A Reconnaissance Survey of the Landscapes, Soils and Vegetation of the Eastern Communal Areas (Otjiozondjupa and Omaheke Regions), Namibia

Ben J. Strohbach, Marianne Strohbach, Josaphat T. Kutuahuripa and Heiner D. Mouton

National Botanical Research Institute and Agro-Ecological Survey Programme
Directorate Agriculture Research and Training
Ministry of Agriculture, Water and Rural Development
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1 Abstract

Most agricultural lands in Namibia are situated in semi-arid to arid lands. In order to achieve sustainable management of these resources, it is essential to know and understand these resources available. With this in mind, the Desert Margins Programme in Namibia initiated a project to map and describe the resources available to communal farmers in the eastern communal areas of Namibia.

The study area comprises the Otjinene district in the Omaheke region, as well as the Okakarara and parts of the Grootfontein and Tsumkwe Districts in the Otjozondjupa Region. The total study area covers 57 414.72 km^2. It receives between 380 and 480 mm of summer rain annually. Most of the study area is covered by relatively homogenous sands of the Kalahari basin, with only in the far western parts some erosion plains of the Central Plateau being present. Some suboutcropping rocks are present in the far southeastern corner (Rietfontein area) as well as the far northeastern corner (Gam area).

A survey of the landscapes and soils was done at a reconnaissance level. Most of the soils belong to the Arenosols (deep sands) of the Kalahari basin. These are mostly with poor horizon development due to the arid environment. Only in the drainage lines (omiramba) and in the areas with suboutcropping geological formations soils with a more distinct horizon development have been found – mainly Calcisols and Fluvisols.

A phytosociological survey of the vegetation was done, also on a reconnaissance level. 20 different vegetation types were identified, grouped together as variants, subassociations and associations of the Terminalia – Combretum savannas and the Acacia savannas. The most widely distributed vegetation type is the *Terminalia sericea – Combretum collinum* shrubland association, covering roughly 80 % of the study area. Many of the Acacia savanna types are related to shallow soils or wetland areas, i.e. special habitats. Characterising species, diversity indicators, the typical composition and structure of the various vegetation types is discussed in detail. An indication is also given of the grazing condition as well as potential threats through poisonous plants.

Other potential sources of income from vegetative resources are discussed.

The vegetation types have been also mapped with the aid of satellite imagery.

2 Introduction

In southern Africa there is an increasing demand for land as human populations increase. Most land available for development, especially agricultural use, is situated in the semi-arid parts of the subcontinent. Namibia is no exception as far as these demands are concerned.

Semi-arid regions are defined by Walker (1979) as regions where the climate is too dry to allow subsistence from annual dryland crop cultivation, thus forcing land users to live off the natural vegetation and its associated wildlife. Vegetation in such regions reacts noticeably to environmental stresses, these being natural or man-induced (Walker 1979, Küchler 1988). Semi-arid regions can thus be considered as being more fragile than more mesic environments, thus also requiring more careful than average management to be able to use natural resources in a sustainable manner (Walker 1979). Suitable management and conservation practices and environmental planning are, however, dependent on a high standard of ecological data (Bredenkamp 2001).

Since Namibia's independence there has been a substantial increase in efforts to develop the country's communal areas. Many of these areas have been, and still are, subjected to poor and indifferent management practices due to a lack of sound ecological (baseline) data and hence a poor understanding of especially the vegetation resource base, its biodiversity, dynamics, its utilisation possibilities as well as its limitations (Hines 1992, Mendelsohn & el Obeid 2002). This is also the case when looking at the communal lands in eastern Namibia, which consist of what was formerly known as Bushmanland, Hereroland West and Hereroland East.

Vegetation is made up of a mosaic of plant communities. Plant communities are associations of plant species co-existing within a particular combination of environmental features and so forming the basis of stable ecological processes. Vegetation reactions to environmental stresses, these being natural or man-induced, can be detected in a change of known species associations and their abundance characteristic for such a plant community. (Daubenmire 1968; Mueller-Dombois & Ellenberg 1974; Küchler 1988, Tainton 1999). Mapping and managing individual plant communities may become problematic: due to environmental variations an infinite number of variations of plant associations exist within a particular area. For practical purposes, similar plant communities are thus grouped into manageable units or veld types. Acocks (1975) defined such a veld type as "a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same farming potentialities". This also implies that we may expect units of a veld type to exhibit the same basic dynamics and to react similarly to the same type of land use. Exact extrapolation of any grazing trial result is limited to the plant community in which the trial was conducted, but predictions of vegetation response is possible wherever the veld type, of which this community is regarded part of, may be found.

A phytosociological study on the vegetation of Bushmanland has been completed by Hines (1992). Information regarding the vegetation of the former Hereroland could so far only be approximated from the Preliminary Vegetation Map of Namibia (Giess 1971) as well as the Relative Homogenous Farming Areas Report (Department of Agricultural Technical Services, 1979). The Relative Homogenous Farming Areas Report lists farming possibilities and constraints of the commercial farming area, including an estimation of the grazing capacity. This map has been found to be inaccurate for quite some time now, albeit not proven (Strohbach 1995); whilst the carrying capacity concept has since changed from a fixed rate per area to the biomass concept, which is an (annually changing) estimate of the amount of fodder produced during that season's rainfall (Bester 1988). The Preliminary Vegetation Map of Namibia is regarded as relatively accurate as far as the delineation of vegetation types is concerned, still, some anomalies have been found. This is especially true for the eastern communal areas, which were largely inaccessible at the time this vegetation map was compiled. This map's description of the

Namibian vegetation types is very elementary. Both reports are based on limited observations and some photographic records, but no actual ecological surveys have been conducted. A more recent vegetation map by Mendelsohn *et al.* (2001) also does not rely on any phytosociological data, but does take into account known distribution lists for some of the more dominant species (trees and shrubs). As indicated earlier, a list of the most dominant and occasionally desirable species is not very useful for the land use manager or conservationist as a change in the abundance of dominant species and more importantly the so far unknown herb layer and presence of rare species is the information needed to assess the condition of veld (Bredenkamp 2001).

The Agro-Ecological Zoning (AEZ) Programme was initiated in 1996 by the Namibian Ministry of Agriculture, Water and Rural Development to assist the country wide agricultural development by collecting baseline data on the soils, climate and vegetation of the country, with emphasis on the production potential of the natural resources.

In collaboration with the AEZ Programme, the goal of the recently initiated Desert Margins Project (Namibia) is the conservation and restoration of biodiversity in Namibia's desert margins. One of the major outputs is the establishment of baseline information about natural resources available to local communities in selected areas, existing land degradation trends and subsequent loss of biodiversity. The target area selected for this study (and hereafter referred to as the study area) is the former Hereroland, consisting of the farming areas of Otjituuo, Okamatapati, Okakarara (Ozonahi Conservancy), Okondjatu (Wild Dog Conservancy), Otjinene, Epukiro, Rietfontein, Eiseb Block and Gam in the Otjozondjupa and Omaheke regions (Figure 1). The study area covers 57 414.72 km^2.

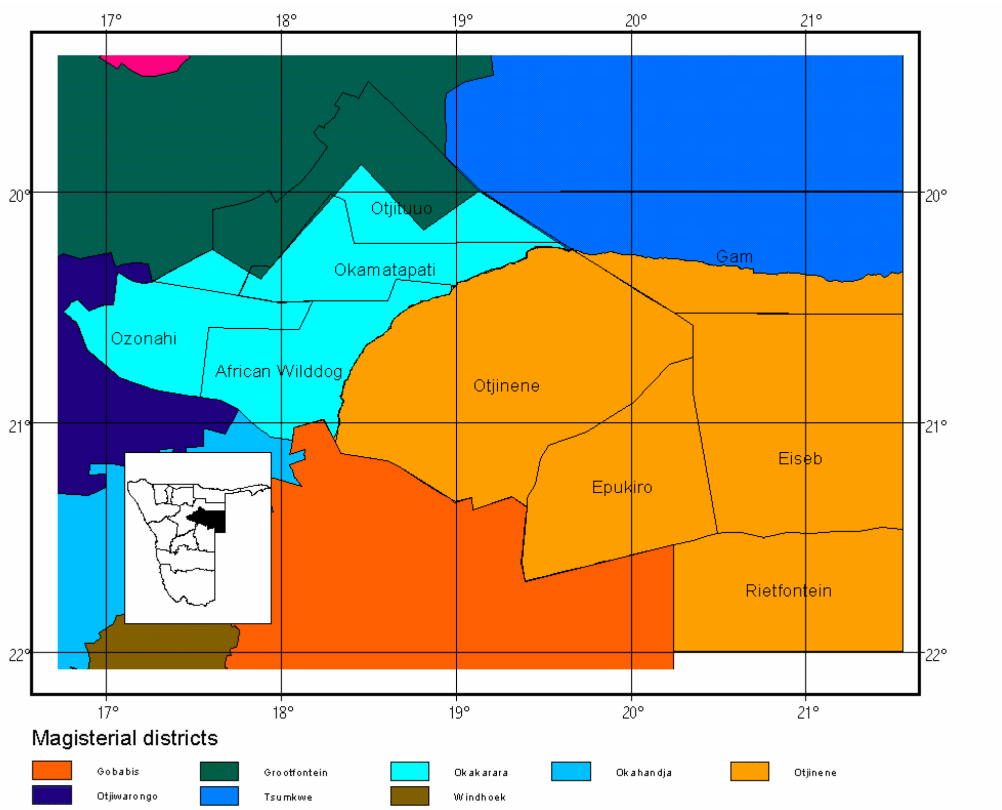

Figure 1: Location of the study area.

The report presented below is a first attempt to describe and map the vegetation types and the soil of the study area. It is divided as follows:

- A brief background description of available information on the physical environment of the study area
- A reconnaissance survey of the soils of the study area
- A reconnaissance survey and phytosociological classification of the vegetation of the study area
- Mapping of the vegetation based on LANDSAT-TM satellite imagery

2.1 The physical environment

2.1.1 Climate

Very little meteorological data has officially been recorded within the study area. Climate variables for the area have been extrapolated from records collected in Gobabis, Grootfontein, Tsumkwe and Ganzi (in Botswana) by Leo Hatz Consulting (1991), Hines (1992 for the former Bushmanland) and de Pauw *et al.* (1989/99). A good overview of the area's climate can be found in Mendelsohn & el Obeid (2002), thus only a short summary will be presented below.

2.1.1.1 Rainfall

Typical for a southern African sub-continental area, most rains fall during a few summer months, with a seven or more dry months in-between (Huntley 1982, Rutherford & Westfall 1994). Average long-term annual rainfall ranges from about 325 to 350 mm in the south-eastern corner (Rietfontein Block) and the most western part (around Okakarara) to about 425 to 450 mm in the central part of the area – roughly from Okondjatu and Otjinene to the Mangetti Dune (Figure 2). An important aspect of this rainfall is its sporadic and often erratic nature within the rainfall season and from year to year. Droughts are regarded as common (Leser 1972, Botha 1998/99).

2.1.1.2 Temperature

For southern Africa, mean daily temperatures characteristic for winter are represented by July temperatures (Schulze & McGee 1998). These range from 2.5°C (minimum) and 22.2° C (maximum) with 8 days frost in the southernmost parts of the study area to about 4.3°C (minimum) and 23.6°C (maximum) with 2 days frost in the northern parts.

Mean daily temperatures characteristic for summer are represented by January temperatures (Schulze & McGee 1998), these ranging from 17.4°C (minimum) and 31.8°C (maximum) in the southern parts to 17.9°C (minimum) and 30.2°C (maximum) in the northern parts. Especially during November and December, however, daytime temperatures can soar to just below 40°C.

2.1.1.3 Evaporation

Much neglected yet important climatic variable are annual evaporation rates. Low humidity coupled with high temperatures has an indirect yet pronounced effect on water availability to the vegetation by influencing the evaporation and evapotranspiration (Schulze & McGee 1978).

Potential evaporation rates range from 2100 – 2240 mm per year over the south-western parts of the study area to 1960 – 2100 mm per year over the north-eastern parts, thus overall far exceeding annual rainfall. An area where rainfall is less than half the potential evaporation is considered to have almost no dependable growing period for crops (de Pauw 1996).

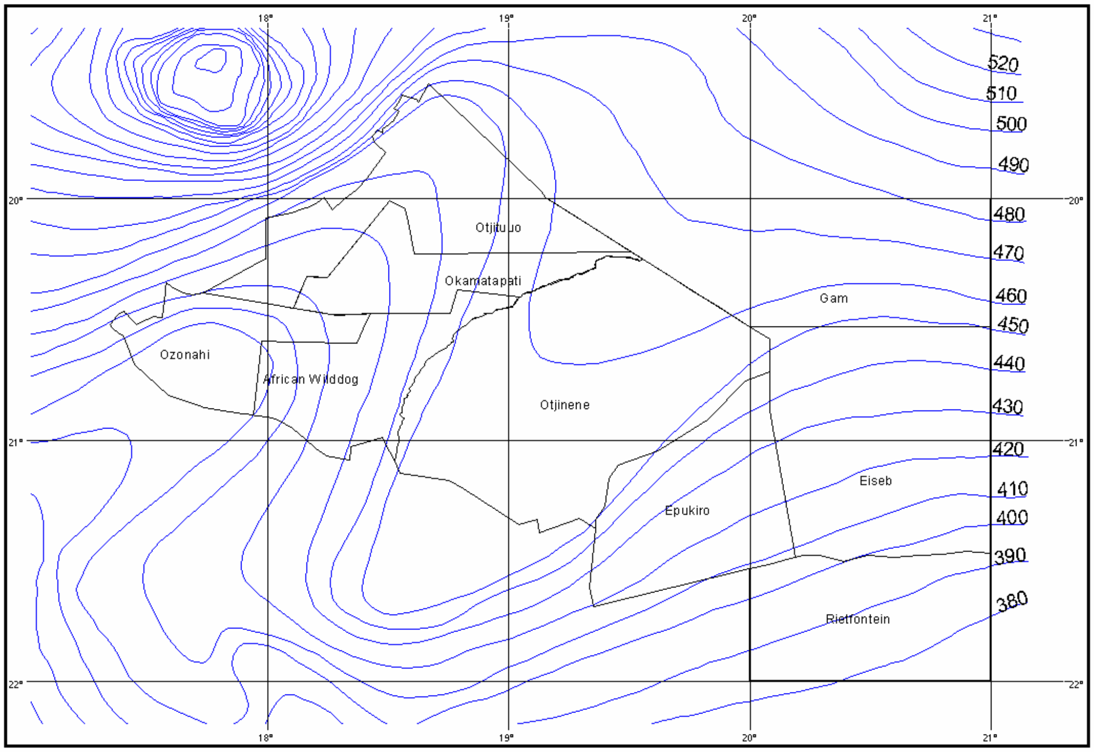

Figure 2: Rainfall ishoyets (in mm) for the study area (AEZ 2001).

2.1.2 Geology

An overview of the geology and landscapes of the area is given in Mendelsohn & el Obeid (2002), and will only be briefly summarised here.

The study area is situated on the vast Kalahari System (Thomas 1988). This ancient basin, which was formed during the Cretaceous (120 – 70 Ma) has been gradually filled up with silt and clay sediments as well as windblown sands during the Tertiary to Quaternary (32 – 39 Ma, Geological Map of Namibia 1980). The windblown sands dominate the surface soils of the study area. Occasionally exposed rock formations can be found – these are mainly sandstone, limestone, schists and dolomite of the much older Karoo Sequence (180 – 500 Ma, Carboniferous to Jurassic age) and the Damara Sequence (720 – 900 Ma, Namibian age).

The sandy landscapes are generally flat to rolling (with 6° – 9° slopes): plains are incised by Omuramba valleys or alternated with vegetated fossil (no longer actively moving) dunes.

Leser (1972) differentiates between coarse-grained yellow sands, which we found mostly on plains, and finer-grained reddish sands, which were found to be present especially on the fossil dunes. Apart from the Omuramba valleys, which often have exposed or underlying calcretes and limestone ridges, occasional pans formed from the limited runoff in the area have grey clays to grey sands. A more thorough study on the soils will be presented below in the chapter on the soil survey.

2.1.3 Agro-ecological Zones

The Agro-Ecological Zones Map of Namibia (de Pauw 1996) divides the study area into eight agro-ecological zones. An agro-ecological zone is defined as a land-entity that is sufficiently uniform in terms of climatic, landform and soil features for broad agricultural planning objectives, and is unique by the specific combination of these land attributes (De Pauw & Coetzee 1998/99). The characteristics of these zones characterising the study area are summarised in Table 1 below. The distribution of these zones is depicted in Figure 3 thereafter.

Table 1: The Agro-Ecological Zones (AEZ) characterising the study area (adapted from de Pauw *et al*. 1999).

Main Zone	AEZ Description	Length of growing Period	Evaluation for crop production	Agricultural Potentials
Central Plateau	CPL1: Southern Omatako plains	Average growing period 63, very short dependable growing period of 6 days	Not suitable for crop production due to short dependable growing period, combined low water holding capacity and low nutrient status	Large livestock production on extensive grazing.
		Average growing period 61-90, dependable growing period 60% of average period.	Not suitable for crop production due to low water holding capacity and low nutrient status	Large livestock production on extensive grazing, limited cropping
	CPL2: Fringe plains	Average growing period 61-90, dependable growing period 60% of average period.	Not suitable for crop production due to low water holding capacity and low nutrient status	Large livestock production on extensive grazing, limited cropping
Kalkveld	KALK3: Kalkveld	Average growing period 61-90, dependable growing period 60% of average period.	Unsuitable for crops due to shallow soils, on deeper soils however good for cropping.	Large livestock production on extensive grazing, limited cropping
Kalahari Sands Plateau	KAL1: stabilised W-E dunes with few pans	Average growing period 63, very short dependable growing period of 6 days.	Unsuitable for crops due to low dependable growing period and sandy soils.	Large livestock production on extensive grazing.
	KAL10: Tsumkwe panveld	Average growing period 63, very short dependable growing period of 6 days.	Unsuitable for crops due to low dependable growing period and sandy soils. Groundwater resources are more readily available, making small-scale irrigation (garden-scale) for food production possible.	Large livestock production on extensive grazing.
	KAL3-4: stabilised sand drift with few pans	Average growing period 63, very short dependable growing period of 6 days.	Unsuitable for crops due to low dependable growing period and sandy soils.	Large livestock production on extensive grazing.
	KAL5: Incised river valleys	Average growing period 63, very short dependable growing period of 6 days.	Unsuitable for crops due to low dependable growing period and sandy soils.	Large livestock production on extensive grazing.

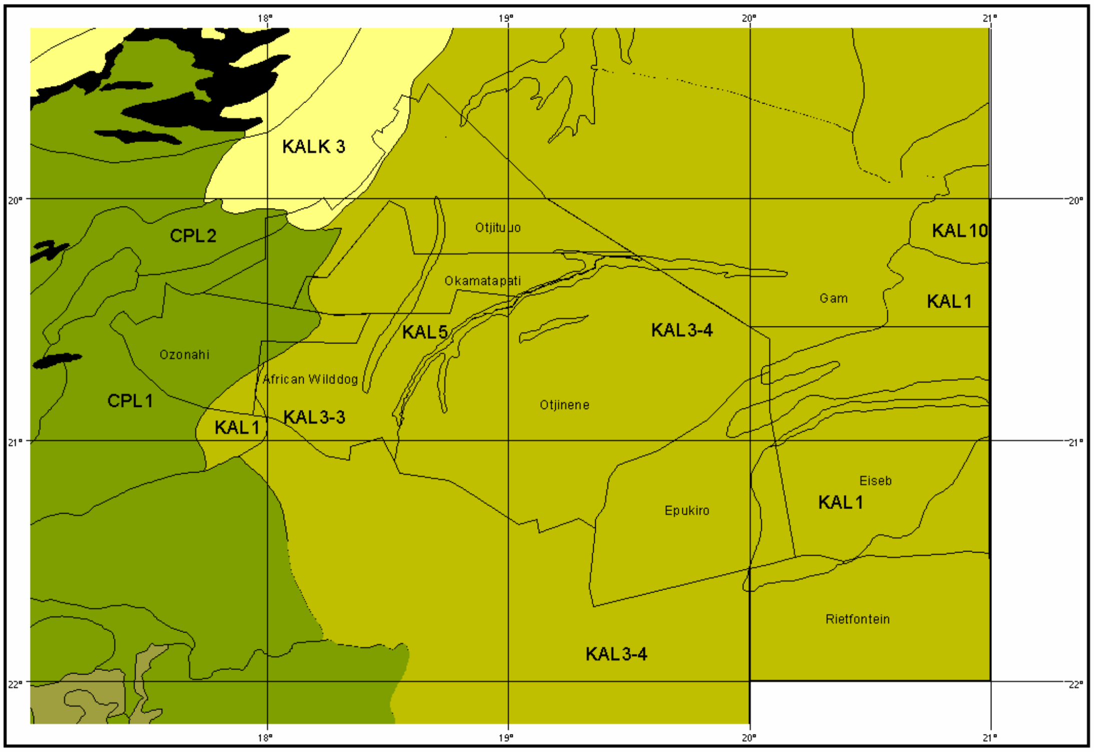

Figure 3: Agro-ecological zones of the study area, after De Pauw *et al.* (1998/99).

3 Soil and Landscape Surveys

3.1 Preparatory Work

Initial stratification was done by visual interpretation of satellite imagery (the same satellite maps as used for the vegetation survey). With overlays of existing data on vegetation, climate, geology and soils, expected soil-mapping units were identified and delineated with on-screen digitising. The resultant maps at a 1:250 000 scale were used for ground-truthing.

3.2 Fieldwork

The survey was carried out at reconnaissance level in terms of observation point density. The fieldwork was done in collaboration with the vegetation survey. Following data was recorded:

- Mini pits were excavated in very shallow, rocky and stony areas.
- Representative soil profiles were dug wherever the soil conditions of the survey sites were suitable (deep soils). 75 profiles were dug and classified according to the FAO Guidelines for Soil Description (1990). Representative soil samples from each horizon were collected for chemical and physical analysis. The depth of the profiles ranged from 80-150 cm. Photos of the different profiles were taken with a digital camera. The exact location of all profiles and minipits was recorded with a Global Positioning System (GPS).
- Each soil horizon within a profile was described according to the SOTER terminology, which is based on colour, texture, consistence, stoniness, landform, and presence of carbonates and position in the landscape.
- Soil colours were checked by using the Revised Standard Soil Colour Chart (Eijkelkamp, 1993).
- The presence of Calcium Carbonates was determined by treating the soil sample with 10% hydrochloric acid (HCl) and checking for effervescence.
- Textures were determined by using the "finger" or "feel method" (Foth *et al*. 1980).
- Soil samples of each horizon within a soil profile were collected for laboratory analysis.

3.3 Laboratory Methods

The Agricultural Laboratory of the Ministry of Agriculture, Water and Rural Development carried out physical and chemical analyses of the soil samples. Samples were tested for: particle size, bulk density, pH, electrical conductivity, cation exchange capacity, exchangeable bases, soluble bases and metals, organic carbon and available phosphorus. A brief summary of methods is given below (based on Rowell, 1998).

3.3.1 Sample Preparation

Soil samples are placed into pans and dried at ambient temperature. Dry samples were ground to break up larger clods, and then sieved to a uniform size (2 mm). Stones and gravel so removed were weighed separately to determine their proportion of the sample.

3.3.2 Particle Size Analysis by the Rowell Auto pipette Method

Samples were dispersed in a sodium carbonate/ sodium hexametaphosphate solution. Silt and clay particles were separated by sampling with an auto pipette at a depth of 6 cm after regular time intervals as determined by Stoke's Law of Sedimentation. These sub samples were dried and weighed. Sand was separated by wet sieving through a 53-micron sieve. The sand was further separated into fine, medium and coarse fractions by dry sieving. The amount of very fine sand is important since it has relatively high moisture retention properties. The texture of the soil was expressed as a summary of % sand, % silt, and % clay and classified according to the United State Department of Agriculture (USDA) Texture Triangle.

This method is suitable to determine the proportion of sand, silt and clay in most mineral soils. Additional treatments are required for soils with organic carbon contents exceeding 2% as well as soils containing high concentrations of soluble salts and cementing agents such as calcium carbonate and gypsum.

3.3.3 Bulk Density

A sample was collected with an Eijkelkamp Undisturbed Core Sampler in a cylinder of known volume and sealed. The sample was dried at 105^{o}C to a constant mass, cooled in a dessicator and weighed. The bulk density was calculated as volume per mass. Unit: g/cm^3 = $^{kg}/dm^3$.

3.3.4 pH of Soil in Water (pHw), 1 M Potassium Chloride (pKCL) and pH of the Saturation Extract

pH of the soil was measured potentiometrically in a supernatant suspension of a 1:2.5 soil: liquid suspension on a mass to volume basis. The liquid was either water (pHw) or 1 M KCl solution (pHk). A saturated paste extract was also used to measure pH.

3.3.5 Electrical Conductivity (EC) in a Saturated Paste or 2: 5 Water: Soil Extract

EC was measured with a conductivity meter, referenced to a standard temperature (e.g. 20 or 25^{o}C). Unit: dS/m.

The content of soluble salts in soil was estimated by measuring the EC in a saturated paste, an extract from a saturated paste or in extracts prepared at varying ratios of soil to water.

3.3.6 Cation Exchange Capacity (CEC) and Exchangeable Bases

Soil samples were pre-washed with de-ionised water to remove all soluble salts. Then they were leached with ammonium acetate to replace exchangeable bases with ammonium ions. Exchangeable calcium, magnesium, sodium and potassium were measured in this effluent. The samples were then leached with sodium acetate to saturate the cation exchange complex with sodium ions. The excess sodium was removed by leaching with ethanol and the cation exchange capacity determined by measuring the sodium subsequently de-sorbed by further leaching with ammonium acetate. For this procedure an automatic extractor was used Unit: cmol (+)/kg

This method is used to estimate the CEC of most soils. However, saturating cations or pH of the equilibrating solution may be varied for soils containing certain clays or minerals. Further, it may be difficult to differentiate between exchangeable and soluble cations in soils containing carbonates, gypsum or soluble salts. In such cases following modifications to the process were made:

Modification for carbonate/non-saline soils: If the pH of the 2:5 H_2O water extract was > 7 with carbonates present but EC 2.5 < 0.4 mS/ cm then no pre-washing was required. A 50:50 mixture of NH_4OAc pH 7 and ethanol was used to displace the bases instead of using NH_4OAc at pH 7 alone to obviate carbonate dissolution.

Modification for carbonate/saline soils: If the pH of the 2:5 H_2O water extract was > 7 with carbonates present but EC 2.5 > 0.4 mS/ cm then a pre-washing as above was done, followed by a 50:50 mixture of NH_4OAc pH 7 and ethanol to displace the bases instead of using NH_4OAc at pH 7 alone to obviate carbonate dissolution.

3.3.7 Analysis using Spectral Atomic Absorption (SOP)

Extract solutions were aspirated as a fine mist into an air-acetylene flame, and nitrous oxide-acetylene in the case of calcium measurement. Atoms of different elements produce a characteristic light absorption spectrum at different wavelengths. The extent of absorption can be amplified and measured using hollow cathode lamps emitting light at these characteristic wavelengths. Unit: meq/l.

This method was used to measure soluble bases and metals in the soil.

3.3.8 Organic Carbon (Colorimetric Walkey-Black Method)

Measurement of organic carbon content allows the estimation of organic matter content of soil. The amount and type of organic matter can be directly related to moisture holding capacity, the reserves of exchangeable cations, storage and supply of plant nutrients such as nitrogen and phosphorus, and the maintenance of stable soil structure and aeration.

Organic matter was oxidised with an excess of a concentrated oxidising mixture containing sulphuric acid and potassium dichromate. The amount of unused $K_2Cr_2O_7$ was determined calorimetrically at 600 nm. Results were calibrated against glucose. Unit: g/ kg C.

A factor was included in calculations to take account of incomplete oxidation. Organic matter content was calculated as organic-C x 1.74.

3.3.9 Available Phosphorus in Soil (Olsen Method)

Samples were extracted with a 0.5 M sodium bicarbonate solution at pH 8.5. Phosphorus in acidic soil extracts was determined calorimetrically at 882 nm, using the Blue Ammonium Molybdate method of Murphy and Riley. Unit: mg/kg P_2O_5 (where P_2O_5 = 2.291 x P). The Olsen Method was used to determine phosphorus content in alkaline to neutral soils.

3.4 Determination of Land Mapping Units and Soil Types

Soil characteristics were mapped as an overlay on maps prepared for the initial stratification. Together with data on especially climate and geology, land mapping units as well soil type occurrences were visually delineated on the satellite images (i.e. no formal classification procedure of digital satellite data). The different land mapping units and soil types are described below, while the delineation is shown in Appendix 1 and 2 respectively.

4 Landscapes and Soils of the Eastern Communal Areas

4.1 Land Mapping Units

A map of the landscapes (land mapping units) is given in Appendix 1.

4.1.1 Land Mapping Unit A: Interdunal depressions (IDp)

The interdunal depressions refer to soils between the well-defined sand dunes (up to 20 m high) in the eastern parts of the study area, which include sandy interdunal depressions and pans, isolated pans and dune streets. This unit reaches from south of Gam settlement up to north of Gemsboklaagte and further towards the Namibia/ Botswana border in the east. In the east and northeast of the study area, the interdunal depressions are not well developed. Drainage mainly occurs through shallow depressions into numerous small pans. The vegetation of this unit is dominated by open to dense shrublands with especially A*cacia mellifera* and *Rhigozum brevispinosum*.

4.1.2 Land Mapping Unit B: High Kalahari sand dunes (Longitudinal dunes), sand ridges and low dunes

4.1.2.1 B1: High Kalahari sand dunes (Longitudinal dunes) (KDs)

This unit is characterised by high (relative to the study area) longitudinal sand dunes. The topography is gently undulating to rolling. The soils of the dunes consist of deep to very deep reddish, unconsolidated coarse-grained sedimentary sands of the ancient Kalahari. The depth of the sand mantle of the Kalahari sandveld increases generally to the north and east. This unit stretches from southeast of Gam settlement to the north of the Eiseb omuramba in the south, east of Ovivapa in the west towards the Namibia/ Botswana border in the east. Well-defined high red dunes (>20 m) occur mainly in the eastern expanses towards the Botswana border. In the western part of the study area the dunes become less prominent. The vegetation ranges from medium to tall open shrubland to bushland. The dominant trees are *Burkea africana, Terminalia sericea,* as well as *Combretum* and *Grewia* species*.* Other common species are *Philenoptera nelsii* and *Croton gratissimus.* At a few locations, especially in the Eiseb Block, *Schinziophyton rautanenii* groves were found on the ridges of such high dunes.

4.1.2.2 B2: Kalahari sand ridges and low longitudinal sand dunes (KDf)

This unit is characterised by ridges and weakly defined sand dunes with deep to very deep yellowish to reddish, unconsolidated coarse-grained sedimentary sands of the Kalahari. The topography is gently undulating to undulating. This unit occurs south of the Eiseb omuramba and stretches to just north of Gemsboklaagte in the south; Otjinoko omuramba forms the approximate western border. To the east, the unit can be found up to the Namibia/ Botswana border. Towards the west of the study area the dunes and ridges become less prominent. *Terminalia sericea* shrub and bushland with *Philenoptera nelsii, Burkea africana* and *Pterocarpus angolensis* cover most of these low dune fields.

4.1.3 Land Mapping Unit C: Kalahari sand plains or sand deposit (KSd)

The topography of the Kalahari sand plains is flat to almost flat. This unit typifies and covers most of the study area and consists of reworked Kalahari sands with weak to little development in the profiles of the predominantly white to reddish sandy textured soils. Vegetation varies from dense to open shrublands with *Terminalia sericea, Philenoptera nelsii* and various *Acacia* species with a variable grass cover, usually with *Stipagrostis uniplumis* present.

4.1.4 Land Mapping Unit D: Flat calcrete plains with pans (KFp)

This mapping unit is relatively small compared to other units. The relief is low with flat to gently undulating topography. The unit occurs north of Gam settlement and stretches from the Namibia/ Botswana border in the east towards Omihama village and Mooiplaas in the west and towards the Tsumkwe/ Gam fence in the north. Patchy distribution of calcrete plains occurs north and south of Okondjatu. The soils are generally shallow to moderately deep with a sandy to loamy texture. These soils are of high (relative to the study area) agricultural potential due to their more favourable nutrient content and water retention properties, which enables higher plant production. Towards the northeast of Gam pale grey aeolian sands are dominant. Due to the deflation (erosion) of sands at some places hard calcrete outcrops are exposed at the soil surface.

Dominant vegetation includes *Acacia,* Combretum and *Grewia* species, while *Terminalia sericea* is common. Also common are small, dense patches of *Catophractes alexandri*, which is often associated with underlying calcretes.

4.1.5 Land Mapping Unit E: Drainages or omiramba (KOm)

This unit represents the fossil drainage lines formed during the wetter phase predominating the early- to mid Pleistocene age. The depth and width of the omiramba depends on the prevailing winds and water flows experienced throughout the ages. Dunes of accumulated wind blown sand commonly fringe the omiramba; where these are more pronounced on southern and eastern banks, they indicate the action of northwesterly winds. Very often calcrete outcrops are exposed at the edges of the major omiramba. These are especially the Otjozondjou-, Epukiro-, Eiseb- and Rietfontein- omuramba. *Acacia* species, *Grewia flava* and *Tarchonanthus camphoratus* with the annual grass *Urochloa brachyura* are typical on the heavier soils, while mixed *Terminalia sericea* shrublands predominate on the sandier soils.

4.1.6 Land Mapping Unit F: Kalahari sand plains with shallow underlying calcrete (KSp)

The topography of the Kalahari sand plains is flat to almost flat. This unit covers the area southwest of Otjinene and southeast of Okondjatu as well as from just south of Gam village up to the northern boundary of the study area. It is characterised by shallow calcrete and shallow calcrete pans and reworked whitish loose unstructured Kalahari sands, which are situated at a lower elevation than the Kalahari sand plains. Soil profiles are weakly to slightly developed. The vegetation of this unit is characterised by open *Grewia flava, Acacia hebeclada* and *Acacia mellifera* shrublands. The herb layer is sparse to patchy with *Aristida* species and *Enneapogon desvauxii* often present.

4.1.7 Land Mapping Unit G: Floodplains and areas subjected to regular flooding (KFu)

This soil-mapping unit occurs between the Klein Omatako omuramba and the Omuramba Omatako and stretches up to Okanguindi village. It is subjected to repeated seasonal flooding due to its relatively low relief. The continuous erosion of the surface horizon by water results in the formation of many pans and watercourses throughout its area.

The vegetation of this mapping unit differs quite markedly in terms of composition and structure. *Acacia* mellifera, *Acacia luederitzii* and *Grewia flava* with occasional patches of *Combretum imberbe* predominate on the heavier soils, while mixed stands of especially *Acacia erioloba* and *Terminalia sericea* can be found on the sandier soils.

4.1.8 Land Mapping Unit H: Plateaux with Karstveld or limestone (CKh)

This unit occurs northwest of Otjituuo and stretches towards Grootfontein. This unit is characterised by almost flat to gently undulating topography. Hard and soft calcrete/limestone outcrops are exposed at the soil surface. Different types of vegetation are found here: *Dichrostachys cinerea* and *Acacia* species as well as *Hyphaene petersiana* palms are dominant on the shallow calcareous soils, while *Grewia flava* and *Catophractes alexandri* occur as inclusions on the heavier soils, with mixed *Terminalia sericea* shrubland on the sandier soils.

4.1.9 Land Mapping Unit I: Eroded surface of the Plateaux (EDr)

Only a small part of this mapping unit falls within the study area. It is characterised by gently undulating to rolling topography that is part of the slopes off the Waterberg Mountains to the west of the study area. The steepness of this land unit leads to continuous erosion by water. The soils of this mapping unit are very shallow to shallow and are of low agricultural potential. The vegetation consists of often dense thickets with *Dichrostachys cinerea, Croton gratissimus* as well as taller woodlands with *Combretum imberbe.*

4.2 Soil Mapping Units

Soil formation is largely determined by climate, temperature, parent material and moisture regimes. The generally low moisture levels due to the seasonal and often erratic rainfall within the study area are the main reason for most soils being poorly developed. This was confirmed by many soil profiles, which show soils to be mostly unstructured and derived from superficial deposits from aeolian and fluvial processes. The main soil types identified according to the World Reference base are described below. A map of the soils is given in Appendix 2.

4.2.1 Soils of the Interdunal depressions / streets and pans

A distinctive characters of these soil was found to be gleying – this is the reduction of iron compounds by micro-organisms which can be seen as mottling of the soil into a patchwork of grey and rust colours. This is the product of seasonal water logging and accompanying anaerobic conditions. Also characteristic was the presence of an E-horizon, which is absent in the omiramba. The pans and incipient pans of the Kalahari are too small to be mapped individually. The agricultural production potential of the interdunal depressions and pans varies: some soils are regarded poor due to the accumulation of calcium carbonate, whilst other soils are prone to water logging, as mentioned.

Soils occurring on the interdunal depressions and isolated small pans of the Kalahari vary in depth from moderately deep to very deep sandy soils. The two major soil types occur within this soil-mapping unit: petric Calcisols and haplic Arenosols, with the former as the dominant soil type in this mapping unit.

4.2.1.1 Petric Calcisols

These are calcareous soils that overlie a hard petrocalcic horizon of C-horizon at a depth of 45 cm or less. Their most distinctive characteristics are summarised in Table 2 below.

Table 2: Differentiating characteristics of the petric Calcisols

Physical information:	
Landform and Topography	Topography: Flat to undulating topography
	Landform: sandy omuramba*, interdunal streets, pans*
Parent material	Aeolian sand
Surface stoniness	None

Salinity/ Alkalinity		Saline
Crust formation		Slightly
Horizon data or information		
Generic Horizon	*Average horizon depth range (cm)*	*Description of the horizons*
A	1 to 4	Colour when moist: dark brown to brownish black Texture: loamy sand pH: slightly acidic (5.8 – 6.1) Drainage: poorly to moderately well drained Other: slightly calcareous, weak fine sub angular blocky, consistence soft, organic content is very low, many fine roots in the A-horizon.
Bw1 and Bwck	4 to 47	Colour when moist: dark brown to dull reddish brown Texture: sandy to loamy sand or sandy clay loam pH: slightly acidic to alkaline (6 – 8.7) Drainage: poorly drained Other: slightly calcareous, weak fine sub angular blocky, few medium to coarse roots in the Bw1 horizon
Bw2	47 to 89	Colour when moist: dark brown Texture: loamy sand to sandy loam pH: slightly alkaline Drainage: poorly drained Other: slightly calcareous, moderately medium sub angular blocky, very few coarse roots in the Bw2 horizon, Slightly cemented with calcium carbonate
C	89 to120	Strongly calcareous petrocalcic horizon, either with powdery or hard calcrete or the accumulation of secondary calcium

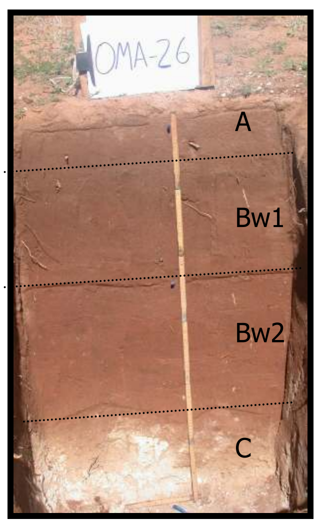

Figure 4A: A typical petric Calcisol, consisting of an ochric A-horizon over a moderately deep B-horizon overlying soft or hard calcrete or petrocalcic horizon (white layer at the bottom).

Figure 4B: Dense cover or stands of *Catophractes alexandri*, north of Gam area, with a ground cover of annual grasses. The *Catophractes alexandri* stands indicate calcareous soils.

The fine particles of the A-horizon tend to become slightly compacted towards their lower end. Erosion of this topsoil exposes calcrete at the surface. This becomes extremely hard when dry, forming a barrier to coarse and medium roots. Only fine roots can penetrate these soils and take advantage of the (relative to the study area) more favourable moisture retention properties. Especially in the sandy omiramba this is reflected by the presence of a dense grass layer and sparse to absent tree and shrub layer. The establishment of crops on these soils will only be possible with costly irrigation and frequent application of nutrients such as nitrogen and phosphorus, but also micronutrients such as iron and zinc. Overall these soils are characterised by especially their A and C horizons (Figure 4).

4.2.1.2 Haplic Arenosols

These are the dull yellowish brown to bright yellowish brown moderately to very deep sandy soils. Their most distinctive characteristics are summarised in Table 3 below:

Table 3: Differentiating characteristics of the haplic Arenosols.

Physical information:		
Landform and Topography		Topography: Flat to almost flat topography.
		Landform: Kalahari sand plain.
Parent material		Aeolian sand
Surface stoniness		None
Horizon data and information		
Generic Horizon	*Average horizon depth range (cm)*	*Description of the horizons*
A	1-12	Colour when moist: dull yellowish brown to bright yellowish brown Texture: sand pH: slightly acidic (5.3 – 6.3) Drainage: excessively well drained Other: carbonate free, loose to very weak and fine to medium sub angular blocky structure, consistence soft, very low organic content, very few fine roots in the A horizon.
Bw1 and Bwck	12-63	Colour when moist: dull yellowish brown to dark brown to bright brown Texture: sand (Bw1) to loamy sand (Bwck) pH: slightly acidic (5.9 – 6.7) Drainage: moderately well to well drained. Other: very low to low soluble salts, carbonate free, phosphorus low to absent, loose structure, many fine roots and few coarse roots which extend into the Bw2 horizon
Bw2	63-133	Colour when moist: dull yellowish brown to grey yellowish brown to bright brown Texture: sand with slight clay content pH: slightly acidic Drainage: excessively well drained Other: carbonate free, loose to weak and fine to medium sub angular blocky structure, consistence slightly hard when dry, very few to few coarse roots in the Bw2 horizon. Sample no. OMA 37/3.

Overall, the haplic Arenosols show very weak to weak horizon development (Figure 5). The sands are generally fine grained or loamy fine sand with slight clay content. Occasionally the sub horizons are sandy loams. Nutrient status and water holding capacity is low. These soils show little to no signs of erosion.

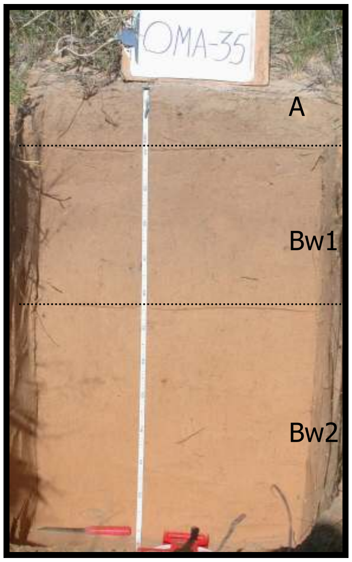

Figure 5A: Typical profile of a haplic Arenosol showing the ochric A horizon overlying a dark brown Bw1 horizon, followed by a leached Bw2 horizon.

Figure 5B: The fairly open vegetation cover is an indication of the infertile soils.

4.2.2 Soils of the longitudinal dunes

The Kalahari sand dunes are stable in terms of soils and vegetation formation. The dunes of the survey area are predominately longitudinal dunes, usually orientated east-west. The topography is undulating to rolling. Soils on the dunes consist of sand to loamy sand. They have low agricultural potential as they have low water holding capacity and low nutrients status. The two major soil types that occur on the dune crest, dune foot and dune slope are ferralic Arenosols or "reddish sandy soils" as the dominant soil type with haplic Arenosols (see 4.2.1.2 above) associated, mostly on the lower foot slopes on the dunes.

4.2.2.1 Ferralic Arenosols

These are the very deep reddish brown to bright reddish brown sandy soils. Their most distinctive characteristics are summarised in Table 4 below.

Table 4: Differentiating characteristics of the ferralic Arenosols.

Physical information:		
Landform and Topography		Topography: flat to undulating to rolling topography
		Landforms: dunes, sand plains, sand ridges
Parent material		Aeolian sand
Surface stoniness		None
Horizon data and information		
Generic Horizon	*Average horizon depth range (cm)*	*Description of the horizons*