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DIRECTORATE OF ENVIRONMENTAL AFFAIRS
MINISTRY OF ENVIRONMENT AND TOURISM

NATURAL RESOURCE MAPPING OF THE KAVANGO REGION

SPECIALIST REPORT 1
VEGETATION OF THE KAVANGO

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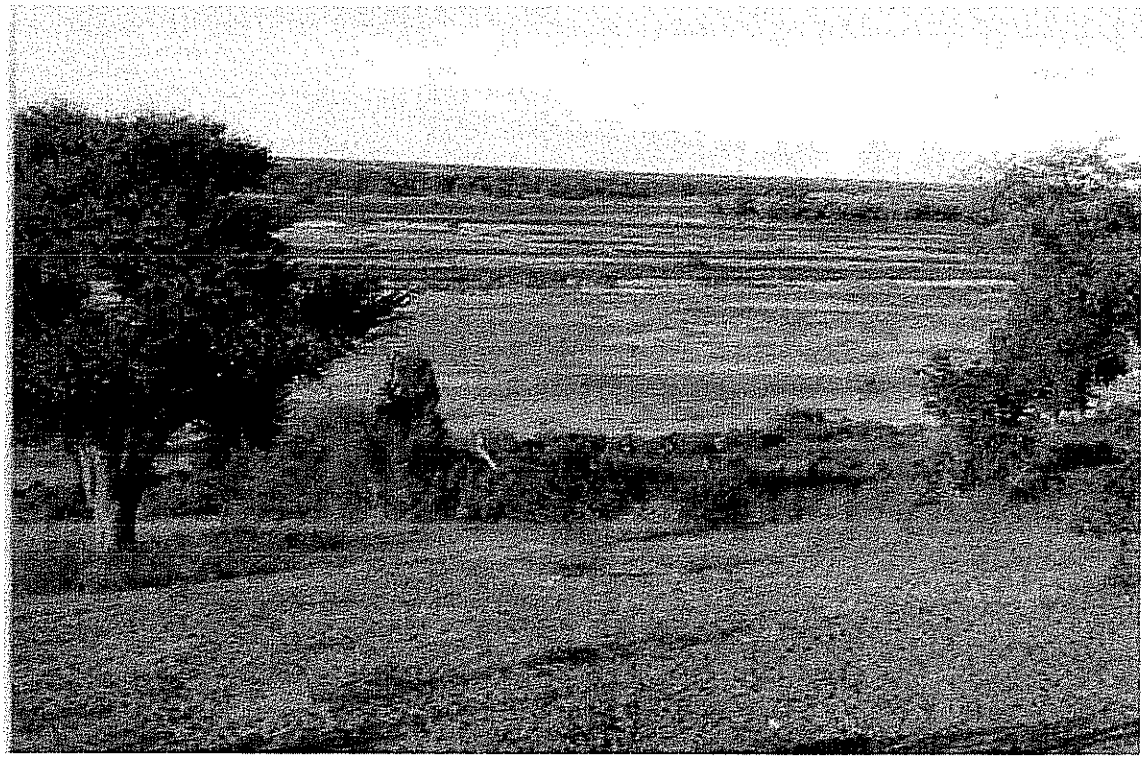
VEGETATION OF THE KAVANGO

for Kavango Environmental Profiles Programme

by Antje Burke



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For:

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Executive Summary

Introduction

The Directorate of Environmental Affairs, Ministry of Environment and Tourism requested the mapping of natural resources of the Kavango Region in a first step to compile baseline information for an Environmental Profile of the region. This document reports on the vegetation of the Kavango Region and is designed to form a supplementary to the map of "General vegetation types of the Kavango Region".

Approach and Methodology

Technical difficulties related to the satellite image interpretation resulted in a largely manual instead of remotely sensed approach. Hence a land systems map was developed and used as a base map for distribution of general vegetation types.

The general vegetation types (i.e. map units) shown on the accompanying map present an amalgamation of field vegetation types recurring in different combinations across the entire Kavango Region. The general vegetation types are accompanied by schematic diagrams depicting the distribution of individual vegetation types recognised in the field in relation to landform.

The vegetation of the Kavango Region has been extensively altered by clearing and burning and presents an intricate mosaic of different phases of recovery from disturbance. During the duration of this project is was not possible to separate the effects of natural environment and human-induced impacts and thus derive a map of "potential natural vegetation" (i.e. vegetation types which would have occurred today, were it not for the impact of man). The map of "General vegetation types of the Kavango Region" thus presents a baseline of general vegetation types and the report provides hypotheses for potential underlying causes determining the distribution of the vegetation. The possible explanations are, however, not conclusive and should be tested in further detailed studies.

Vegetation Types

A total of 37 field sampling points with detailed information to vegetation structure and composition and 441 data points of vegetation boundaries in the field resulted in 13 map units (i.e. general vegetation types) with about 30 field vegetation types associated in different combinations with these map units.

Except for the overriding factors of fire and clearing, topography with its associated microclimate and substrate conditions appeared to be important factors controlling the distribution of vegetation types in the Kavango.

In general terms, stabilised dunes of the western Kavango support Teak – Mangetti woodland (*Baikiaea plurijuga – Schinziophyton rautanenii*) largely on dune crest and dune slopes, while shrubland with *Acacia erioloba, Acacia fleckii, Combretum hereroense* and other shrub species prevail in dune valleys.

Pediplains in the southwest corner of the Kavango are mainly covered by Camelthorn – Silver *Terminalia* shrubland (*Acacia erioloba – Terminalia sericea*) with occasional remnants of Teak – Mangetti woodlands on dune fringes.

The northern sandplain is largely covered by Kiaat - Mangetti woodland (*Pterocarpus angolensis – Schinziophyton rautanenii*) with occasional pockets of Teak (*Baikiaea plurijuga*) and *Burkea* woodland (*Burkea africana*).

The Omatako drainage supports grassland and shrubland in valleys and mainly *Burkea* woodland and shrubland on the surrounding slopes, forming a transition to the stabilised dunes in the west and sandplain in the east.

A multitude of substrates and varied micro-relief support a mixture of numerous shrubland types within *Burkea* woodland on the ephemeral catchment divide. Characteristic are extensive pans with grasslands and palms (*Hyphaene petersiana*) near the pan margins.

The eastern-flowing palaeo drainage is characterised by less sand cover than the west, a network of pans and two wide dry rivers draining eastwards. In general terms *Burkea* woodlands dominate, accompanied by False mopane (*Guibourtia coleosperma*) in areas with thicker sand cover and shrub vegetation (e.g. *Baphia massaiensis*) where sand cover is lower. Possibly caused by underlying quartzite, the south-east corner presents a subsurface hardpan with Silver *Terminalia* shrubland and occasional pockets of Teak (*Baikiaea plurijuga*) and *Terminalia prunioides* woodland.

Remnants of dunes and a transition to the panveld in the south, which is prevalent in many parts of Bushmanland, support Silver *Terminalia* – Blade thorn (*Acacia fleckii*) shrubland.

Conclusion

The general vegetation types presented in this map and described in the accompanying report provide a baseline but do not contain adequate information to develop detailed guidelines for sustainable land use planning.

However, the provided information does give directions to focussed research which would elucidate the underlying factors determining vegetation distribution in detail and would thus allow to make predictions about the impact of different land use practises.

Since the Kavango is a highly dynamic system with:

- fire as a regular significant impact with (as yet unknown) multiple consequences
- variable rainfall (in terms of amount, timing and intensity)
- extensive human impact in form of slash-and-burn agriculture and
- migrations of large herbivores regularly traversing parts of the area (e.g. elephants),

understanding the effects of these environmental factors on vegetation dynamics is critical to develop guidelines for land use planning and wildlife management in this region.

As such the map of "general vegetation types" based on land regions and systems could provide a useful tool for stratifying the region and developing targeted research projects addressing the questions posed above.

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1. Introduction

1.1 Project Background

The Directorate of Environmental Affairs, Ministry of Environment and Tourism requested the mapping of natural resources of the Kavango Region in a first step to compile baseline information for an Environmental Profile of the region. The profile aims to document the major environmental processes and resources in the region, as well as the major demands placed on those resources. The final product aims at providing one or more publications which document major environmental issues and processes as well as a set of environmental data which can be used for further analysis and monitoring.

This document reports on the vegetation of the Kavango Region and is designed to form a supplementary to the map of "General vegetation types of the Kavango Region".

1.2 Study Area

1.2.1 Climate

The climate of the Kavango Region is semi-arid with average annual rainfall of 400 – 600 mm (van der Merwe 1983). The rainfall conditions during the past three seasons were extremely variable with an exceptionally good year in 1997 (Table 1). The average annual temperature is 22.5° C and frosts can occur during the winter months.

Table 1. Total rainfall per season (July – June) measured at Rundu Airport and corresponding activities during this project.

Season	mm	Activity
1996/97	791.5	satellite image taken
1997/98	254.5	
1998/99	485.6	field survey

1.2.3 Geology and Geomorphology

Aeolian, tertiary sands of the Kalahari group comprise the substrate of the largest part of the study area. Basalt and quartzite underlie some localised areas on the Kavango River and in the south-east, but do not surface in the Kavango Region.

Although the Kalahari sands appear to have created a homogenous landform across the region, several periods of sand deposition have resulted in variation of sand thickness and age of the sands. These variations and associated processes provide the main landforms encountered today. The general topography is flat with maximum altitude differences of approximately 200 m across this vast region. The steepest relief gradients are encountered towards the Kavango River and where dry rivers (omiramba) have incised the sand sheet. Calcrete crusts and hardpans caused by alternating dry and wet cycles have formed at many places in the past and appear near the surface where sand cover is thin or lacking.

1.2.2 General Vegetation

In broad terms classified as forest savanna and woodland (Giess 1971), the Kavango Region is largely wooded with broad-leafed, deciduous trees dominating the largest part, while frost tolerant savanna species (e.g. *Acacia* trees) protrude from the south (De Sousa Correira & Bredenkamp 1987).

Although vegetation was included in previous land use surveys (Page 1980; De Sousa Correira & Bredenkamp 1987), vegetation mapping based on satellite image interpretation was expected to provide more detailed results than the earlier surveys based on topographic maps and aerial photography. De Sousa Correira & Bredenkamp's work (1987) resulted in 12 land use units with a description of dominant vegetation associated with each land use unit, while Page's 18 veld types included quantitative information on species composition for each veld type. The only vegetation cover survey based on satellite imagery, maps produced for the forest mapping project (Chakanga 1995), lack information on species composition in many parts and are not accompanied by a field database.

1.2.3 Land Use

Slash-and-burn agriculture is practised throughout the region, although activities are concentrated along the perennial Kavango River and other areas where water is available. All major dry rivers (omiramba) serve as access routes and water points for settlements from where agricultural activities have extended far into the woodlands.

In addition to clearing for agriculture, fires appear to be raging through the Kavango woodlands more frequently than in the past (Trigg 1997). This can largely be attributed to burning for traditional hunting and resource management (Powell 1998), burning of fields and possibly war-time activities in the past.

As a result the vegetation in the Kavango Region has been extensively altered by clearing and burning and presents an intricate mosaic of different phases of recovery from disturbance.

2. Approach and Methodology

Technical difficulties related to the satellite image interpretation resulted in a complete shift in the proposed methodology from remotely sensed to largely manual, based on a multitude of background sources. The following steps were required:

1. Unsupervised classification of satellite image
2. Reconnaissance field survey
3. Preparatory work for main field survey
4. Main field survey
5. Data analysis and interpretation
6. Verification of land system boundaries
7. Final data analysis and mapping.

2.1 Unsupervised Classification

According to standard remote sensing procedures, an unsupervised classification of a composite of six Landsat TM satellite images of 17 April, 24 April and 1 May 1997 prepared by the GIS specialist was used as an first approximation for a land cover classification.

2.2 Reconnaissance Field Survey

A reconnaissance field survey was carried out during the period 5 – 9 February 1999 with the main objective to test whether or not correlations between boundaries of the unsupervised classification and boundaries perceived in the field could be established. The reconnaissance fieldtrip also served to sample vegetation field data and to train technical staff to carry out field surveys at a later period.

The unsupervised classification showed no correlation with vegetation or soil cover. Based on similar difficulties with satellite image interpretation in the neighbouring North Central Region it became evident that even a supervised classification using the reconnaissance field data may not produce the desired result. However, due to the GIS expert's time constraints a supervised classification was never carried out.

2.3 Preparatory Work for Main Survey

Replacing a supervised classification of the satellite images, information on possible underlying environmental parameters determining vegetation and/or soil resources in the Kavango Region was collated and prepared in a GIS-compatible format to enable overlays of different parameters. The reviewed information included:

- False colour satellite images of the Landsat TM images
- Geology (Geological Survey 1980)
- Land use units (De Sousa Correira & Bredenkamp 1987)
- FAO land units (1984)
- Veld types (Page 1980)
- Agroecological zones (De Pauw 1996)
- Soil types (Dept. Water Affairs 19[?]),
- Topographic maps and

- Water rest level contours (Dept. Water Affairs 19[?]).

According to potential main land regions and accessibility a survey route was established.

2.4 Main Field Survey

The main field survey was carried out during the period 24 April – 5 May 1999 and covered parts of western Kavango as well a traverse through the eastern section of the Kavango.

The main objective of the survey was to establish an extensive network of field data points with information on landform, vegetation and soil. Each sampling point was geo-referenced and data to habitat, general soil type, landform, potential disturbance and vegetation were collected using a previously prepared data sheet.

The two main descriptors used for vegetation were structure and composition. Vegetation structure was determined by estimating average height and canopy cover for each stratum (herb, grass, shrub and tree layer), while vegetation composition was obtained by listing all plant species per stratum with corresponding estimate of cover abundance according the Braun Blanquet method (Kent & Coker 1994). Thirty-seven sampling points with detailed information on vegetation structure and composition were established in this manner. Voucher specimens of unknown plant species were collected for later identification and lodging at the National Botanical Research Institute in Windhoek.

In addition to the information described above, the extent of vegetation types was recorded by logging the position of each perceived vegetation boundary with a Geographic Positioning System en route.

2.5 Data Analysis and Initial Interpretation

The boundary points of main vegetation types recognised in the field (a total of 441 data points) were displayed on various false colour versions of the satellite image, on orthophotos and on the scanned and digitised background information used to prepare the main field survey.

Neither satellite image, nor any other background sources showed a satisfactory correlation with vegetation types. Based on the field observations is was evident that the main woodland and shrubland types recur throughout the entire region, but often localised and associated with different landforms. Since none of the prepared remotely sensed information allowed mapping of these often localised vegetation types, the initially proposed land systems approach was considered the most important mapping source for vegetation cover.

A draft land systems map was prepared based on a combination of field data, satellite image and orthophoto which was later refined using digital topographic information obtained from the Surveyor General.

2.6 Verification of Land System Boundaries

A two-day flight survey was undertaken on 25 and 26 August 1999 to cross-check boundaries and extent of the proposed land systems. With the help of an additional 103 geo-referenced waypoints and general notes made during the flight, the draft map was reviewed, corrected and finalised accordingly. The final map comprises a combination of land regions, largely

determined by drainage patterns, and land systems within these broader land regions. The seven land regions are:

1. Stabilised dunes
2. Pediplain
3. Northern sandplain
4. Omatako drainage
5. Ephemeral catchment divide
6. Eastern panveld and
7. Eastern-flowing palaeo drainage.

2.7 Final Data Analysis and Mapping

As none of the remote sensing sources (various versions of analysed satellite imagery or black and white orthophotos) provided a satisfactory basis for mapping individual vegetation types, the final map of land regions and systems was used as a base map to depict the distribution of general vegetation types in the Kavango Region.

The majority of vegetation types recognised in the field was distributed across the entire region, but not necessarily associated with the same land system in different parts of the region. Hence, in order to derive general vegetation types, the vegetation types recognised in the field were listed according to presence in a particular land system and a map unit was assigned based on the dominant one to two field vegetation types. A map unit thus presents an amalgamation of different field vegetation types and is thus referred to as "general vegetation type". The general vegetation types are accompanied by schematic diagrams depicting the distribution of individual field vegetation types contained in each map unit in relation to landform (Fig. 1 - 6).

Due to extensive disturbances related to land use and fires throughout the region, the conventional aim of vegetation mapping to map "potential natural vegetation" (i.e. vegetation types which would have occurred today, were it not for the impact of man), could not be fulfilled. The prepared map thus presents a baseline of general vegetation types in the late 1990's which are expected to undergo further development and changes according to local and regional impacts of different land use practices.

Each map unit is associated with a set of vegetation types which in turn are linked to appropriate data of species composition and structure in a database (Table 2.).

Table 2. Linkage of map, field and database information.

Map unit	Schematic diagram	Database
General vegetation type	Vegetation type 1 (field)	Sample data 1
	Vegetation type 2 (field)	Sample data 2
	Vegetation type 3 (field)	Sample data 3

2.8 Data Structure

The field data are contained in an Excel workbook (Kav_veg_data.xls) with five individual worksheets containing data on habitat, environmental parameters and vegetation structure and composition. Appendix 1 provides a description of individual worksheets and explanatory

notes to the data structure. Map units (worksheet: map_unit), environmental data (worksheet: env), site data (worksheet: site), data on species composition (worksheet: cov) and species names (worksheet: species) have been stored in individual worksheets to enable linking of appropriate tables in a relational database.

3. Vegetation Types

Landform and disturbance regime (fire and clearing) appeared the two most significant environmental factors controlling the distribution of vegetation types in the Kavango Region. Overall climate (a gradient of decreasing rains from north-east to south-west) was proposed to play a significant role in defining the distribution of vegetation, and resulted in the division of the Kavango Region into two distinct agroecological zones with different growing periods (De Pauw 1996). However, local topography reflecting different microclimatic influences and underlying substrate are expected to play a more significant role.

Because of the severe impacts of clearing and fire, natural sequences of vegetation types in the field often had to be inferred and extrapolated. The interpretation of the vegetation types thus has to be seen in the light of these difficulties.

The description of the vegetation types is organised according to land region, general vegetation type represented in a map unit, associated land systems, field vegetation types contained in each map unit and a general description of the field vegetation types.

3.1 Stabilised Dunes

3.1.1 *Baikiaea plurijuga – Schinziophyton rantanenii* Woodland on Stabilised Dunes

Simplified map unit	**Teak – mangetti woodland**
Associated land systems	1.1 Wide dunes, 1.2 Narrow dunes
Associated vegetation types	*Baikiaea plurijuga* woodland, *Schinziophyton rautanenii* woodland, *Pterocarpus angolensis* woodland, *Burkea africana* woodland, *Acacia erioloba* shrubland – woodland, *Acacia erioloba – Acacia fleckii* shrubland, *Terminalia sericea* shrubland, *Bauhinia petersiana* shrubland

This map unit comprises several woodland and shrubland types which are associated with the west-east running stabilised dunes of western Kavango. The typical sequence of vegetation types is closely associated with landform and likely determined by rooting depth. Thus *Baikiaea* and *Schinziophyton* woodlands with deep-rooted trees dominate on dune crests, followed by *Pterocarpus angolensis* (Kiaat) on dune slopes and shrubland with *Acacia erioloba, Terminalia sericea, Acacia fleckii* and *Bauhinia petersiana* prevalent in dune valleys (Fig. 1).

Within the woodlands trees are widely spaced, averaging about 20 % crown cover. *Croton gratissimus, Terminalia sericea, Combretum collinum* and *Baphia massaiensis* form often dense stands of shrub undergrowth, while *Digitaria seriata* is the most important grass component.

The dune valleys are covered by a mosaic of grassland and shrubland with occasional *Acacia erioloba, Lonchocarpus nelsii* and *Combretum collinum* trees. The shrubs *Combretum hereroense, Acacia fleckii* and *Bauhinia petersiana* often form single species thickets. Occasional depressions support grassland with species such as *Anthephora pubescens*. Shallower rooting depth possibly caused by impeding layers of cemented fine material (hard pan) may explain the prevalence of shrubs and grasses in these habitats.

Today the majority of dune valleys has been cleared for agriculture and multiple sequences of re-growth of shrubs and trees mask the natural distribution of vegetation types.

3.1.2 *Burkea africana – Bauhinia petersiana* Woodland and Shrubland on Dune Fringes

Simplified map unit	***Burkea – Bauhinia* woodland and shrubland**
Associated land system	1.3 Dune fringes
Associated vegetation types	*Burkea africana* woodland, *Bauhinia petersiana* shrubland, *Baikiaea plurijuga* woodland, *Burkea africana – Terminalia sericea* shrubland, *Dichrostachys cinerea* shrubland, *Terminalia sericea* shrubland, *Catophractes alexandri* shrubland

The dune fringes present a transitional zone between dunes and sandplain, still showing the west-east alignment of dunes where dunes are present, but the dunes are lower, widely spaced and often not continuous. The vegetation of sandplains and dune valleys is thus more prominent.

Burkea africana woodlands are prevalent on dune crests and areas with reasonable sand cover, while *Baikiaea plurijuga* woodlands form occasional outliers on higher dunes.

The dunes valleys support mainly *Bauhinia petersiana* shrubland, with patches of *Terminalia sericea* shrubland and *Catophractes alexandri* and *Dichrostachys cinerea* indicating possible hardpan formation and calcrete crusts in the subsoil. *Schmidtia pappophoroides* is one of the dominant grasses in these shrublands.

3.2 Pediplain

3.2.1 *Acacia erioloba – Terminalia sericea* Shrubland on Pediplain

Simplified map unit	**Camelthorn – Silver *Terminalia* shrubland**
Associated land region	2. Pediplain
Associated vegetation types	*Baikiaea plurijuga* woodland, *Burkea africana* woodland *Acacia erioloba* shrubland, *Combretum collinum* shrubland, *Bauhinia petersiana – Terminalia sericea* shrubland, *Catophractes alexandri* shrubland

Thought to be forming the fringe of an apron surrounding the Karstveld region, the pediplain in the south-west corner of the Kavango Region is characterised by shallow sand cover, numerous pans and calcrete surfacing at many places.

Only remnants of dunes and the fringes of pans support larger trees, e.g. *Baikiaea* and *Burkea* woodland patches on dunes and *Acacia erioloba* trees near pans (Fig. 2). Occasional *Ziziphus mucronata* and *Peltophorum africanum* trees occur as well. However, shrubs such as *Terminalia sericea, Bauhinia petersiana, Combretum hereroense, Acacia fleckii, Baphia massaiensis* and *Combretum collinum* dominate the vegetation cover. Dense patches of *Catophractes alexandri* indicate calcrete crusts near the surface.

Grasses can form locally dense patches in depressions with *Hyparrhenia hirta* and *Anthephora pubescens* being the most prominent.

3.3 Northern Sandplain

3.3.1 *Pterocarpus angolensis – Schinziophyton rautanenii* woodland on Northern Sandplain

Simplified map unit	**Kiaat – Mangetti woodland**
Associated land systems	3.1 Okavango River and terrace, 3.2 sandplain incised by short omiramba
Associated vegetation types	*Pterocarpus angolensis* woodland, *Schinziophyton rauntanenii* woodland, *Baikiaea plurijuga* woodland, *Burkea africana* woodland, *Acacia nigrescens – Peltophorum africanum* riverine forest, *Combretum imberbe – Acacia erioloba* shrubland, *Terminalia sericea – Bauhinia petersiana* shrubland, *Catophractes alexandri* shrubland, floodplain grasslands

The northern sandplain is dissected by various north and east-flowing omiramba and is bordered by the perennial Kavango River in the north. Although the permanently flowing Kavango River is associated with wetland and riverine vegetation distinctly different from the hinterland, their localised distribution limits mapping of these vegetation types at a regional scale. They are thus included and discussed in broad terms within this section.

Floodplain, river bank, terrace and terrace slope comprise the main sequences of landforms bordering the Kavango River (Fig. 3). Grasslands with species such as *Vossia cuspidata, Cynodon dactylon* and *Setaria sphacelata* dominate the floodplain, while riverbanks originally supported riverine forests with *Acacia nigrescens, Peltophorum africanum* and *Diospyros mespiliformis* as dominant tress and a dense shrub undergrowth of various species. However, due to intense clearing and cultivation along the river, riverine forest has disappeared almost entirely and only few, localised patches remain. Today's river banks and terrace present an open parkland with few trees, cultivated land and many villages in between. Remnants of shrubland with *Combretum imberbe, Acacia erioloba, Terminalia sericea* and *Bauhinia petersiana* indicate the potential vegetation types of former terraces. However, human impact has also resulted in an increase in shrubs, often on old farmland and may thus give a false indication of what may have occurred naturally on these terraces.

The terrace slopes support open stands of *Schinziophyton rautanenii,* possibly still prevalent despite human impact because of their value as fruit trees.

The northern sandplain forms a sheet of several meter of sand cover with very few pans. Although *Pterocarpus angolensis* and *Schinziophyton rautanenii* woodlands are prominent, localised patches of *Baikiaea plurijuga* and *Burkea africana* woodlands occur throughout this map unit. *Combretum collinum* forms another important tree component, while *Combretum zeyheri, Combretum psidioides, Bauhina petersiana* and *Baphia massaiensis* are prominent in the shrub layer. Common grasses associated with these woodlands comprise *Digitaria seriata, Schmidtia pappophoroides* and *Urochloa brachyura.*

3.3.2 *Acacia erioloba* Shrubland in Northern Omiramba

Simplified map unit	**Camelthorn shrubland**
Associated land system	3.3 northern omiramba
Associated vegetation types	*Acacia erioloba* shrubland, *Terminalia sericea* shrubland *Terminalia sericea – Bauhinia petersiana* shrubland

Also heavily transformed by human activities, the shallow, dry rivers (omiramaba) of northern Kavango support a mosaic of cultivated fields, old fields with largely shrubby re-growth and occasional patches of *Acacia erioloba* trees and shrubland. In addition to *Acacia erioloba*, common shrubs are *Terminalia sericea* and *Bauhinia petersiana*.

3.4 Omatako Drainage

3.4.1 Omatako Omuramba

Simplified map unit	**Omatako Omuramba**
Associated land system	4.1 Omatako Omuramba
Associated vegetation types	*Acacia erioloba* shrubland, *Terminalia sericea* shrubland *Terminalia sericea – Bauhinia petersiana* shrubland, *Acacia erioloba – Acacia fleckii* shrubland, *Dichrostachys cinerea* shrubland, *Cynodon dactylon – Enneapogon desvauxii* grassland, *Cynodon dactylon* grassland

Because of its extent and influence far beyond the Kavango Region, the Omatako Omuramba has been assigned an individual map unit. The Omatako valley is covered by a mosaic of recent and old fields, grassland and localised patches of shrubland (Fig. 4). Occasional *Acacia erioloba* trees, and shrubby forms of *Acacia erioloba* and *Acacia fleckii* are the most prominent woody components of the vegetation. *Cynodon dactylon, Enneapogon desvauxii, Aristida stipitata* and *Stipagrostis hirtigluma* are some of the important grasses. The majority of the Omatako has been greatly altered by agricultural activities.

3.4.2 *Burkea africana* Woodland and Shrubland on Omatako Slopes

Simplified map unit	***Burkea* woodland and shrubland**
Associated land system	4.2 Omatako slopes
Associated vegetation types	*Burkea africana* woodland, *Burkea africana* shrubland, *Dichrostachys cinerea* shrubland, *Terminalia sericea* shrubland, *Catophractes alexandri* shrubland

The Omatako slopes show a sequence of shrubland and woodland similar to the dune and dune valley arrangement. As such the slopes form a transition to the stabilised dunes to the west and sandplain to the east. Shrubland with *Terminalia sericea* and *Burkea africana* are followed by *Burkea africana* woodlands towards the top of the slopes (Fig. 4). As agricultural activities are still evident in the tributaries to the Omatako, *Burkea* shrubland could also indicate the impact of disturbance by clearing and thus present re-growth of former *Burkea* woodlands. Where calcrete appears at the surface and possible other impeding layers limit root penetration, *Catopharactes alexandri* and *Dichrostachys cinerea* shrubland prevail.

3.5 Ephemeral Catchment Divide

3.5.1 Burkea africana Woodland on Ephemeral Catchment Divide

Simplified map unit	**Catchment divide**
Associated land region	5. ephemeral catchment divide
Associated vegetation types	*Burkea africana* woodland, *Baphia massaiensis* shrubland, *Terminalia sericea* shrubland, *Acacia erioloba – Peltophorum africanum* shrubland, *Acacia erioloba – Hyphaene petersiana* shrubland, *Bauhinia petersiana – Terminalia sericea* shrubland, *Eragrostis lehmanniana* grassland, *Combretum hereroense – Acacia fleckii* shrubland, *Dichrostachys cinerea* shrubland

One of the most complex map units, the ephemeral catchment divide provides a mosaic of localised differential substrate conditions ranging from deep sand to calcrete outcropping and possible calcrete and silcrete based impeding layers in the subsoil. As such the vegetation is dominated by open *Burkea africana* woodlands, intercepted by many localised vegetation types associated with pans and other hard substrates not visible at the surface (Fig. 5).

Except for *Burkea africana*, other prominent trees are occasional stands of *Pterocarpus angolensis* and *Combretum collinum*. The tall palm *Hyphaene petersiana* is usually associated with pan margins (Fig. 5). Shrublands are diverse and include almost all shrub vegetation types encountered in previous map units. *Acacia erioloba, Peltophorum africanum, Acacia fleckii, Combretum hereroense, Baphia massaiensis, Terminalia sericea, Dichrostachys cinerea* and *Bauhinia petersiana* occur in different combinations throughout this map unit.

Accordingly the same grasses associated with these woodland and shrubland vegetation types are prevalent and include *Digitaria seriata* and *Schmidtia pappophoroides*.

The centre of pans support grassland, often formed by a single species, such as *Eragrostis lehmanniana*.

3.6 Eastern-flowing Palaeo Drainage

3.6.1 *Burkea africana - Baphia massaiensis* Woodland and Shrubland on Eastern Sandplain

Simplified map unit	***Burkea – Baphia* woodland and shrubland**
Associated land system	7.1 Sandplain with small pans
Associated vegetation types	*Burkea africana* woodland, *Burkea africana – Guibourtia coleosperma* woodland, *Baphia massaiensis* shrubland, *Combretum imberbe – Acacia erioloba* shrubland, *Burkea africana* shrubland, *Teminalia sericea* shrubland, *Acacia erioloba- Acacia fleckii* shrubland

Moderate sand cover and numerous small pans characterise the landforms contained in this map unit. *Burkea africana* woodlands are associated with deeper sand, while shrubland prevails on shallower soils near pans (Fig. 6). *Baphia massaiensis* forms one of the most

prevalent shrub vegetation types, followed by *Combretum imberbe- Acacia erioloba, Acacia erioloba - Acacia fleckii* and *Terminalia sericea* shrubland.

3.6.2 *Burkea africana – Guibourtia coleosperma* Woodland on Eastern Sandplain

Simplified map unit	***Burkea* – False mopane woodland**
Associated land system	7.2 sandplain with large pans
Associated vegetation types	*Burkea africana – Guibourtia coleosperma* woodland, *Burkea africana* woodland, *Acacia erioloba* shrubland, *Combretum imberbe – Acacia erioloba* shrubland, *Burkea africana* shrubland

Although similar to the previous map unit, larger and more widely spaced pans characterise this general vegetation type. The most conspicuous feature is the presence of *Guibourtia coleosperma* trees, thus resulting in *Burkea africana – Guibourtia coleosperma* woodland as the dominant vegetation type (Fig. 6). Shrubland is less prominent than in the previous unit and includes *Acacia erioloba, Combretum imberbe* and *Burkea africana* shrubland.

3.6.3 *Terminalia sericea* Shrubland on Hardpan

Simplified map unit	**Silver *Terminalia* shrubland**
Associated land system	7.3 hardpan
Associated vegetation types	*Terminalia sericea* shrubland, *Baikiaea plurijuga* woodland, *Terminalia prunioides* woodland, *Acacia fleckii* shrubland, *Catophractes alexandri* shrubland, *Acacia mellifera* shrubland

Underlying quartzite, although not surfacing, is probably responsible for the formation of a hardpan in the subsoil. This map unit shows a curious pattern of a matrix of *Terminalia sericea* shrubland on shallow soils with numerous, interspersed patches of *Baikiaea plurijuga* and *Terminalia prunioides* woodlands. Although almost no relief is evident, the *Baikiaea* woodlands are thought to be growing on remnants of dunes, while a hardpan near the surface supports the growth of *Terminalia prunioides* woodland.

Terminalia prunioides woodland shows shrub undergrowth of largely *Dichrostachys cinerea, Mundulea sericea* and *Croton gratissimus*, while prevalent grasses are *Aristida stipitata* and *Enneapogon cenchroides*.

3.6.4 *Cynodon dactylon* Grassland in Eastern Omiramba

Simplified map unit	**Eastern omiramba grassland**
Associated land system	7.4 eastern omiramba
Associated vegetation types	*Cynodon dactylon* grassland, *Acacia mellifera* shrubland, *Terminalia sericea* shrubland, *Combretum imberbe – Acacia erioloba* shrubland

The eastern omiramba (with the Khaudom River and Nhoma River as the two main channels) are part of an ancient drainage system and, thus been exposed to erosion processes for long periods, present today wide open valleys, mainly supporting grassland in the centre and shrubland along their fringes (Fig. 6).

Although *Cynodon dactylon* is the dominant grass in most parts, other grasses such as *Setaria sphacelata* and *Eragrostis echinochloidea* are locally common. In the vicinity of surface water *Phragmites australis* forms dense conspicuous stands. Dense stands of *Acacia mellifera* shrubs likely indicate the presence of subsurface calcrete.

3.6.5 *Terminalia sericea – Acacia fleckii* Shrubland on Dune Fringes

Simplified map unit	**Silver *Terminalia* – blade thorn shrubland**
Associated land regions and systems	7.2A dune fringe with hardpan, 1.1 eastern outlier of wide dunes, 6. eastern panveld
Associated vegetation types	*Terminalia sericea* shrubland, *Acacia fleckii* shrubland *Catophractes alexandri* shrubland, *Burkea africana – Terminalia sericea* shrubland, *Burkea africana* shrubland

Remnants of west-east aligned dunes and wide open valleys characterise this map unit. *Terminalia sericea* and *Acacia fleckii* shrubland are the most prominent vegetation types in this unit. Calcrete crusting occurs locally supporting *Catophractes alexandri* shrubland. *Burkea africana* shrubland may present re-growth in fire impacted areas or indicate subsurface hardpans preventing the growth of taller trees.

4. Implications for Map Interpretation

In view of the difficulties experienced during the interpretation of vegetation cover from remotely sensed sources the map presents a very generalised and interpolated product. It will thus not be possible to provide area coverage for each vegetation type at a scale that would enable an evaluation of the resource value. The "general vegetation type" represented as a map unit is too coarse and diverse in itself to allow a satisfactory analysis of its resource value.

For the same reason an analysis of vegetation change by comparing the present map with previous vegetation maps (e.g. Page 1980) cannot be attempted.

However, this map should be viewed as a baseline of general vegetation types in the late 1990's and the report as an explanatory, but not a conclusive document. Although the report indicates potential underlying environmental factors responsible for the distribution of vegetation types in the Kavango Region, these explanations should be viewed as hypotheses to be tested in further detailed investigations.

One of the most problematic aspects which could not be addressed adequately in this study is the separation of human-induced (e.g. clearing and fire) from natural causes (e.g. substrate and landform) controlling the distribution of vegetation types. This was perceived particularly difficult as fire is part of the natural system, but fire regimes have been altered due to human activities.

5. Problems and Unavailable Information

5.1 Lack of Useful Satellite Image Map Base

The lack of a useful map base, i.e. a satellite image depicting vegetation types in the field, seriously compromised the outcome of this project. It resulted in a largely interpolated and coarse map of very general vegetation types linked to land region and systems rather than to land cover patterns perceived on the image.

External factors responsible for the difficulties are thought to be:

- The strong influence of fires depicted on the image, masking the natural patterns of land cover.
- The time of the image taken not corresponding to the time of the ground survey.
  (In fact, as a result of two years between image and ground survey, two fire seasons are not shown on the image. Thus notes to recent fire impact taken in the field are fairly meaningless for the interpretation of the available image. Similarly recent clearing activities would not have been represented on the older satellite image).
- The image was taken in an exceptionally good rainy season, while the field survey was carried out in a poor season (Tab. 1).
  (Hence denser cover of vegetation than encountered during the field survey may be depicted on the satellite image. It is also likely that responses to a good rain year differ between vegetation types thus further complicating linking "poor" season field data with a "good" season image.)

Internal problems were related to:

- Effectively timing the inputs of the GIS expert with field surveys, and
- Time and budget constraints of the GIS expert.

Although external factors were largely responsible for the failure of producing a useful map base, time and budget constraints on the GIS side prohibited the testing of a different remote sensing approach.

5.2 Lack of Recent Soil Map

Although detailed soil information from this survey was available and on-going discussions relating to the plant-soil interface assisted the interpretation of the vegetation types, the information was not available in a mapped format at the time the vegetation map was produced. It was thus not possible to incorporate soil boundaries in the vegetation map.

5.3 Influence of Fire and Clearing

The contemporary vegetation in the Kavango presents a mocaic of climax vegetation and multiple successional stages caused by disturbance (fire and clearing). Due to lack of understanding the dynamics of Kavango vegetation in sufficient detail, climax and successional vegetation could not be separated effectively during this survey.

The predominance of shrubland, for example, has been suggested to often be attributed to impeding layers limiting root penetration (De Sousa Correira & Bredenkamp 1987), but the successive impact of fires could have a similar effect.

This pattern is further complicated by the fact that fires are not only changing vegetation composition, but also soil structure and soil development, possibly resulting in additional water deflecting or impermeable layers.

All these processes need to be understood to properly interpret the perceived patterns.

5.4 Time and Budget Constraints

In addition to not being able to test different methods of satellite image interpretation, the time spent with preparing a suitable map base, curtailed the time available for field data collection and analysis.

Thus no field data are available for the panveld and the Kavango floodplain. A multivariate analysis could not be carried out due to time constraints either.

In addition, the regional approach of vegetation cover mapping asked for generalisation, thus likely not all small-scale vegetation types have been included in this survey.

5.5 Lacking Plant Information

Two factors need to be taken into account should the field database be used for further analysis:

1. The main field survey was carried out at the very end of the growing season and thus missed many of the short-lived herbs and geophytes present during the early growing season.

2. About 20 plant identifications are still awaiting confirmation by the National Botanical Research Institute.

6. Recommendations

To be able to develop a more detailed map depicting individual vegetation types and thus providing a useful base for land use planning, two fundamental problems have to be resolved:

1. development of an appropriate methodology for satellite image interpretation on Kalahari sands and
2. understanding natural and human-induced environmental factors and their role in determining vegetation distribution in the Kavango.

6.1 Appropriate Methodology for Satellite Interpretation on Kalahari Sands

Two main factors are potentially masking the land cover shown on satellite images of the Kavango Region: the impact of fire and the variation in thickness of sand cover.

The following suggestions are based what a vegetation scientist would ideally like to use as map base for mapping vegetation cover only:

- image prepared without showing the effects of fires (e.g. by eliminating certain band widths?) and
- supervised images prepared for each land region separately (e.g. one image for stabilised dunes in western Kavango, one for eastern palaeo drainage).

In addition, other factors which likely contributed to the difficulties in interpreting the recent Kavango images could be avoided by:

- selection of images taken as closely as possible during the growing season in which the ground survey is carried out.

Taking practical considerations into account this could be achieved by:

1. conducting a reconnaissance ground survey during or shortly after images are taken,
2. producing a supervised classification with these field data once the satellite information becomes available and
3. carrying out the main ground truthing and field survey during the following season.

6.2 Understanding Natural and Human-induced Environmental Factors and Their Role in Determining Vegetation Distribution in the Kavango

Separating the effects of natural and human impacts on vegetation are fundamental to understand vegetation dynamics in the Kavango Region and thus make appropriate suggestions for sustainable land use planning.

Important natural environment parameters appear to be:

- landform and associated microclimate and
- substrate, particularly the presence of subsurface impeding layers.

The two main significant impacts correlated with human activities are:

- fire and
- the impact of clearing.

Only more detailed studies, possibly with monitoring over several seasons will enable addressing these questions.

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Acknowledgements

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8. Appendices

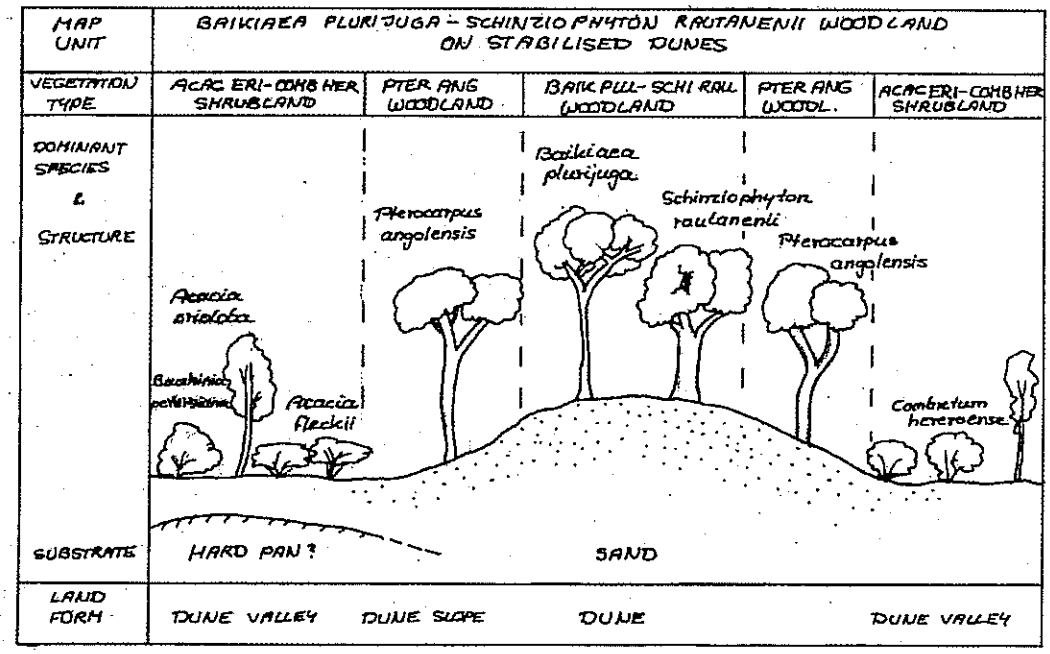

Fig 1. Schematic diagram (not to scale) of vegetation types of *Baikiaea plurijuga – Schinziophyton rautanenii* woodland on stabilised dunes (simplified map unit: **Teak – Mangetti woodland)** (Species abbreviations use first four letter of genus and first three letters of species name).

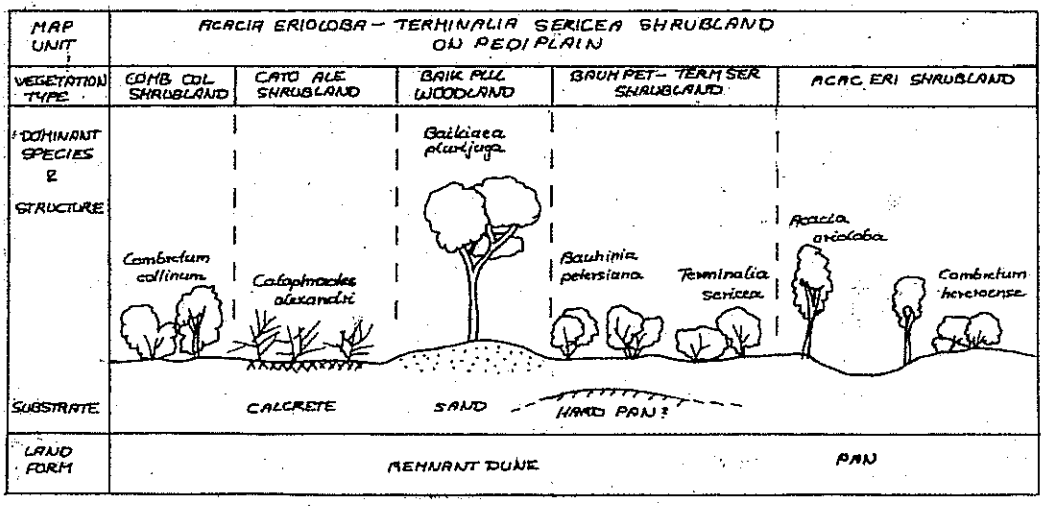

Fig. 2. Schematic diagram (not to scale) of vegetation types of *Acacia erioloba – Terminalia sericea* shrubland on pediplain (simplified map unit: **Camelthorn – Silver Terminalia shrubland)** (Species abbreviations use first four letter of genus and first three letters of species name).

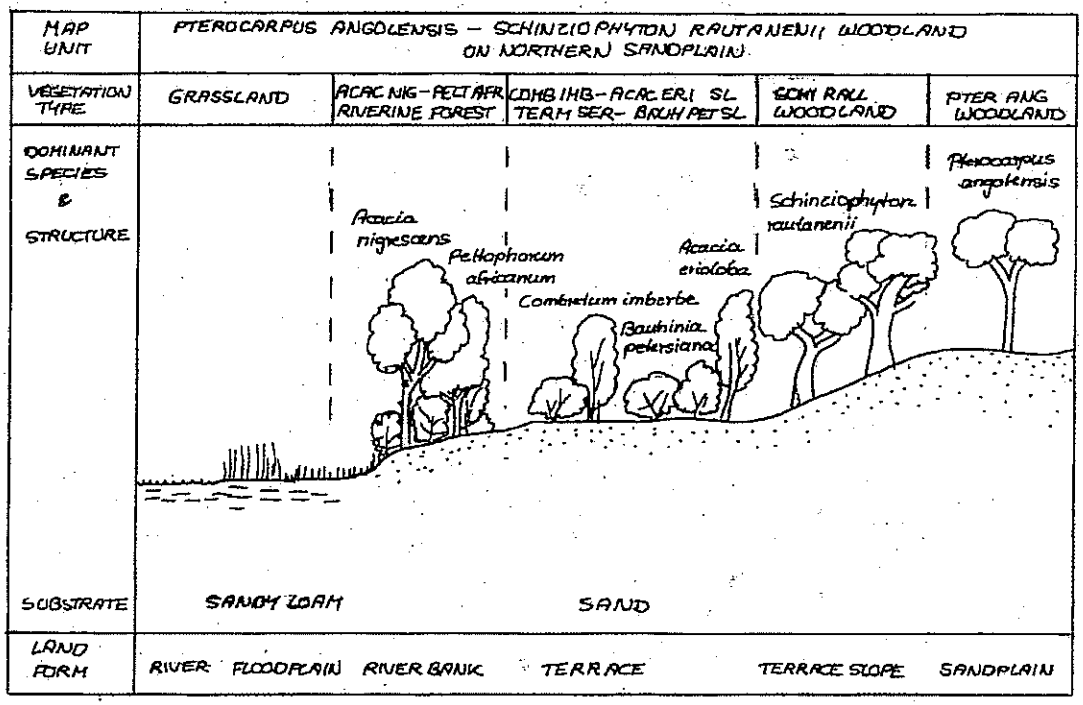

Fig. 3. Schematic diagram (not to scale) of vegetation types of *Pterocarpus angolensis* – *Schinziophyton rautanenii* woodland on northern sandplain (simplified map unit: **Kiaat – Mangetti woodland)** (Species abbreviations use first four letter of genus and first three letters of species name, SL = shrubland).

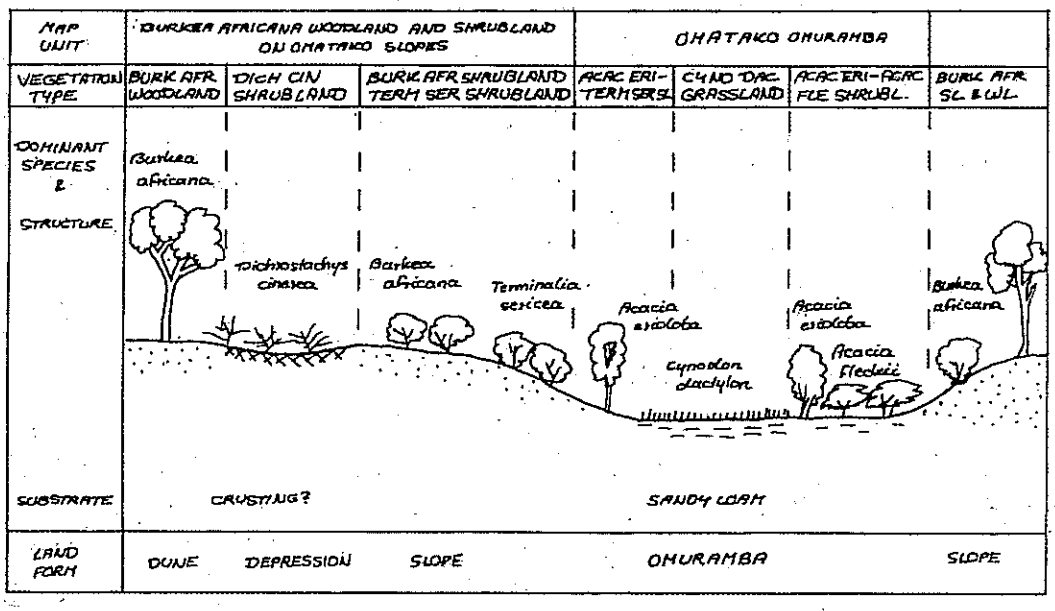

Fig. 4. Schematic diagram (not to scale) of vegetation types of Omatako Omuramba and Omatako slopes (simplified map units: **Omatako Omuramba** and ***Burkea* woodland and shrubland)** (Species abbreviations use first four letter of genus and first three letters of species name, SL = shrubland, WL = woodland).

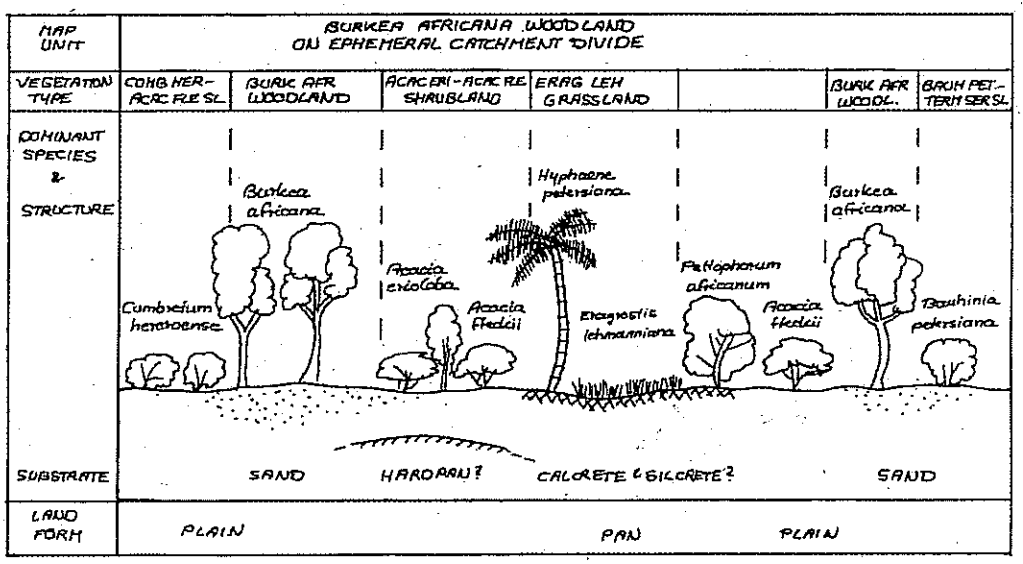

Fig. 5. Schematic diagram (not to scale) of vegetation types of *Burkea africana* woodland on ephemeral catchment divide (simplified map unit: **Catchment divide)** (Species abbreviations use first four letter of genus and first three letters of species name, SL = shrubland).

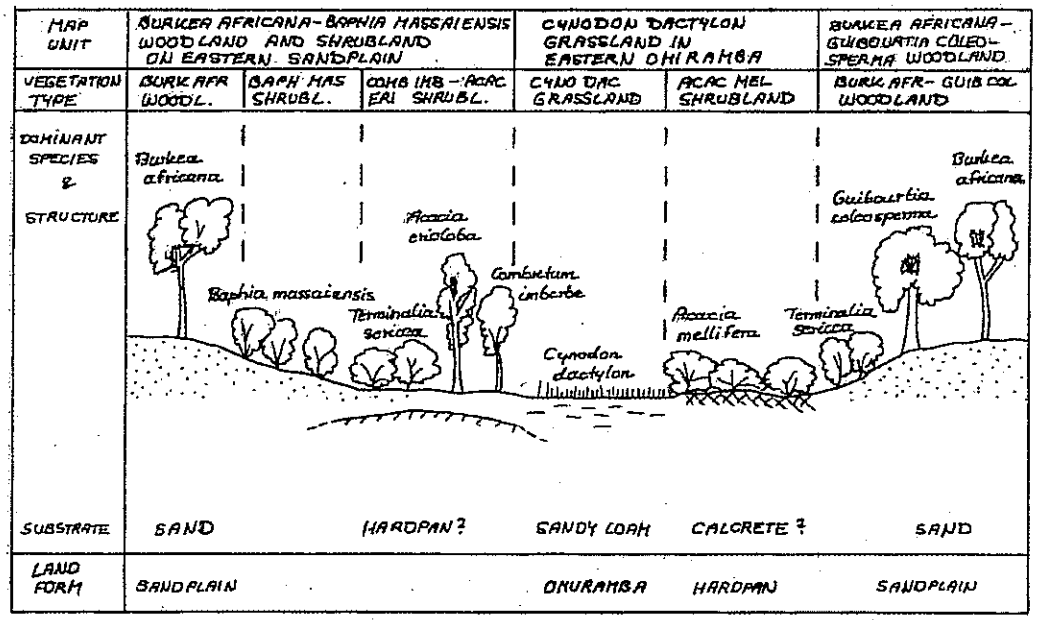

Fig. 6. Vegetation types of eastern-flowing palaeo drainage (simplified map unit: ***Burkea* – *Baphia* woodland and shrubland**, ***Burkea* – False mopane woodland** and **Eastern omiramba grassland)** (Species abbreviations use first four letter of genus and first three letters of species name).

Appendix 1. Structure and contents of Excel workbook Kav_veg_data.xls

1. Worksheet "map_unit"

Fields	Description
map_unit	worksheet name
draft map	unit name on hand-drawn map
"Scientific" legend	full species names and land system
"Popular" legend	short common name

2. Worksheet "env"

Fields	Description
env	worksheet name
Site	site name
Sample	sample number
degS	degrees South
minS	minutes South
degE	degrees East
minE	minutes East
LAT	latitude in decimal degrees
LON	longitude in decimal degrees
Landform	landform
Aspect	aspect
Slope	slope
Disturbance	disturbance
HerbH	average height of herb stratum
GrassH	average height of grass stratum
Shr1H	average height of first shrub stratum
Shr2H	average height of second shrub stratum
Tree1H	average height of first tree stratum
Tree2H	average height of second tree stratum
HerbC	total cover of herb stratum
GrassC	total cover of grass stratum
Shr1C	total cover of first shrub stratum
Shr2C	total cover of second shrub stratum
Tree1C	total cover of first tree stratum
Tree2C	total cover of second tree stratum
Vegetation type	vegetation type
Map unit	map unit

3. Worksheet "site"

Fields	Description
Site	worksheet name
Site	NW = North-west
Date	
Survey	
Samples	
Geology	

Appendix 1. Continued....

4. Worksheet "cov"

Fields	Description
cov	worksheet name
Sample	sample number
Spp_ab	abbreviated plant species name
Strata	T2 = Tree 2, T1 = Tree 1, S2 = Shrub 2, S1 = Shrub 1, G = Grass, H = Herb
COV	percent cover according to mean of Braun-Blanquet scale

5. Worksheet "species"

Fields	Description
species	worksheet name
Spp_ab	abbreviated plant species name
Full name	full species name with authority
Short name	short species name

Appendix 2. Vegetation types in the Kavango Region.

Photo 1. *Burkea africana* woodland is today one of the most widespread vegetation types in the Kavango region.

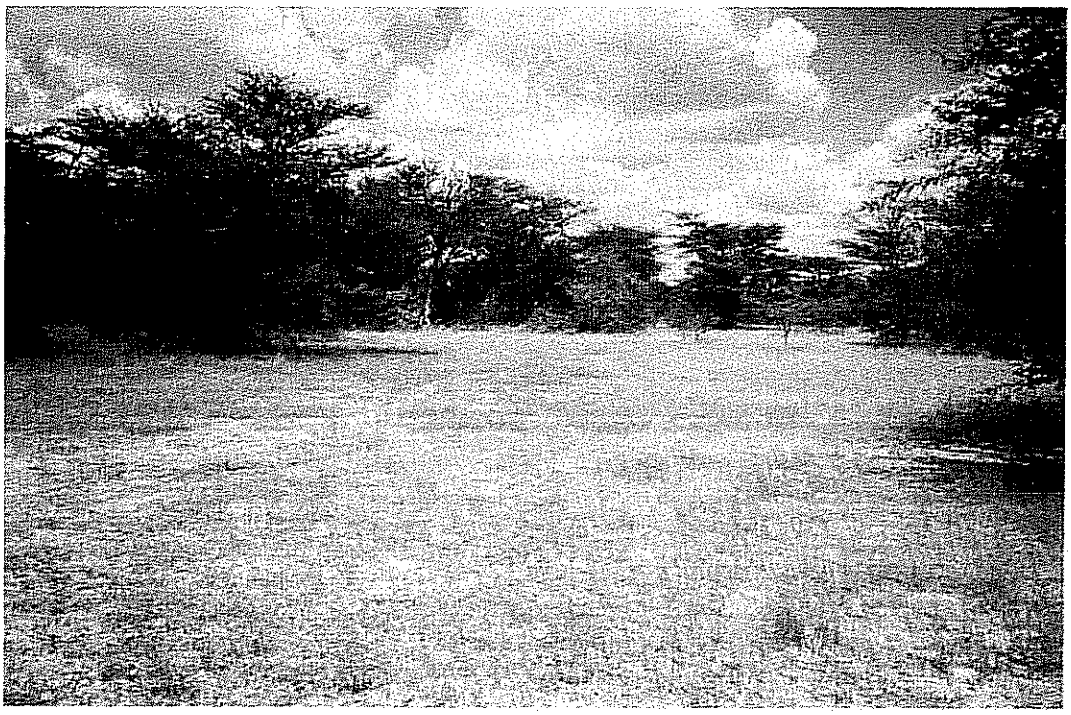

Photo 2. Many pan margins are surrounded by *Acacia erioloba* (Camelthorn) shrubland forming various transitions to the surrounding woodlands.

Photo 3. *Burkea africana – Guibourtia coleosperma* (*Burkea* – False mopane) woodlands are prevalent on deep sand in the eastern part of the Kavango Region.

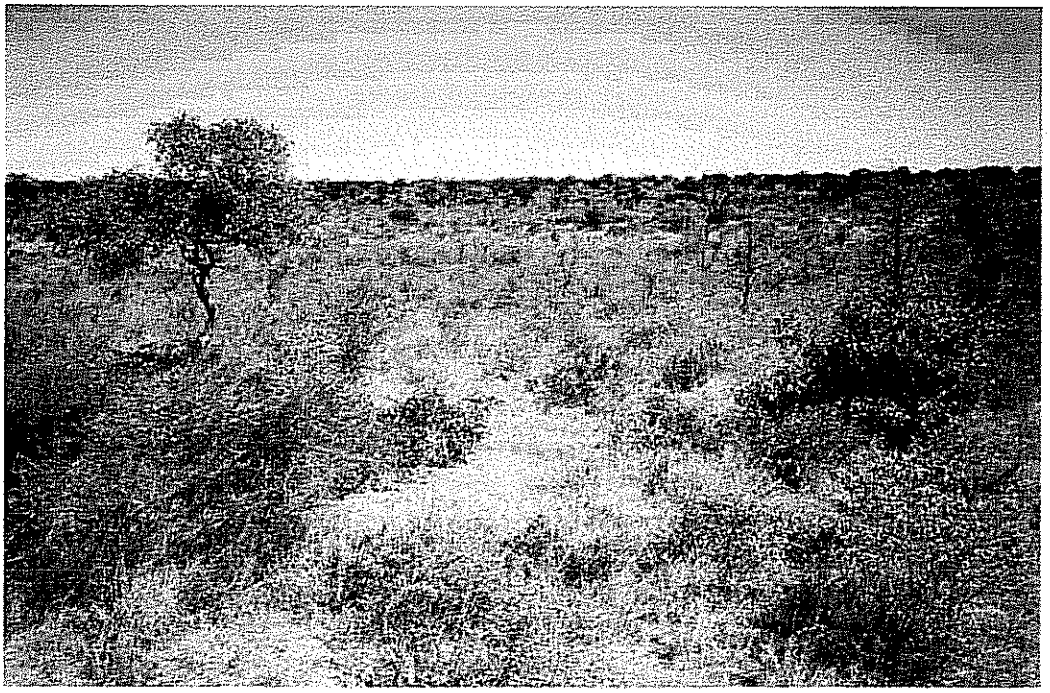

Photo 4. *Terminalia sericea* (Silver *Terminalia*) shrubland is common in valleys in the eastern Kavango, while *Baikiaea plurijuga* (Teak) woodland occurs on remnants of dune crest (see background of photograph).