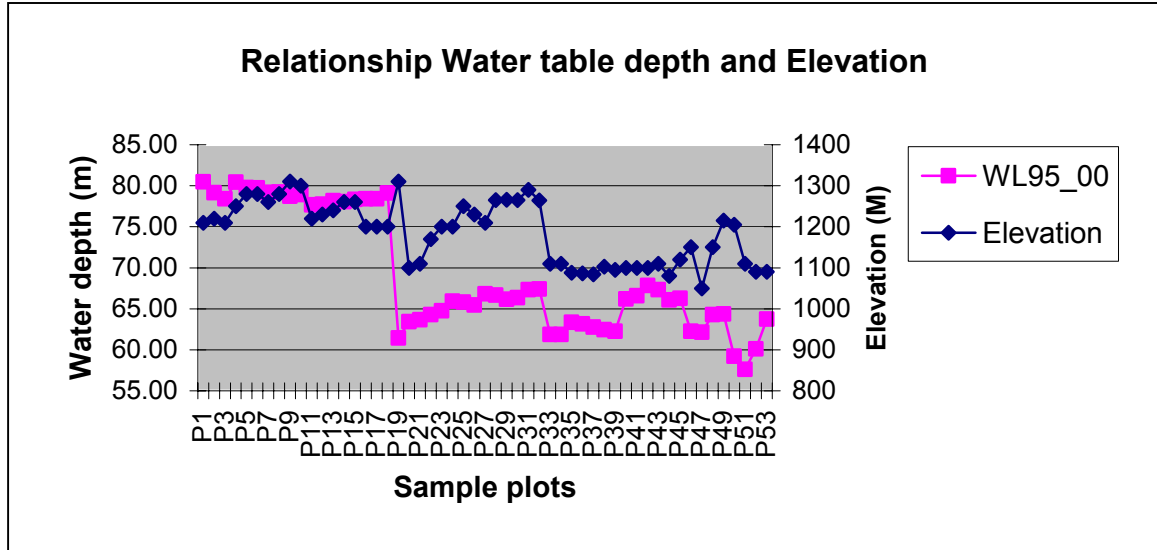


Figure 4-11 Relationship between Water table depth and Altitude for Serowe region.

4.8.2.2 Relationship between vegetation cover and sensor bands

In the analysis with the objective to find the correlation between sensor bands’ digital values and vegetation cover first CCA was applied. When the data were displayed in diagrams, an arch effect could be observed. In this case it was therefore advisable to use DCCA, which is a method that removes this problem through detrending by segments or polynomials. In this case detrending was done using a 2nd order polynomial. DCCA permitted to identify the main sensor bands related to the first two axes.

4.8.2.2.1 Relationship between vegetation cover and Landsat TM bands

Figures 4-12 and 4-13 show the relationship between species, sites and digital values of the different bands of Landsat TM. The software-output (using “eigenvalues” to explain variance within an axis) indicated a reasonably good separation among the species and the sites along both axes (“eigenvalue” for axis 1=0.490; “eigenvalue” for axis 2=0.306).

The software-output also shows that the first two axes account for 14% of the total variation in the species data. The correlation between the first species axis and the first sensor band axis was high (0.9274). Also correlation between the second species axis and the second sensor band axis was high (0.8863).

When analyzing the first species axis and its correlation with the different bands a strong negative correlation with TM5 (-0.6745) and TM7 (-0.5128) could be observed. The highest correlation with the second species axis was observed for TM3 (0.3439) (Appendix 6). The seven Landsat TM bands explained 22% of the total variance in the species data. The bands that contributed most to the explanation of the species data variation were TM3 (6%), TM5 (4%) and TM7 (4%) (Figure 4-14)

Chapter 4. Results

The “Monte Carlo Permutation Test” was significant at $P < 0.05$ for the first axis. This result indicates that the result of the canonical ordination analysis could not be obtained by chance only.

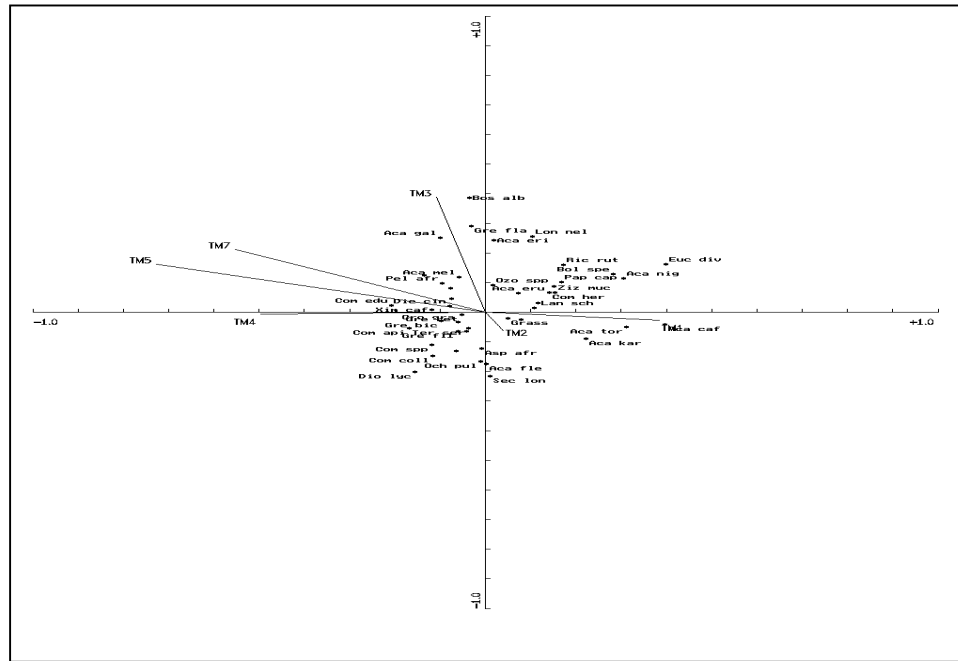


Figure 4-12 Ordination diagram based on DCCA showing the relationship among Landsat TM bands and species data of Serowe region.

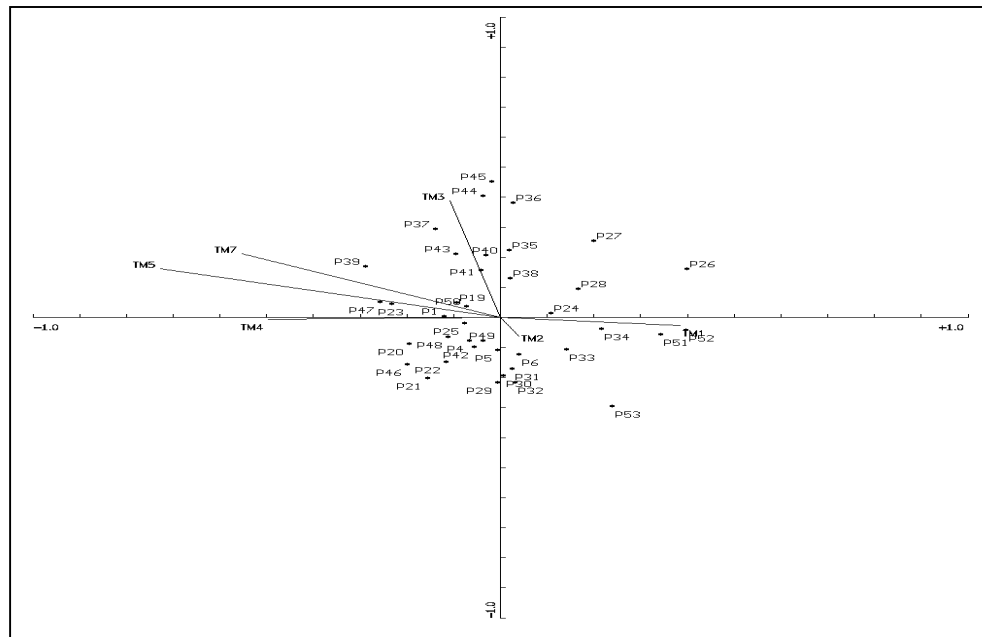


Figure 4-13 Ordination diagram based on DCCA showing the relationship among Landsat TM bands and sites of Serowe region.

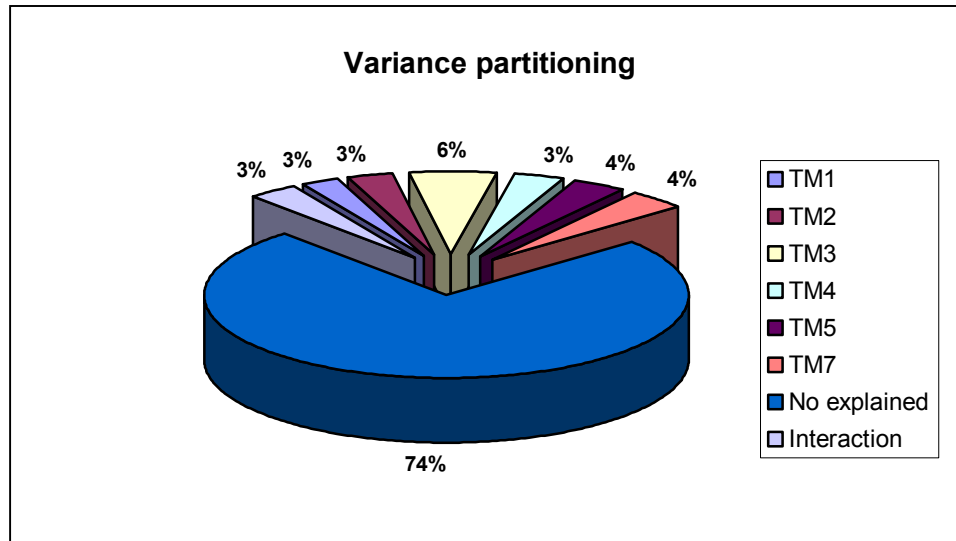


Figure 4-14 Variance or spread of species scores explained by each of the Landsat TM bands of Serowe region vegetation.

4.8.2.2.2 Relationship between vegetation cover and ASTER bands

The analysis for the ASTER image followed the same procedure as described above for the Landsat TM image.

Figures 4-15 and 4-16 show the relationship between species, sites and digital values of the different bands of ASTER. The software-output (using “eigenvalues” to explain variance within an axis) indicated a reasonably good separation among the species and the sites along both axes (“eigenvalue” for axis 1=0.517; “eigenvalue” for axis 2=0.387).

The software-output also shows that the first two axes account for 15% of the total variation in the species data. The correlation between the first species axis and the first sensor band axis was high (0.9216). Also correlation between the second species axis and the second sensor band axis was high (0.8714).

The software-output also shows that the highest correlation between the first species axis and sensor bands was observed for the AB4 band (-0.7138) and the AB9 band (-0.6167). For the second species axis best correlation was observed for the AB5 band (-0.2997) (Appendix 5). The nine ASTER bands explain 29% of the variance in the species data. The bands that contributed most to the explanation of this variation were AB3 (5%), AB9 (4%) and AB2 (4%). Bands like AB1, AB5 and AB9 contributed approximately 4% (Figure 4-17).

Chapter 4. Results

The “Monte Carlo permutation test” was significant for $P < 0.05$ for the first axis. This result indicates that the result of the canonical ordination analysis could not be obtained by chance only.

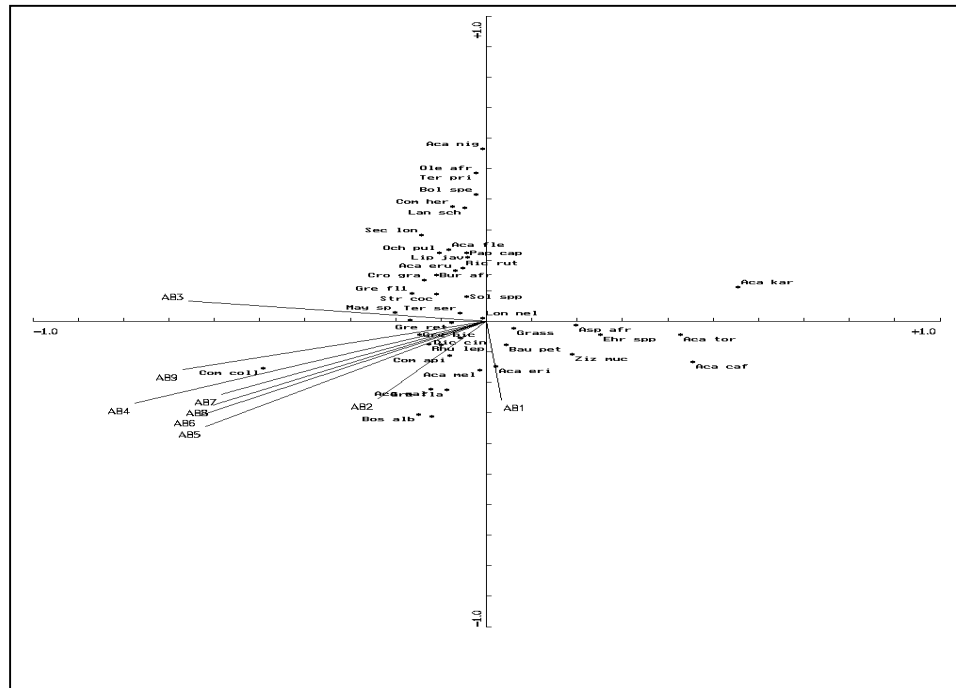


Figure 4-15 Ordination diagram based on DCCA showing the relationship among ASTER bands and species data of Serowe region.

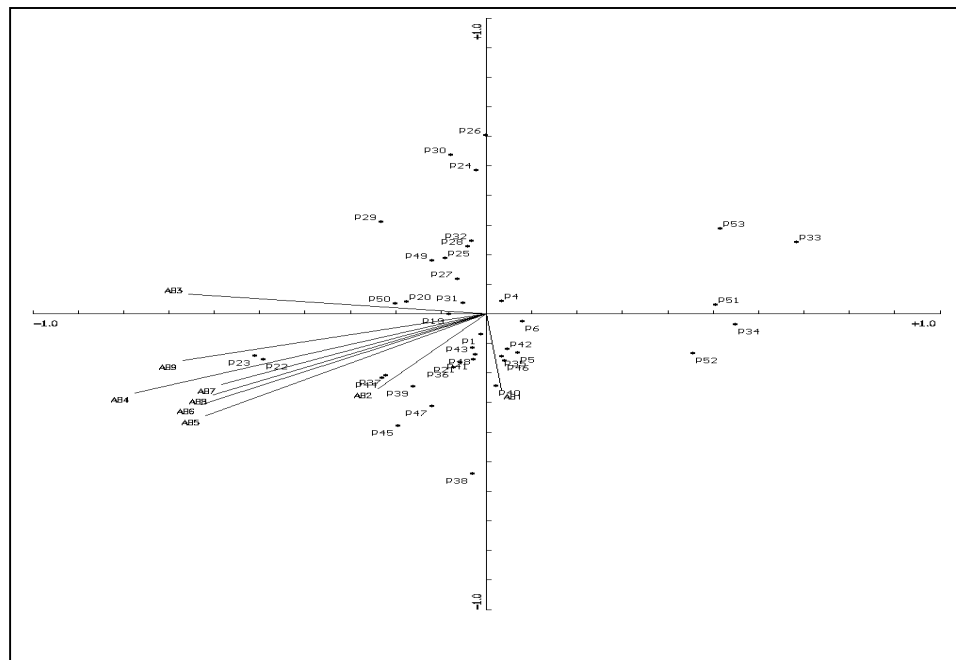


Figure 4-16 Ordination diagram based on DCCA showing the relationship among ASTER bands and sites of Serowe region.

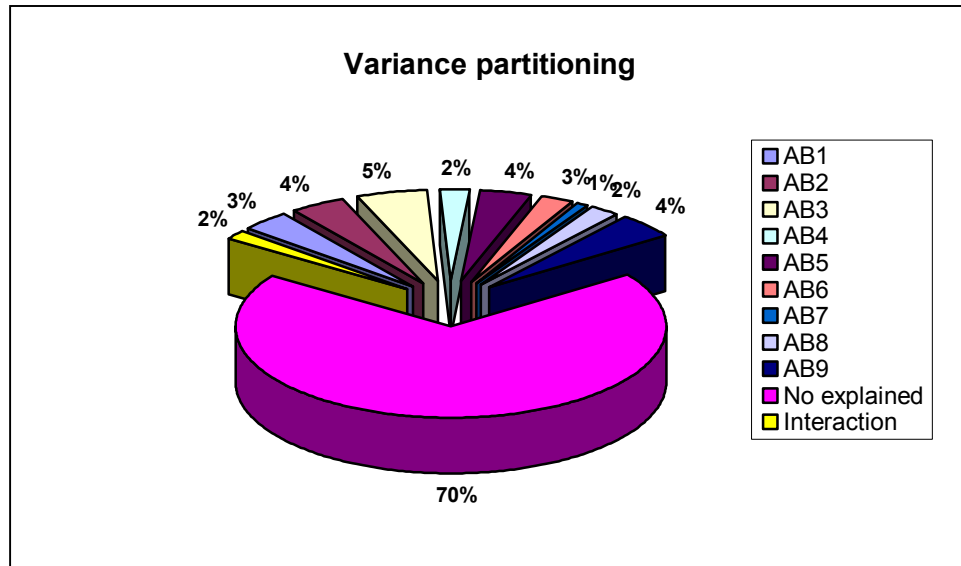


Figure 4-17 Variance or spread of species scores explained by each of the ASTER bands of Serowe region vegetation.

5. DISCUSSION

5.1 VEGETATION CLASSIFICATION USING LANDSAT TM IMAGE

The results achieved when using Landsat TM for mapping vegetation at community level demonstrated that the satellite image data acquired by this sensor are suitable to produce reliable maps when mapping vegetation in arid regions. Accurate results, however, seem more likely in areas where vegetation is homogeneous, as the low resolution of this sensor might give problem in more heterogeneous vegetation. It is also obvious that the use of a false color composite with bands 4,3,2 is feasible to differentiate between plant communities in arid regions.

It is important to observe here that in vegetation mapping using this kind of satellite data the plants' growing stage is an important factor to take into account. Challenges are introduced when mapping vegetation in areas where plants are without leaves for prolonged periods and where background reflection has a strong influence due to the open canopy, influencing the interpretation of the satellite data (Ravan *et al.*, 1995). The above could well be the cause of the low reliability percentage (29%) obtained when mapping the plant community *G.flava_G.retinervis_A.mellifera* with this sensor. This plant community is relatively open and was largely without leaves in the period of acquisition of the image.

Comparison of the two classification approaches based on the confusion matrices suggests that the two approaches were not significantly different. This statement is confirmed by the 'Z' test, which shows that there is no significant difference between these two vegetation mapping approaches, in spite of the fact that the kappa value obtained with in the structure approach is higher than the one obtained with the floristic approach. Which approach to use in this case would depend on your specific objective with the vegetation mapping.

5.2 VEGETATION CLASSIFICATION USING ASTER IMAGE

The maps resulting from ASTER image classification showed a high accuracy and reliability. Given that this image was acquired in the dry season when many species were leafless, it suggests that this sensor is capable of overcoming the problems with background reflection mentioned above. These outcomes demonstrate that ASTER data can be used as an important information source in vegetation mapping (Kato *et al.*, 2001).

It was observed that the vegetation map using the structure approach had a significantly lower overall accuracy as compared with the vegetation map obtained using the floristic approach. An explanation for this could simply be that in the floristic approach a smaller number of classes (4) were used as compared to the structure approach (6), although one could argue that this should not have made any difference when having the high spatial resolution of ASTER. One could maybe also state that leaflessness of vegetation in the dry season, because of low levels of effective photo-synthetically active radiation emitted by plants (Ringrose *et al.*, 1999), affects the structure approach more than the floristic approach.

5.3 VEGETATION CLASSIFICATION USING IKONOS IMAGE

As explained in chapter 4, the IKONOS image was not classified using the floristic approach because the whole area covered by this sensor belonged to the same plant community. Because of the very high spatial resolution of this sensor, discrimination of individual tree canopies was possible, which in turn allowed for quite detailed interpretation of vegetation structure (Univ. Arizona, 2002). In spite of low quality of the image, it can be said that this sensor in principle facilitates vegetation analysis based on visual interpretation, which was previously only possible using aerial photographs (Dare *et al.*, 2001).

5.4 COMPARISON BETWEEN SENSORS ACCORDING TO CLASSIFICATION APPROACH

Comparison between sensors (Landsat TM and ASTER) showed the superiority of ASTER over Landsat TM in respect of accuracy obtained when using the two different types of approaches to classification.

Both sensors distinguished the 4 plant communities using the floristic approach and both sensors distinguished 6 classes using the structure approach. The vegetation structure classes distinguished by the two sensors were different, with Landsat TM seemingly more suitable for bushy vegetation discrimination and ASTER for woodland vegetation discrimination.

Although both sensors detected a decrease of *Bushland* cover type going from Sandveld to Hardveld and at the same time detected an increase of *Woodland* cover type going in the same direction, the two sensors showed differences in area covered by these two cover types.

Especially when analyzing the ASTER data, seasonality should be considered as an important factor. The seasonality causes large changes in the vegetation component, which in turn affect the information gathered by the sensor. Spatial resolution is another important factor to take into account. High ASTER spatial resolution (15m) compared with lower Landsat TM resolution (30m) is also likely to influence the ASTER results.

Comparison between these two sensors, however, would be more objective when images could be compared that were acquired in the same season.

5.5 DIRECT GRADIENT ANALYSIS (using DCCA and CCA)

5.5.1 Relationship between vegetation distribution and sensors bands (using DCCA)

An overall result given by both sensors (Landsat TM and ASTER) analyzing the relationship between species crown cover and sensor bands was an almost full negative correlation between bands and species crown cover percent. It means that for high values of digital number (DN) were found low crown closure values and the other way around.

5.5.1.1 Relationship between vegetation cover and TM bands

The Landsat TM results show a negative correlation between bands TM5 and TM7 with the first species axis and a positive correlation between TM3 and the second species axis. This indicates that these bands are suitable for mapping vegetation cover in the dry season of arid regions, which confirms observations made by Ringrose (1999) when assessing vegetation changes in the Kalahari in Botswana.

Analyzing the distribution of sites (sample plots) and species in relation to different bands, it was observed that sample plots 52, 51, 26, 33 and 34, located in the right part of the diagram, had a negative correlation with bands TM3, TM5 and TM7 and a positive correlation with band TM1 (figure 4-13). The fact that these sample plots had different vegetation cover percentages (i.e. plot 52 (94%); 51 (35%)) in spite of being close to each other dismissed the idea of vegetation cover influence on their location. Another aspect to consider is the vegetation phenology. These same sample plots were mostly covered by the species *A. caffra*, *A. nigrescens*, and *A. tortilis* (figure 4-12) (Appendix 5), which in this season drop their leaves. Also this suggests that there is possibly another factor stronger than vegetation cover influence affecting the relationship band – ground feature. These two sample plots show higher DN values in TM1, low DN values in TM2, TM3 and TM7, and still lower DN values in TM4 and TM5, which suggests an effect of dry vegetation (no chlorophyll) on band information. Contrary to 52 and 51, sample plots 33 and 34 had DN values of zero in bands TM4, TM5 and TM7 and a slightly higher DN values in bands TM1 and TM2. This result was accredited to the strong absorption power of black soils covering these sample plots (Photo 5) and also to the darkening effect produced by the foliage of *A. karroo* (Ringrose *et al.*, 1990).

Analysis of sample plots 47 and 23, located in the left side of the diagram, showed that these were less negatively correlated with regard to bands TM5 and TM7. This relationship could be explained mainly by the strong soil signal or under-story brightness, caused by soil color and incomplete canopy closure (Franklin, 1986). In this case the sample plots had brighter soils.

With regard to the second species axis, there was positive correlation with the TM3 band and negative correlation with the TM2 band. Influence of the TM2 band, however, was not very significant. Sample plots correlated with the TM3 band were 44 and 45, located in the upper part of the diagram and sample plots 53, 29 and 32 located to the right side of the lower part of the diagram. The negative correlation of sample plot 53 was related to presence of dark soil and low crown cover. However, location of sample plots 29 and 32 was most likely related to high cover of dry grass and also to the presence of some trees and bushes coming into leaf like *O. pulchra*, *T. sericea* and *G. retinervis*, which had major reflectance peak in TM4. In contrast to this, the location of sample plots 44 and 45 is positively correlated with band TM3. This is more likely to be related to the influence of soil reflectance. Although in these sample plots *B. albitrunca*, an evergreen species, was present; they did not have enough crown cover to influence the pixel information.

5.5.1.2 Relationship between vegetation cover and ASTER bands

ASTER results were quite similar to those obtained with Landsat TM, although the negative correlation between bands and crown cover was stronger than with Landsat TM. Bands most strongly correlated with species axis 1, were AB4, AB9 and AB3. However, when analyzing the AB9 variance inflation factor (VIF) in the CANOCO software-output, it could be observed that this factor was higher than 20, which indicates that AB9 was almost perfectly correlated with the other bands. This in turn means that the information that this band can give about species cover cannot be uniquely attributed to this band. Rather it should be attributed to the influence of other bands (Ter-Braak, 1986). In this case it is therefore better to use band AB3. This band shows approximately similar correlation, but has a VIF lower than 20.

In figure 4-16, sample plots 33, 34, 51, 52 and 53 were the ones most negatively correlated with all bands. These sample plots were positioned to the far right of the diagram. These sample plots were covered mainly by *A. karroo*, *A. tortilis* and *A. caffra* (Appendix 3). Points 33 and 34 had similar reflection in bands AB1, AB2 and AB3 and lower reflection in bands AB4 up to AB9. Reflection in some of the latter bands reached DN value 0. It was first thought that the DN value 0 was due to a sporadic shower in the area where these sample plots were located on the same day that satellite over-passed, after which the high water content of the soil would bring such a result. However, looking at the Landsat TM DN values of the same sample plots, similar DN values of 0 were found in TM5, TM7 and also TM4. Rather, it is therefore thought that the high-energy absorption capacity of the dark soil has led to the low reflection in the ASTER image. The location of sample plots 51, 52, and 53 with a vegetation cover percent of *A. spp.* oscillating around 45% was associated with the darkening effect produced by foliage, as well as with dark soil absorption.

Sample plots 24, 26 and 30 in the upper part of the diagram, were highly correlated with species axis 2. These sample plots were very poor in vegetation cover percent. The results suggest dark soil influence (point 26) and high absorption because of high iron content of ferralitic soils (point 30) (Bakker *et al.*, 2000). The position of point 24 in the diagram was more related to the effect of vegetation cover and a bit to soil reflectance influence.

Moreover, the position of points less negatively correlated with band AB5, located in the lower part of the diagram, was more likely to be due to low vegetation cover percent and also the presence of brighter soils in these areas.

5.5.2 Relationship between vegetation cover and environmental factors (using CCA)

The direct gradient analysis demonstrated that vegetation distribution in the Serowe region is governed by many environmental factors (Ter-Braak, 1987). The species *A. karroo*, *A. caffra*, *O. africana* and *A. tortilis* (Appendix 3) are strongly correlated with both soil type S_Vre11 (Appendix 2) as well as with clayey soil texture. These same species were also highly dependent on water table depth and terrain elevation, occurring both in areas with lower water table depths as well as in areas with lower elevation.

Chapter 5. Discussion

Analyzing this strong dependence and knowing that hydrotopes may be described as terrain-mapping units with hydrological information added (Meijerink, *et al.*, 1997), these species might be considered as hydrotope indicator species.

Clay soil type S_Arl29 seems to favour the species like *P. capensis*, *L.javanica* and *R. rutananii*, in contrast to *A. mellifera*, *B. albitrunca* and *A. fleckii*, which preferred sandy soils, type S_Arl30 and S_Aro21 at medium elevation and low water table depth. It was also noticed that the species *C. molle* was found to be growing more often in zones with higher elevation and higher water table depth.

Occurrence of species like *D. cinerea*, *G. retinervis*, *C. apiculatum* and *T. sericea* did not seem to have any relationship with environmental factor and were found to be growing everywhere.

Figure 4-9 Shows that most sample plots were located on S_Aro21 soil type with a sandy texture, high elevation and high water table depth. Comparing this figure with the figure 4-8, it can be observed that most plant species prefer clayey soils with shallow water tables and lower elevations. This suggests that the elevation gradient is possibly an important factor influencing vegetation distribution (Velazquez, 1993).

The results obtained suggest a strong influence of soil type and soil texture on species distribution in the study area. This confirms other studies, which have also demonstrated that soil type has a strong influence on landscape heterogeneity and diversity (Dahlberg, 2000).

The location of most species in the right part of the diagram also suggests that species distribution is influenced by the spatial distribution of groundwater (Skarpe, 1990).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

- The vegetation distribution in the study area is strongly associated with either one of three main landscapes types, which can be found in the area: Sandveld, Escarpment and Hardveld.
- The vegetation occurring in the study area can be classified in 4 main plant communities. *T.sericea_G.retinervis_D.cinerea* plant community is thereby mainly representative of the Sandveld area, whereas the other three plant communities *A.karro_A.tortilis_Z.mucronata, D.cinnerea_C.apiculatum_G.bicolor*, and *G.flava_G.retinervis_A.mellifera* are more representative of the Hardveld area and the Escarpment area.
- It is possible to classify the vegetation in the study area into 10 main structure classes using the system adopted by the Kenyan Soil Survey. It can thereby be observed that 45% of the area is covered by Bushland and 42% by Woodland, as the main classes.
- Landsat TM satellite imagery is feasible for vegetation mapping at plant community level based on a floristic approach in dry seasons in arid regions. With this sensor a combination of TM4, TM3, and TM2 bands is adequate to differentiate plant community. Use of this kind of satellite data permits a better classification of Bushland (based on structure approach) if compared with ASTER data.
- Comparison between different vegetation classification methods using Landsat TM data demonstrated that there was no significant difference between them at 95% confidence level. Taking this into consideration, it is suggested to use the easier and quicker method for vegetation mapping to save time and money.
- Detrended Canonical Correspondence Analysis of crown cover percent and Landsat TM bands' DN values, demonstrated that use of bands TM5, TM7, TM3 could give better results for vegetation classification in these areas as compared to a traditional false color composite.
- ASTER satellite imagery is also feasible for vegetation mapping at plant community level using a floristic approach. Good spatial resolution and detail level of this sensor permits to obtain reliable maps also in the dry season when most vegetation is leafless. The use of a false color composite using bands AB3, AB2, and AB1, gives adequate vegetation mapping results using both classification approaches (floristic and structure). Using this satellite data permits better differentiation of woodland areas (based on structure approach) as compared to Landsat TM.
- Comparison between vegetation classification approaches using ASTER data showed that these two approaches were significantly different at a 95% confidence level. In this respect the floristic approach was better than the structure approach.
- Detrended Canonical Correspondence Analysis of crown cover percent and ASTER bands' DN values, demonstrated that use of bands AB4, AB3 and AB5 could be more appropriate for vegetation classification in arid regions.
- Classification of the IKONOS image using the structure approach allowed discrimination of individual tree canopies and permitted interpretation of precise details of vegetation structure present in the area, such as separation of grassland from bushland, due to the fine spatial resolution of this

Chapter 5. Conclusion and recommendations

sensor. Vegetation mapping with this sensor becomes suitable mainly when detailed mapping is required.

- The comparison of accuracy between the two sensors (Landsat TM and ASTER) was significantly different at the 95% confidence level using both floristic and structure approach. The results show that use of ASTER satellite data gives more reliable vegetation maps than when using Landsat TM satellite data.
- It can be concluded that under-story brightness because of dry vegetation (no chlorophyll), strong soil signal of brighter soils, absorption power of black soils and also the darkening effect produced by vegetation canopy, introduces noise in vegetation classification.
- The analysis in both sensor showed that images from the visible part of electromagnetic spectrum can be used to classify vegetation in arid zones, but the statistical analysis yield that images, mainly from NIR and MIR part of electromagnetic spectrum has better correlation with vegetation cover data than the images in the visible part.
- Soil types and soil texture types were found governing vegetation distribution. Ground water table depth and elevation gradients had a lower effect on vegetation distribution in the area than soil environmental variables.

6.2 RECOMMENDATIONS

- Use of TM5, TM7 and TM3 bands from Landsat TM and AB4, AB3 and AB5 bands from ASTER, rather than traditional false color composite combinations, is recommended when mapping vegetation and when using floristic and structure approach.
- In order to compare Landsat TM and ASTER sensors more objectively, data acquired in the same season should be analyzed. In this way, the effect or differences produced by seasonality could be avoided.
- In the gradient analysis geology and rainfall as other gradients influencing the vegetation distribution should be included. The first one would permit to identify and analyze patterns related to vegetation distribution and fault direction, and the second one would permit to distinguish and analyze patterns related to rainfall distribution.
- Instead of using single bands in the analysis of correlation between species cover and DN values, also NDVI should be used.
- Unsupervised classification and visual interpretation as other methods to identify and map vegetation (using both classification approaches) is also recommended. It would permit comparison with the vegetation maps obtained in this study, which could yield additional interesting information.

7. REFERENCES

- Apan, A. A. (1997). Land cover mapping for tropical forest rehabilitation planning using remotely-sensed data. *International journal of Remote Sensing*, 18(5), 1029-1049.
- Bakker, W. H., & et al. (2000). *Principles of remote sensing* (L L F Janssen ed.). Enschede: International Institute for Geo-information Sciences and Earth Observation.
- Banko, G. (1998). *A review of assessing the accuracy of classifications of remotely sensed data and methods including remote sensing data in forest inventory* (Interim report IR-98-081). Luxemburg: International Institute for Applied Systems Analysis.
- Berry, H., & Ritter, B. (1995, December 23, 1999). *Vegetation and Shoreline Characteristics* (Department of Natural Resources), [Article]. Washington State Department of Natural Resources Aquatic Resources Division Nearshore Habitat Program. Available: <http://www.wa.gov/dnr/htdocs/aqr/nshr/methods.htm#top%20of%20page> [2001, August 24, 2001].
- Blanco, J. L. (1994, June 20, 2000). *The role of GIS-User interactive process in the delineating boundaries of environmental units for land managing: An application in Baja California, Mexico* (University of Maine), [Article]. University of Maine. Available: <http://spatialodyssey.ursus.maine.edu/gisweb/spatdb/gis-lis/gi94068.html> [2001, August 22, 2001].
- Caballero, L. L. (2001). *Monitoring forest Fragmentation using GIS and RS techniques. Study case of Makwanpur District, Hetauda, Nepal*. Unpublished MSc, ITC, Enschede.
- Cantero, J. J., Cisneros, J. M., Zobel, M., & Cantero, A. (1998). Environmental relationships of vegetation patterns in saltmarshes of central Argentina. *Folia Geobotanica*, 33(2), 133-145.
- CEC, BMZ, & GTZ. (1986). *Towards Control of Desertification in African Drylands. Problems, Experiences, Guidelines* (Vol. Sonderpublication der GTZ; No 168). Eschborn: Comm. of the Europ. Communities (CEC), BMZ, GTZ.
- Charney, I. (1975). Dynamics of deserts and drought in the Sahel. *Journal of the Royal Meteorological Society*, 101, 193-202.
- Chilume, C. J. (2001). *Hydrogeological assessment of the south-western Karoo basin. A case study from Lokalane, Botswana*. Unpublished MSC, ITC, Enschede.
- Cole, M. M. (1986). *The savannas: Biogeography and Geobotany*. (Harcourt Brace Javanovich ed.). London: Academic Press, Inc.
- Congalton, R. G., Oderwald, R. G., & Mead, R. A. (1983). Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques. *Photogrammetric Engineering and Remote Sensing*, 49(12), 1671-1678.
- Conway, J. (1997). Evaluating ERS-1 SAR data for the discrimination of tropical forest from other tropical vegetation types in Papua New Guinea. *International journal of Remote Sensing*, 18(14), 2967-2984.
- Cowen, D. J., Jensen, J. R., & Hodgson, M. (1998, September 25, 1998). *State of knowledge on GIS databases and land use/cover patterns: South Carolina* (LU-CES Program Office), [Article]. University of South Carolina. Available: <http://inlet.geol.sc.edu/luces2/cowen.html> [2001, August 24, 2001].
- Dahlberg, A. C. (2000). Vegetation diversity and change in relation to land use, soil and rainfall - a case study from North-East District, Botswana. *Journal of Arid Environment*, 44, 19-40.
- Dare, P., & et al. (2001). *Investigation of spaceborne and airborne remote sensing technologies for mapping Manna Gum (Eucalyptus viminalis) health in South-Eastern Australia*. Paper presented at the 22nd Asian Conference on Remote Sensing, Singapore.
- DeGier, A. (1998). Lecture Note: Sampling Basics. In ITC (Ed.) (pp. 38). Enschede: ITC.

Reference

- Diaz, V. L. (2000). *Applying remote sensing and GIS for monitoring of fragmentation in an area of atlantic dry forest of Southeastern Brazil : sustainable management of natural resources*. Unpublished MSc, ITC-Wageningen University, Enschede-Wageningen.
- Drysdale, R. (2000, June 12, 2001). *Geography 204 - Geomorphology of Australia. The Arid Zone Geomorphology of Australia* (University of Newcastle), [Lecture]. Available: <http://www.newcastle.edu.au/departement/gg/g204/processes.htm> [2000, July 6, 2001].
- Dube, O. P. (1998). Monitoring vegetation Cover over Diverse Landscape Types in Semiarid South Eastern Botswana. *Geocarto International*, 13(2), 43-51.
- Dye, P. J. (1996). Climate, forest and stream flow relationships in South African afforested catchments. *Commonwealth Forestry Review*, 75(1), 31-37.
- ECOSUR. (1998). *Vegetation Mapping and Ground Truthing for Radar Imagery* (Vegetation report). Serowe: ECOSUR project.
- FAO. (1989, July 11, 2001). *Arid zone forestry: A guide for field technicians* (FAO), [A guide]. FAO. Available: <http://www.fao.org/docrep/T0122E/T0122E00.htm> [2001, July 11, 2001].
- FAO. (ND, December 31, 2000). *Forestry-Botswana* (FAO). Available: http://www.fao.org/forestry/fo/country/index.jsp?lang_id=1&geo_id=14 [2001, June 8, 2001].
- Favreau, G., Leduc, C., & Marlin, C. (2001, June 30, 2001). *Increase of groundwater recharge induced by a change in land use: comparison of hydrodynamic and isotopic estimates in semi-arid Niger* (International Association of Hydrological Sciences). International Association of Hydrological Sciences. Available: http://www.cig.ensmp.fr/~iahs/maastricht/s34/S3.1_13.htm [2001, July 11, 2001].
- Franklin, J. (1986). Thematic mapper analysis of coniferous forest structure and composition. *International journal of Remote Sensing*, 7(10), 1287-1301.
- Gaston, G. G., Bradley, P. M., Vinson, T. S., & Kolchugina, T. P. (1997). Forest Ecosystem Modelling in the Russian Far East Using Vegetation and Land-Cover Regions Identified by Classification of GVI, Photogrammetric Engineering and Remote Sensing. *International journal of Remote Sensing*, 63(1), 51-58.
- Gjertsen, A. K. (1993, Aug 18-21). *Testing TM and SPOT Data as Input to a Canopy Reflectance Model for Mapping Density and Size of Trees in Forest Stands*. Paper presented at the International Geoscience and Remote Sensing Symposium, Tokyo, Japan.
- Grunner, T. (1999, ND, 2000). *Scaling of vegetation and ecosystem properties in Mediterranean-climate ecosystems* (James Marquez), [Article]. University of California Santa Barbara. Available: http://www.icess.ucsb.edu/esrg/ess_sum97/Students_ESS.1999/grunner/report_Tatjana.htm [2001, August 24, 2001].
- Higgins, J. (2000, June 1, 2001). *Vegetation* (John Higgins). EarthWare Systems (Australia) Pty Ltd. Available: http://www.nlwra.gov.au/full/30_themes_and_projects/50_scoping_projects/04_methods_papers/14_Higgins/Vegetation.html [2001, July 6, 2001].
- Hudson, N. W. (1987, July 2001). *Soil and water conservation in semi-arid areas* (Silsoe Associates Ampthill, Bedford United Kingdom), [Book]. FAO. Available: <http://www.fao.org/docrep/T0321E/t0321e00.htm#TopOfPage> [2001, July 9, 2001].
- Jacobberger, P. A., & Hooper, D. M. (1991). Geomorphology and reflectance patterns of vegetation-covered dunes at the Tsodilo Hills, north-west Botswana. *International Journal of Remote Sensing*, 12(11), 2321-2342.
- Kato, M., & et al. (2001, November 5-9, 2001). *ASTER data utilization for wetland mapping and forest mapping*. Paper presented at the 22nd Asian Conference on Remote Sensing, Singapore.
- Kent, M., & Coker, P. (1992). *Vegetation description and analysis* (John Wiley and Sons ed.). London: Belhaven Press.

Reference

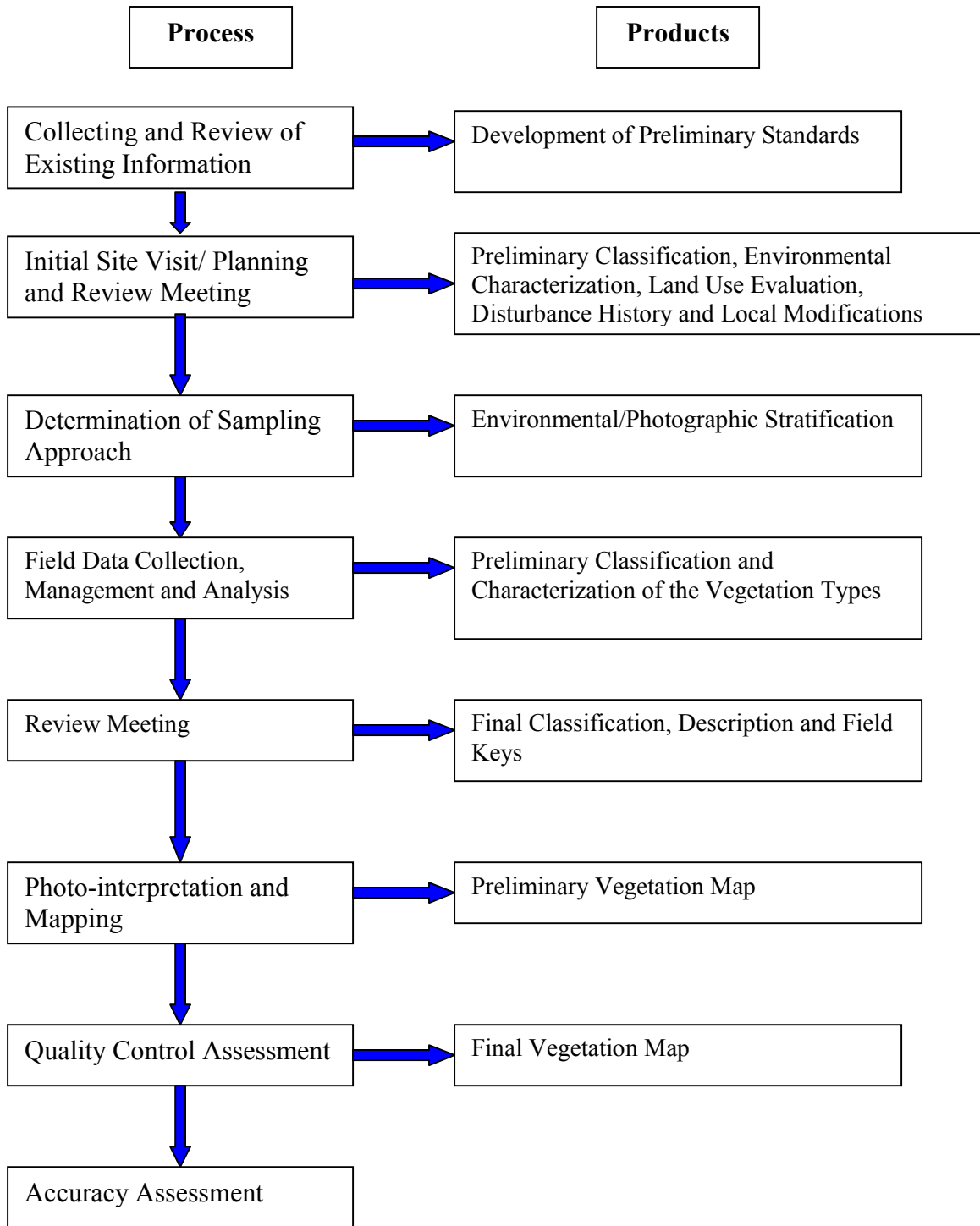
- Kgathi, D. L., Sekhwela, M. B. M., Tietema, T., & Mpotokwane, A. (1994). Biomass in Botswana. In D. O. Hall & Y. S. Mao (Eds.), *Biomass energy and coal in Africa* (pp. 67). London-Gabrone: Zed Books Ltd in Association with African Energy Policy Research Network.
- Kingsford, R. T. (1997, June 8, 2001). *Wetlands of the world's arid zones*. Available: http://www.ramsar.org/about_arid.htm [2001, June 8, 2001].
- Lambin, E. F. (1997). The identification of tropical deforestation fronts at broad spatial scales. *International journal of Remote Sensing*, 18(17), 3551-3568.
- Leistner, O. A. (1967). The Plant Ecology of the Southern Kalahari. *Botanical Survey Memoir, No. 38*, 172 p.
- LeMaitre, D. C., Scott, D. F., & Colvin, C. (2000). Information on interactions between Groundwater and Vegetation relevant to South African Conditions: A review. *Groundwater: Past Achievements and Future Challenges, Silili et al. (eds). Balkema, Rotterdam*, 959-962.
- Leps, J., & Smilauer, P. (1999). *Multivariate analysis of ecological data*. Bohemia: Faculty of Biological Sciences, University of South Bohemia.
- Lewis, M. M. (1994). Species composition related to spectral classification in an Australian spinifex hummock grassland. *International Journal of Remote Sensing*, 15, 3223-3239.
- Lillesand, T. M., & Kiefer, R. W. (1994). *Remote Sensing and Image Interpretation* (3rd ed. ed.). New York: John Wiley & Sons, Inc.
- Lubczynski, M. W. (2000). Application of a Numerical Flow Modelling Combined with Remote Sensing and GIS techniques for the Quantification of Regional Groundwater Resources in Hard Rock Terrains. *Groundwater: Past Achievements and Future Challenges, Silili et al. (eds). Balkema, Rotterdam*, 199-204.
- Luman, D. E., & Ji, M. (1995). The Lake Michigan Ozone Study: An Application of Satellite-Based Land-Use and Land-Cover Mapping to Large-Area Emissions Inventory Analysis. *Photogrammetric Engineering and Remote Sensing*, 61(8), 1021-1032.
- Marceau, D. J., & Hay, G. J. (1999, June 29, 2001). *Remote sensing contributions to the scale issue* (Danielle J Marceau, Geoffrey J Hay), [Article]. Laboratoire de Géomatique et d'Analyse Spatiale. Available: <http://blues.lemig.umontreal.ca/gc/PDFs/Rspaper.htm> [2001, August 24, 2001].
- Mazambani, D. (1997, July 2001). *Land use in Sadziwa Ward: Manyica Communal Land* (LEAD International), [Paper]. Available: <http://www.lead.org/lead/training/international/zimbabwe/1997/papers/d2MAZAM2.html> [2001, July 11, 2001].
- McGwire, K., & et al. (2000). Hyperspectral mixture modelling for quantifying sparse vegetation cover in arid environments. *Remote Sensing of Environment*, 77, 360-374.
- Meijerink, A. M. J., Lubczynsky, M., & Wolski, P. (1997). *Remote sensing, hydrological analysis and hydrotopes*. Paper presented at the Regionalization in Hydrology, Braunschweig.
- Mistry, J. (2000). *World Savannas. Ecology and Human Use* (Jayalaxshmi Mistry ed.). London: Pearson Education.
- Moleele, N. M. (1998). Encroacher woody plant browse as feed for cattle. Cattle diet composition for three seasons at Olyphant Drift, southeast Botswana. *Journal of Arid Environments*, 40, 255-268.
- Moleele, N. M., & Perkins, J. S. (1998). Encroaching woody plant species and boreholes: is cattle density the main driving factor in the Olyphant Drift communal grazing lands, south-eastern Botswana? *Journal of Arid Environments*, 40, 245-253.
- Muchoney, D., & et al. (2000). Application of the MODIS global supervised classification model to vegetation and land cover mapping of Central America. *International journal of Remote Sensing*, 21(6 & 7), 1115-1138.
- Muñoz-Reinoso, J. C. (2001). Vegetation changes and groundwater abstraction in SW Doñana, Spain. *Journal of Hidrology*, 242(3-4), 197-209.

Reference

- Nagendra, H. (2001). Using remote sensing to assess biodiversity. *International Journal of Remote Sensing*, 22(12), 2377-2400.
- Obakeng, O. T. (2000). *Groundwater recharge and vulnerability. A case study at the margins of the south-east Central Kalahari Sub-basin, Serowe region, Botswana*. Unpublished MSc, ITC, Enschede.
- Perkins, J. S., & Thomas, D. S. G. (1993). Spreading Deserts or Spatially Confined Environmental Impacts? Land degradation and Cattle Ranching in the Kalahari Desert of Botswana. *Land Degradation & Rehabilitation*, 4, 179-194.
- Peterson, D. L., M A Spanner, Running, S. W., & Teuber, K. B. (1987). Relationship of Thematic Mapper Simulator Data to Leaf Area Index of Temperate Coniferous Forests. *Remote Sensing of Environment*, 22, 323-341.
- Ravan, S. A., Roy, P. S., & Sharma, C. M. (1995). Space remote sensing for spatial vegetation characterization. *Journal of Biosciences*, 20(3), 427-438.
- Ringrose, S., Matheson, W., Tempest, F., & Boyle, T. (1990). The Development and Causes of Range Degradation Features in Southeast Botswana Using Multi-temporal Landsat MSS Imagery. *Photogrammetric Engineering and Remote Sensing*, 56(9), 1253-1262.
- Ringrose, S., Muisi-Nkambwe, S., Coleman, T., Nellis, D., & Bussing, C. (1999). Environmental Auditing. Use of Landsat Thematic Mapper Data to Assess Seasonal Rangeland Changes in the Southeast Kalahari, Botswana. *Environmental management*, 23(1), 125-138.
- Ritter, M. (2001, March 27, 2001). *World Biomes: Savanna Biome* (Michael Ritter). University of Wisconsin. Available: http://www.uwsp.edu/geo/faculty/ritter/geog101/modules/biosphere/biomes_savanna_page_1.html [2001, July 11, 2001].
- Rossouw, N. J. (1997). Mapping Vegetation and Erosion Changes on the Northern Slopes of Table Mountain using Multi-Temporal Aerial Photography and GIS, 1944-1992. *The South African Geographical Journal*, 79(2).
- Sandison, D. C. (1999, January 2001). *Using a Four-Dimensional Geographical Information System to Visualise the Environmental Impact of Smog* (Daniel Calvin Sandison), [Master Science Thesis]. Available: <http://www.users.bigpond.com/dsandison/> [2001, August 1, 2001].
- Scott, D. F., & LeMaitre, D. C. (1998). *The interaction between vegetation and groundwater - research priorities for South Africa* (WRC Project K5/730/1/98).
- SECWMB. (2000, December 18, 2000). *Groundwater Dependent Ecosystems* (URS Australia Pty Ltd), [Report]. South East Catchment Water Management Board (SECWMB). Available: http://www.secatchment.com.au/technical_reports.html [2001, July 11, 2001].
- SIE. (2000). *IKONOS* (Space Imaging Eurasia(SIE)). Available: <http://www.sieurasia.com/content/IKONOS/#top> [2001, 13 November 2001].
- Siegel, S., & Castellan, N. J. (1988). *Nonparametric statistics for the behavioral sciences* (Second edition ed.). New York: McGraw-Hill.
- Skarpe, C. (1990). Structure of woody vegetation in disturbed and undisturbed arid savanna, Botswana. *Vegetatio*, 87, 11-18.
- Skidmore, A. K. (1999). Accuracy assessment of spatial information. In A. Stein & F. v. d. Meer & B. G. H. Gorte (Eds.), *Spatial Statistic for Remote Sensing* (A Stein et al, ed., pp. 197-209). Dordrecht: Kluwer Academic.
- Snetsinger, S., & Ventura, S. (2001, August 14, 2001). *Land cover change in the great lakes region from mid-nineteenth century to present* (Susan Snetsinger and Steve Ventura), [Article]. North Central Research Station. Available: <http://www.ncrs.fs.fed.us/gla/reports/LandCoverChange.htm#INTRODUCTION> [2001, August 24, 2001].
- Ter-Braak, C. J. F. (1986). Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67, 1167-1179.

Reference

- Ter-Braak, C. J. F. (1987). Ordination. In C. J. F. T. Braak (Ed.), *Data analysis in community and landscape ecology* (R H G Jongman C J F Ter Braak O F R van-Tongeren ed., pp. 91-173). Wageningen: Centre for Agricultural Publishing and Documentation (Pudoc).
- Ter-Braak, C. J. F. (1987). The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio*, 69, 69-77.
- Timmermans, W. J., & Meijerink, A. M. J. (1999). Remotely sensed actual evapotranspiration: Implications for groundwater management in Botswana. *ITC Journal*, 222-233.
- Tripathy, G. K., & Ghosh, T. K. (1996). Monitoring of desertification process in Karnataka State of India using GIS. *International Journal of Remote Sensing*, 17(12), 2243-2257.
- Trisurat, Y., et al. (2000). Improvement of tropical vegetation mapping using a remote sensing technique: a case of Khao Yai National Park, Thailand. *International journal of Remote Sensing*, 21(10), 2031-2042.
- Tucker, C. J., Townshend, J. G. R., & Goff, T. E. (1985). African Land-Cover Classification Using Satellite Data. *Science*, 227(4685), 369-375.
- Tyson, P. D. (1986). *Climatic Change & Variability in Southern Africa*. Cape Town, South Africa: Oxford University Press.
- Univ. Arizona. (2002, Jan 26, 2002). *Modelling Elk Habitat with remote sensing* (Univ. Arizona). Univ. Arizona. Available: <http://aria.arizona.edu/synergy/remotesensingmodel.html> [2002, February 05, 2002].
- USGS. (1994, 19 July 2001). *Field Methods for Vegetation Mapping*. USGS-NPS. Available: <http://biology.usgs.gov/npsveg/fieldmethods/> [2001, 24 August 2001].
- Van-Wijngaarden, W. (Ed.). (1985). *Elephants, trees, grass, grazers : relationships between climate, soils, vegetation and large herbivores in a semi - arid savanna ecosystem :Tsavo, Kenya* (Vol. Publication 4). Enschede: ITC.
- Velazquez, A. (1993). *Landscape ecology of Tlaloc and Pelado volcanoes, Mexico : with special reference to the volcano Rabbit - Romerolagus Diazi, its habitat, ecology and conservation*. Unpublished PhD thesis, University of Amsterdam, Enschede. ITC publication; 16.
- Walker, I., & Rowntree, P. R. (1976). *The effect of soil moisture on circulation and rainfall in a tropical model.*: U.K. Meteorological Office.
- Wellfield, C. S. (2000). *Serowe Wellfield 2 Extension Project* (Main Report TB10/3/10/95-96). Gaborone, Botswana: Consulting Services.
- Zhu, L., & Tateishi, R. (2001, November 5-9 2001). *Application of linear mixture model to time series AVHRR NDVI data*. Paper presented at the 22nd Asian Conference on Remote Sensing, Singapore.



Appendix 1 Overview of the Vegetation Mapping Process

Appendices

Common name	Scientific name	Code
Mhata	Lonchocarpus nelsii	Lon nel
Mmaba	Securidaca longepedunculata	Sec lon
Mmoopudu	Mimusops zeyheri	Mim zey
Mochlono	Maytenus sp	May sp
Modubana	Combretum collinum Fresen	Com coll
Modubatshipi	Combretum molle	Com mol
Modumela	Lannea schweinfurthii	Lan sch
Mogonono	Terminalia sericea	Ter ser
Mogorogorwana	Strychnos cocculoides	Str coc
Mogosi	Bauhinia petersiana	Bau pet
Mogotlho	Acacia erioloba	Aca eri
Mogwana	Grewia bicolor	Gre bic
Mohahu	Acacia fleckii	Aca fle
Mohalatsamaru	Asparagus africanus	Asp afr
Mohata	Diospyros lycioides	Dio lyc
Mohudiri	Combretum apiculatum	Com api
Mohurokwana	No scientific name	Spp1
Mokabi	Combretum hereroense	Com her
Mokala	Acacia galpinii	Aca gal
Mokgalo	Ziziphus mucronata	Ziz muc
Mokgomphatha	Grewia flavescens	Gre fla
Mokhu	Acacia tortilis	Aca tor
Mokoba	Acacia nigrescens	Aca nig
Mokongwa	Ricinodendrum rutananii	Ric rut
Mokumoto	Commiphora edulis	Com edu
Moloto	Acacia erubescens	Aca eru
Monamane	Cassine transvaalensis	Cas tran
Monato	Burkea africana	Bur afr
Mongana	Acacia mellifera	Aca mel
Monokane	Ozoroa sp	Ozo spp
Monyelenyele	Ochna pulchra	Och pul
Mooka	Acacia karoo/A.luederitzii	Aca kar
Moologa	Croton gratissimus	Cro gra
Moretologa	Ximenia caffra	Xim caf
Moretwa	Grewia flava	Gre fla
Morobe	Ehretia spp	Ehr spp
Morutlhare	Acacia caffra	Aca caf
Morutlhatshana	Acacia caffra	Spp2
Morutlwa	Rothmannia capensis	Rot cap
Moselesele	Dichrostachys cinerea	Dic cin
Mosethla	Peltophorum africanum	Pel afr
Mosokaphala	Bolusanthus speciosus	Bol spe
Mosu	Acacia tortillis	Aca tor
Mosukutsane	Lippia javanica	Lip jav
Mothakula	Euclea divinorum Hiern.	Euc div
Mothata	Pappea capensis	Pap cap
Mothware	Olea africana/ O. europea	Ole afr
Motlhagwe	No scientific name	Spp3
Motlhakola	Euclea undulata	Euc und1
Motlhakolane	Euclea undulata subsp. myrtina	Euc und2
Motlhwane	Vangueria infausta	Van inf
Motlhwane	Olea africana/Olea europea	Ole afr
Motopi	Boscia albitrunca	Bos alb
Motshotho	Rhus leptodictya	Rhu lep
Motsiara	Terminalia prinioides	Ter pri
Motsotsojane	Grewia retinervis	Gre ret
Seroka	Commiflora spp	Com spp
Tholwana	Solanum spp	Sol spp

Soil Type	Description
S_Arl 29	Luvic arenosols
S_Arl 30	Luvic arenosols
S_ARo 21	Ferralitic arenosols
S_ARo 35	Ferralitic arenosols
S_LVk 20	Calcic luvisols
S_RGe 31	Eutric regosols
S_VRe 11	Eutric vertisols
Soil texture	Description
Sandy	Sand
Sa_Lo	Sandy Loam
Sa_Cla_Lo	Sandy Clay Loam
Clay	Clay
Loa_Sa	Loamy Sand

Appendix 2 Soil environmental variables tested in the gradient analysis.

Appendix 3 Species common name, scientific name and code how used in the ordination diagrams.

	SPEC_AX1	SPEC_AX2	ENVI_AX1	ENVI_AX2	WL95_00	Elevation	S_ARo_Z1	S_Art_29	S_RGe_31	S_VRe_11	S_LVx_20	S_Art_30	Sandy	Sa_Lo	Sa_Cla_L	Clay	Loa_Sa
SPEC_AX1	1.0000																
SPEC_AX2	-0.0440	1.0000															
ENVI_AX1	0.9599	0.0000	1.0000														
ENVI_AX2	0.0000	0.9231	0.0000	1.0000													
WL95_00	-0.4545	-0.0416	-0.4735	-0.0450	1.0000												
Elevation	-0.3536	0.4141	-0.3684	0.4487	0.5260	1.0000											
S_ARo_Z1	-0.3704	-0.1389	-0.3859	-0.1504	0.8411	0.5741	1.0000										
S_Art_29	0.0113	0.3689	0.0117	0.3996	-0.2019	0.0132	-0.2694	1.0000									
S_RGe_31	-0.0335	0.4743	-0.0349	0.5138	-0.2060	0.3015	-0.2998	-0.2425	1.0000								
S_VRe_11	0.6515	-0.3070	0.6788	-0.3326	-0.3143	-0.4437	-0.2011	-0.1626	-0.1810	1.0000							
S_LVx_20	-0.0470	-0.0190	-0.0490	-0.0206	-0.2528	-0.3408	-0.2122	-0.1716	-0.1910	-0.1281	1.0000						
S_Art_30	-0.2004	-0.4700	-0.2088	-0.5092	-0.0046	-0.3599	-0.2102	-0.1700	-0.1891	-0.1269	-0.1339	1.0000					
Sandy	-0.6330	-0.4187	-0.6595	-0.4535	0.4369	0.1001	0.4889	-0.3612	-0.2677	-0.1739	0.0290	0.3072	1.0000				
Sa_Lo	-0.0017	0.2194	-0.0018	0.2377	-0.1771	0.0185	-0.2145	0.4773	0.1058	-0.1295	-0.1366	-0.1353	-0.4405	1.0000			
Sa_Cla_L	0.3301	-0.0692	0.3439	-0.0749	-0.2166	-0.1545	-0.2196	-0.0049	0.2864	0.2416	-0.1398	-0.1385	-0.4509	-0.1414	1.0000		
Clay	0.6288	0.4517	0.6550	0.4893	-0.1656	0.0404	-0.2207	0.1279	0.0697	0.1853	-0.0996	-0.1392	-0.4533	-0.1421	-0.1455	1.0000	
Loa_Sa	-0.0350	0.0355	-0.0364	0.0384	-0.1536	-0.0899	-0.1185	-0.0958	-0.1067	-0.0715	0.5585	-0.0748	-0.2434	-0.0763	-0.0781	-0.0785	1.0000

Appendix 4 Matrix of correlation coefficients for species data and environmental variables in the Serowe Region

	SPEC AX1	SPEC AX2	ENVI AX1	ENVI AX2	TM1	TM2	TM3	TM4	TM5	TM7
SPEC AX1	1									
SPEC AX2	-0.0292	1								
ENVI AX1	0.9274	0.0000	1							
ENVI AX2	0.0000	0.8863	0.0000	1						
TM1	0.3571	-0.0244	0.3850	-0.0275	1					
TM2	0.0371	-0.0559	0.0400	-0.0630	0.7884	1				
TM3	-0.0995	0.3439	-0.1072	0.3880	0.6665	0.8700	1			
TM4	-0.4612	-0.0063	-0.4973	-0.0071	0.1418	0.6052	0.6491	1		
TM5	-0.6745	0.1441	-0.7273	0.1626	0.2184	0.5893	0.7287	0.8578	1	
TM7	-0.5128	0.1882	-0.5530	0.2123	0.4251	0.7012	0.8577	0.7629	0.9333	1

Appendix 5 Matrix of correlation coefficients showing the relationship between species data and Landsat TM images in the Serowe Region

	SPEC AX1	SPEC AX2	ENVI AX1	ENVI AX2	AB1	AB2	AB3	AB4	AB5	AB6	AB7	AB8	AB9
SPEC AX1	1												
SPEC AX2	0.0177	1											
ENVI AX1	0.9216	0.0000	1										
ENVI AX2	0.0000	0.8714	0.0000	1									
AB1	0.0306	-0.2235	0.0332	-0.2565	1								
AB2	-0.2199	-0.2213	-0.2386	-0.2539	0.9144	1							
AB3	-0.6046	0.0578	-0.6560	0.0663	0.6267	0.8131	1						
AB4	-0.7138	-0.2341	-0.7745	-0.2687	0.3375	0.4641	0.6691	1					
AB5	-0.5699	-0.2997	-0.6184	-0.3439	0.6135	0.6854	0.7498	0.9201	1				
AB6	-0.5794	-0.2686	-0.6287	-0.3082	0.5503	0.6437	0.7405	0.9477	0.9840	1			
AB7	-0.5379	-0.2073	-0.5837	-0.2379	0.5642	0.7091	0.7866	0.7805	0.8686	0.8608	1		
AB8	-0.5558	-0.2391	-0.6031	-0.2743	0.6362	0.7508	0.8200	0.8863	0.9729	0.9626	0.9000	1	
AB9	-0.6167	-0.1377	-0.6692	-0.1580	0.5233	0.6277	0.7463	0.9356	0.9575	0.9579	0.8365	0.9558	1

Appendix 6 Matrix of correlation coefficients showing the relationship between species data and ASTER images in the Serowe Region

Photos



Photo 1 Open vegetation growing in the Sandveld area.

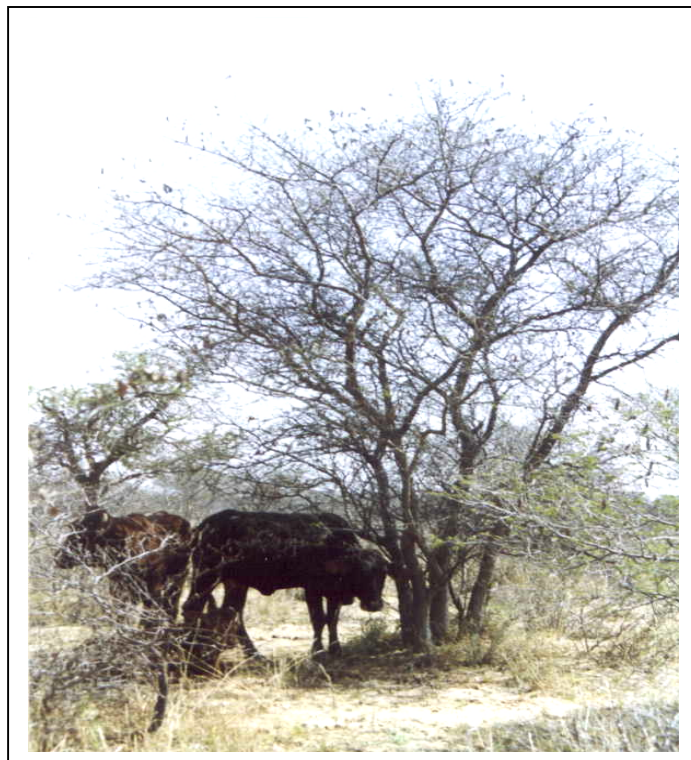


Photo 2 Cows getting shadow under an *Acacia fleckii* (Mohahu) tree in Sandveld area.

Photos



Photo 3 Vegetation growing close to the escarpment edge. A leafless tree of *Ricinodendrum rutananii* (Mokongwa) can be observed in the background of the picture.



Photo 4 Thick vegetation mainly of Acacia trees growing on a dry riverbed.

Photos

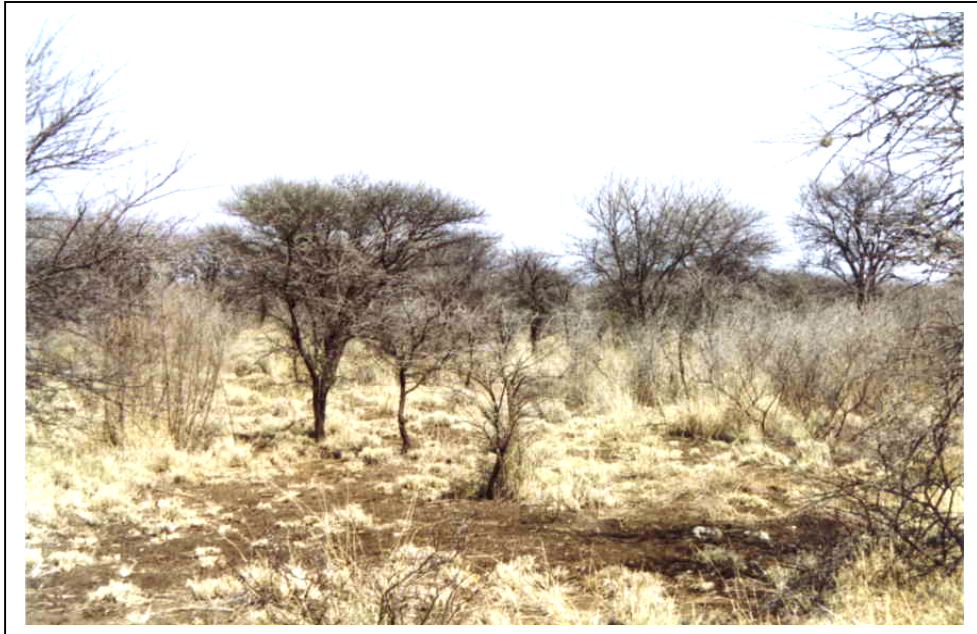


Photo 5 *Acacia karroo* (Mooka) and *Acacia tortilis* (Mosu) trees growing on dark soils in the hardveld area.



Photo 6 Cattle post in the Hardveld area close to the riverbed area.