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ABSTRACT

Namibia is one of the driest countries in the sourthern Africa and therefore it is not surprising that the majority of the agricultural activities are located in arid and semi-arid zones. Approximately 65% of the total area of Namibia is a semi-arid while the 30 % of the total area falls within the arid zone and only 5% is subhumid zone. In order to manage projects in these areas it is important to understand the characteristics of Namibian's fragile and arid environment. Apart from being the driest countries in southern Africa, Namibia is also confronted with many challenges such as soil erosion and land degradation, desertification, deforestation and rangeland degradation. Present intensive development and expanding of Namibia agricultural sector makes it necessary to utilise natural resources in a sustainable manner. One of the very important natural resource that needs to be managed and utilise in a sustainable manner is the "land". In order to assessment the land suitability for agriculture it is important to determine the physical, biological and chemical properties of the different soil types, the land cover and landforms. On the basis of each properties a number of soil morphological, analytical and spatial land criteria, economical-, social and environmental aspects needs to be considered. The delineation of the land mapping and soil mapping units were done on a semi-detailed scale (1:85 000), while the finale maps were printed on a reconnaissance scale (1:250 000). The soils of the pilot are shallow characterised by many medium to coarse quartz gravels and deep sands of the Kalahari Basins. In general all the soils of the pilot are shows poor horizon development and structural development and thus can be as a result of the prevailing dry environmental conditions.

CHAPTER 1: GENERAL INFORMATION

1.1 Introduction

The staff of the Agricultural Laboratory of the Ministry of Agriculture, Water and Forestry (MAWF) had been involved since the mid-90's in the systematic compilation of inventories of the natural agricultural resources that determine agricultural potential, namely climate, terrain, soils, vegetation and land use. This project is known as the Agro-ecological Zoning (AEZ) Programme of Namibia. The main objective of the AEZ Programme is the delineation of homogeneous zones in terms of agricultural potential. The main climate-soil-physiographic classes that occur in each demarcated zone can be defined and areas estimated. Yield potential and production technique data can be linked to these classes in information storage-retrieval systems. The data can be used as inputs to crop production and other models. This programme includes many projects such as Soil Mapping and Characterization; Namibian Agricultural Information System (including FARM GIS, MAWRD GIS and NAMSOTER); Vegetation Mapping and Characterization; Climate Variability and food security (Agrometeorology); Climate Variability and food security: Drought Monitoring and Indicators; Climate Variability and food security: Crop Yield and Growth Modelling; Vegetation Productivity Indicators (dormant); Estimation of Total Seasonal Biomass Production Using Satellite Imagery; Estimation and Modelling of Rangeland Productivity (including land cover mapping) and Quantification of Land Production Potential (at present in pilot phase).
The AEZ programme is a huge task being carried out by a very small team of four researchers and four technicians with variety of other responsibilities. Within the framework of the AEZ programme the pilot project “Quantification of Land Production Potential” was carried out during 2004 and 2005 financial year. This project is co-funded by the German development cooperation agency, GTZ. The Coordinator of the programme, Mrs. ME Coetzee, and two technicians, Messrs. HD Mouton and JK Kutuahupira, is responsible for the soil-terrain survey that forms an integral part of this pilot project.

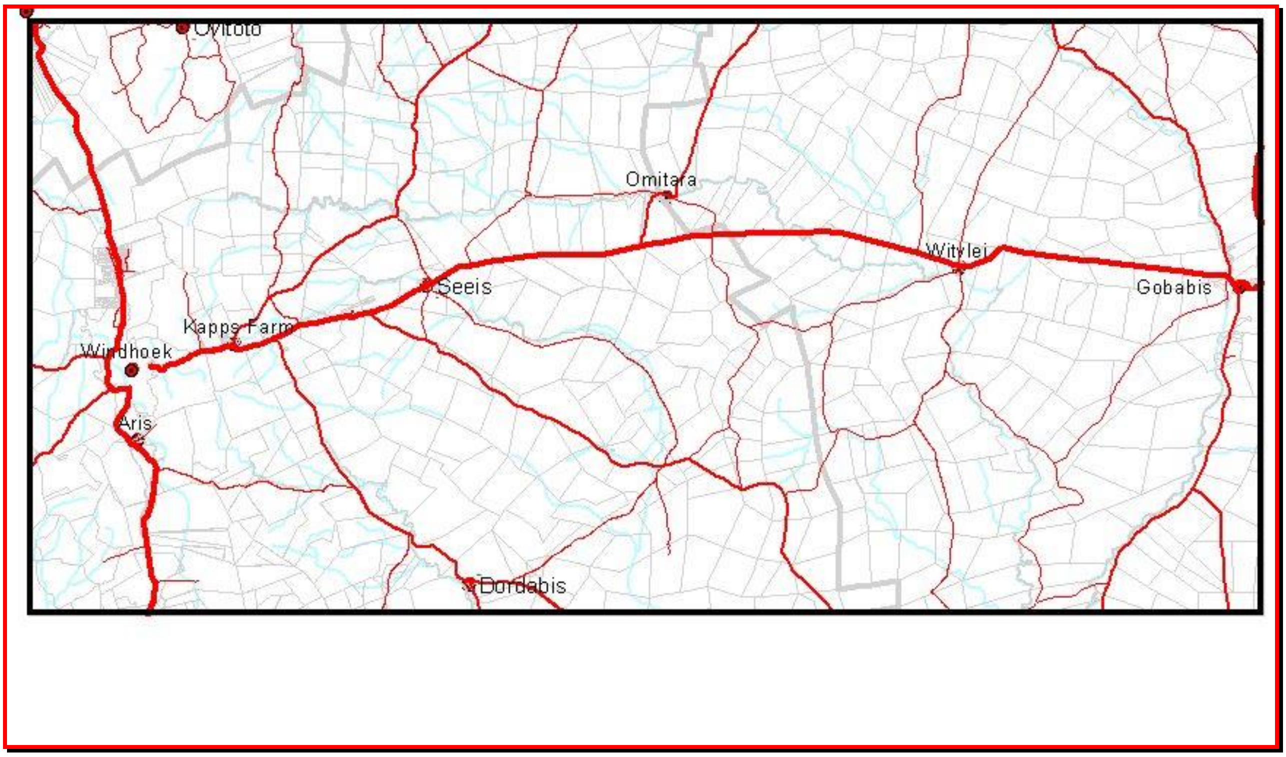
The collection and processing of quantitative data on land productivity and carrying capacity at a national scale, is a long-term undertaking. Thus it was decided in consultation with the other stakeholders (particularly the Ministry of Lands, Resettlement and Rehabilitation (MLRR), and the Deutche Gesellschaft furTechnische Zusammenfassung or German Technical Cooperation Agency (GTZ) that pilot activities should be undertaken with the main aim to develop methodological approaches which can be expanded to a national level for the production of quantitative land data and land productivity as inputs for land use planning, land valuation and the land taxation program in Namibia. These pilot activities will allow for the conceptualisation of land productivity and carrying capacity, as well the development of appropriate methodologies for natural resources assessment for a selected area. It will further build capacity and promote the necessary institutional frameworks of co-operation.

The proposed pilot activities will focus on a key study area, and the outputs will provide information on the time and costs involved in such an exercise, data requirements and human capacity and infrastructural needs which can be extrapolated for mapping the whole country at a scale relevant for planning. A main aim of the pilot activities will be to demonstrate to the stakeholders the primary data requirements for assessing land productivity, as well as the time frame and resources required for such an exercise. Requirements for nation-wide application will be developed concurrently.
To summarize, the aim of the pilot project on Quantification of Land Production Potential, is to develop methodological approaches which can be expanded to national level, for production of quantitative land data/ land productivity as inputs for land use planning, land valuation and the land taxation programme in Namibia. Various steps will be undertaken to reach this aim. One of the key activities is a soil survey of the pilot area, and characterising the soils in terms of their fertility and contribution to land productivity.

1.2 The pilot area

The pilot area is located between longitudes 17° to 19° East and latitudes 22° to 23° South within the Khomas-, Otjozondjupa- and Omaheke region respectively. The area covers an estimated total area of 22 790 km2 (approximately 2.3 million ha).
The total pilot area spans two degrees in an E-W direction, 17-19oE, and one in the N-S direction, 22-23oS. It thus covers the eastern half of the 'Windhoek' 1: 250 000 toposheet and the western half of the 'Gobabis' 1:250 000 toposheet, with a total of 32 x 1:50 000 toposheets. It is approximately 200 km x 100 km in extent. The area had been selected to include a variety of landscapes and soils, land cover types, land uses (cattle/sheep/ game/ecotourism/hunting/irrigated cropping) and farming systems, vegetation types, mean annual rainfall and ownership types (commercial, communal, resettlement farms, 'affirmative action loan scheme' farms). For logistical purposes, it is relatively close to Windhoek.
Windhoek, the capital city of Namibia forms part of the pilot area. Other towns and villages included in the pilot area are Gobabis, Witvlei, Omitara, Okandjira settlement and Hosea Kutako International Airport. The pilot area boost with good infrastructures such as trunk roads, main roads, railways, international airport, dams etc.

Figure 1.1: Map illustrating the location of the "Soil Survey Area".



The pilot area is central located in terms of number of developing markets: local, national and international. It also boats with some of the country greatest industrial, agricultural, mining, tourism, and manufacturing resources. The pilot area is one of Namibia's riches agricultural and industrial areas. The industrial and manufacturing sector is mainly concentrated on main towns, expecially the capital Windhoek. While the sand plateau and the central highlands are devoted for cattle and game ranching. The pilot area has an abundance of minerals resources, for example the Otjihase Copper Mine.
The sophisticated infrastructure such as roads, railways and airport lines the pilot area is fast growing and expanding to other regional and international destinations. The opportunities can be found in the meat processing, game product (trophy and skin) and minerals such as sand (for filters) and copper. The pilot area is characterised by scenic landscapes mainly surrounding Windhoek the capital city and one of the pleasant tourism attraction centres in the world. Apart

from it's a many nature-based tourism opportunities, the pilot area has a rich cultural heritage and various archaeological significant places.
On the otherhand the pilot area is flourishing with abundant wildlife and plants, which result in the developing and growing of the eco-tourism. Game farming has become a lucrative business in the pilot area and is busy surpassing the cattle farming in the pilot area.

1.3 Literature review

1.3.1 Preparatory work

All existing information, topographic maps and satellite imagery relevant to the terrain and soils of the pilot area were collected and studied. 'Terrain types, each displaying a marked uniformity of terrain form, were delineated on the 1:50 000 topographic maps. This exercise was first done on the hard copies of the 1: 50 000 topographical maps. Secondly the same units were digitized on screen in ArcView on the 1: 50 000 scanned topographical maps.

The background information on soils, geology, geomorphology, vegetation and landforms was collected, analysed and compiled by the Agro-Ecological Zoning Programme team within the Ministry of Agriculture, Water and Rural Development (MAWRD). Baseline data of natural resources such as soils, climate, vegetation, land use, carrying capacity and wildlife were collected and interpreted. Visual Satellite imagery analysis was done and the different soil mapping units were identified and delineated. The delineation of the boundaries on the satellite imagery was done at a scale 1:50 000, the final map was printed at 1:250 000 scale.

1.3.2 Desk study

The desk study started shortly after all the available data or literatures on soils, geology, geomorphology and agriculture, vegetation and agriculture, were collected from primary and secondary sources. The main objective was to provide a broad baseline overview of the current environmental, ecological and social situations in the pilot area.
As few studies or information about soils of Namibia are available. The Ministry of Agriculture, Water and Rural Development has established the Agro-ecological Zoning programme in 1994. The aim of the project is to survey, to collect, to evaluate, and to analyse all relevant information on agricultural, environmental, ecological and socio-ecological resources.

The pilot area is covered by thirty two (1:50 000) topographical back dated in 1972. The topographical have been scanned by the National Planning.

The Landsat TM Satellite Imagery used in this exercise by the staff of the Agricultural Laboratory were taken in the year 2000. The delineation of the soil and landform mapping units on the Landsat TM Satellite Images were done at a scale of 1: 50 000 while the final map was compiled at a scale of 1: 250 000.
Using on screen digitizing, the Landsat TM Satellite Images were interpreted and lines separating different soil groups or soil types and land mapping units were drawn in the office and verified in the field through the process of ground truth.

1.3.3 Data recording or capturing

All information gathered in this way is stored in and processed with a Geographical Information System (GIS), by using ArcView 3.2 software. This makes the generation of thematic maps possible. These are maps of selected soil and land characteristics which can be easily interpreted, such as effective soil depth, rooting depth, textural classes, soil fertility, drainage classes and much more.
The attribute data is stored in the SOTER (Soil and Terrain Digital Database) structure. The soil- and land mapping units are printed on the satellite imageries.

1.3.4 Fieldwork

The fieldwork started with identification and description of the morphological units, terrain types, soil types and vegetation types. The survey was designed to acquire field data pertaining the characteristics and distribution of soils and terrain types occurring in the pilot area. The survey was carried out at reconnaissance level in terms of observing distinct points or density, and adopted to a catenary transect approach by driving and walking through the identified units in order to gain an overview of the existing relationships between soils, landforms and topography.
Soil mapping units were drawn based on a compromise between free survey, contours, drainage pattern and density and satellite imagery interpretations.

1.3.5 Types of observation methods used to describe the soil profiles

Mini pit were open in very shallow, rocky and stony areas. During this process each soil horizon was described according to the Soil and Terrain Digital Database (SOTER) terminology, by looking at the physical characteristics such as soil colour, texture, consistence, stoniness, terrain, presence of carbonates and position in the landscape. Soil colours were checked by using Munsell Soil Colour Charts (Eijkelkamp, 1998).
Calcium carbonates were determined by treating the soil sample with 10 % hydrochloric acid (HCl) and checking for effervescence (gas volumetry).
Textures were checked by using the “finger” or “feel method”. Moist soil samples are rubbed between the thumb and forefingers.
Representative profiles were open in moderate to deep soils. In each soil mapping unit representative profiles were open and described according to the FAO guideline. Three hundred and sixty-eight (368) soil pits or profiles were dug and described in accordance with the FAO Guidelines for Soil Description (FAO, 1990). Representative soil samples were taken from each horizon for chemical and physical analysis. The soil depths of the different profiles were ranging from 10-180 cm. The chemical analyses of the samples are being done by the Agricultural Laboratory in Windhoek. The physical properties were determined in the field.
Photos of the different profiles or soil pits were taken with a digital camera. The exact location of all profiles and mini-pits are plotted accurately with the Global Positioning System (GPS). For methods used to describe the mini-pits and representative soil pits or profiles see Appendix I.

1.3.6 Soil classification system used and soil profile descriptions

The soils of the pilot area were classified and described according to the Guidelines of the FAO/UNESCO/ISRIC Revised Legend (1988), using the general principles and nomenclature recommended by the Food and Agricultural Organisation (FAO, 1990). The WRB (World Reference Base for Soil Resources) system was used to classify the different soil types within the pilot area.
The world Reference Base for Soil Resources (WRB, 1998) is an international standard for the classification system endorsed by the International Union of Soil Science. It was developed by the International Soils Reference and Information Centre (ISRIC) and sponsored by the International Union of Soils Science (IUSS) and the FAO via its Land and Water Department. It supercedes the Legend to FAO Soil Map of the World.
The classification system is based on soil morphology which thought to express the effect of soil genesis. A major difference with Soil Taxonomy is that soil climate is not part of the system. The system is design for regional mapping, not for semi-detailed or detailed mapping.
Within the study area five major soil groups that were identified and classified were further subdivided into the second and third levels or levels.

1.3.7 Laboratory methods

1.3.7.1 Sample Preparation

Soil samples received in the laboratory are registered, mixed and placed into drying pans at room temperature or using mild heat. Dry samples are grinned with a pestle and mortar by hand or using a machine to break up the larger clods, sieved to a uniform size (2 mm) and stored in a plastic container. Stones and gravel are removed by sieving and weighed separately where they constitute a significant proportion of the sample.

1.3.7.2 Particle Size Analysis by the Rowell Autopipette Method

The samples are dispersed by shaking with a sodium carbonate/ sodium hexametaphosphate solution. Silt and clay sized particles are separated by sampling with an autopipette at a depth of 6 cm after time intervals (related to ambient temperature) using Stoke's Equation of Sedimentation. These are dried and weighed. Sand is separated by wet sieving through a 53-micron sieve. The sand can be further separated into fine, medium and coarse fractions by dry sieving. The amount of very fine sand may be important since it has very high moisture holding and release properties. Unit: % sand, % silt, % clay.
The United State Department of Agriculture (USDA) Texture Triangle is used to determine the texture class (PSCL).
The method is suitable to determine the proportion of sand, silt and clay in most mineral soils but treatments may be needed for soils with organic carbon contents >2% and soils containing high concentrations of soluble salts and cementing agents such as calcium carbonate and gypsum. The method is not suitable for volcanic ash soils, which do not occur in the study area.

1.3.7.3 BULK: Bulk Density

The sample is collected with an Eijkelkamp Undisturbed Core Sampler in a cylinder of known volume and sealed. The sample is dried at 105oC to a constant mass, cooled in a desiccator and weighed to 0.001g precision. The bulk density is calculated as volume per mass. Unit: g/cm3 = kg/dm3. PH of Soil in Water (pHw) and 1 M Potassium Chloride (pKCL).
The pH of the soil was potentiometrically measured in the 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).

1.3.7.4 Electrical Conductivity in a Saturated Paste or 2 : 5 Water : Soil Extract

EC was measured with a conductivity meter with two electrodes placed in the supernatant of a soil : water suspension at a set distance from each other. The EC of an aqueous salt solution increases with increase in temperature (about 2 % per degree oC) hence EC is referenced to a standard temperature (e.g. 20 oC or 25oC). Unit: dS /m.
The content of soluble salts in a soil can be estimated by measuring the EC in a saturated paste, or an extract from a saturated paste or in extracts prepared at varying ratios of soil to water. To prepare a saturated paste extract, water is added to a soil sample until a given mechanical property of the soil is attained equivalent to the liquid limit. The amount of water held at saturation is called the saturation percentage.
The 2:5 method was used generally on all samples, while the saturated extract method was used for saline and/or sodic soils.

1.3.7.5 Cation Exchange Capacity and Exchangeable Bases

Soil samples were pre-washed with de-ionised water to remove soluble salts. Thereafter it was 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 a further leaching with ammonium acetate. The method required an automatic extractor where samples were mounted in plastic syringes for the leaching operations. (Unit: cmol (+)/kg).
The method may be used to estimate the CEC of most soils. The choice of saturating cation or pH of the equilibrating solution may be varied for soils containing certain clays or minerals. It may be

difficult to differentiate between exchangeable and soluble cations in soils containing carbonates, gypsum or soluble salts.

1.3.7.6 Modification for carbonate/non-saline soils

If the pH of the 2:5 H2O water extract was > 7 with carbonates present but EC 2.5 < 0.4 mS/ cm then no pre-washing was needed, but instead a 50:50 mixture of NH4Oac/pH 7 and ethanol to displace the bases instead of using NH4OAc pH 7 alone, to obviate carbonate dissolution.

1.3.7.7 Analysis using Atomic Absorption

Solutions were aspirated as a fine mist into an air-acetylene flame, and nitrous oxide-acetylene in the case of calcium measurement. The atoms of different elements absorb light at different wavelengths characteristics of their spectral banks. The extent of absorption can be amplified and measured using hollow cathode lamps emitting light at these characteristics wavelengths. Unit: meq/l.
The method described here was used to measure soluble bases and metals in water samples or extracts and digests of plant leaf tissue and soil. This SOP concentrates on such elements in plant and soil. The standard calibrating solutions should contain the same background matrix as the samples. Lanthanum chloride is added as a suppressant in the measurement of calcium, magnesium, sodium and potassium.

Element	Wavelength (nm)
Calcium	422.7
Magnesium	285.2
Sodium	589.0
Potassium	766.5

1.3.7.8 Organic Carbon (Colourimetric Walkey-Black Method)

Measurement of organic carbon content gives a way of estimating the organic matter content of the 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 K2Cr2O7 was determined colourimetrically 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 (Literature Reference).
The method is suited to the measurement of the organic carbon content of soils low in organic matter content. The method can also be used to measure the organic carbon content of humus extracts, soil water or polluted waters.

1.3.7.9 Available Phosphorus in Soil (Ohlsen Method)

The sample was extracted with a 0.5 M sodium bicarbonate solution at pH 8.5. Phosphate in the extract is determined calorimetrically at 882 nm, by the blue ammonium molybdate method of Murphy and Riley, using ascorbic acid as reducing agent. (Unit: mg/kg P_2O_5 (where P_2O_5 = 2.291 x P)). The Ohlsen Method is recommended for alkaline to neutral soils.

The Agriculture Laboratory of the Ministry of Agriculture, Water and Rural Development carried out the physical and chemical analyses. Three hundred and sixty eight (368) profile were dug with a total of 544 soil samples tested for: pH (H2O); electrical conductivity in a saturated paste of 2:5 water: soil extract; organic carbon (Colourimetric Walkey-Black Method); available phosphorus in soil (Ohlsen Method); cation exchange capacity and exchangeable bases; particle size analysis by the Rowell Autopipette Method (Appendix I, the chemical and physical properties of the different soil types within the pilot area). For detailed information on the laboratory analysis read through the methods and procedures by Michael Rowell, 2000.

CHAPTER 2: CLIMATIC INFORMATION

2.1 Introduction

In the past the collection of climatic data such as rainfall, wind, length of sunshine, temperature were overlooked. This has resulted in the lack of climatic data of the study area under discussion. Little research has been done to collect in the past in terms of the climatic data of the pilot area. The collection of climatic data receive attention now in recent years under the AEZ programme. The following authors and researchers who comprehensively collect, compile and described of the pilot area are Bertram and Broman (1999/2000), du Pisani (1999), Koeppen (1923), Department of Water Affairs and Kempf (2001) just to mentioned a few.

Climate factors such as temperature, wind, rainfall and moisture regime contribute indirectly or directly to the breakdown and formation of the soil types of the pilot area. How these factors influences the formation and development of the soils are described in more details below.

2.2.1 Climate

One of the most important climatic factors that influences the formation and development of soils in the pilot. The climate of the pilot area is characterised as a semi-arid and the climatic region is defined as Hot Steppe, according to the Koeppen classification system (1923). The climate of the pilot area has been classified and summarised by the Department of Water Affairs (2004), Kempf (2000), du Pisani (1999), Beernaert (1996), Thomas (1991) and the Weather Bureau (1986).
The pilot area is not well covered with first order weather stations and private rainfall gauges. The first order or synoptic weather stations are located in Windhoek Weather Bureau and Hosea Kutako International airport respectively.
Accumulative rainfall data are available from certain private farms or commercial farms and some of the administration centres within the pilot area.
The climate is heavily influenced by an anticyclonic, high pressure cell that is located over the eastern South Africa for most of the year and provides drier, stable conditions. During the summer month, the anticyclonic migrates off the coast of southern Africa and allows for the cyclonic, unstable air masses of the Indian Ocean to move into the interior of southern Africa. Wind direction from the northeast dominate for the winter and spring months and secondary, summer, winds are oriented from a westerly to southwest direction (Lancaster, 1987).

2.2.2 Precipitation

The annual rainfall within the pilot area increases from west to the east with an average of 250 mm/a in the west, through 400 mm/ a in the vicinity of Witvlei and north of Witvlei. In the far east the rainfall can reach more than 550 mm/a. It is the area around Gobabis. According to Koeppen (1923), the study area is a region of semi-arid hot steppe/ savannah climate with summer rains (BSh).
The region is receiving about 300 mm per annum, with minima and maxima estimated to range between 250 mm and 400 mm. As the rainfall is having the greatest impact on the plant production (growth and development) of all the above-mentioned parameters (Westoby et al., 1998; Rutherford, 1980), the seasonality and variability in rainfall both in time and space, it has high influences on the management and utilisation of the vegetation. Field fire is another parameter that influences the vegetation or plant production within the communal and commercial areas.

According Kempf (1999) the rainfall in the pilot area is highly erratic and variable in both time and space. The mean average rainfall for the pilot area has been extrapolated as 200 to 300 mm per annum. More than 90% of the expected rainfall within the pilot area lies within range of 250 mm and 550 mm (Dealie et al. 1993). The rainfall of the pilot area is highly seasonally bound, meaning that 80-90 % of the rainfalls between November and April (van der Merwe, 1983). Most of the rain falls in the form of thunderstorms. Drought is not a common phenomenon in the pilot area. But due to high concentration of animals in the communial areas such as Ovitoto the area is highly subjected to overgrazing.

The hottest period of the year start from mid December to January when an average daily temperature reach 35o C, on average the maximum daily temperature exceeds 30o C from some 150 days per year. In July, which is the coldest month, temperature can drop to 0 oC or just below. The daily minimum temperature during July is 4-5 oC.

Humidity is low, with an annual average relative humidity of 40% and a diurnal range of 25%. The potential annual average evaporation is calculated as being between 2,750 mm and 3,000 mm, keeping with the high temperatures (Mendelson, 2002).
Rainfall is generally high in mountains and in the eastern part of the pilot area. However, due to the favourable topographical conditions, i.e. the mountainous topography and very high elevation around Windhoek, the average annual rainfall is also generally high. It ranges between 200-500 mm.

The main precipitation period is from November to April. A brief summay of the climate in terms of maximum, minimum, total rainfall and fog is given. It is only summarising the climate parameters for Windhoek and Gobabis stations. These stations were selected based on their longest historical cimatic data in the pilot area.

Table 1.1: The summary of climatic parameters as recorded at Gobabis (1920 – 1983) and Windhoek (1968-1984) respectively. The climatic data were obtain from the Weather Bureau Station in Windhoek (1986).

Stations	**Gobabis**				**Windhoek**			
Month	**Max1. temp**	**Min2. temp**	**Rain3**	**Frost4**	**Max1. temp**	**Min2. temp**	**Rain3**	**Frost4**
September	30.7	11.7	2	0.1	28.8	8.8	4	0.8
October	32.0	15.7	16	0	30.8	13.3	16	0
November	31.7	17.1	48	0	31.6	15.3	34	0
December	31.9	17.6	68	0	32.4	16.9	41	0
January	30.2	17.9	162	0	31.8	17.4	85	0
February	28.9	17.3	138	0	30.4	16.7	81	0
March	28.3	15.9	101	0	29.1	15.1	68	0
April	27.4	12.9	40	0	27.3	11.6	34	0.1
May	25.5	8.0	7	0.1	24.6	6.3	6	1.3
June	23.2	4.8	1	1.3	21.9	3.2	2	5.4
July	23.6	4.3	0	1.6	22.2	2.5	1	7.8
August	26.7	7.2	2	0.6	25.0	4.5	1	3.8

1Mean maximum temperature is measured in degrees Celsius.
2Mean minimum temperature is measured in degrees Celsius.
3Mean monthly rainfall in millimetres.
4Frost days per month on the ground.

2.2.3 Evaporation

The pilot area has been defined as a semi-arid region which receives a significant a small amount of rainfall. In contrast the little water that falls is subject to high rates of evaporation. While evaporation is high within the pilot area, the northern areas of Witvlei loses less water than the rest of the pilot area. The rate of evaporation are highest during the warm summer months before the rains begin, this is due to higher temperatures, greater solar radiation and subsequently low humidity.
The average annual evaporation for the whole pilot area varies between 1,960-2,100 mm. While the northern area closed to “The Mark farm” varies between 1,820-1,960 mm/ year (Mendelson, 2002).
There are some stations that record or capture the potential evaporation within the pilot area.

2.2.4 Wind

The wind speed is generally low over the whole study area. Strongly winds occur mostly in the afternoons and early evening as a result of the high central grounds that is being heated more than the surrounding areas.
The prevailing wind in the central highlands is the easterly wind and is higher during April and July, while in the Kalahari is the north-easterly trade wind and blows during April and August. They are the strongest in September and October. Hines (1992) recorded long running winds or “warrel winde” in the Gobabis area and this was as the result of compounding factor of the evaporation.

2.2.5 Temperature

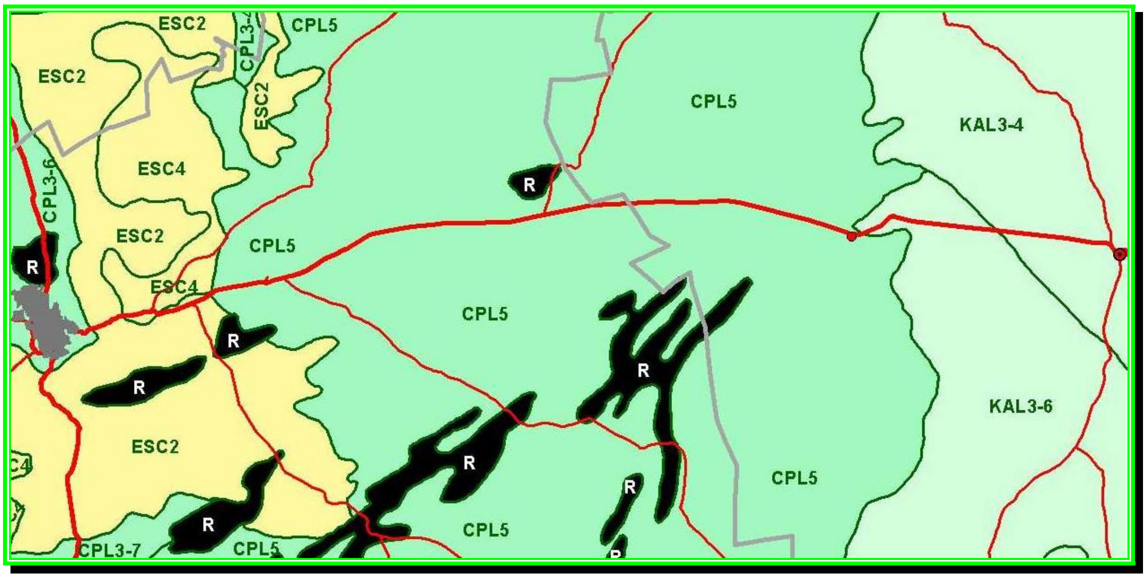
The pilot area does not encounter any significant changes in the daily and night temperatures. The changes in temperatures are aa a result of many factors such as the altitude, the cloud cover and the proximity to the coastal regions.

The high altitude in the central region highlands makes it cooler than the rest of the pilot area. Mean monthly air temperature varies between a minimum of 1° C for winter nights and 20° C for summer nights. On average, maximum day temperatures exceed 30° C for 150 days per annum, while frost occurs on average for less than 10 nights per annum.
From above it is concluded by saying that there is no distinct growing period for crops or plants during most part of year (de Pauw, 1996). This is because that the rainfall or precipitation is less half the potential evaporation in the pilot area.

2.2.6 Agro-ecological zones

The pilot area has been divided into different agro-ecological zones according to de Pauw in 1998. The Agro-Ecological Zones Map of Namibia (de Pauw, 1996, de Pauw., et al., 1998/9) divides the pilot area into three main agro-ecological zones with eight sub growing period zones. The main agro-ecological zones are the Ecarpment, Kalahari sand plateau and the Central plateau. The distribution and location of this zones follows the terrain morphical units and the rainfall patterns. The full description of the dominant and sub growing period zones in terms of the length of growing seasons or period, evaluation for crop production and their agricultural potentials are figure 1.2 below.

Figure 1.2: The three agro-ecological zones namely the Escarpment, Kalahari sand plateau and the Central plateau covering the pilot area. A larger part of the pilot area is covered by the central plateau (CPL).



Detailed summary of the description of the growing period zones (GPZ's) in terms of their agricultural production, the length of growing period, evaluation in terms of crop production and land uses are given in table 1.2 below.

Table 1.2: Preliminary Dominant Growing Period Zones within the pilot area according De Pauw (1998).

Dominant	Description	Growing period zone	Length of growing Period	Evaluation for crop production	Agricultural Potentials
Central Plateau	Central Plateau, strongly dissected inselberg plains,	CPL3-4	Average growing period 63, dependable growing period 6 days; very short dependable growing period	Not suitable for crop production due to short dependable growing period, combined low water holding capacity and low nutrient status	Large stock production or grazing
	Central Plateau, strongly dissected inselberg plains, average growing period 41-60	CPL3-6	Average growing period 48 days, no dependable growing period	Not suitable for crop production due to short dependable growing period combine with sparsely distributed deep soils.	Mixed large stock and sheep grazing
	Central Plateau, strongly dissected inselberg plains, average growing period 21-40 days	CPL3-7	Average growing period 35 days, no dependable growing period		mixed large stock and sheep grazing
	Central Plateau, flat plains on metamorphic rocks	CPL5	Average growing period 48 days, no dependable growing period	Not suitable for crop production	Mixed large stock and sheep grazing
Escarpment	Escarpment, high mountains on Basement Complex rocks	ESC-2	Average growing period 58, dependable growing period 33 days (75% of the average)	Not suitable for crop production	Livestock production or grazing
	Escarpment, high plateaux on Basement Complex rocks	ESC-4	Average growing period 48 days, no dependable growing period	Not suitable for crop production	Good for large livestock production
Kalahari Sands Plateau	Kalahari Sands Plateau, stabilised sand drift with few pans, average growing period 61-90 days, very short dependable growing period	KAL3-4	Average growing period 73 days, dependable growing period 6 days; very short dependable growing period	Suitable for short growing period crop such as sorghum and millet	Livestock production or grazing
	Kalahari Sands Plateau, stabilized sand drift with few pans, average growing period 41-60 days, no dependable growing period	KAL3-6	Average growing period 48 days, no dependable growing period	Suitable for many crop grown in Namibia but limited soil moisture and nutrient status.	Mixed large stock and sheep grazing
		KALK3-3	Average growing period 61-90, dependable growing period 60 percent of average.	Unsuitable for crop production due shallow soils and low dependable growing period.	Only animal grazing

Rocks	Mountains and shallow, stony soils.	R	Average growing period 73, dependable growing period 6 days, very short dependable growing period.	Very shallow and gravely soils.	Not suitable for animal or crop.

(Source: Adopted from the Agricultural Laboratory (MAWRD), 1998)

2.2.7 Rock outcrop (R)

Subsurface rock outcrops and boulders are found scattered on the soil surface in the pilot area. They are mainly formed from the three main rocks types namely the ignenious-, metamorphic and sedimentary rocks. The unit covered with rocks and boulders has been mapped and delineated as different entity or zone. The reason is simple because the unit needs special management practices in terms of soil and water conservation. This unit largely covers the central plateau and the escarpment of the pilot area. The general topography is hilly to mountainous. Due to the steep slopes the water runs quickly on the surface and enhance the formatioin of gullies and dongas. On the otherhand the continious removal of the topsoil leads to the formation of shallow soils. The shallow and gravely soils (Leptosols) are characteristics soils of these regions and are of low to medium agricultural potential. The pilot area is underlying by different geological formation of various ages. The highlands or the central plateau and the escarpment is underlying by mica-schist and amphibolite. The transitional zone between the central plateau and the Kalahari the geology consist of gneiss, quartzite, gneiss, conglomerate. While the Kalahari Basin is underlying by conglomerate, sandstone and marble as parent material. It is estimated that this unit covers more than 40% of the land surface area.
Nota Bene: In general, the growing period is the time during a growing season when air temperature, soil temperature and soil moisture permit crop growth. The length of growing period is normally defined as the number of days, on which precipitation exceeds half the potential evapotranspiration, plus the number of days to evapotranspire an assumed 100 mm (or less, if not available) of water from excess precipitation. There is a further prerequisite that the average air temperature during the whole period must not exceed 6.5° Celsius, or average soil temperature must exceed 5° (Coetzee, 1991).

CHAPTER 3: PHYSIOGRAPHY

3.1 Topography

According to the Land Type of Namibia (1977) of the FAO (DP/NAM/78/004) the pilot area is characterised by three different land or terrain types. The three main land types (geomorphological units) are the mountainous and hilly region or the Escarpment, the Namibian central plateau and the Kalahari sand plateau region.
These landforms or terrain types have been further subdivided into smaller units called the land components. The topography of the main landforms and land elements of the pilot area are very complex which make the description of these units very complex as well. The general topography of the pilot area ranges between flat or nearly level to roling. The Kalahari sand plateau is characterised by flat to nearly level topography. The central plateau or the central plains which covers the largest area part of the pilot area is having an undulating to rolling relief. The escarpment which comprises of the high mountains, koppies and hills is characterised by rolling to undulating topography. It is further characterised by steep slopes which gives this land units a rugged terrain. Due to the steep slopes of the rolling highlands and mountains these unit are drained by many channels which eroded and dissect the landforms. The formation of gullies and dongas are highly subjected to severe soil and water erosion. In the pilot are it is evident that many gullies and dongas have formed and developed at the foot slopes were the water collect and accumulate because of the high velocity.
The great escarpment is found at the highest elevation within the landscape or landform. The high mountains within this unit are the Auas-, Otjihavera- and Bismarck mountain. The escarpment is surrounded by the central plateau. The central plateau is sloping towards the east (Kalahari sand plateu), the north and west (Swakop river drains towards the Namib desert) and the south (Krum-Aris-Goachanas valley) of the pilot area. This is quite well reflected in the flow direction of the ephemeral rivers or watercourses. The important ephemeral rivers within the pilot area are the White- and Black Nossob-, Skaap-, Olifant river which flows in the eastern direction before they divert to the Orange river (Atlantic ocean) and endothermic systems (Kempf, 2001). The three major AEZ zones which are based on the landform and lithology namely the escarpement, central plateau and the Kalahari sand plateau are going to described in more details below.

3.1.1 Escarpment: Mountainous and hilly area

The escarpment is characterised by an undulating to steeply dissected topography. Windhoek lies within a broad valley open to the north and flanked by the Auas Mountain in the south, Khomas Highlands in the west, and Otjihavera mountain and Neudamm Kuppe in the east. The Auas Mountain forms the highest mountain summit with an elevation of approximately 2,479 meters. Other high mountains are the Grimmrucken mountain which is north of Dordabis settlement, the Okambara, Klee- and Groot Kleeberg covering the central part of the pilot area and the Nicodemus mountain west of Gobabis. The steep concave, straight and convex slopes give this land mapping unit or the hilly to mountainous landscape a regional slope range >60%. According de Pauw (1996) the escarpment is having a relatively high relief ranging between 100-300 m.

The elevation of the highlands northeast of Windhoek the “Otjihavera mountain” is in the range of 2000 m a.s.l. The Windhoek valley is in lying at a lower elevation than it surrounding with a mean altitude of 1450 m a.s.l. and is sloping towards the north. The northern flow of the Otjihavera river can fully indicate the sloping of the landform. Due to the high elevation, the rugged topography and steep slopes of the escarpment most of the drainage lines or watercourses found their origin form this land unit or land mappping unit.

3.1.2 Namibian central plateau

The Namibian central plateau is characterised by a complex topography due to the different geological activities and structural formation. The topography of the Namibian central plateau is being classified as flat to gently undulating landforms, with moderately dissected and weakly defined watercourses or drainage lines. It is found east of the escarpment and west of the Kalahari

plateau. Due to its relatively low relief compare to the central plateau of the highlands a large number of drainages or watercourses cut through this mapping unit.
The rivers that cut through this unit found first make their way towards the east crossing the low elevation or relief and than divert towards the south into the Orange river. The Orange river drained towards the Atlantic ocean. The Olifant River originates south of the Auas Mountin, while the Seeis-and the Nossob River originate from the Neudamm Kuppe and Otjihavera Mountain respectively.
The Usib and the Otjihavera are the two rivers within the pilot area that flows in the southern and northern directions respectively. The height of the central plateau ranges between 900-1,300 m a.s.l and a regional slope of between 0-15%. The area has a relatively low relief of between 10 and 30 m (de Pauw, 1996).

3.1.3 Kalahari sand plateau

The Kalahari sand plateau covers the whole area east of Okambaraberge, the Karstveld region and stretches towards the eastern border of the pilot area. The topography of the Kalahari sand plateau is flat to gently undulating. The western part of the Kalahari sand plateau is characterised by gently to undulating landform as a result of the dunes, hills and mountains. The rest of the unit becomes more flat towards the east with deeper sands. The general evelation of the Kalahari plateau is estimated at 1050-1400 m a.s.l. As the name implies the Kalahari sand plateau is covered by extensively deep reddish sand of the “Kalahari”. The dominant soil type is the feralic Arenosols.
The flood plains or the omiramba the White- and Black Nossob has washed away quite a large quantity of fine loose soil particles from the riverbeds and slopes, resulting in the remaining of coarse fragments and stones on the soil surface. This phenomina is evident along the Nossob river and their tributaries. The coarse fragments and stones on the surface are characteristics of “Leptosols” and “Regosols”.

The three geomorphological units or terrain units have been further subdivided by De Pauw (1996) according the Agro-Ecological Zoning Report of Namibia into the different land types. This has been described in terms of broad landform, SOTER landform classes, regional slope classes, altitude range, relief intensity, drainage pattern, geological substrata and SOTER geological codes.

These is the criteria used to sub divide the major landforms into subclasses or terrain components within the pilot area.

Broad soil patterns have been identified to construct a common soil legend for the final pedo-type maps (a pedo-type is land where the terrain form and soil pattern displays a marked degree of uniformity). At present the most comprehensive database on the soils of Namibia is the 1:1 000 000 soils map and report (ICC/MAWRD, 2000). The WRB (FAO, 1998) soil groups and soil subunits used in the map legend could be used as a first approximation to construct a common soil legend.
The geomorphologic development and formation of the central and eastern part of Namibia has been described by Kempf (2000). The geomorphological units have been divided into the following classess.

The flood plains or watercourses, high mountains, sand plains, isolated hills and koppies and ridges are some of the physiological units that occur within the pilot area. The pilot area is characterised by diverse landscapes or topographical units. The different landscapes or landscapes various from steeply dissected and rocky mountains that covers the Auas- and Otjihavera mountains, the undulating to rolling landform of the central plateau, the isolated and stoney hills, ridges and koppies, the gently to undulating topography of the central highlands, the isolated hills and mountains and the sandy plain with dunes and depressions that slopes towards the east.
The terrain units observed and identified in the pilot area were described and subdivide into terrain components accordance the South African Landform Classification System (1967). The physiological units or terrain types were divided into the following subclasses:

The major landforms with their subclasses or groups found in the pilot area are described in more details below:

Land unit		Land Unit Symbol
Plains		
A1a	Flat to nearly level or flat plain on lowland	A
A1d	Flat to nearly level or flat plain on highland	A
A2a	Smooth plains with some relief (> 75% level land on low land)	A
A2c	Smooth plains with some relief (50-75% level land on highland)	A
A2d	Smooth plains with some relief (>75% on highland)	A
B1c	Irregular plain with low relief (50-75% on highland)	B
B1d	Irregular plain with low relief (>75% on highland)	B
B2c	Irregular plains with moderate relief (50-75% on highland)	B
B2d	Irregular plains with moderate relief (>75% on highland)	B
Highlands of the central plateau with hills, ridges, koppies and mountains		
A3c	Highlands with moderate relief (50-75% level land on highland)	C
A3d	Highlands with moderate relief (>75% level on highland)	C
A4d	Highlands with considerable relief (50-75% level on highland)	C
A5c	Highlands or plains with high relief on highland	C
Plains with isolated hills, ridges, koppies and mountains		
B3c	Plains with isolated hills	B
B3d	Plain with high hills	B
Open Hills, ridges, koppies and mountains		
C1c	Open very low hills	D
Hills and Mountains		
D1c	Very low hills (50-75% level land on highland)	E
D1d	Very low hills (>75% level land on highland)	E
D2c	Low hills (50-75% level land on highland)	E
D3c	Moderate hills (50-75% level land on highland)	E
D3d	Moderate hills (>75% level land on highland)	E
D4d	High hills (>75% level land on highland)	E
D5d	High mountains (>75% level land on highland)	E
Watercourses or drainage lines (Valleys)		
Va	Ephemeral rivers or watercourses	F
Stabilized sand dunes		
Du	Sand dunes and interdunal depressions	G

The different terrain types or landforms identified and classified in the pilot area have been described fully in terms of the percentage level land, local relief and profile type according the South-African Soil Classification system (1967). See table 1.3 for detailed descriptions of the landforms.

Table 1.3: Illustrate how the terrain types, percentage level land, local relief and profile type was determined or calculated.

Terrain types		Percentage of level land			Local relief			Profile type	
Symbol	**Map ID**	**Class**	**% of area with slopes less 8 %**	**Average slope %**	**Class**	**Criteria**	**Average slope**	**Class**	**% of level land on lowlands or highlands**
Plains									
A1a	1	A	More than 75 % of the area is level land	1%	1	0-30 m	11 m	a	>75% on lowlands
A1d	2	A	More than 75 % of the area is level land	1%	1	0-30 m	18 m	d	>75% on highlands
A2a	3	A	More than 75 % of the area is level land	1.4 %	2	0-30 m	16 m	a	>75% on lowlands
A2c	4	A	50-75 % of the area is level land	1%	2	0-30 m	23 m	c	50-75% on highlands
A2d	5	A	More than 75 % of the area is level land	1.5%	2	0-30 m	19 m	d	>75% on highlands
B1c	6	B	50- 75 % of the area is level land	3%	1	30-100 m	56 m	c	50-75% on highlands
B1d	7	B	50-75 % of the area is level land	3.3 %	2	30 – 100 m	38 m	d	50-75% on lhighands
B2b	8	B	50-75 % of the area is level land	3.3 %	2	30 – 100 m	38 m	b	50-75% on lowlands
B2d	9	B	50-75 % of the area is level land	2-4%	2	30-100 m	66 m	d	50-75% on highlands
Highlands of the central plateau									
A3c	10	A	50-75 % of the area is level land	1.5%	3	0-30 m	19 m	d	50-75% on highlands
A3d	11	A	50-75 % of the area is level land	1-2 %	3	0-30 m	25 m	d	50-75% on highlands
A4c	12	A	50-75 % of the area is level land	1.4%	4	0-30 m	19 m	d	50-75% on highlands
A5c	13	A	50-75 % of the area is level land	2 %	5	0-30 m	25 m	d	50-75% on highlands
Plains with hills, ridges and koppies									
B3c	14	B	50-75 % of the area is level land	2-3%	3	100-170 m	130 m	c	50-75% on highlands
B3d	15	B	50-75 % of the area is level land	5%	3	100-170 m	145 m	d	50-75% on highlands
Open or isolated hills, ridges, koppies and mountains									
C1c	16	C	50-75 % of the area is level land	8%	1	170 – 300 m	210 m	c	50-75% on highlands
Hills and mountains									

D1c	17	D	Less than 20% of the area is level land	33 %	1	100 – 170 m	130 m	c	>75% on highlands
D1d	18	D	Less than 20% of the area is level land	33 %	1	100 – 170 m	130 m	d	>75% on highlands
D2c	19	D	Less than 20% of the area is level land	31 %	2	170 – 300 m	290 m	c	>75% on highlands
D3c	20	D	Less than 20% of the area is level land	33 %	3	170-300 m	130 m	c	>75% on highlands
D3c	21	D	Less than 20% of the area is level land	33 %	3	170 – 300 m	130 m	c	>75% on highlands
D4c	22	D	Less than 20% of the area is level land	31 %	4	170 – 300 m	290 m	c	>75% on highlands
D5c	23	D	Less than 20% of the area is level land	53 %	5	300 – 1000 m	309 m	c	>75% on highlands

The terrain type has been described in terms of the terrain morphological units present. Each morphological unit has been defined according to its range in percentage slope; range in length; slope shape (convex, concave, straight); and area in hectares. The determination or calculation of the slope percentage was however problematic because there is no DEM available for the whole of Namibia to make this exercise somehow easier. The calculation or the estimation of the slope percentage was done manually which is a time consuming and tidious exercise.

3.2 Hydrology

The pilot area is clearly divided by an important regional watershed the central Namibian Highland. It is separating the western fluvial systems of the Swakop - and Kuiseb rivers draining more or less directly through the Namib plains towards the Atlantic Ocean, the eastern fluvial systems of the Back- and Wit Nossob and Olifant drain eventually towards the Orange river. The gradient of the western system is about 3-4 times than that of the eastern zone. Some 200 km further to the east, the continental watershed separates Atlantic drainage areas from those draining to the Indian Ocean, including the Kalahari endorheic system.
Many of the drainage lines strongly correspond with tectonically disturbed zones such as rupture fissures from warping (Kempf, 2000).
Especially in the proximal areas of the elevated highlands, valleys often meet at right angles.

3.3 Geomorphology

The geomorphology in this context refers to the primary subdivision of the soil survey and is defined by the environment, the soil texture and characteristics of the deposition of the parent material. The pilot area forms part of the larger part of the Kalahari basin. It can be divided into two development phases namely the central plateau and the Kalahari plateau. The plateau can be further divided into three levels. Three major levels of geomorphological plateau formation that has been identified, the oldest of which, most likely of Late Cretaceous age, has only been preserved in the silcrete-capped plateaus of the Gamsberg mountainous.
The extensive block of the deeply dissected Khomas Highlands form the second or Khomas level, planation of which will have come to an end in Mid-Oligocene to Mid-Miocene, as it cut across Olicene volcanic plugs and trachyte veins. East of Windhoek basin, the Khomas level continues as the top level of the Eros Mountains. In the pilot area it is represented, among other location, by the flat top of the Neudamm Kuppe inselberg and in the Onyati Mountains. The slightly dissected parts of the Khomas level the regional watershed have been rejuvenated during the Pliocene and now

form the Neudamm highlands or Seeis level 50-10 m below the Khomas level. Consequently the topography of the pilot area flattens from west to east, changing from long and steep, concave slopes bare rocks surface, over hills with pointed ridges and steep, concave slopes to a gently undulating upland slightly dissected by streams (FAO. 1991, Bertram & Broman, 1999).

The Kalahari plateau was formed during the Late Quaternary age. The topography of the Kalahari plateau is flat to nearly level. During the Late Tertiary the climate was extremely dry and this has resulted in the formation of vast longitudinal dune around Kanibis 54 and Kanibis 55 farms south of Molteberge. The omiramba White Nossob and Black Nossob were formed during the wetter phase in the early-middle Pleistocene ages.

The landscape of the Kalahari plateau can be divided into the following three major geomorphological units: the sandveld, hardeveld or calcrete plains and the alluvial landscapes or omiramba with and without pans. The last mentioned unit is heavily eroded and steeply dissected and gives to some extend the Kalahari plateau and undulating to rolling relief.

The geomorphology of the Kalahari semi-desert reflects the tectonic, fluvial and aeolian processes. The formation of the Namibian Highland mountains range were created by the synclinal nature of the Kalahari basin. The Kalahari has act as a “continental sedimentary basin” (Adams, Goudie, Orme p. 215) since the Cretaceous period. The Kalahari land elements the pans, interdunal depressions, fossilized dunes and the stabilized sand ridges are covered with sparsely to dense vegetation of shrubs and tree. The shrubs abd trees are doiminantly the acacia species such as the Acacia erioloba, Acacia mellifera, Grewia species, Terminalia species and Lonchcarpus nelsii species.

The interdunal depressions and watercourses were once though to be formed by high volume of runoff from the central Namibian mountains during the more humid and wetter climatic conditions in the Tertiary. After more through research and studies it has been shown that groundwater seepage plays a significant role in these geomorphic formations (Nash, 1996). The drainages are surrounded with tall acacia tortilis, acacia erioloba and ziziphus mucronata as dominant plant species. The vegetation along the watercourses grows tall and immerse because of suffucient soil moisture.

3.4 Geology or Lithology

The geological formation of the pilot area under review is diverse and complex. It comprises of rocks that have been divided into three main periods of activites namely the Damara orogenic (mountain forming) phase, the Carboniferous and the lower Cretaceous. The pilot area consists of a variety rock of different evolution and formation. The rocks are exposed to the soil surface and forms rugged terrains or landforms such as hills, mountains, valleys, ridges, sand dunes and the open flat plains. The eastern part of the pilot area the rocks are covered by thick sand of the Kalahari and other sediments that have been deposited in recent years. It is also observed that the calcrete have been deposited along the watercourses. The calcrete and conglomerate are quite visible on the highly eroded banks of the rivers.

Larger part of the pilot area is underlying by the Damara Sequence, while a small part north and south of Gobabis is covered by the reddish Kalahari sand. The Kalahari sand is the latest geological formation in the Namibian history. The soils of the Kalahari sands are mostly of sandy textured nature with low nutrient content especially low phophorus content. The sand is characterised by poor nutrients status because most of the microp- and micro-nutrients are leaching out of plant roots zone and being deposited in the lower horizons.

Geological studies indicate that the pilot area belongs to the Kalahari basin. These date back to the formation of the Gondwana period. A wide range of different rocks occurs in the pilot area and they differ in terms of age and structural development. In table 1.4 below a summary of the stratigraphy, divisions and lithology of the rocks types are been given.

The Palaeoproterozoic and the rocks of the Neoproterozoic Damara Sequence occur as the bases of the central plateau or the highlands while the Cainozoic sediments of the Kalahari and Kamtsas formation of the Nosib are underlying the Kalahari plateau. The pilot area underwent several major geological formations. The formation or phase’s starts way back during the Hohewarte Complex ages of 1800 Ma to Kalahari group. The oldest rock types are the paragneiss and metamorphic rocks which belong to the Hohewarte complex and occur south of Bismarck mountain.

Table 1.4: The stratigraphy and lithology of the pilot area after amended by Mendelson (20 Kempf (2001) and Ploethner et al., (1997).

Era	System	Sequences (age)	Divisions	Group	Symbol	Lithology	Colour
Cenozoic	Tertiary to Quaternary	Less 70	Kalahari Group (70 – present)	Kalahari	Nks	Sand, gravel and calcrete	Yelllowish
Palaeozoic	Cambrian to late Namibian	500	Nama Group 600-543 Ma	Kuibis and Schwarzran d	Nk	Shale, sandstone, minor limestone, conglomerate	Dark green
	Namibian		Damara Supergroup and Gariep 850-600	Gariep Complex	Nk	Sandstone, Marble, schist, quartzite, graphitic schist	Green
	Namibian	850	Damara Supergroup and Gariep 850-600	Khomas	Nk	Mica-schist, minor quartzite, marble, graphitic schist	Light green
	Namibian	850	Damara Supergroup and Gariep	Witvlei	Nk	Limestone, Schists, conglomerate, marble	Dark green
	Namibia	850	Namaqua Metamorphi c Complex 1,400-1,050	Sinclair	Nk	Shale, basalt, schist, rhyolite, conglomerate, marble, ignimbrite	Gray
Protezoic	Molokian	More 1,400	Oldest rocks	Rehoboth and associated rocks	Mho	Para-orthogneiss, metasediment ary rocks, granite, intrusive metabasite dykes	Brown

A considerable part of the pilot area is made up of quartzite, mica-schist, granite, conglomerates, metamorphic limestone and other rocks belonging to the Proterozoic Damara Sequence. Interspersed by the archaic Mokolian Complex of the Kalahari in the east of the pilot area.

The rocks were formed during the Precambrian Damara Orogen, which is about 700 to 1100 Ma years of age (SACS, 1980; Geological Survey Map, 1996). The western part of the pilot area lies within the Onyati-Mountain Schist Belt, which is part of the tectonostratigraphic Khomas Terrane (Kasch, 1988). The Khomas subgroup is the youngest of the Damara Sequence and consists of metamorphic rocks such as mica-schist, traversed by quartzite, subordinate calcareous schist and impure marble, and amphibolite schist (Geological Survey, 1996). In the centre of the pilot area a striking faults occurs. It is believed to be during the intense Precambrian folding and it is running from northeast to southwest direction (Krenkel, 1928).

The area covered by Okambaraberge, Groot Kleeberg, Hartebees Rucken Kuppe and Nicodemus mountains belongs to the Mokolain ages, which is more 700 million years.

A small-elongated area west of Okambaraberge stretching north to south of the central highlands belongs to the Sinclair Sequence. The geology consists of basalt, quartzite, conglomerate, and rhyolite as rock types. The youngest rock formation within the pilot area is the Kalahari. It was deposited at least 70 Ma years ago.

The lithology or geology plays quite an important role in the development and formation of the soils. There is a correlation between the geology or the parent material, relief, climate and the soils. The soils of the pilot area are largely governed by the parent material and relief. It is obseved that the geology influences also the formation and type of the relief. The underlying geology determines the soil type within the region. The Kalahari is characterised by the flat to almost flat plains while the mountainous regions are having an undulating relief and underlying by metamorphic rocks at shallow depth. Four major lithological developments were recorded and are being desrcibed in more details below:

- Tertiary to Quaternary Kalahari Sands (>150 cm deep) (Pp)
- Damara Sequence (D)
    a) Molokian Sequennce (Mo)
    b) Sinclair sequence (S)
    c) Rehoboth sequence (R)
- Khoabendus group (K)
- Gariep and Nama group (G)

The geology or lithology of each terrain unit and landform unit within the pilot area are being described in more details below:

3.4.1 Damara orogenic phase

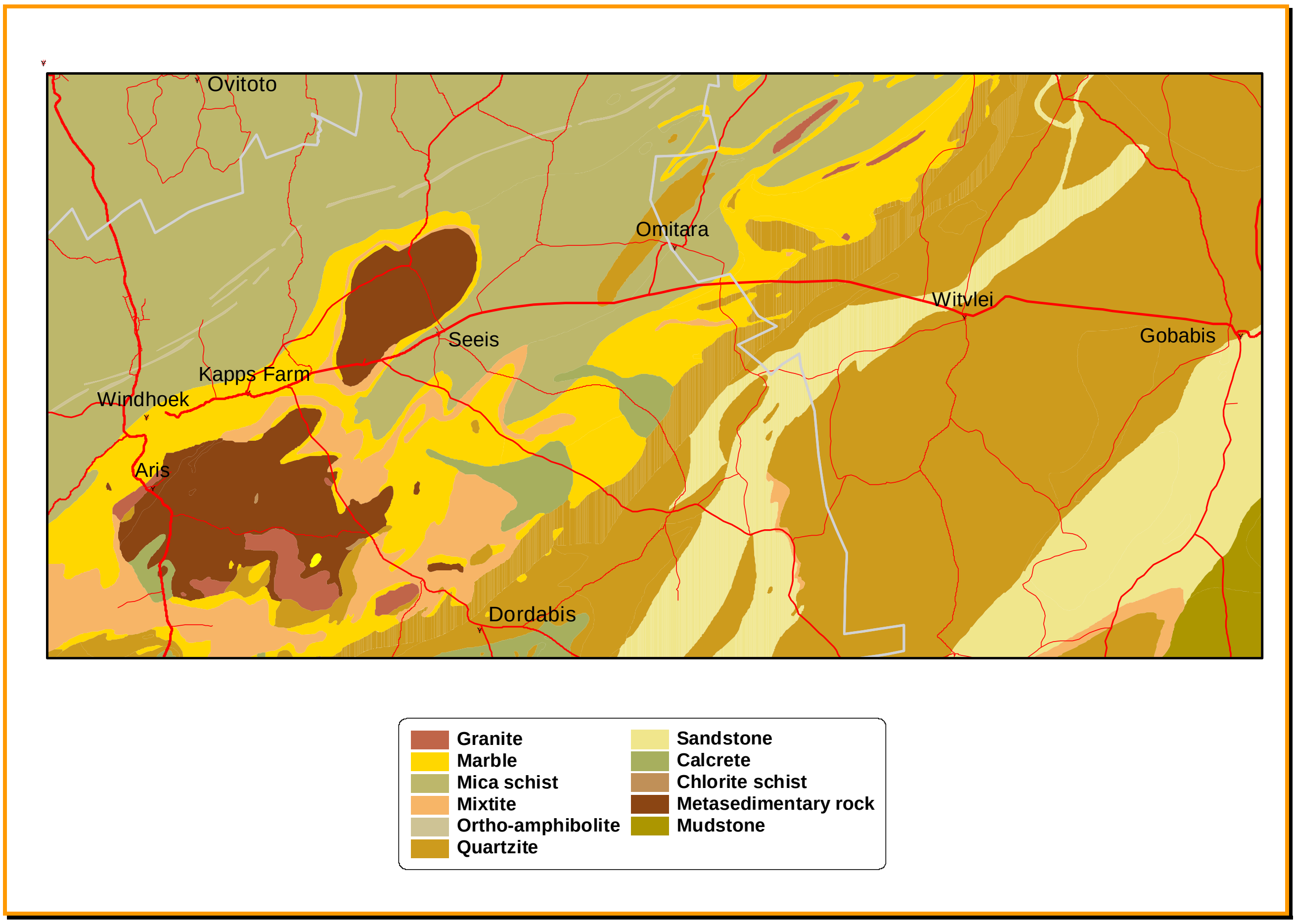
The oldest rocks within the pilot area are probably ancient quartz-feldspar gneiss interlayered with marble and amphibolites associated with the Palaeoproterozic Hohewarts complex. The rocks form the base of the Auas Mountain, Blaukrans Mountain and the Neudamm Kuppe in the central plateau.

3.4.2 Khomas Highlands

The Khomas Hochland lies roughly between the Swakop River towards the north, the Great Escarpment towards the west, the Auas Mountains towards the south and the Otjihase and Neudamm Mountains towards the east. It is an elevated peneplain at an average elevation of 2000 m above mean sea level. Schneider (2004) describes its origin as a narrow elongated branch of the sea between the Congo Craton towards the north and the Kalahari Craton towards the southeast, some 750 Ma ago, which eventually became the Damara Mobile Belt. Clayey-sandy sediments were eroded from the two cratons, deposited in this narrow sea and underwent extensive folding during the subsequent Damara Mountain Building event around 650 Ma ago. Plate tectonics moved the two cratons together in a collision similar to that of the present-day Asian and Indian plates that is creating the Himalayas and Tibetan plateau. The clayey-sandy sediments were metamorphosed to mica-schists intercalated with quartzites.

The Damara Mountains were subsequently eroded over millions of years to form an extensive peneplain. After the break-up of Gondwana, around 120 Ma ago, the area was extensively uplifted. Further erosion over the aeons resulted in the present plateau with its rolling to hilly topography.
The Khomas Hochland is mainly comprised of the Kuiseb Formation of the Damara Sequence. This is a 10,000 m thick sequence of intercalated mica-schist, quartzite and meta-greywacke that has been deposited in a spreading ocean and has undergone metamorphism during the Damaran Orogeny (Schneider, 2004).

Figure 1.3: The simplified geological map of the pilot area (Geological Survey Map of Namibia, (1997) amended by the staff of the Agricultural Laboratory in June 2006.



3.4.3 Windhoek valley

Windhoek is situated near the eastern limit of the Khomas Hochland in a graben formed in the mid-Tertiary (±35 Ma ago) by north-south-trending faults. This tectonic feature is roughly 150 km long by 20 km wide. Its origin lies in the major extensional forces exerted on the continental crust in the Mid-Jurassic (±170 Ma ago), before the break-up of Gondwana. The Windhoek valley is covered by Cenozoic sediments deposited on the schist of the Kuiseb Formation of the Damara Sequence.

3.4.4 Area south of Windhoek towards Rehoboth

The block faulting was accompanied by volcanism, resulting in the emplacement of thrachytes and phonolites of mid-Tertiary age in the southern extensions of the Windhoek graben. Examples of these are the Schildkrötenberg and Huquanis phonolites north of Aris and the Gocheganas trachyte, known as the Backenzahn.
Older granitic intrusions from the Kibaran (1200 Ma) and Damaran (500 Ma) Orogenies also occur in the Aris area. A good example is Falcon Rock some 2 km north of Aris, east of the trunk road. Further south of Aris the Naos Formation, of glacial origin, of the Damara Sequence covers the Hohewarte Complex. This formation, which is exposed west of the trunk road towards Rehoboth, as well as the Nosib and Hakos Groups of the Damara Sequence visible towards the east, were thrust to the southwest onto the Hohewarte complex, where they now form tectonic nappes.
The Oamites mine used to produce chalcopyrite and bornite, but has been inactive for the last 20 years. It lies approximately 50 km due south of Windhoek in the Oamites Formation of the Hohewarte Complex.

3.4.5 Matchless amphibolite belt

The Matchless Amphibolite Belt is a striking and economically important linear feature running through the Khomas Hochland, from Homeb in the Namib to xxxxx over a distance of ±350km. It is a remnant of the basaltic ocean floor of the ancient Damaran Southern Zone Ocean, which was sheared off during the subduction of the oceanic crust beneath the continental crust of the two colliding cratons. The high pressure and temperatures prevailing during the mountain-building event transformed the basalt into amphibolite. The Matchless Amphibolite Belt indicates the contact between the original Congo and Kalahari Cratons. It is up to 3 km wide, running southwest to northeast, forming lenses and layers of amphibolites interbedded with Kuiseb Formation schist. It has a MORB geochemical signature, interpreted as metamorphosed, syn-sedimentary submarine volcanics emplaced into sediments covering a mid-ocean ridge. It contains several massive sulphide ore bodies. In the study area, copper is mined from one such body at Otjihase Mine.

The traverse from Windhoek to Gobabis along road B6 starts in the central Namibian highlands and ends on the western fringe of the Kalahari Basin. It skirts a metamorphic complex of Mokolian (Paleoproterozoic) age, crosses the Southern Margin of the Damara Orogen, then crosses Mesoproterozoic rocks and continues in early Damaran rocks (Schneider, 2004).

3.4.6 The area between Windhoek and Hosea Kutako International Airport

The first formations east of Windhoek are the Kleine Kuppe Formation (Wasserberg Member), containing mainly quartzites, intercalated with the Kuiseb Formation that is mostly comprised of schists. Micaceous quartzite beds of the Kleine Kuppe Formation are well exposed in road cuts near Kapps Farm, some 19km east of Windhoek.
From the Dordabis turn-off to about 3km before the Hosea Kutako international airport, a series of thrusts in schist and quartzite can be seen. These belong to the Hakos Group. Thrusting is towards the southwest and is a result of compressive forces active during the Damaran Orogeny. The schist and quartzite are extensions of the Auas Mountains south of the road.

3.4.7 Auas Mountains

These are composed of the Auas Formation sediments that were laid down ±730 million years (Ma) ago in a spreading ocean on the continental shelf of a passive margin. During the Damaran Orogeny they underwent intense folding and thrusting towards the southwest. They highest peaks of the Auas Mountains, which are among the highest in Namibia, are capped with weathering-resistant quartzites, forming steep south-facing cliffs. The Moltkeblick is, at 2479m, the second highest peak in the country.

3.4.8 Bismarck mountains

Quartzite of the Auas Formation thrust onto Nosib Group schist form the Bismarck Mountains southeast of the Dordabis turn-off.

3.4.9 Hohewarte metamorphic complex

The Hohewarte Metamorphic Complex (>1800 Ma), one of the oldest crustal domains in Namibia, underlies the extensive peneplain in the area of the Hosea Kutako International Airport. The lithology is dominated by mica schist, porphyro-blastic ortho- and para-gneiss, migmatite, granite gneiss and amphibolite.

3.4.10 Area from airport to Witvlei

East of the airport, ridges of Nosib quartzite emerge above Cenozoic sediments of the Kalahari Group. Northeast trending folds and thrusts with large displacements are found, and several deformation events have been recognized in the Omitara area.
Near Omitara the Kamtsas Formation of the Nosib group, consisting of quartzites with characteristic heavy mineral layers, conglomerate bands and scattered pebbles, are found. The Kamtsas Formation was deposited in a southern half-graben during the early stages of rifting some 750 Ma ago.
This quartzitic zone band is some 10km wide; further east they are thrust over the Mesoproterozoic red-brown quartzites of the Eskadron Formation of the Sinclair Sequence. The latter contains copper deposits in three broad zones which are believed to have been deposited in shallow basins. To date no mining has started, despite extensive exploration.
Witvlei is located in a gap between a ridge of sandstone Kuibis Subgroup of the lower Nama Group and quartzite of the Nosib Group. Feldspatic quartzites of the Kamtsas Formation underlies the area further east up to Gobabis. The town itself is situated on the contact of Nosib and Nama Group sediments.

3.4.11 Kalahari

The sedimentation of the Kalahari Sequence followed the break-up of Gondwana and the subsequently isostatic uplift of the continental edges about 120 Ma ago. Southern Africa was brought into a gigantic bowl with coastal mountains, the Great Escarpment, around the edges, and a large depression, the Kalahari Basin in the centre of the sub-continent. In Namibia, most rivers east of the Great Escarpment drained into this basin, allowing deposition of erosion material originating from the central plateaux. The Kalahari Sequence, which covers about one third of Namibia’s surface, includes calcretes, conglomerates, sandstones and shales in addition to the stabilised red sand dunes of the ‘geographic Kalahari’.
The regions forms the eastern portion of the major continental basin filed with aeolian sediment of the Quaternary age.
The thickness of the Kalahari varies from a few centimetres at the western and northern margins of the Kalahari basin to maximum recorded thickness of in excess of 100 m. The Sub-Kalahari topography is irregular, as a result of tectonic as well as erosional process, and the thickness and character of the Kalahari sediments varies markedly over short distances. Bedrock protrudes through the Kalahari cover south of Witvlei on the southern border.

CHAPTER 4: METHODOLOGIES USED TO CLASSIFY TERRAIN TYPES OR LANDFORMS

4.1 Methods used to define the landforms

Landforms are described as land patterns at the broader scale while the units that make up these patterns are described as components. Speight (consult Landform Description Chapter in MacDonalds, 1990 (p. 34)) describes landform patterns (broad landforms) in terms of relief, modal slope, stream channel occurrence, mode of geomorphological activity, geomorphological agent, status of geomorphology activity and component landform elements. Whilst landform elements (components of landforms) are described in terms of slope, morphological type, dimensions, mode of geomorphological activity and geomorphological agent.

In summary, landforms can be described in terms of their morphology and process. Landforms have been divided into two levels namely the first and second level. The fisrt level separation is based on the slope gradient while the second level on sub division of the different landscapes or the position of the landform.

The second level landform can be further divided into small units is refers to as the “terrain unit”. A terrain unit is any part of the land surface with homogeneous form and slope. Terrain types can consist of the following terrain units such as crest, slope (midslope, upper slope, foot slope) and valley bottom or a flood plain. A terrain type in this context refers to an area of land cover over which there is a markedly uniformity of surface form and which, at the same time, can be used on a map of a scale of 1: 250 000. Terrain type shown on the map can be a single or multiple terrain units. Some examples of single terrain units are the crests, flood plains or valley bottoms. Multiple terrain units refer to the second phase and third phases of the terrain units such as 2nd midslope or 3rd slope etc.

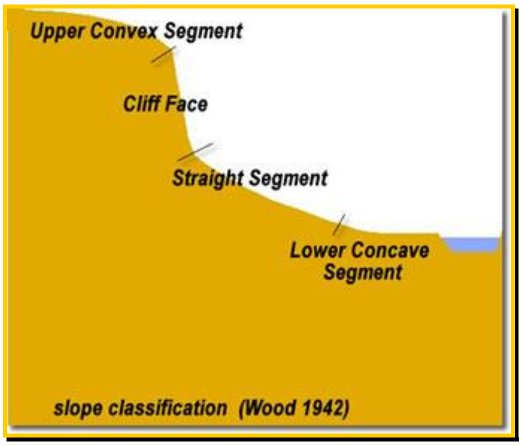
The following numbers are denoted to the different terrain units, 1 represent a crest, 2 a scarp, 3 a midslope, 4 a foot slope, and a 5 a valley bottom. While 3(1) indicate a second phase midslope and 3(2) refers to a third phase midslope (Based on the South African Binominal Classification).

4.2 Terrain types

Any terrain type within the contest of soil survey and mapping consist of aspects such as terrain form, soils, geological and climatic aspects (South African Terrain Types and Inventory Bulletin, 1996). But due to limited or the lack of sufficient data on climatic data such as rainfall, sunshine, evaporation, temperature, wind and climate of the pilot area these parameters will not used the classify the different terrain types.

By definition a terrain type is refers to as an area on a map that need to be shown at scaleof 1:250 000 that display a marked degree of uniformity with respect to terrain form, soil pattern and climate. A terrain type differs from another in terms of one or more terrain forms, soil patterns and climatic factors. The terrain differ from one and another in terms of slope percentage, slope angle and gradient.

The schematic diagram of a catena from a high summit to the lower river bottom of a single “terrain type”. Different slopes segement are clearly show and they comprise of the upper convex slope, cliff face, straight segment and the lower concave segment and the flood plain (blue colour)



A mountain cliff chractersied by hard and soft weathered parent material. The hard parent rock are forming steep slopes while the soft tend to form straight slopes.

Within the pilot area the formation of terrain type arevery complex and tus is because of different geological and morphological activities. Mountain or hill slope can be broke into five segments namely the summit, shoulder, back slope, foot slope and toe slope. The land mapping unit and soil mapping unit follows clearly the patterns of the terrain types and the contour intervals. The soil and landform boundaries were delineated by using the stereo-photographic and satellite imageries supplemented by field observation. The field observation includes opening of soil pits and augers. Other observation methods used were the description of rivers, gravel pits and road cuts. The landforms within the pilot area were defined and classified by using the South African Terrain Types and Inventory Bulletin (1996), SOTER classification system and Dikau terrain classification system (1991).

Because the SOTER landform classification is recommended for broad scale mapping it was used to supplement the South African Terrain Classification and the Dikau method. According to Dikau the pilot has been divided into four landform types namely the plains, highlands, plains with hills and the mountains and hills. These mjor landform types have been further divided into 25 landform classes and 100 subclasses. The main landforms with their classes and subclasses according Dikau (1991) are illustrated in the table below.

Table 1.5: Indicate the major landform types found in the pilot area with their classes and subclasses according Dikau (1991).

Landform Type	Landform Classes (2nd level)	Landform Subclasses Code
	Flat or nearly flat	A1a, A1b, A1c, A1d
Plains (A)	Smooth plains with some relief	A2a, A2b, A2c, A2d
	Irregular plains with low relief	B1a, B1b, B1c, B1d
	Irregular plains with moderate relief	B2a, B2b, B2c, B2d
	Highlands with moderate relief	A3c, A3d, B3c, B3d
Table lands or Highlands (B)	Highlands with considerable relief	A4c, A4d, B4c, B4d
	Highlands with high relief	A5c A5d, B5c, B5d
	Highlands with very high relief	A6c, A6d, B6c, B6d
	Plains with hills	A3c, A3d, B3c, B3d
Plains with Hills and Mountains	Plains with high hills	A4c, A4d, B4c, B4d
(A)	Plains with mountains	A5c, A5d, B5c,B5d
	Plains with high mountains	A6c, A6d, B6c, B6d
	Open very low hills	C1a, C1b, C1c, C1d
	Open low hills	C2a, C2b, C2c, C2d
Open Hills and Mountains (C)	Open moderate hills	C3a, C3b,C3c,C3d
	Open high hills	C4a, C4b, C4c, C4d
	Open low mountains	C5a, C5b, C5c, C5d
	Open high mountains	C5a, C5b, C5c, C5d
	Very low hills	D1a, D1b, D1c, D1d
	Low hills	D2a, D2b, D2c, D2d
Hills and Mountains (D)	Moderate hills	D3a, D3b, D3c, D3d
	High hills	D4a, D4b, D4c, D4d
	Low mountains	D5a, D5b, D5c, D5d
	High mountains	D5a, D5b, D5c, D5d

Two methods were used to delineate the soil-terrain mapping unit. The different terrain types, each displaying a marked uniformity of terrain form, were delineated on the 1:50 000 topographic maps. The delineation of the mapping units were first drawn manually on the hard copies of the 1: 50 000 topographical maps. Secondly, the same units were digitized on screen in ArcView on the 1: 50 000 scanned topographical maps.

The different terrain types abstracted from the 1:50 000 topographic maps were then defined in terms of percentage level land and local relief by using the SOTER Produces Manual Guideline.

Secondly, the terain types or different landforms were delineated on screen on the "Landsat TM Satellite Imageries" of 1987. The reason being some of the features appears more clear on the satellite imigaries than on the topograpgical maps. The topographic sheets and satelite imageries suppliment each other quite well. For example, it is observed that the degree and extend of erosion or dissection on the satelliete imagery are clear than on the topographical sheets. Rivers or watercourses show a high degree of dissection and the area expansion are quite visible on the imageries. The boundaries of the different landform types abstracted from the 1:50 000 topographic maps and Landsat TM Satellite Imageries merge well. The landforms or terrain types were further divided into smaller units in terms of slope percentage or level land classes, profile type classes and the local relief classes.

4.3 Percentage level land

Precentage level land can be express in terms of slopes. Simply means a percent level land is the estimated angle or wedge of a slope of less than 8%. The reason for using the 8% slope as the maximum slopes is because it is a slope gradient were mechanical limitation or hazards start taking place. Thus slope percentage were advice and recommended by the south Africans.According the South African Terrain Types and Inventory Bulletin (1996) were are four main estimated slope classes in which level land can be expressed. The four main classes of estimated slopes in terms slope percentage level are categories as follows A, B, C and D.

Class	Description
A	> 75 % of the area is level land
B	50-75 % of the area is level land
C	20-50 % of the area is level land
D	< 20 % of the area is level land

4.4 Profile type

The profile type has been divided into four classes of profile type in the pilot area. A profile type is being defined as the relative percentage of the level land (≤8%) that occurs within the highland or lowland. The four classes of profile types are described in more details below as follows:

Class	Description
a	> 75 % of the level land occurs in lowland
b	50-75 % of the level land occurs in lowland
c	50-75 % of the level land occurs in highland or upland
d	<75 % of the level land occurs in highland or upland

4.5 Local relief unit (elevation)

The local relief estimates were based on Agro-ecological Zoning Map of Namibia of Prof de Pauw (1996) and Kruger (1973). The local relief can be expressed as the difference in altitude (meters) between the locally adjacent higher (elevation) and lower (elevation) of the land surface, normally the interfluve crest and the valley floor. For example, the second highest mountain pick in the in the pilot area is the Molteblick which is 2,479 m high while the lowest point in the landscape is the Windhoek valley which is about 1500 meters above sea level. The local relief is estimated or calculated as the difference between the highest point minus the lowest point in the landscape. The difference between the two points is the "local relief". In this case it is 1,479 m (2,479-1,500). According to the preliminary AEZ Map of Namibia the country is divided into six local relief classes. Those classes are been given in the table below.

Table 1.6: Local relief units of Namibia adapted from Agro-ecological Zoning Map (de Pauw, 1996).

Class	Criteria Kruger, 1973	Description
1	0 –30 m	very low relative relief
2	30 – 100 m	low relative relief;
3	100 – 170 m	moderate relative relief;
4	170 – 300 m	high relative relief
5	300 – 1000 m	very high relative relief
6	>1000 m	extremely high relative relief

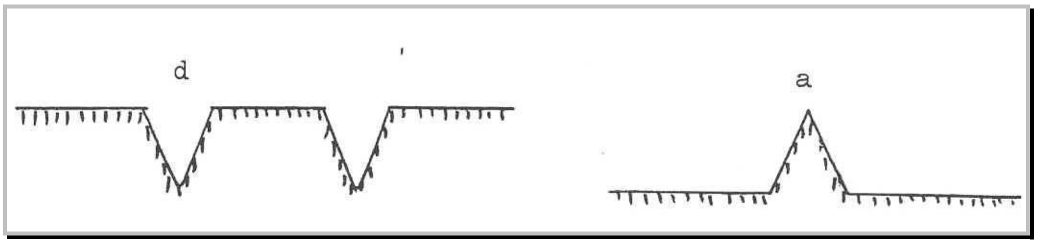
By combining the percentage level, local relief and profile type a symbol has been constructed that describe the nature of the terrain type.

4.6 What is a highland or lowlands

There is no clear cut definition between the lowland and highland. The terms highland and lowlands refers to the relief of the landscape. Simply means it is refering to the difference in height above sea level. Within the pilot area the land mapping units or terrain types that occur above 1500 m a.s.l. is being regarded as "highlands" or the central plateau. While the lowlands are covering the area below the 1500 m a.s.l. or the Kalahari sand plains. These two regions

correspond well with the occurrence and the formation of the three main rock types namely the igneous-, metamorphic- and sedimentary rocks.
Apart from climatic conditions the rock types within the pilot area influences the formation of soil type and the distribution. It is quite evident that the soils of the cetrnal plateau or highlands originate from the igneous and metamorhic rocks. They tend to be gravelly and show poor profile development.
The soils of the Kalahari sand plateau were formed millions years ago and show well deep soil profile development. They originate from the rocks of the old basins which comprises of sedimentary rocks and deposits of tertiary rocks. Apart from the geological activities the height above the sea level is another factor used to distinguish between the lowland and the highland.

Figure 1.3: Is illustrating the differences between the highlands and the lowlands in terms of occurrence in the landscape. The Khomas Highland within the central plateau is good example of the "highland", while the Kalahari plateau is a good example of "lowlands."



Highlands* (d) Lowlands* (a)

4.7 Method used to calculate the slope gradient

Terrain type units have been described and classified in terms of the phases of the terrain, slope angle, that occur in the terrain units. Each terrain unit whether it is a crest (1), a scarp (2), foot slope (4) or valley (5) it is being define according to the following criterias:
Range in percentage slope (using a slope wedge).
Range in length
Shape of the terrain unit: concave (X), convex (Y), irregular (I) and straight (Z).

Difference of A/ B = A (Maximum height)/ B (Minimum height)

Slope (%) = Difference (A-B)/ length of the line x 100

For more details on the calculations of the different regional slope according to SOTER, 1998 see **Appendix II**.

4.8 Drainage patterns

The density and length of the drainage lines or watercourses are some of the land elements that influence the formation and development of the major landscapes and soils of the pilot area. The different drainage lines take various patterns, shapes and size depending of parent rock and the topography in which they occur. Their densities differ markedly from the central highlands to the flat or nearly level Kalahari sand plateau. The watercourses of the central highlands are denser with very steep slopes and narrow riverbeds, while they are weakly developed and broad in the Kalahari sand plateau. The drainage's within the central plateau and the escarpment have a V-shape while the drainages in the Kalahari sand plateau have a U-shape. Two drainage patterns have been identified within the pilot area namely the dendritic- and rectangular pattern.

The common drainage pattern in the pilot area is the "dendritic".The dendritic pattern is a tree-like pattern composed of branching tributaries to a main branch, characteristics of essentially flat-lying areas and homogenous rocks. This pattern is a typical of adjust sytems on eroded sediments and uniformly dipping bedrock (www.physicalgeography.net/fundamentals/10aa/html). It is characteristics of the Kalahari sand plateau.

Rectangular on the other side is typical of the central highlands and the escarpment. It is an angular drainage and is associated with the dendritic pattern. The pattern is characterized by abrupt change of streams and develops where a tree-like drainage pattern prevails over a broad area. It is caused by faulting and jointing and is generally associated with massive igneous rocks. Metamorphic rocks surface such as the rock comprising of mica-schist as well (www.physicalgeography.net/fundamentals/10aa/html).

CHAPTER 5: MAIN LAND MAPPING UNITS AND THEIR MESORELIEF

5.1 Introduction

Landform or terrrain morphologicla unit classification in SOTER is based on morphometric criteria. At the first hierarchic tier, three major landforms the level land, sloping land and steep land are distinguished on the basis of the "characteristic slope". This is dominant slope gradient within a terrain unit. A further breakdown of these three main classes is achieved through classes of relief intensity, position of the unit in relation to surrounding land and hypsometry. The criteria are changing within each major landform class:

- for level lands (slopes <8%) the relief intensity is always less than 100m/km while the absolute height above sea level is taken as hypsometric criterion;

- for steep land (slopes >8%) relief intensity is more than 600m/2km and the relative height above the local base level defines the hypsometric class;

- for sloping lands (slopes 8-30%) the same hypsometric criteria are valid as for steep land, but relief intensity may be less than 600m/2km while always more than 50m/slope unit.

A further delineation is achieved according to the relative position of a terrain unit vis-a-vis the surrounding terrain, e.g. distinguishes plain from plateau.

Detailed information on the SOTER methodology with special emphasis on small scale physiographic mapping is given by Wen's (1993) report and the SOTER Procedures Manual (van Engelen, 1993; 1995).

The pilot area is characterized by different landforms/ mesorelief that range from flat to undulating topography with the exception of the dunes and the drainages or omiramba (dry, ephemeral water courses) which are incised into the Kalahari plains and central plateau. The major physiographical units which were identified and described in he pilot area are the mountains, open hills and mountains, plains with hills, koppies, ridges and plains or sand plains. The seven main landform types or land mapping units have been further subdivided into twenty-three (23) classes according to their degree of dissection, density of drainage, slope length and slope percentage. It is also observed that the different soils types within the different landforms differ dramatically in terms of the depth, chemical - and physical properties, soil texture, colour and the presence of the parent material from which they are formed.

The different landforms or terrain morphological units of the pilot area were based on the Terrrain Morphological Map of Southern Africa by Kruger (1983) and the Global and National Soil and Terrain Digital Databases, Procedures Manual (1995) respectively.

In general topography of the pilot area is alomost flat to gently undulating with the exception of the mountains and the drainages or omiramba (dry, ephemeral water courses) which, are incised into the Kalahari plains and the central plateaux. The five major terrain morphological units within the pilot area are the mountains, hills and ridges, lowlands (hills and ridges, plains with moderate relief and plains with low relie (Kalahari sand plains), drainages or omiramba underlying by calcrete and conglomerate at shallow soil depth. The table below summaries the main land maping units, the landscape description and their lithology as found in the pilot area.

Table 1.7: The different land mapping units, the landscape types and their lithology within the pilot area.

Land mapping unit	Landscape Type Description	Lithology	Area km2	Area %
Plains				
A1a	Flat to almost flat sand plain	Kalahari sand, sedimentary and volcanic rocks		
A1d	Flat to almost flat sand plain	Damara sequence- conglomerate, quartzite, schist and marble		
A2a	Smooth plain with some relief	Damara sequence- conglomerate, quartzite, schist and marble		
A2d	Smooth plain with some relief	Gariep complex and Nama group- sandstone , conglomerate, shale and black limestone		
B1c	Nearly level to gently undulating plain with minor rock outcrops	Damara sequence- marble, schist, quartzite and graphitic schist		
B1d	Flat to gently undulating plain with minor rock outcrops	Damara sequence- marble, schist, quartzite and graphitic schist		
B2d	Flat to gently undulating plain with minor rock outcrops	Damara sequence- marble, schist, quartzite and graphitic schist		
Highlands of the central plateau with ridges, castle granite koppies and high hills or mountains				
A3c	Gently undulating plain	Mica-schist, quartzite and ortho-ampholite rocks		
A3d	Flat to gently undulating plain	Mica-schist, quartzite and ortho-ampholite rocks		
A5c	Flat to gently undulating plains with mica-schist rock outcrops	Mica-schist, quartzite and metamorphic rocks		
Plains with open or isolated hills, ridges and koppies				
B3c	Plains with isolated high hills and koppies	Damara sequence- Para gneiss and metamorphic rocks		
A3b	Flat to gently undulating plains	Kalahari sand, sedimentary and volcanic rocks		
Highlands of the central plateau with high hills and ridges				
C1c	Steeply dissected undulating highlands	Damara sequence- schist, marble, quartzite, graphitic schist		
A4d	Moderately to steeply dissected undulating highlands	Damara sequence- schist, marble, quartzite, graphitic schist		
High hills and mountains				
D1d	Isolated hills and mountains with rocks outcrops	Damara sequence- schist, marble, quartzite, graphitic schist		
D1c	Isolated hill in the extreme southern region of the Back Nossob river (Schwarzrand subgroup)	Gariep complex and Nama group- sandstone , conglomerate, shale and black limestone		
D2c	Hills consisting of igneous rocks (Damara Formation)	Gariep complex and Nama group- sandstone , conglomerate, shale and black limestone		
D3c	Hilly areas with mica-schist rock outcrops	Khomas- , Huab formation- mica-schist, quartzite and metamorphic rocks		
D4c	Mountains area from preferably sedimentary rocks (Damara sequence) with plenty rocks outcrops	Kuiseb- and Rehoboth formation- mica-schist, quartzite, gneiss and metamorphic rocks		
D5c	Mountains area from preferably sedimentary rocks (Damara sequence) with plenty rocks outcrops	Damara sequence, Auas formation – marble, mica-schist and quartzite		
Kalahari sand dune (Small unit which have been included in land unit)				
Dua	Longitudinal sand dunes covered with natural vegetation	Gariep complex and Nama group- sandstone , conglomerate, shale and black limestone		
River valleys (Mapped as separate unit)				
Va	Major rivers valleys and fluvial basins	Cut through various sedimentary and metamorphic rocks		

Explaination of codes not indicated the Terrrain Morphological Map of Southern Africa by Kruger (1983) and the Global and National Soil and Terrain Digital Databases, Procedures Manual (1995). Some of the mappping units such as the sand dunes and rivers were mapped as separate entities which is not the case with the guideline of the Terrain Morphological Map of Southern Africa and SOTER do to the small scale we worked on. To localize the legend it was felt necessary to create our own local codes for the two land mapping units.

Dua Kalahari sand dune

Va River valleys and streams

The seven (7) above-mentioned terrain morphological units have been divided into 22 subclassess according their morphology, lithology, drainage density, drainage pattern and slope percentage level land. The main terrain morphological units and their sub division are being described in more details below:

5.2 Land unit E: Hills and Mountains-Mountainous region (D1; D2; D3; D4 and D5)

Land unit E-10: High Hills or Mountains (D5c) areas from Damara Sequence of the Duruchaus-, Kamtsas and Auas formation preferably sedimentary rocks.

Mountain is being defined as a piece of land with steep slopes with an intensity of more than 600 meters per km2 and is surrounded by outstanding summit (SOTER, 1995). The mountain ranges unit occur mainly in the central plateau of Namibia. High mountains makes about 80% of the highland, the rest being mostly lowland. They are characterised by the highest dispersion of both altitude and slope values of the country. Total relief locally exceeds 2 000 m, mean slopes values reaches 32%. The topography is characterised by steeply dissected undulating with steep concave and convex slopes.
This land unit covers larger section of the southern west part of the pilot area. The highest mountain within the pilot area is the Auas Mountain which is on the southern outskirts of Windhoek. The Mountain ranges found in this land unit are the Auas Mountain range with its highest peack “the Molteblick” (2,479 m). Other mountains are the Bismarckberge (2,252 m), the Hoher Schein (2,268 m), the Lichtenstein (2,299 m), the Gross Hertzog/ Friedrich mountains (2,336 m), the Oamites and the Bischmarkfelsenberge (2,417 m). The highest mountains occur at an average elevation of approximately 2280 m.a.s.l with an average slope is >32%.

Appendix III, Plate 1: shows the Auas Mountain photo taken from the north western side of the mountain. The mountains are patchly distributed mainly through the western section of the pilot area. The topography is steeply dissected, undulating or mountainous landforms with steep concave slopes.
Due to the steep slopes and ruggedness of the terrain the land unit is covered with very shallow soils with many to abundant rock fragments and rock outcrops of resistance quartz, mica-schist, granite and sandstone. These soil type makes >10% of the total area and have been described as the “lithic Leptosols” with abundant rock outcrops. Rocks outcrops and fragments of quartzite, mica-schist and gneiss are covering 90% of the soil surface. Auas Mountain geology comprises of quartzite and mica-schist rocks. The geological formation of Oamites consists of the Duruchaus formation with quartzite, conglomerate, schist and marble.
The mountains are highly subjected to water - and wind erosion and this can be clearly evident in the formation of deep gullies along the deep, steep slopes. Fine soils particles are continously removed by the water resulting in the exposure of fragment, stone and boulders on the surface.

Land unit E-20: High hills and mountains (D4c) from Damara Sequence preferably the mica schist as the parent material or bedrock exposed on steep slopes.

Land unit E-20 covers the high hills of the central plateau of Namibia. The land unit is found at a lower elevation than the mountains but higher elevation than the moderately high hills.
The average height varies between 1800-2000 m.a.s.l. This land mapping unit occurs north of Auas Mountain, east of Windhoek valley and it stretches towards of Okahandja.
The high hills cover the area west of Neudamm experimental farm namely the Hoffnung-Neudamm Kuppe high hills area, the Otjihavera mountains range. In the south of the pilot area it covers the Grimmrucken Mountains north and northwest of Dordabis. The Kleeberge occurs northwest of Mountain View lodge. The land unit characterised by high hills occurs northwest of Dordabis settlement and stretches from Kransnek to Blaukrans Mountains. The Kransnek-Blaukrans-Grimmrucken Mountain chain belongs to the oldest geological formation within the pilot area. High hills cover the area south of Okatjosorui and Oruua settlements. Other settlements covered by high

hills are Satan, Otjiserandu, Otjivahiona, Ombungururu and Okatjongua in the Ovitoto communal land. A large part of this land unit is covering the southern part of Ovitoto communal land.
The land mapping unit has underwent various geological formation and structural development which resulted in the formation of different rock types and landform shapes. The high hills of Otjihavera Mountain consist of Damara rocks sequence which is built up of mica schist and quartzite. The quartz is highly resistance to weathering while the mica schist is easily weathered rock type. The Grimmrucken Mountain north of Dordabis consists mainly of lithology of the Gariep and Nama complexes.
When mica schist is weathering it tend to forms flat to platy shape structured plates. The rocks are easily subjected to weathering and result in the formation of very shallow, gravely soils underlying by platy bedrock at shallow depth.
The land unit is this characterised by very shallow to shallow soils lithic Leptosols and skeletic Regosols. The lithic Leptosols is overlying by soft to hard mica-schist at depth. The shape of the high hills slopes takes varies forms and shapes such as concave-, convex - and straight slopes with an average slope of 25% depending on the presence of the bedrock and to some extend the degree of dissection.

Appendix III, Plate 4: Showing steeply dissected “Otjihavera highland” of the central plateau with remnant of semi- or partly weathered mica-schist rocks.

Land unit E-30: Moderate hills (D3c) areas with mica-schist rock outcrops belonging to the Khomas and the Huab formations.

Moderate hills belong to the central plateau or highlands of Namibia. The land unit covered by moderate hills is also known as the rolling “Khomas Hochlands”. The moderately hills is found at an average height of 1750 (1700-1800) m a.s.l. The unit is cut by many watercourses or drainage lines that cause severe soil erosion. Another contributing factor that causes the high degree of dissection and runoff is the steep convex and straight slopes. The expose of parent rock and rock outcrops on the soil surface are indicators of erosion. The highlands or moderate hills are covering the areas west of Windhoek and the Windhoek valley. The land unit is also occuring west and east of Krumhuk-Aris-Gocheganas valley. Another part of this unit is found south of the Gross Hertzog Tower and extend southwards until the Oamites Mountain, north of Oamites millitary base. The land unit is also found south of the Auas Mountain and extend towards the Kranznek Mountains.Both units are running parallell to the main road (tarred) from Windhoek to Rehoboth. Up north of the pilot area the moderate hills occur south of the Von Bachdam near Okahandja. They cover mainly the southern part of Ovitoto communal land. Some settlements south of Ovitoto that are surrounded by surounded by moderate hills are Otjiserandu, Ombungururu and Okatjongua. A small section or part of moderate hills is found east of the Otjiterazu-Otjozonjati plains east of the mighty Otjihavera Mountains. It is also covering the Onyati-Klein Onganga Mountains north of Hosea Kutako International airport.
This land unit is characterised by rolling to undulating topography. The moderate hills is further characterised by pointed ridges and steep concave slopes. In general the soils of this land unit are shallow to very shallow with many to abundant coarse fragments of quartz. Mica-schist forms the parent rock.

Appendix III, Plates 3: The “Khomas Highland” the typical steeply dissected landscape within the pilot area. The rolling landform is having rounded hilltops with straight slopes.

Land unit E-40: Low hills (D2c) consisting of igneous rocks belonging to the Damara sequence as parent material.

The land unit with low hills is characterised by isolated patches of hills and ridges consisting of igneous rocks of the Damara sequence. Low hills cover the area east of Bulskop no. 1 and Bulskop no 2 in Ovitoto communal land with a mean height of 1600 m a.s.l. The land unit forms part of the central highlands or plateau of Namibia. The highest summit within this land unit is found north of Bulskop no 1 with a maximum height of 1657 meters above sea level. Another part

of this land unit also occurs west of Otjiterazu-Otjozonjati plains covering the farms west of Midgard lodge and Otjiterazu farms.
Further down south in the pilot area this land unit is found in the vicinity of Noukomob 272, Stinkwater 282 and Langbeen 86 farms.
The land unit with low hills forms a distinct natural boundary between the central plateau and the Kalahari sand plateau. The Groot Klee- , Okambaraberge and Hartebeest rucken hills forms part of this land unit. The Nicodemus hills near Gobabis in the east formspart of this land unit. The Omitara Mountain, Otjivero Mountain, Omieveberge are some of the isolated and patchly distributed low hills within the pilot area. The low and isolated hills were formed many years back during the wet era. The floods of the wet era has removed all the loose and fine soil particles with the resulted in the remaining of remnant of the unweathered sandstone and gneiss rocks on the surface. These renmants of hard rocks are today what we called the “low hills”. The low hills are further characterised by showing a slightly to moderately degree of dissection. The low hills are having concave and straight slopes.
Apart from being dominanted by rock outcrops of gneiss and sandstone the middle- and lower slopes of the low hills are covered with many to abundant quartz gravels and stones. Resulting in shallow to moderately deep soil with many coarse gravel’s refers to as the “skeletic Regosols”. Depending on the geological formation below a large area of this land unit is underlied by soft weathered mica-schist. The soft partly weathered parent material is refers to as the “saprolite”. In some instance the regosols is directly overlying on top of the hard or unweathered parent bedrock of mica-schist. Within the Kalahari region the rocks on the low hills are covered with pocket of shallow to moderately deep sandy soils blown in from neighbouring areas by wind. Sand are deposited mainly on the eastern lower and middle slopes of the hills. The sand particles consist mainly of quartzitic and sandstone.

Appendix III, Plate 13: A typical low hill (D2c) landscape at Okomakuara south of Okandjira settlement in Ovitoto communal land.

Land unit E-50: Very low isolated hills (D1c) areas of Damara sequence consisting of mica-schist and quartz.

This land unit is mainly confined to the central plateau of Namibia but very few isolated low hills are also found in the Kalahari sand plateau. The land unit characterised by isolated low hills occurs on both sides of the main road from Windhoek to Okahandja. It is found south of the sandplains at Ozona millitary base and ends in the Windhoek valley. The land unit is characterised by gently undulating to undulating topography with many weakly defined easterly flow drainages. The high number of watercourses indicates a high degree of dissection. The Windhoek valley lies at a lower elevation than the surrounding landscape.
The very low hills are found east of the Otjihavera mountain and west of the Klein Okapuka mountain, at the foot of the Otjihavera mountain and north of Hoffnung-Neudamm Kuppe at Neudamn Agricultural college. The land unit with low hills occurs also west of the flat plains within the surrounding of Ongombo-Ost and Ongombo-West plains. The unit also borders from Neudamm experimental farm in the north and extend down south passing between the Auas- and Bismarck Mountains up to the north of Krans mountain. It is also extending further south up to Bergland 264 and Nabitsaus 263 farms that forms the southern border of the pilot area. The high hills Kranznek-Blaukransberge, Elisonhohe and Paviansberge form the eastern boundary of this land unit. In the north land unit D2d forms the northern boundary.
The western and the northern part of Ovitoto communal land is characterised by very low hills. Very low hills occur in the extreme western corer of the pilot area which is the area around Melrose and Regenstein farms. Isolated low hills are also found north of the Grimmrucken mountain north of Dordabis settlement and south of the Seeis river. They are also occurring north of the Okambara Mountains. The Omitara mountain is a good example of the very low mountain. The very low isolated hills are scattered all over larger part of northern section of the pilot area.
Very low hills area characterised by one soil type. This soil type varies in depth and the presence of rock fragments. Meaning the soil type varies from “gravely soils” to “very shallow soil” pending on their position in the landscape. The soil type is underlying by partly weathered mica-schist (saprolite) or hard mica-schist at shallow depth and this result in high waterholding capacity. The

saprolite serve as sponge and absorb quite a significant amount of water creating a favourable conditions for natural vegetation.

Appendix III, Plate 14: Mountains and hills were formed millions years ago during the folding and eroding era. This peneplain with undulating topography and steeply dissected concave slope covering the central plateau of Namibia was formed during the above mentioned era. The photos were taken at Bulskop in Ovitoto communal land.

5.3 Land unit D: Highlands of the central plateau with open high hills and ridges (C1)

Land unit D-60: Open high hills of the central plateau (C1c) areas of Damara sequence.

Central highlands characterised by open hills and ridges belongs to the central plateau. This land unit is characterized by undulating to rolling topography with many drainage lines. The local relief is being classified as very low relief. This land unit serves as a transition zone between the central plateau and the Kalahari sand plateau. The reason is simple because it is adjecent to the low Kalahari in the east and west by the high central plateau.

The land unit found it origin in the high central plateau or highlands and is drained by many watercourses or drainages. The watercourses and streams take the water from the higher parts to the lower positions in the landscape and deposited the finer and lighter fragments in the level or flat areas. The water stagnates for a couple of days and forms water pools and pans. The high density of watercourses is eroding the hills and mountains at a fast rate and causes siginicant soil erosion.

All the water that accumulate in to the lower positions found their way finally into the lower Swakop valley.

The land units characterised by open high hills are found on the left, right and south sides of the Onyati-Klein-Onganya-Okaramakuje high lands. The low hills unit are found at a higher elevation than the flat plains but lower than the very low hills (D2d).

Land unit with open high hills and ridges serve also as a transition zone between the very low hills, moderate hills and the flat plains. It is characterised by steep valley slopes with nearly level relief. The topography is flat to gently undulating. The unit is characterised by shallow to moderately deep soils. The dominant soils covering the hills and ridges are shallow while the soils on the level plains are moderately deep sandy loam textured soils.

Land unit C: Plains with isolated hills and inselberge of the central plateau (B3c and A5c)

Land unit C-70: Plains with isolated koppies and inselberge (B3c and A5c) areas of metamorphic and sedimentary rocks.

The highlands and plains with the moderate hills, ridges and inselberge occur in the central plateau of Namibia. The land unit lies at a lower elevation within the central plateau. The land mapping unit is found at the foot of high hills and mountains regions and due to its lower lying position in the landscape it tends to form “depressions” or places were water collects. It is assumed that in the past this land unit used to be part of the highlands or high Otjihavera mountain. But because high erosivity of the soils all fine particles washed downstream resulting in the remaining of the coarse fragments on the surface. During the wet periods the soils have been eroding away and lifted only the hard unweathered rocks which form the isolated hills and mountains renmants today. The remnant consists mainly of unweathered bedrock of granite, gneiss and sandstone which forms isolated hills and mountains in the flat pains. The land unit caharcterised by typical remnants of mica-schist, sandstone and quartz shows a slight degree of dissection than usual. We assume that it might be that during the wetter phases or period in Namibia the water have removed all the loose and fine soil particles and left only the hard and unweathered rocks fragments of granite, quartz and gneiss on the sil surface. These phenomina have resulted in the formation of high hills and ridges with steep eroded slopes.

This land unit is also patchy distributed throughout the pilot area. It is also covering the area in and around the Krumhuk 30, Aris 29 Gocheganas 26 flat plains. In general the topography is flat ot

almost flat. It is only the hillls or ridges that gives the area an undulating topography. The highest summit in this land mapping unit is called the “Schildkrotenberg” which is 2028 m.a.s.l.
The area east and west of Grimmrucken Mountain and west of White Nossob in the south of the pilot area is also characterised by isolated hills and koppies. Plains with isolated koppies and ridges are also covering the following farms Ibenstein 55, Protea 105 and Klee forte 104.

The land unit (A5c) with isolated ridges and koppies is characterised by undulating topograhpy. It is occurring in the northeastern part of the pilot area. The Witvlei mountain near Witvlei forms the southern boundary of this unit. The Ottawaberge, Kudukoppe and Okomakuaraberge are examples of isolated hills and mountains that form the low hills and low mountain land mapping unit. This land unit stretches until the northern boundary of the pilot area. This area is also sometimes refers to as the “Hardeveld” or “Karstveld”. It is because of the presence of the calcrete ridges that run through this land unit form north to south. The calcrete outcrops are clearly visible in the vicinity of Sachsenwald 940, Delville 146 and Gottesgabe 195 farms.
The soils within this land unit vary widely in terms of composition, texture, depth and their position in the landscape. The soils on the ridges, inselberge and hills consist mainly of unconsolidated coarse grained sediments and are predominately very shallow. The dominant soils are shallow and gravely. While soils on the level lands or plains are moderate deep to deep and are of fine sandy to sandy loam texture. The vegetation composition on the sand plains are characterised by tall and open Acacia erioloba trees while the ridges and undulating areas are covered by open to closed thicket of Acacia mellifera shrubs. Other vegetation are the Glewia spp, Campbor bushes and terminalia sericea which are sparsely distributed.

Appendix III, Plate 3: This photo show the deep soils of the Krumhuk-Aris-Gocheganas intermountain valley with tall and sparsely distributed Acacia erioloba trees south of the farm Aris in the Windhoek district. The trees are growing taller because the enviornmental conditions in which they grow are favourable. The trees are also having strong tap roots which explore water and other minerals at deeper depth and makes them survive during the harsh dry periods.

Land unit C-80: Highlands with considerable hills, ridges and inselberge (A4d) comprising of ortho-ampholite, granite and quartz rocks.

The land unit with considerable hills is characterised by plains with isolated granitic hills and ridges with moderately steep slopes drained by few well defined water courses. The hills covered with dome of granitic rocks comprises of more than 90% stones and boulders. A good example, of this land unit is the Kanon koppies north of Omitara settlement, the granitic rock outcrops east of the Schildkrotenberge northwest of Aris. The topography is gently undulating to undulating with considerable relief. Because of the undulating relief or steep slopes this unit highly subjected to erosion. Throughout this land unit there are gullies causes by the many drainage channels. The small tribuaries or watercourses drained or flows into the White Nossob which later flows in the eastern direction of the pilot area. The water channels transport a large volume of finer particles and deposited along the banks of the channels.
The land mapping unit is located in the vicinity of Omieveberge west of Omitara settlement. Gumtree farm 326 forms the eastern boundary while the Wit Nossob river at Omitara forms the southern boundary. It stretches towards Onganja highlands in the west.
Due to the ruggedness of the terrain the soils are mostly gravelly and stony with many to abundant quartz and mica-schist fragments. Along the channels or at low lying areas or depressions the soils are deep to very deep and are of sandy texture. These soils are having a high potential for agricultural development but the limiting factor is they are patchly distributed. At some places within this land unit the calcrete outcrops are fairly exposed to the surface.

Land unit C-90: Highlands with low sand ridges and isolated inselberge (A3b, A3c and A3d).

The land unit occurs both in the central plateau and the Kalahari sand plateau. The Kalahari sand have been deposited on the ancient sandstones. The sand gives a flat to nearly level topography while the sandstones give the land unit the gently undulating relief. Land unit (A3b) is located east of the Okambara mountain, south of Witvleiberge and west of the Nicodemusberge. The water has

eroded some of loose soil particles along the White Nossob which resulted in the remaining of low ridges and low isolated hills. This area is sometimes refers to as the “sand region”. The mean slope ranges between 1-5° and the differences in altitude of the landscape vary between 100-300 m. The meso-topography is flat to slightly rolling with some small but shallow depressions. Rock outcrops of sandstone and gneiss can be seen in some lower parts in the landscapeof this land unit. This unit is also moderately dissected due to the watercourses that drain into the Nossob river.
The land unit is mainly covering the Kalahari sand plateau. The sand plains with isolated sand ridges and inselberge form a typical remnant area. The ridges form the heighest summits in this land unit and shows slight degree of dissection. Milllions years ago the water have removed all the loose soil particles and left only the hard unweathered rocks of granite, quartz and gneiss on the soil surface. This hard and unweathered rock outcrops are forming the low to high hills and ridges with low to moderately steep slopes.
The land unit (A3c) in the central plateau is located within the vicinity of Ongombo-west 56, Ongombo-ost 110 and Frauenstein 227 farms. It is also covering the Midgard plains near Midgard farm. The land unit is ranked as medium to highly agricultural production in terms of crop and animal production.
Land unit (A3c) forms quite a very small unit in the pilot area. Another similar land unit (A3c) is found in the vicinity of Tsatsachas 87 southwest of Elisenhohe hill in Khomas region and is characterised by low to moderate hills. The low to moderate hills givesthis land unit an irregular relief. It is further characterised by deep to very deep sandy to loamy sand textured soils. The soils are formed from reworked old whitish, fine, loose grains and structureless sand of the Kalahari. The unit is further characterised almost flat to flat relief. The soil profiles are weakly development or shows very little development in terms of strucural development, texture and colour.
The vegetation of this land unit are characterised a mixer of palatable and unplatable bushes and shrubs. The most favourable species are the Glewia flavences, Glewia bicolor and Grewia flava. The Acacia mellifera forms thickets in the overgrazed areas. On the banks of the drainage channels and at the foot of the ridges the vegetation are growing more higher and denser and they are dominanted by Acacia tortilis, Acacia erioloba and Ziziphus mucronata.

5.4 Land unit A: Flat to nearly level plains covered with deep to very deep Kalahari sands (A1a/ A1d); A2a/ A2d; B1c/ B1d and B2d)

Land unit A-100: Flat to nearly level plains (A1c/d) on sedimentary rocks

The flat to nearly level land is characterised by flat (nearly level) to almost flat highlalnds (upland) of the central plateau and on lowland of the Kalahari sand plains. The flat to almost flat plain is features without well defined or structured water courses or drainage’s. Due to the sandy nature of the soils the water penetrates rapidly into the soils and leads to no accumulation of water on the surface which resulted in soil erosion and the formation of gullies. This is one of the reasons why this land doesn not have watercourses or drainage lines.
The general topography of this land unit can be defined as flat to almost flat with very low relief. The land unit is found east of the Black Nossob river and stretches from the northern border to the southern border of the pilot area. A small part of this land unit or plain is also occuring north of Omitara settlement and covers the following farms such as Boomlager 328, Vendette 202, Apex 327 and Iowa 133. The land unit with deep sand cover is also found south of White Nossob river near Omitara settlement and north of the Okambaraberge. The rock outcrops and ridges are some of the characteristics of this land unit. A small unit of this land unit occurs in the eastern corner of the pilot area surrounded by “dykes” field. The interdunal depressions or lowlying area between the calcrete dykes or ridges are covered with deep sandy textured soils. The dominant soils are having a fine to medium sandy texture. The top of the ridges and the foot of the ridges are covered with very shallow soils with high content of gravels or skeletons.
The vegetation comprises of open to dense Terminalia sericea, sparsely distributed and tall Acacia erioloba with open and close thicket Acacia mellifera shrubs and trees. The Camphor bushes are also sparsely distributed throughout this land unit.

Appendix III, Plate 8. The deep to very deep reddish Kalahari sand covers an extensive part of the eastern pilot area.
Appendix III, Plate 9. The sand plains are characterised by flat to almost flat plain with very low relief (>2%).

Land unit A-110: Smooth plain with some relief (A2a, A2c and A2d) areas with stunning geological formation from Damara Sequence (conglomerate, quartzite and marble), sedimentary and Gariep formation.

Land unit A2a: The land unit with plain is having a smooth relief nearly level to gently undulating topography. This unit is characterised by stunning and beautifull geological formation. The very few pans and depressions give this land landform the shape. The drainages are very weakly defined and the pans are small in size with rounded shape.
This land unit (A2a) is found on the central plateau or highland as well as the Kalahari sand plateau. The land unit occuring on the central plateau is characterised by gently undulating topography. It is found at the minimum elevation of 1300 m a.s.l.
The land unit on the central plateau is found on the western part of the pilot area. It is covering the farms in the vicinity of Osona Military Base near Okahandja. The area south of Osona Military Base is characterised by old fossil dunes.
Another land unit (A2a) occurs in the east of the pilot area. A small portion of this unit occurs in the vicinity of Okasewa 102, Okasewa 103, Suliman 215 and Weshof 585 north of the Okambaraberge and Groot Kleeberge. A large part of the A2a occurs west of the Black Nossob river and east of Wit Nossob river and extend northwards until main road from Windhoek to Gobabis. The topography is nearly level with smooth relief.
A very small unit of the (A2a) is found at the east of the sandstone ridge at Aurora no. 62 farm.
In this land unit two major soil types have been identified and classified namely the deep sandy textured soils or the Arenosols and moderately deep Cambisols. The plains around Okasewa 102, Okasewa 103, Suliman 215 and Weshof 585 farms are covered by “Cambisols”.

Land unit A2c: The unit occurs on the Kalahari sand plateau. The Kalahari sand plains deposited on sandstones. The sandstones and sand ridges give this unit a gently undulating topography. The land unit (A2c) in the Kalahari is having a nearly level lowland (Kalahari sand plateau) plains which a maximum elevation of 1500 m a.s.l. The land unit (A2c) is located east of Okambara mountain, south of Witvleiberge and west of the Nicodemusberge. The water has eroded some of loose soil along the White Nossob which leads to the formation of low ridges and hills. This area is also refers to as the “sand region”. The mean slope ranges between 1-5° and the differences in altitude of the landscape vary between 100-300 m. The meso-topography is flat to slightly rolling with some small but shallow depressions. Rock outcrops of sand have been observed in this mapping unit. The unit occur within the Kalahari sand plateau. This is a typical remnant region although the degree of dissection is minimal. During the wetter phases the water have removed all the loose soil and left the resistant rocks of granite, quartz and gneiss. These have resulted in the formation of this unit (A2c) to be surrounded by high hills and ridges of calcrete with moderately slopes.

They differ markedly in terms of their structure, texture, colour and depth. In the sand plain the soils are sandier and in the lower positions or depressions calcareous soils are found. In the lower lying areas or places were water accumulate tend to form a hard impermeable layer or cambic horizon.
These soils are of moderate to high agricultural potential for extensive grazing and of low value arable value due to the hard layer or cambic horizon, shallow depth and poor drainage. The hard layer or cambic horizon is impermeable and may result in poor water infiltration, poor roots penetration and water stagnation.

Land unit A2d: The land unit is characterised by smooth plains with some relief. It is located in the central plateau of Namibia. The smooth plain with smooth relies is surrounded by high hills the Grimmrucken and the Okambara mountain. The Black Nossob river divide this land unit into two parts. The Grimmrucken forms the western border while the Okambara the eastern one. Very few rock outcrops of the Nama group and Gariep complex are found within the land unit A2d. Tall

Acacia erioloba are found on the lower lying or flat plains while the Acacia mellifera forms thicket and occurs on the ridges and loamy textured soils.

Appendix III, Plate 6: This land unit is characterised by almost flat to flat plain with very few depression. The soils are shallow to moderately deep. Calcisols and Cambisols are the soil type associates with this land unit.

Land unit A-120: Irregular plains characterised sand ridges and very few drainage line (B1c and B1d) areas Damara sequence of the Khomas formation.

The topography of the land mapping unit is being define as largely flat to gently undulating. The land unit (B1c) forms the largest part of the two units. Both units occur on the central plateau of Namibia. Land unit (B1c) covers the area north of Grimmruckenberge and stretch northwards to Okanjati highlands north of Omitara settlement. This land mapping unit with irregular plains and sand ridges covers the area around the following farms Otjihaenena 298, Orumbo north 199, Orumbo 198, Okatumba south 197, Muambo 130, Springbokvley 132, Bernhausen 337. It stretches further south and covers all the farms between Kleeberge, Elisenhoheberge and Humansberge. The land mapping unit occurs mainly within the central plateau of Namibia.

The land unit (B1d) makes a relatively small land unit and is found at the western slopes of the Bushmanklippe and the Groot Kleeberge. It is covering the Gannavlakte 291 and Okapandje 217. The topography of this land unit is characterised by nearly level to gently undulating topography with moderate relief. The drainage lines are weakly oriented and drained through sand ridges. The sand ridges gives gently undulating relief to the land unit.
The soil type dominanting this land unit are gravely and stony with sandy loam texture. It is occuring in the lower positions in the landscape such as omiramba and pans or depressions.

Appendix III, Plate 11: A flat to gently undulating sandy loam plain east of Grimmrucken hill covered by an open to closed savanna bushes.

Land unit A-130: Irregular plain with few to many drainages lines and streams (B2d) areas Damara sequence of the Khomas formation.

The land unit with irregular plain (B2d) occurs in the vicinity of Hosea Kutako International airport, Deutsch-Krone 437, Oupembameva 78 and Oupembameva 79 farms. It is northwest of the Bismarckberge and it is sloping towards the Seeis river. The Seeis river find it origin from this land unit. The main road from Windhoek to Gobabis is cutting this land unit into two portions the north and south. In the south and south east it borders the Humans- and Koanusberge respectively. The White Nossob forms the northern at Bodenhausen 191 farm.
Land unit (B2d) is characterised by irregular topography with many well defined water courses and considerable relief. It forms part of the central plateau of Namibia.The striking feature of this land unit is the appearance of the granitic and gneiss rock outcrops. The rock outcrops are clearly visible or exposed to the soil surface along eroded areas and drainagelines and road cuts. The gneiss rock outcrops which are the bedrock are uite visible from the main road between the H.K. International Airport and Neudamm Agricultural College. Rock fragments mainly of quartz are scattered throughout the soil surface. The gravels takes various shapes and sizes.

Skeletic Regosols is the soil type covering the gently undulating landscape while the nearly level landscapes are characterised by moderately deep to deep sandy textured soils.

Appendixes III, Plate 11: Shows the area in the vicinity of Hosea Kutako International airport with it flat to gently undulating topography. The airport is located at fairly flat topography.

5.6 Land unit B: Flood plains and alluvial terraces on calcrete and conglomerate (Va)

Land unit B-140: River channels and alluvial terraces (Va), cutting through sedimentary, metamorphic rocks and Gariep Complexes.

The rivers have been delineated as individual entities or land units because their forms the livelihood of the community of Omaheke region. The river serves as a source of water for human and animal consumption. On the otherhand they are large enough to be mapped as separate land units. The rivers within the different landscapes take different shape. The rivers of the Kalahari sands plateau and sandy terrain have saucer shape with flat topography. Drainages within the central plateau have V-shape with steeply dissected topography.
The river-flood plain and terrace unit are patchy distributed and smaller in size and thus makes the delineation and description as separate identities difficult. At the scale of mapping this unit has been incorporated with other units but will be described as an individual entity.
This land mapping unit represents the fossil drainage lines, formed during wetter phases of the early-mid Pleistone age (Kempf, 2000).The larger ephemeral rivers that flows through this unit mapping unit are the Black Nossob, White Nossob, the Seeis river and the Skaapriver. Other rivers are the Klein Windhoek river which flows northwards, the Usip which flows southwards, the Seeis and Olifant rivers flows in the south-eastern direction respectively.
In the case of the streams or rivers draining towards the east such as the White Nossob, their depth of incision into the underlying calcrete or bedrock deepens towards the east which results in the narrowing of rivers water channels downstream. It is apparent that the wind and the water influence the formation of the valleys and their environments. The dunes or windblown sand commonly fringes the omiramba, being more pronounced on southern and eastern riverbanks. This indicates the action of north-westerly winds. Calcrete and rock outcrops are exposed to the soil surface at some places of the major drainages.

Appendix III, Plate 7: Calcrete plains with petrocalcic horizon at shallow depth and other instances it is exposed to the soil surface due to water and wind erosion. This is a typical example of the calcrete plain which is found south of Dordabis settlement.

Appendix III, Plate 15: A dry stream or ephemeral dry river channel in the hilly to mountainous region of the central high ground.

5.7 Land unit F: Stabilised Kalahari sand dunes (Du) of the Rehoboth sequence (Marienhof Formation) and consist of quartzite, weakly metamorphosed basalt and conglomerate

Land unit F-150: Kalahari sand dunes (Du)

The dunes make a relatively small portion of the total land mapping units. The dunes on the southern margin of the pilot area are active and no vegetations grow on them. Open and sparsely tall Acacia erioloba trees grow favourably in the interdunal depressions were the water collects and pans forms. The sand dunes and sand ridges occur west and east of the Nossob river just were the Langer Forst mountain crosses the White Nossob. The land unit (Du) is underlying by stunning geological formations of various ages. The well established sand dunes occur also west in the pilot area south of the Osona military base near Okahandja. The main from Windhoek to Okahandja cut these dunes. The fossil dunes occurs just south of Bergquell river.This land unit belongs to the central plateau of Namibia.
Unstabilised sand dunes with broad dunes strate or valleys are also found in the Kalahari sand plateau. The land unit occur in the extreme southern part of the pilot area at the foot of the White Nossob river. It is characterised by gently undulating to undulating topography with irregular relief. The area is mainly confined in the extreme southern part of the pilot area along the White Nossob river. The geology is the Damara sequence (Khomas Formation) and consists of quartzite, mica-schist and ortho-ampholite rocks. The dunes were formed a couple years ago and shows immerse sign of weathering. The dunes area well stabilised and well vegetated with annual and perennial grasses.

The dunes in the southern part of the pilot area consist of quartzite, weakly metamorphosed basalt and conglomerate of the Marienhof formation. The soils on the dunes are deep to very deep with sandy texture. While the soils within the pans and interdunal depressions are very shallow to shallow soils with a petric horizon underneath. According the WRB these soils are refers to as “petric Calcisols”. Petric Calcisols refers to the presence of the hard calcrete at the lower depth. The vegetation of the pans and interdunal depressions are sparse distributed Acacia mellifera species with shrubby appearance. The shrubby or dwarf growth of the trees are as result of the impermeable hard calcrete which restrict root growth.

5.8 Miro-relief features (indicate with small letters)

Most of the major landforms or terrains types within the pilot area do not differ widely in terms of geology, topography, slope gradient and slope shape. It was found the necessary that to differentiate the major landforms the second order clasification should be introduce. The second order of classification is refers to as the “micro-relief features”. The micro-relief in this regard is just term used to distinquish between two or more similar or identical “major landform”. The subdivision or subclassification of the micro-relief was done by detailed characterization and morphological description of the relief types, drainage patterns and densities, special landform features and lithology or geology. Based on the work scale or mapping scale and the size of the elements an accurate assessment of the different subdivision was necessary. For mapping purpose the main landforms were further divided into smaller unit or sub units or landforms granitic hills, sand plains, colluvial plains, plains covered with gravels.
It was found that according the SOTER Digital Database the micro-relief features are not taken into consideration at this scale we are working on. In this report the micro relief features were categories into the abiotic and biotic components. In terms of the abiotic components two main classes were identified namely the physiography and the soils. While under the biotic components we are looking at the vegetation component and not the microbes - and animals community. The codes used as references are based on personal preferences. The letter refers to the major landorms while the second described the micro feature or component within it. For example, pn refers to the sand plains without well defined watercourses and pans. Below are summmarising some of the physiographical and soils micro-relief components which influences the major landforms in the pilot area.

Plains

pn: kalahari sandplains without well defined features such drainages, topography and pans etc.
pd: flat to almost sandplains characterised by subrounded to rounded calcrete depressions
pg: kalahari sandplains with gently undulating topography with some relief.
pp: plain with gently undulating topography and low relief intensity.
pu: undulating to rolling landscape characterised by moderate relief (rolling).
pw: flat to nearly level plain with relief and well defined drainages channels or watercourses.
ps: plains characterised by nearly level topograhy and few drainages and some depressions.
pm: flat to nearly level plains with many well defined and structured drainages channels.

Highland or central plateau with isolated ridges, hills and inselberge

hm: highlands characterised by moderate relief (undulating topography).
hc: highlands with considerable relief of the central plateau (rolling landscape)..
hi: highlands or the central plateau characterised by isolated granitic hills.
hl: highlands characterised by isolated high hills covered with loose irregular quartzitic fragments.
hh: highlands or central plateau with high mountains ranges
hr: central plateau of Namibia dominanted by isolated hills, ridges and inselberge
hg: highland and plains with complex geological structural development of granitic, mica schist, sedimentary-, volcanic and igneous rock outcrops.
hf: central highland with soil surface covered with many to abundant quartzitic and conglomerate rocks fragments.
gg: granitic landscapes with smooth surface topography, granite boulders and caste koppies (domes).

Hills and Mountains

ms: hills and mountains characterised by steep slopes and folded structures.
mc: mountains covered with coarse fragment and stones of quartz.
md: highly dissected mountain with dense drainage lines or watercourses.
hr: hilly terrain characterised by some ridges.

Dunes and dunefields

dn: longitudinal sand dunes covered with thick aeolian sand without clearly defined interdunal depressions.
dw: longitudinal sand dunes covered by thin Kalahari sand with clearly defined interdunal depressions and drainage lines.
dc: interdunal depressions overlying by soft to hard calcrete or petro-calcrete at depth.

Drainage or watercourses patterns

wu: saucer or U-shape drainage lines is mainly confined to the Kalahari sand plains
wv: V-shape drainage lines is occurring in the central highland or plateau

CHAPTER 6: SOILS TYPES AND SOIL ASSOCIATIONS OF THE PILOT AREA

6.1 Introduction

The term "soil" generally is used to describe the material on the surface of the earth that has been under the influence of certain physical and biological process. Soil is considered primarily as a natural resource in a pedological or ecological sense.

Soil formation in Namibia is largely determined by climate, topography and parent material (Technical and Economical feasibility study of the Tandjieskoppe Irrigation Project, 1999; Etosha Consult, 1997 and SOTER, 1995). Little work has been done in the past regarding surveying and mapping the soils of the pilot area. The information on the soils within the pilot area is derived from observations and literature consulted during the desk study. The soil survey of the pilot area was aimed at collecting and interpreting field data on the distribution and character of soils and land mapping units. The survey was done at a semi-detailed scale (1: 80,000 scale) in terms of observation density. Relationships between slope, landforms and soil types were identified. The final map (printed map) was produce at reconnaissance level (1: 250, 000).

Within the pilot area the most significant factors that influence soil development are parent material, relief and the climate. The rainfall is low and variable and has little influence on the formation of soils compare to the tropical regions of Africa. Temperature is one the climatic factors that influences the formation of soils in arid region. There are extreme fluctuations between day and night temperatures, causing thermal stresses in rocks. Due to the lack of moisture and the erratic rainfall within the pilot area, the soils generally are in a weakly developed stage or inception stage. Soils are, therefore, largely poorly structured.

The soils of the pilot area are predominantly shallow and highly skeletic. It is estimated that Leptosols and Regosols cover more than 60% of the total area. The soils in general have low to moderate natural soil fertility (low cation exchange capacity, CEC) which results in plant nutrient deficiencies and imbalances. The micro-nutrients that have been recorded deficiency in the pilot area are boron, molybdenum and zinc. Topsoil horizons are characterised by low organic matter- and the phosphorus content. The silt content is recorded to be very low to low (1-20%), while the clay content varies between 1 and 18%.

6.2 Formation of the soils of the pilot area

The five major factors of soil formation are (1) parent material, (2) climate, (3) living organisms, (4) topography, and (5) time.

Parent material is the unconsolidated mass from which a soil forms. Living organisms include plants, animals, insects, bacteria, and fungi. Topography is the relief or terrain of the land. The factors of soil formation are closely interrelated. For example, climate and living organisms, conditioned by relief and length of time, act on parent material to change it into a soil that contains genetically related horizons, or layers. The parent material determines to a great extent the physical and chemical composition of a soil, but the composition is also influenced by climate, relief, living organisms, and length of time. The relationship of some upland and bottom land soils to their respective topographical positions and parent materials is shown in the figure below.

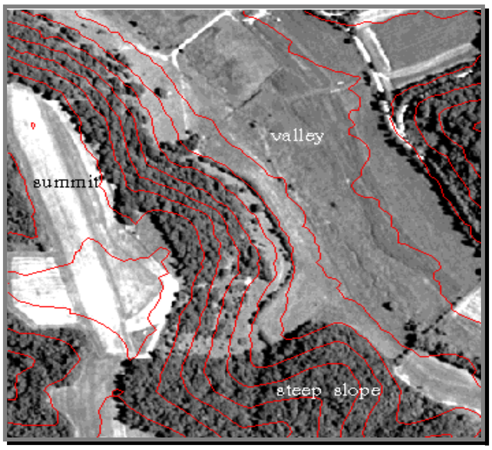


Figure 1.4: An orthophoto shows the summit, valley and steep slope in relation to slope and parent material.

6.2.1 Parent Material (Ministry of Environment and Tourism, Tour Guide Manual, 2004)

The pilot area is characterised by different geological or rock type of different ages as from Cenozoic to quarternary ages. With parent material we meant the unconsolidated mass from which a soil forms. It determines, to a great extent, the mineralogical composition of the soil. The pilot area consist of three important physiological units namely the Namibian central plateau, The "Great Escarpment" and the Kalahari sand plateau or basin in the east of the pilot area. The Khomas Highlands which forms part of the Auas Mountain has the oldest rock formation within the pilot area while the Kalahari sands are the youngest rock formation.
The Khomas Hochlands geology comprises of mica-schist, quartzite, graphitic schist, marble and quartz, while the Kalahari sand plateau is characterised by sand, conglomerate, schist and marble as parent rock.
In many of the profiles a partly weathered parent material or saprolite was observed on the remnant of the old mountain plateau. In many instance it is covering the middle and upper slopes. This weathered rock or mica-schist is very important ecologically, because it has fairly good water storage capacity and can be penetrated by both plants roots and also by small animals and insects. Infiltration is significantly higher than in other lithic Leptosols (Kempf, 2000).

6.2.2 Climate

Climate change, denudation cycles, erosive phases and all the influencing factors during the past had an impact not only on the morphology and soil-terrain relations, but also on the properties of the soils themselves. Therefore, the soils of the pilot area cannot fit the description of typical soils developed under nothing but a semi-arid regime (Brady, 1990; Faniran and Areola, 1978). The absence of characteristic supposed to be common for semi-arid region, such as upwards movement of soluble constituents or distinct alkalinity, in all likelihood is due to the long denudation history of the area.

The weathering rate and the distribution of fines particles shows the soils to be of very old age, which implies that they have a long time to develop and thus reflect a whole range of climatic change. The highland morpho-position, right at the boundary of arid and semi-arid region, might explain the multi-factor pedogenesis in this region (Kempf, 2000).

The balance between temperature and precipitation in this area has an unfavourable influence on soil formation and contributes to an undesirable growing season. Where rainfall is slightly greater, the Kalahari soils are deeper, leached and less fertile. Where rainfall is slightly less, the soils are shallower, fertile but the amount of available moisture is too low for favourable growing conditions.

This is clearly evident in the mountainous areas such as the Hartebeest-rucken Kuppe, Okambaraberge, Grimmrucken- and Bismarckberge with little sparsely distributed vegetation. Because the climate is fairly heterogeneous throughout the pilot area, it has caused major differences among the soils and vegetation compositions.

6.2.3 Living Organisms

Living organism is one the factors that is mainly overlooked by many farmers, researches and soil scientists especially in the dry arid regions. Plants, animals, insects, bacteria, and fungi affect the formation of soils. Most noticeable in pilot area are the contrasting soils formed under two main types of vegetation: annual and perennial grasses and mountainous plants. Soils formed on the mountainous and hills have a lighter, coarser or gravelly surface layer than soils formed under flat plain with many to dense trees and shrubs because the small amount of sparsely, fine roots decays slowly and adds very small amount of organic matter to the surface layer. Bacterial activity is very low. Soils that formed under sloping terrain make up about 60 % of pilot total area. Lithic Leptosols, skeletic Leptosols and Regosols are good examples of soils associated with mountainous, ridges and hilly terrains.
Soils formed under flat to nearly level lands are having a more denser trees with darker coloured subsurface layer, are slightly acidic, and have a very thin, dark-coloured surface layer. As leaves decompose, solvent acids leach out the surface layer and the subsoil. There are more bacteria and earthworm activities are slightly more comparing to the previous soils. The Arenosols, Cambisols and Luvisols soils formed under denser trees and shrubs. They are adjacent to streams, water courses and on flat plains.

6.2.4 Relief

Relief or topography affects soil formation through its influence on runoff, erosion, plant cover, and soil temperature. Slow or very slow runoff in the nearly level areas of the lowlands and highlands contributed to the formation of Luvisols, Cambisols and Arenosols soils, which have moderate to rapid internal drainage, a leached, light-greyish subsurface horizon, and a dense claypan. These soils formed under grass plains.
Rapid runoff on steep slopes causes erosion. Even under native vegetation, the soils erode to some degree during formation. The steeply and dissected mountains, ridges and hills slopes have shallow soils with sparsely distributed vegetation and grasses and are better drain soils. Leptosols and Regosols are good examples of soils that are influences by relief.
Both the gradient and the direction of slope influence the temperature of the soil. The soils that have south-facing slopes thaw out and warm up earlier in summer and cool more quickly in winter. These conditions are reversed on north-facing slopes. The steeper, better drained soils also warm up earlier in summer.

6.2.5 Time

The time frame is clearly reflected in the geological period of the pilot area. Time, usually a long time, is required for the formation of soils that have distinct horizons. The difference in length of time that parent material has been in place, therefore, is commonly reflected in the degree of development of the soil profile.
The older soils in the pilot area are on the central highlands, where they formed in 1,650 Ma years (Mendelson et al., 2002). The soils of mountainous and hilly area are typical examples of older soils. This parent material has been in place thousands of years' and the soils on highlands have well-defined horizons. The weathering process has moved the finer particles downward, where they accumulated in the subsoil, making it more clayey than the surface layer. In addition, some of the minerals and humus have been leached from the surface layer and have made the subsurface layer light coloured, as in Cambisols and Leptosols soils, for example.
The young soils are forming near streams, where overflow deposits new material from time to time. The Luvisols are a good example of the younger soils within the pilot area. Luvic properties refer to the migration or increasing of clay within the B horizon.

6.3 Soil characteristics that influences management and land use

The pilot area is clearly divided into two distinct land types, namely the Kalahari and the Central Plateau.
The soils of the Kalahari are predominantly of sandy texture and low to very low nutrient status. These soils are generally deep to very deep and lack proper structure and horizon development, due to low concentrations of organic matter and clay. They are heavily leached and containing few soluble salts.
The soils in central plateau (mountainous/hilly region) are generally very shallow to shallow, often gravelly or skeletic, with low organic matter content. They are not heavily weathered, mostly contain insoluble elements such as iron and aluminium, and are of low fertility - often deficient in potassium, phosphorus and trace elements.

The common soils identified in the pilot are Arenosols, Cambisols, Leptosols, Luvisols, Calcisols and Regosols.

6.3.1 Soil depth

Depth is a characteristic often is used to classify soils. The depth of soils within the pilot area varies widely, from very shallow soil in the Central Plateau to very deep in the Kalahari. The effective rooting depth is determined by physical and chemical impediment, such as presence of rock fragments or hard layers (stones, gravels, water-table). Soil depth classes had been assigned according to the FAO (1990).
The depths of all the diagnostic as well as non-diagnostic horizons and or materials encountered in a profile are coded with a number symbol in front of the references soil group symbol. Five depth classes and codes that has been identified and described according to the FAO (1990) soil methodology.

X The very deep soils (> 150 cm) soils are predominantly found on the Kalahari sand plateau in the eastern part, and in intermontane valleys in the western and central parts of the pilot area.

D The deep soils (100-150 cm) in the study area are found on the Kalahari sand plateau, as well as on footslopes and in vallley bottoms of the mountainous areas, where they are derived from colluvial material, mainly mica-schist and gneiss.

M The moderately deep soils (50-100 cm) formed in Kalahari sands and colluvial material from the mountains.

S The shallow soils (30-50 cm) are mainly formed in colluvial material on mountains and hills (MAWRD, 1999; Kempf, 2000).

V The very shallow soils (<30 cm) are formed in thin colluvial deposits or *in situ*, overlying hard parent rocks of mica-schist, sandstone, gneiss, quartzite and marble.

R Rock outcrops and areas of stones, boulders and gravel without significant quantities of soil, were put in a separate class.

6.3.2 Classification of the soil according the WRB (FAO, 1998)

The reference soil groups and qualifiers used in the soil code are according to the World Reference Base for Soil Resources (FAO, 1998).

Table 1.8: Reference soil groups and soil subunits found in Namibia (NSS, November 2001)

Reference Soil groups		Soil Subunits			
Soil symbols	**Soil groups**	**Symbol**	**Soil unit**	**Symbol**	**Soil unit**
AR	Arenosol	**ar**	arenic	**li**	lithic
CL	Calcisol	**ca**	calcaric	**lv**	luvic
CM	Cambisol	**cc**	calcic	**mo**	mollic
FL	Fluvisol	**cr**	chromic	**na**	natric
GY	Gypsisol	**fl**	ferralic	**pt**	petric
LP	Leptosol	**fv**	fluvic	**pc**	petrocalcic
LV	Luvisol	**gy**	gypsic	**rz**	rendzic
PL	Planosol	**gp**	gypsiric	**sk**	skeletic
RG	Regosol	**ha**	haplic	**so**	sodic
SC	Solonchack	**cch**	hypercalcic	**um**	umbric
SN	Solonetz	**szw**	hyposalic	**vt**	vertic
VR	Vertisol	**le**	leptic	**ye**	yermic

6.3.3 Physical soil characteristics

This information deals with soil properties that have a direct influence on land use and soil management. The characteristics are: presence of rocks, texture, clay content and drainage class.

Table 1.9: Surface rockiness / stoniness, according to FAO classes(1990)

Symbol	Description	Rock Outcrops (% of area)
N	none	0
V	very few	0 – 2
F	few	2 – 5
C	common	5 – 15
M	many	15 – 40
A	abundant	40 – 80
D	dominant	> 80

Table 1.10: Textural classes according to FAO classes(1990)

Symbol	Textural classes
co	coarse
me	medium
fi	fine

Table 1.11: Clay percentage according to "A Taxonomic System for South Africa (1991).

Symbol	Clay content (%)
1	0 – 5
2	5 – 10
3	10 – 15
4	15 – 20
5	20 – 35
6	35 – 55
7	> 55

Table 1.12: Codes for internal drainage of the soil according to FAO classes(1990)

Symbol	Description	Explanation
E	excessively drained	water is removed from soil very rapidly
S	somewhat excessively drained	water is removed from soil rapidly
W	well drained	water is removed from soil readily, but not rapidly

M	moderately well drained	water is removed from soil somewhat slowly during some periods of the year; soils are wet, within rooting depth, for short periods
I	imperfect drained	water is removed slowly so that soils are wet, at shallow depth, for a considerable period
P	poorly drained	water is removed so slowly that soils are commonly wet for considerable periods; soils commonly have a shallow water table

6.4 Soil Phases

A soil phase is a subdivision of the soil unit based on certain characteristics which are imperative to the use and management of arable land (wrb, 1998). The petrocalcic phase is common in the pilot area. It mainly occurs along watercourses. The upper part of the petrocalcic horizon is less than 100 cm deep. A petrocalcic horizon is a continuous cemented or indurated calcic horizon, which is cemented by calcium carbonate or magnesium carbonate. A petrocalcic horizon inhibits the horizontal and vertical penetration of roots and free movement of water in the soil. This can lead to waterlogged or stagnated conditions with formation of gleyic properties58.

6.5 Diagnostic horizons and properties

Diagnostic horizon can be defined as the three dimensional pedological bodies which are more or less parallel to the earth surface. Each soil horizon can be characterised by similar properties, which occur at various depths. The most common diagnostic horizon in the pilot area is the ochric topsoil horizon. It is found on all parent materials. The ochric horizon is an A horizon of 5-20 cm thickness with a texture of predominantly fine sand to loamy fine sand and a carbon or organic matter content of less than 0.5%.

Soil properties are a combination of soil characteristics which are known to occur in distinctive soils and which are considered to be indicative of present or past soil-forming properties such as soft consistence, low waterholding capacity, non sticky when wet etc.

6.6 The Qualifiers

Qualifiers are described in terms of established diagnostic horizons, properties and other characteristics. The following qualifiers were identified and described in details based, on World Reference Base no. 94 of 2001.
Table 1.13: Descriptive overview of soil qualifiers based on the FAO (1991).

Qualifiers	Description
Arenic (ar)	Having, throughout the upper 50 cm soil layer, a texture of loamy fine sand or coarser.
Eutric (eu)	Having more than 50 percent base saturation (in 1 MNH4Oac at pH 7.0) between 20 and 100 cm from the soil surface.
Ferralic (fl)	Having ferralic properties within 100 cm from the top or A-horizon.
Fluvic (fu)	Having within the 100 cm from the soil surface, fluvic soil material. Due to the arid climate condition in Namibia the fluvisols shows slight sign of stratification.
Haplic (ha)	Having a typical expression of Soil Reference Group in the sense that there is no further or meaningful characterisation.
Hyperskeletic (hy)	Having, to a depth of 75 cm or more or to continuous hard rock, more than 90 percent (by weight) gravel's or other coarse fragments.
Lithic (li)	Having a continuous hard rock within 10 cm from the soil surface.
Skeletic (sk)	Having, to a depth of 100 cm from the surface, between 40 to 90 percent (by weight) gravel or other coarse fragments

6.7 Concepts of soil associates and inclusions in the pilot area

Soils found in the pilot area are predominantly of comprised of weathering products of mica-schists, sandstone, gneiss and quartz. The dominant soils comprising of 60-70%, including the loamy sand developed on 0-2% and is the deep to very deep reddish sandy soils or the “ferralic Arenosols”. The physical and chemical characteristics of the dominant soils within the pilot area will be described in more details below.

6.7.1 Leptosols (LP)

Leptosols can be define soils which either are limited in depth by continuous hard rock within 25 cm of the soil surface, or contain or overlie within the depth material with high calcium carbonate content, or are very gravely throughout. Leptosols represent the initial phase of soil formation or may be the product of severe erosion (World reference Base for Soil Resources, 1998).
Leptosols are soils conditioned by parent material and relief. The soils are limited by continuous hard rock within 25 cm or overlying coarse material of 40% within the 25 cm from the soil surface. They are very shallow to shallow (< 10 cm) soils, poorly to moderate drained, dark greyish brown to brown. The texture is sandy to loamy sand.
The Leptosols developed on steep to very steep slopes (15-30%) with an average depth of 30 cm. The soils consist of 70-90% fine, medium and course gravels with varying percentage of sand, silt and clay contributes making up the 10-30%.

6.7.2 Calcisols (CL)

The name Calcisols is connotative of Latin word calx, or soils in which there is a substantial accumulation of calcium carbonate. The central concept of Calcisols is that of soils in which an accumulation of calcium carbonate, forming calcium horizon, is or ahs been dominant soil forming process. A calcic horizon is a horizon in which calcium carbonate has accumulated either in a diffuse impregnation of the soil matrix, or as discontinuous concentration as pseudomycelia, cutans, soft powdery, nodules (sift or hard), veins or as continuous layers which may cemented (World reference Base for Soil Resources, 1998).
Calcisols are soils conditioned by the accumulation of calcium carbonate or magnesium carbonate. These soils occur in lower position and drainage lines of the pilot area. They occupy the lower position in the landscape and are associated with shallow calcrete deposits. The most distinctive feature of the Calcisols is the translocation of calcium carbonate from the surface to an accumulation layer at depth. This layer can be soft, powdery or hard depending on the age and status of the calcrete. The pedon is shallow to moderately deep, imperfectly drained dark brown to brown soil, with sandy loam to sandy clay textured (See Appendix 6: Plate 4 A and Plate 7 A). Calcisols are mainly concentrated to the lower area in the landscape and areas susceptible to water or flood plains. The slope gradient varies from 2-5% with an average depth of 30 cm. The soils consist of high calcium content (40-60%) and varying percentage of sand, silt and clay.

6.7.3 Arenosols (AR)

Arenosols (from Latin word arena, sand or sandy soils with slight to moderate profile development, or sandy soils without marked profile development (World reference Base for Soil Resources, 1998).
Arenosols are largely determined by the parent material. Arenosols are defined as soils, which are coarser texture than sandy loam to a depth of at least 100 cm from the surface, with less than 15% of rock fragment or coarser fragments in all sub-horizons within 10 cm from the sub-horizon. In the pilot area the sandy texture soils occurs in the eastern part which is covered by thick reddish Kalahari sand. The soils are deep to very deep, well to somewhat excessively drained, yellowish brown to yellowish red fine, with fine to medium textured.
The sandy soils developed on flat to almost flat 0-2% plains with an average depth of 150 cm. The soils consist of 70-90% sand with varying percentage of silt and clay contributes making up the 10-30%.

6.7.4 Luvisols (LV)

The name Luvisols was coined from the Latin word luere, meaning to wash, connotative of clay being “washed out” from the upper part of the soil surface. The most dominant characteristic of

Luvisols is the textural differentiation in the profile showing a surface depletion in clay and an accumulation of clay in subsurface argic saturation (World Reference Base for Soil Resources, 1998).
Luvisols are soils conditioned by topography and relief. They are young deposits of floodplains and ephemeral rivers. Luvisols are very young soils and show some prominent horizon differentiation, especially under the semi-arid conditions of Namibia. (See Appendix 6: Plate 2 A and 3 A). The soils show a well-defined B-horizon in terms of colour, structure and texture.
The moderately deep loamy sand soil developed on flat to almost flat (0-2%) flood plains with an average depth of 100 cm. They consist of 70-80% loamy sand with varying percentage of silt and clay contributes making up the 20-30%.

6.7.4 Regosols (RG)

The name Regosols (from Greek word rhegos, blanket) is connotative of a mantle of loose material overlying the hard core of earth, or soils with weak or no development (World reference Base for Soil Resources, 1998). Soils show very little soil development. Regosols are in the initial state of pedogenesis representing recently deposited, or recently exposed, earthly materials at the soil surface. It is a shallow to moderately deep, well drained medium textured, non-differentiated mineral. Regosols show minimal development of diagnostic horizons, properties and no differentiation other than an ochric horizon (See Appendix 6: Plate 1 A).

The Regosols is characterised by gently undulating to undulating topography (5-15%) with an average depth of 60 cm. The soil consists of 80% fine to coarse gravels with the remaining 20% consisting of sand, clay and silt.

6.7.5 Cambisols (CM)

The name Cambisols comes from Latin word cambiare, to change, thus soils with horizon differentiation through changes in colour, structure and/ or texture (World reference Base for Soil Resources, 1998).
The Cambisols are soils that were formed quite recently in geological times, mainly from medium to fine-textured parent material deposits during the sporadic flooding. Since the parent material is only slightly weathered, Cambisols are characterised by the absences of appreciable quantities of accumulated organic matter, clay and minerals such as aluminium and iron.
The Cambisols is restricted to flat and slightly flooded area in the pilot area with a slope of less than 2%. In some instance the soils are underlying by deep to very steep slopes (15-30%) with an average depth of 30 cm. The soils consist of 70-90% sand with varying percentage of silt and clay contributes making up the 10-30%.

CHAPTER 7: SOIL MAPPING UNITS

7.1 Introduction

Within the pilot area more than twenty soil mapping units were identified and describe accordingly. In total twenty four (24) soil mapping units has been identified and described in the pilot area according to the Food and Agriculture Organisation Soil Classification System (FAO) 1990, and the World Reference Base for Soil Resources (1998). Five main soil groups that have been identified are the Calcisols, Arenosols, Luvisols, Regosols and Leptosols. The main soils groups have been further sub divided into the second and third classes pending on their physical and chemical properties. The main soils and their subgroups have been described in more details in **Appendix II**.

In the table 1.13 the different soils mapping units, soils units which comprises of soils associates and inclusions are given. The soils associations and inclusions have been expressed as percentage proportions of shares in the study area in total.

The soils within the pilot area are spatially distributed in terms of locality and occurrence. The soils of the Kalahari plateau are more or less homogeneous while soils of the central are sparsely distributed. The dominant soils within the pilot area are the Regosols, Leptosols and Arenosols while Cambisols, Fluvisols and Calcisols occurs as soil associations. Table 1.13 indicate the percentage soil associations and soil inclusions. Soil associates are being define as dominant soils within the a single mapping units while soils covering less than 15% of the total area of the soil mapping units are described and classified as inclusions.

Table 1.14: Soil Mapping Units with their soil associates and inclusions in the pilot area.

Soil mapping symbol	Soil association*		Inclusions+	Area km2	Area %
X. Associations of relatively deep reddish sandy textured soils of the nearly level Kalahari (>150 cm) (V)					
X1	ferralic Arenosols	90		A1a	X
X2	ferralic Arenosols	80	arenic Regosols	A1d	X
Associations of deep to very deep sandy loam soils on the nearly level to gently undulating sand plains (100-150 cm) (IV)					
D1	haplic Arenosols ferralic Arenosols	70 20	skeletic Regosols	A2a	X
D2	haplic Arenosols petric Calcisols	50 30	arenic-skeletic Regosols	A2a	X
D3	haplic Arenosols	60	arenic-skeletic Regosols	A2a	X
D4	haplic Arenosols	70	petric Calcisols chromic Luvisols	A2c	X
M. Association of moderately deep soils of plains with castle granite koppies, ridges and boulders (50-100cm) (III)					
M1	chromic Cambisols haplic Arenosols	50 40	Arenic-skeletic Regosols	A3d	X
M2	skeletic Regosols haplic Arenosols	30 30	Calcaric Calcisols	A4d	X
M3	skeletic Regosols haplic Cambisols	50 30	leptic-petric Calcisols haplic Arenosols	A5c	X
M4	ferralic Arenosols haplic Cambisols	50 30	skeletic Regosols haplic Regosols	A2d	X
M5	skeletic Regosols leptic-skeletic Regosols	40 40	lithic Leptosols arenic Fluvisols	A3c	X
M6	haplic Arenosols skeletic Regosols	60 30	lithic Leptosols Rocks outcrops	B1c	X
M7	ferralic Arenosols petric Calcisols	60 20	leptic-skeletic Regosols	B1d	X
M8	skeletic Regosols	50	haplic Arenosols	B2c	X

	haplic Arenosols 20	lithic Leptosols		
M9 Okasewa	chromic Cambisols (Okasewa) 80	arenic-skeletic Regosols	A2a	X
M10	haplic Arenosols 70	Leptic Leptosols	A2a	
S. Association of shallow soils of the steeply dissected highlands and ridges (30-50 cm) (II)				
S1	skeletic Regosols on mica schist rocks 80	eutric Leptosols lithic Leptosols	D1c	X
S1	skeletic Regosols on mica schist rocks 80	eutric Leptosols lithic Leptosols	D1d	X
S2	lithic Leptosols on metamorphic rocks 80	skeletic Regosols	D3c	X
S3	skeletic Regosols on mica schist rocks 80	lithic Leptosols	C1c	X
S4	skeletic Regosols 60 haplic Areonsols 30	Skeletic Leptosols	A5c	X
V. Association of very shallow soils and rocks outcrops of the ridges, high hills and mountains (<30 cm) (I)				
V1	lithic Leptosols with plenty rocks	eutric Leptosols	D2c	X
V2	Mica-schist and para-gneiss stones and boulders	lithic Leptosols	D4c	X
V3	Quartzitic rocks and mica schist	lithic Leptosols	D5c	X
D. Association of shallow to moderately deep sand of the dunes and interdunal depressions (30-100) ((I-V)				
Du	Haplic Arenosols 60 Petric Calcisols 30		Dua	X X
V. Association of shallow to moderately deep sand to sandy-loamy soils of river valleys, river terraces (30-100) (I-V)				
Va	arenic- skeletic Regosols 60 haplic Arenosols 15 lithic Leptosols 15	petric Calcisols	Vad	X
M. Miscellaneous: Bare rocks and non-agricultural lands (>10 cm) (I)				
R1-D	Damara seq. and Khoabenus Hohewarte Formation (paragneiss and metamorphic rocks, marble, quartzite (Auas and Blau-Kranzberge	lithic Leptosols	R1	
R2-K	Khoabenus Hohewarte Formation (paragneiss and metamorphic rocks, marble, quartzite (Grimmruckenberge, Omitaraberge)	lithic Leptosols	R2	
R3-R	Rehoboth seq. Marienhof formation (quartz, conglomerate and weakly metamorphosed basalt (Okambaraberge, Witvleiberge)	lithic Leptosols	R3	
R4-G	Gariep complex and Nama Group (sandstone, limestone and conglomerate) Nicodemusberge, ridge at Tahiti farm.	lithic Leptosols	R4	

* Inclusion covers less than 10% of a mapping unit.
** the percentage (%) soil associates within the pilot area (NB: the given percentage are not real figures but filed estimated values)

7.2 Descriptionof the soils associations and inclsions in the pilot area.

In this chapter we are dealing with miscellaneous, soil complex and soils inclusions because of the magnitude of working scale. The delineation of the soil mapping units (SMU's) boundaries were done at the 1:85 000 scale and the final printings was done at 1: 250 000 (reconnaissance scale). Because of the magnitude of the final scale all the smaller mapping units were included included into the larger mapping units. The smaller mapping units entail the delineation of the isolated footslopes, pans, hills, koppies and ridges.
The soils are greatly influences by the sum of all processes operating in the ecosystem, as well as by the history of the landscape. Considering the complex landscape evolution of the pilot area, with several phases of more or less restrictive etchplanation altering with phases of linear dissection, sedimentation and erosion indicative of climate change, one really should not expected any relationships, as realistic correlations will only occur where the soil-forming processes are in equilibrium with the surface and subsurface process acting on the slopes. Another factor that plays an important role in the Namibian soil is the management. It is observed the around the water points or smaller the soil structure have been destroyed by animal. Traffic and rainfall impact also disturb the soil structure and this an irreversible move especially in the arid environment of our country.

7.3 Soil mapping unit R: Unit characterised by rock outcrops such as the mountains, hills and ridges.

This soil unit is mainly characterised by rocks of different age and lithology or geology. The ages varies from 32-1960 millions years. Different rock types can be found within the pilot are and based on the geological formation they have been divided into four major categories as follows:

Damara sequence (R1) - metamorphic rocks

The Damara sequence or sedimentary rocks are covering the largest part of the pilot area. The rocks of the Damara sequence can be group into various formations. The rocks dominating the mapping unit are mica schist, marble, quartz and ortho-ampholite.

Gneiss, metasedimentary rocks and ortho-amphibolite sequence (R2) - sedimentary rocks

The Rehoboth sequence is the oldest rock types within the pilot are. These rocks form the foundation of the Auas Mountain and the Grimmruckenberge close to Dordabis. The rocks comprises of sedimentary and sedimentary rocks. They are gneiss, metasedimentary rocks and ortho-amphibolite sequence (R2)- sedimentary rocks.

Rehoboth sequence (R3) - sedimentary rocks

The Rehoboth sequence is also covered by various formations which consist of the following rocks: red quartzite, shale, basalt and rhyolite.

Gariep Complex and Nama Group (R4) - sedimentary rocks

The Gariep complex and Nama sedimentary rocks covers just a small part of the pilot area and mainly confined to the eastern section south of the Nicodemusberge. The rocks forming the complex are sandstone, conglomerate, shale, and black lime stone.

Within the pilot twenty four (22) soil mapping unit were identified and described in details. There is a correlation between the soils, terrain and landform. Based on the soil-terrain relationship it is clearly observed that the soils of the central plateau are very shallow and gravely while the soils of the Kalahari origin are deep and of sand nature. For example, if one makes a transect from Windhoek to Gobabis you will see that will be a correlation between the landscape and the different soils type. It is quite evident that the soils on the central plateau are largely gravely, skeletic and very shallow while the soils of the Kalahari sand are predominantly deep with medium to coarse sand. The soil mapping unit and their soil associates are fully described in more details.

7.4 Soil mapping unit 1: Characterised by rocks outcrops of mica schist with very thin soils over mica-schist.

Soil unit 1 covers larger part of the central highlands of the pilot area. It is covering the Khomas Highlands west of Windhoek, the hills surrounding the Krumhuk-Aris-Gocheganas flat plains and the Otjihavera mountain. The geology comprises mainly of the ancient mica-schist. This mapping unit is characterised by mica-schist rock outcrops with many to abundant coarse fragments to stones of hard quartz. The topography of this soil mapping unit is gently undulating to rolling with steep slopes and low to medium drainage lines.
Mica-schist stones and boulders are some of the prominent features within this soil mapping unit. A thin layer of sand or loamy sand is covering the parent material. Where the rocks peeled to the surface the soils particles fills the gap or spaces between the coarse gravels and stones. The soil forms small pockets between the rock outcrops. The soils are very shallow to shallow in depth with many to abundant coarse fragments and gravels.
The typical soil types of this soil unit are the lithic Leptosols (liLP) and the hyperskeletic or saprolitic (hyLP) - and both occur as inclusions. Semi- or partly weathered (saprolite) or hard mica-schist rock overlies these soils types at a very shallow depth. Throughout the profiles unweathered quartz gravels are observable which gives the soils a course or gravelly and stony appearance.

Lithic Leptosols (liLP)

The lithic Leptosols occurs as inclusions in this soil mapping unit. While the rocks outcrops of Damara sequence of different shapes and sizes is covering this soil unit. The soils are very shallow and overlaid by partly weathered or continuous hard rock of mica-schist. Irregular quartzitic coarse gravels and stones which are resistant to weathering are scattered all around the soil surface. Within the profile the skeleton conent can be estimated at >70%. As a matter of fact that cobbles and stones influencing the workability of machinery and other equipments. On the otherhand, they are also protecting the bare soils (without vegetation) from drying out completely and from water erosion.

“Lithic” horizon is approximately 5 cm thick with sandy to loam sand texture. Throughout the profile abundant medium and coarse gravels of quartz have been noticed.
The colour of the ochric horizon is grayish brown (7.5YR 4/2) to dull reddish brown (5YR 4/3). The effective depth of the horizon is 9-13 cm. The pH is slightly acidic with values of 5. The horizon is highly humic with organic carbon values 12-16%. The EC content in the horizon is around 7. Lithic Leptosols are having high phosphorus content in the pilot area. This is a result of the high organic matter from dead plants debris and roots. The horizon is also rich in the clay. The clay content was measured at 23-27%. Because of the rugged terrain and steep slopes the soils are continuously subjected to water- and wind erosion. This is one of the reason why the parent rock are exposed to the soils surface and also why unweathered fragments or coarse fragments can be seen lying on the surface. Partly weathered or hard mica-schist outcrops give the landscape the undulating topography.
It is advisable that this soil should be left under natural vegetation. The Leptosols have too low water holding capacity for agronomic applications, and the gravel soils are too difficult to cultivate. Therefore they are suitable for livestock grazing. Lithic Leptosols soil occurs mainly on the middle- and upper slopes, crest of the hills and steeply dissected landscape.

Representative soil profiles for soil unit 1 are the following KH 28, KH 35 and KH 41.

The hyperskeletic or saprolitic Leptosols (hkLP) have brown (7.5YR 4/3) to dull reddish brown (10YR 4/3) colour. The soil is deeper than lithic Leptosols. It is characterised by two main horizons namely the ochric or A - and the Bw1 horizon underlying by saprolite or partly weathered mica schist. The ochric horizon thickness varies 2-13 cm. The texture is sandy loam to loamy sand with a strong acidic pH of around 5. The phosphorus is high with values 4-7 ppm. The clay content ranges 12-17%. The soil horizon is slightly humic with organic carbon values 6-12%. The soil structure is weak, medium to coarse subangular blocky structure.
The Bw1 thickness varies 13-21 cm. The effective soil depth is 21 cm. Below, the Bw1 horizon is a partly weathered mica schist rocks which is the parent material. The moist colour of the Bw1 horizon ranges from brown (7.5YR 4/3) to dull reddish brown (10YR 4/3). The texture is sandy loam to loamy sand and the pH values is neutral (7). The horizon is having a very low phosphorus content of less than 1ppm. The clay content is higher in the B horizon than in the ochric horizon with values varying 13-29%. It is attributed to the migration of the clay particles to the lower sub horizons. The organic carbon is high with values of 7-8%. It is an indication of slightly humic soils under the arid environmental conditions. The structure is of weak medium, coarse subangular blocky. Many to abundant fine, medium and coarse quartz gravels are scattered all over the soil surface. Within the first two horizons the skeletic or course gravels contributed more than 80% and the stones (2-6 cm) makes around 40-50%.
The representative profiles for soil mapping unit 1 are: Oam-68, Hai-51, Kh-50, Kh-69, P 107, P 108, P 109 and KH 52.

7.5 Soil mapping unit 2: Very shallow and gravelly soils with mica-schist at shallow depth

This soil mapping covers a large part of the Ovitoto communial land. It is also found on the eastern foot slopes of Otjihavera mountain. A relatively small part of this soil unit occurs between the Lichtensteinberge and the Bischmarkfelsenberge and south of Bischmarkfelsenberge. Another part of this soil unit is also found south of the Kranzneus- and Schwarzkopf mountain (north of Groot

Aub settlement) and it strecthes to the southern boundary of the pilot area. The general topography of this soil unit is gently undulating with moderate relief.

The soils covering this soil unit are the hyperskeletic Regosols (hyRG), hyperskeletic Leptosols (hyLP) and leptic-skeletic (le/sk) Leptosols (LP). The hyperskeletic Regosols occur as dominant soil types and are found at the foot- and middleslope of the ridges, foot- and middleslope of low hills and low lying areas within the landscape. While the hyperskeletic Leptosols (hyLP) and leptic-skeletic Leptosols (le/skLP) is mainly found on the crests of the ridges, koppies and low hills and are found as an inclusion.

Hyperskeletic Regosols (hyRG)

As the name hyperskeletic implies this soil type is characterised by hyperskeletic horizon. Meaning that the gravel or fragments content throughouth the soil profile makes >80%.
Regosols is further characterised by three distinct horizons namely the ochric horizon or the A-, the Bw1- and the C-horizon. The moist colour of the ochric- or A-horizon is dull reddish brown (5YR 4/4). The soil texture is sandy with loose structure. The pH is in the range of 7 throughout the soil profiles. The EC is higher in the ochric horizon but decreases with depth. The EC values in the ochric horizon varies between 29-33. The organic carbon is <1 with low clay content of <3%. The low organic carbon is attributed by the low or poor addition of organic matter from plants.
The Bw2 is also having a dull reddish brown (5YR 4/4) colour when moist. The texture is predominantly sandy with slightly developed weak medium sub-angular blocky structure. The EC content ranges between 7-21 um. The organic carbon content is also very low of <1. The horizon is approximately 36 cm thick.
The lower horizon or the partly weathered C consists mainly of many to abundant coarse gravels and stones of mica schist. The horizon contains little soil which occur between the coarse fragments and is sandy loam texture
The moist colour is reddish brown (5YR 4/4) and the maximum depth is 64 cm. The soil reaction was measured at 7. The EC was slightly higher than the Bw1 and the value is 2 um. The skeleton content ranges from 40-80% fine gravel (0.2-0.6 cm) and coarse gravels (0.6-2 cm).

Hyperskeletic Leptosols (hsLP) is the dominant soil type within this soil unit. The most typical characteristic of the soils is the presence of many to abundant coarse fragments. The fragment consists mainly of irregular to subrounded quartz which is resistant to weathering. The mean depth of the Leptosols of this soil mapping unit varies 40-56 cm. Based on the depth of the soil it automatically qualifies as “shallow to moderately deep” soil. Many to abundant (40-80%) medium (0.2-0.6 cm) to coarse (0.6-2 cm) gravels of quartz covers the soil surface. The moist colour is brown (10YR 4/6). The texture of the ochric (A-horizon) is fine sand with single grains or structureless structure. The pH of the ochric horizon (A horizon) is strongly acidic with values of 5. The phosphorus content is also high and was measured at 4 ppm. The soil horizon is humic with organic carbon value of 12-17.9%. The skeletic material within the soil profile makes 40-50% fine gravel (0.2-0.6 cm) and approximately 10-30% coarse gravel (2-6 cm). The ochric (A horizon) is 18 cm thick.
The Bw1 horizon has brown (7.5YR 4/3) colour when moist. The effective depth of the horizon ranges 40-42 cm. The structure is weak, fine medium to coarse subangular blocky. The texture is sandy loam to sandy clay loam. The clay content values ranges 13-29%. The high clay content results in hard consistence of the soils when they are dry. The phosphorus content is being regard as very low to none existing with values ranging 0-1 ppm. Organic carbon is slightly high and the values were measured at 6-9%. Below, the Bw1 horizon lies a soft weathered or partly weathered mica-schist rock or the C horizon. The C horizon is still in the stage of development and consists mainly of coarse gravels of the parent rock.
The soft weathered rocks is sometimes refers to as “saprolite”. The World Reference Base System (WRB) of 1998 does not make provision for the partly weathered material or the “saprolite”. We therefore describe this partly weathered mica-schist as the “subsoil horizon”. The “saprolite” is having brown (10YR 4/3, 7.5YR 4/3) colour. The structure is platy like with gritty or gravelly texture. Due to the presence of high quantity of coarse gravels the texture is very difficult to estimate. The coarse gravels (2-6 cm) make 10-30% of irregular quartz are scattered all over the soil surface.

Representative soil profiles are P 105, P 106 and NH 38. For analytical data see Appendix I, table 2.5.

In soil unit 2 the leptic-skeletic Leptosols (le/skLP) is occurring as inclusion. The mean depth of the Leptosols in this soil mapping unit varies 17-19 cm. The soil is having a sandy loam texture. The colour when moist is brownish gray (10YR 4/1). The texture of the ochric (A-horizon) is fine sand with single grains or structureless structure. The soil pH varies from slightly acidic to neutral 6-7. The EC is slightly high with mean values of 61-89 ppm. The soil is rich in phosphorus and it was measured at 5-17 ppm. The clay content as percentage varies 13-14. Organic carbon in the horizon is medium 5-8%. This is because of the accumulation of the plant material from the grasses and herbs. The soil surface is covered with many to abundant fragments (15-80%) of quartz gravels of different sizes such as medium (0.2-0.6 cm) and coarse (0.6-2 cm). The skeletic material within the soil profile makes 40-50% fine gravel (0.2-0.6 cm) and coarse gravel (2-6 cm). Underneath, the ochric horizon (A horizon) is a soft weathered or partly weathered mica-schist rock. The partly weathered mica schist is refers to as the "saprolite". The saprolite is having a waterholding capacity and good permeability.

Profiles representing soil mapping unit 2 are P 108 and P 28.

7.6 Soil mapping unit 3: Shallow to moderately deep soils

This soil mapping unit is surrounded by high hills of the central plateau and is found south of the Auas mountain. It forms an intermountain valley plain south of Aris farm. Soil mapping unit 3 is also found west of the foot of the Onganjaberge and east of Ovitoto highlands. This soil mapping unit is characterised by nearly level to gently undulating plains with moderate to high isolated granitic hills. The soils around the highly resist granite has been eroded away which resulted in the formation of "granite domes".

Soil mapping unit 3 is characterised by three main soil types. The soils that occur as soil as associations are shallow and gravely while the soil inclusions are moderately deep with sandy texture. Hyperskeletic Leptosols (hsLP), haplic Leptosols (haLP) and calcaric Cambisols (caCM) occurs as soil associates while the ferralic Arenosols (flAR) occurs as the inclusion.

Hyperskeletic Leptosols (hsLP) covers larger parts of this unit and is found on the higher areas such as ridges and slopes. Fine (0.2-0.6 cm) to coarse (2-6 cm) resistant quartzitic and granitic gravels lies scattered all over the soil surface. The soil is characterised by grayish yellow brown (10YR 4/2), grayish brown (7.5YR) to brown (7.5YR 4/3) colour with an average depth of 21/25 cm. Thus result in the classification of this soil type as "very shallow to shallow". The ochric (surface horizon) consist of single grains with fine to medium sandy loam. The clay content is within the range of 12-17%. The soil is having strong pH of 5. The phosphorus values are slightly high and ranges between 4-7 ppm. The ochric horizon is rich in organic carbon with values ranging 6-12%. The structure is well developed subangular blocky. The content of skeletic material within the topsoil horizon varies 5-25% fine gravel (0.2-.6 cm) to coarse gravel (2-6 cm). The horizon is 5-15 cm thick.
The Bw1 horizon have brown (7.5YR 4/3) colour with weak fine subangular blocky structure. The texture is fine loamy sand. The Bw1 is approximately 17 cm thick. It is having a low to medium clay content. The pH of the horizon is neutral and is favourable for many crops. The organic content is lower than the ochric with values between 7-8%.
The C horizon comprises of irregular quartzitic fine to coarse gravels. The soil drainage is being regarded as good. Due to the high content of skeletons the plants roots found it difficult to penetrate through. The skeletic content of the gravels (fine, medium and coarse) are estimated at of 40-70%. At the depth of 22 cm fine, medium and coarse gravel are deposited direct on soft saprolite or on hard granite or mica schist. Within this soil mapping unit 10-30% rock outcrops of granite or mica schist are exposed to the surface. For analytical data see Appendix I, table 2.5.

Haplic Leptosols (haLP) are being defined as very shallow soils with moderate drainability and permeability. The soil is characterised by a very thin loose fine earth particles over the parent

material. The soil colour is dull yellowish brown (10YR 4/3) with an effective soil depth of 18/22 cm. The soil pH is slightly acidic 6. The texture is fine to medium loamy sand with a weakly developed soil structure. The electrical conductivity was measured at around 21 um. The soil horizon is having high phosphorus content with values of around 11 ppm. The organic carbon is 3% and the clay content is very low 5%. The skeleton content is about 10-30% quartzitic stones and conglomerate (6-20 cm).
The parent material is just below the ochric horizon. In some profiles the parent material consists of soft or hard parent material of mica-schist, marble and conglomerate. The soft mica schist results in the improvement of the drainageability and waterholding capacity of the soil, because it serves as a sponge that absorbs the water. Haplic Leptosols in general is characterised by moderate internal drainage conditions and insufficient water holding capacity. In some profiles the ochric horizon A horizon is found directly on top of hard rock or partly weathered (know as saprolite) of mica schist. It is estimated that the rocks outcrops within the unit makes 5-25%. The chemical information on this soil type is given in Appendix I, table 2.3.

This soil type occupies the middle and lower slope of the terrain within the unit. The calcaric Cambisols (caCM) have grayish yellowish brown (10YR 4/2) colour with mean depth of 100 cm. The texture of the ochric horizon is fine loamy sand to sandy loam with very weak, fine subangular blocky structure. The horizon is just 18 cm thick.
Below is grayish yellowish brown (10YR 4/2) Bw1 horizon with fine sandy loam texture. The structure is very weak, fine subangular blocky.
The Bw2 horizon is also dull yellowish brown (10YR 4/3) with sandy loam texture. The structure shows slightly sign of development and is weak, fine subangular blocky. As the clay content increases with depth it is becomes evident that the horizons are getting more compact and dense.

Ferralic Arenosols (flAR) in this soil unit is mainly confined to the flat sand plain in the unit and being defined as an inclusion. The soil unit is characterised by the ochric, Bw1 and Bw2 horizons. The ochric horizon thickness varies 13-15 cm. The moist colour is dull reddish brown (5YR 4/3) with a sandy to loamy sand texture. The structure is structureless or single grains. The pH values of the ochric - and the Bw1 horizons are the same and were measured at 6. The EC in the ochric horizon varies 14-22 um. The horizon is having a low phosphorus content with 1 ppm as the maximum values recorded in the ochric horizon.
The Bw1 is having the same colour as ochric horizon. The horizon depth varies 41-62 cm. The texture is sandy loam with very little clay content. The colour is dull reddish brown (5YR 4/3) when moist. The pH is the same as the ochric horizon 6. The EC is slightly higher than the ochric and the Bw2 with values 15-41 um. There is no phosphorus in this horizon.
The moist colour is dull reddish brown (5YR 5/4) of this horizon. The texture is fine to medium loamy sand to sandy loam with weak to moderate, medium to coarse subangular blocky structure. The content of the skeletic material varies between 0-1% fine gravel (0.2-0.6 cm). Thus is due to the partly weathered quartzitic rock fragments at the lower depth. The effective soil depth is 100 cm. The soil reaction is slightly acidic 6. The EC values range 11-21 ppm. The physical and chemical properties have been summaries in Appendix I, table 2.8.

Profiles number P 115, P 107, P 111, P 7, P 8, NAM 979, P 27 and NH 38 are the representative profiles for the soil mapping unit 3.

7.7 Soil mapping unit 4: Shallow gravely soils with many to abundant quartzitic gravels

The soil unit is characterised by gently undulating plains of the central plateau. It is steeply dissected by many water courses that south-eastern direction of the pilot area. More than 20% of this unit is covered with rocks outcrop of different mineral compositions such as gneiss, mica-schist, quartz, granite. The soil unit occurs south of Bismarckberge and Auas mountain and west of main (tarred) road from Windhoek. The Ziegenberge, Rosaberge, Pavianberge, Humansberge and Elisenhoheberge form the eastern border of this soil unit. The Schwarzkopf-Hoher-schein-Kransnek mountain range forms the southern border. The rolling highland around Waldeck 28 and Bethlehem 27 forms the western border of this soil unit.

Within this soil unit two major soil types appear to be dominanting the unit. The soils are shallow and contain a large quantity of coarse quartz gravels. The soils are hyperskeletic Leptosols (hsLP) and leptic-skeletic Regosols (le/skRG). The Leptosols (LP) occur as associates while the Regosols (RG) occurs as an inclusion in this mapping unit.

The soils contain a large amount of coarse gravels and stones throughout the profile. The skeletic content within the profile ranges from 40-70% fine gravel (0.2-0.6 cm). The ochric horizon is approximately 12 cm thick. The soils are very shallow to shallow and fill the gaps between the coarse fragments. The parent rock can be found at a very shallow depth. This is soil type can be classified as “hyperskeletic Leptosols”. Why skeletic because it contain more than 70% coarse fragment which influences the workability of mechanic and implements.
The hyperskeletic Leptosols (hsLP) have dull reddish brown (5YR 4/4) and mean depth of 23 cm. The texture is medium loamy with weak fine subangular blocky structure. The ochric is approximately 11-13 cm thick. The clay content is slightly higher and was measured at 20-29%. The horizon is rich in organic matter with an organic carbon of 6-12%. The pH is slightly acidic 6. It is having a high phosphorus content of 4-7%.
The Bw1 horizon has thickness of 22-25 cm depending on the depth of the parent rock. The soil reaction is neutral and was at around 7. The colour is dark reddish brown (5YR 3/4) colour with single grain or structureless structure. The clay content is high in this horizon with values ranging 13-29%. The horizon is very humic with values 7-8% organic carbon.
There occur skeletic fragment in both horizons. The gravels content which is the fine-.medium -and coarse gravels are scattered on the soil surface. It is estimated that the skeletic content is around 40-50%. The quartz stones (2-6 cm) are dominating the soil surface. Rock outcrops of granite, sandstone and granite covers 5-10% of the soil surface.

Leptic-skeletic Regosols (le/skRG) as the name implies is characterised by shallow to moderate depth with abundant irregular coarse fragments of quartz. The leptic-skeletic Regosols has grayish brown (7.5YR 4/2) to dull reddish brown (5YR 4/3) colour with an effective depth of 23-32 cm. The texture of the ochric horizon is medium sand to loamy sand with single grain or structureless to very weak fine subangular blocky structure. The skeleton content within the ochric horizon ranges within 14-25% coarse gravel (2-6 cm) and is 11-22 cm thick. The pH is neutral 7 with very low organic carbon of 1%. The EC is high in the ochric horizon with values of around 8 ppm.
Below the ochric horizon is the Bw1. The horizon is 16-26 cm thick. It has grayish brown (7.5YR 4/2) to dull reddish brown (5YR 4/3-4) moist colour. The structure of the Bw1 loose or consist of single grains. In some cases the structure is very weak fine subangular blocky structure. The texture is medium loamy sand and the effective depth varies 25-32 cm deep. The pH is neutral 7 with very low EC of less than 1. There is no organic carbon in this horizon and the values are below 1.
Within the Bw1 the coarse fragements predominantly medium size gravels (0.6-2 cm) was estimated 10-35%. In other soil profiles a saprolite overlying and hard mica-shist was found at the depth of 32-43 cm.

Profiles representing this soil unit are: P 110, P 109, KH 22, P 124, P 123, P 127, P 126, P 122, P 4, P 128, P 10, P 3, P 9, P 2, P 27, NAM 970, NAM 971, NH 31 and NH 32.

7.8 Soil mapping unit 5: Characterised by gneiss and granitic rocks outcrops covered with very shallow soils

The soil unit 5 is characterised by isolated hills and ridges. The paragneisss and metamorphic rocks form elongated domes or ridges that follow a south-western to north-eastern direction. The soil unit is located north of Blaukrans- and Koedoe mountain and east of the Hohe-schein and northwest of Grimmrucken. The topography is rolling to hilly covered with paragneiss and metamorphic rock outcrops. The unit is mainly characterised two soil types namely the lithic Leptosols (liLP) and leptic-skeletic Leptosols (le/skLP).

Lithic Leptosols (liLP)

The lithic Leptosols cover the hills and ridges occur on the western margin of Gimmrucken Mountain. The lithlogy belong to the Rehoboth sequence and the Hohewarte Formation which is the oldest rocks within the pilot area.

"Lithic" horizon is approximately 5 cm thick with sandy to loam sand texture. Throughout the profile abundant medium and coarse gravels of quartz have been noticed.
The colour of the ochric horizon is grayish brown (7.5YR 4/2) to dull reddish brown (5YR 4/3). The effective depth of the horizon is 5-10 cm. The pH is slightly acidic with values of 5. The horizon is highly humic with organic carbon values 12-16%. The EC content in the horizon is around 7. Lithic Leptosols is having a high phosphorus content. This is a result of the high organic matter from dead plants roots. The horizon is also rich in the clay. The clay content was measured at 23-27%. Because of the rough terrain and steep terrain the soils are continuously removed by water and wind and thus result in the exposure of the parent material on the surface. Partly weathered or hard mica-schist outcrops give the landscape the undulating topography.
It is advisable that this soil type should be left under natural vegetation. The Leptosols have too low water holding capacity for agronomic applications, and the gravel soils are too difficult to cultivate. Therefore they are suitable for livestock grazing. Lithic Leptosols soil occurs mainly on the middle- and upper slopes, crest of the hills and steeply dissected landscape.

Representative soil profiles for soil unit 5 are the following KH 28, KH 35 and KH 41.

Leptic-skeletic Leptosols (le/skLP)

The leptic-skeletic Leptosols are very shallow soils which are limited by depth and is further characterised by many to abundant medium, coarse gravels and stones. At the depth of 13-19 cm a partly weathered to hard mica-schist of the Kubis subgroup has been observed.
Leptic-skeletic Leptosols consists of the ochric horizon or the A horizon and the parent material. The soil reaction of the ochric is neutral to slightly alkaline (7-8). The horizon is having a high EC of 61-87 um. The phosphorus content is also very high and was measured at 5-17%. The very shallow soils depth varies 13-19 cm with grayish yellowish brown (10YR4/2), dull yellowish brown (10YR4/3). The structure is structureless with fine sand to sandy loam texture. It is estimated that the fine gravels (0.2-0.6 cm) contribute 10-20% while the coarse gravel (2-6 cm) makes 30-50% of the soil volume. Underneath the A horizon or ochric horizon is the soft weathered mica schist or saprolite (so). Appendix I, table 2.4 shows the physical and chemical properties of the leptic-skeletic Leptosols.
The soil mapping unit 5 is presented by the following soil profiles: P 9, P 8, P 6, P 14, and P 17.

7.9 Soil mapping unit 6: Shallow to moderately deep soils on mica-schist rocks

Soil unit 8 is characterised by moderately steeply dissected undulating topography. The soil unit occurs east of the Otjihavera mountain and north of the Neudamm Kuppe (Koppe). It is bordering the Ongombo west no. 56 and Ongombo north no. 140 flat plains in the west and stretch northwards to the Swakophohe flood plains. Soil unit 6 covers the area covering the Windhoek valley. The soils of Windhoek city falls within this soils unit.The topography is characterised as gently undulating to rolling with very low isolated ridges and hills.

Soil unit 6 is characterised by the following soil associates and soil inclusions: skeletic Regosols (skRG), haplic Luvisols (haLV) and leptic-skeletic Leptosols.
The haplic Luvisols (haLV) and leptic-skeletic Leptosols (le/skLP) have been identified and classified as soils inclusions. Skeletic Regosols occurs as the soil associates. It is has been further divided into the different the second and third level classes (soil units and groups) according to the WRB Soil Classification System. The soil has been divided into the following classes leptic-skeletic Regosols (le/skRG) and arenic Regosols (arRG).

The Regosols (RG) in soil mapping unit 8 takes many different colours such as brownish gray (10YR 4/1), grayish yellowish brown (10YR 4/2) and dull yellowish brown (10YR4/3, 7.5YR4/3) with effective depth ranging from 30-48 cm. The variation in soil colours can be attributed by

various parent rocks, evolution of landscape processes and climatic changes. The environmental factors such as wind have significant influences on the soil colour because it is mixing the different finer soil particles.
The soil reaction of the skeletic Regosols (skRG) is slightly acidic (6) in the ochric horizon while in the Bw1 is neutral at around (7). The soil profile is characterised by three horizons the A-Bw1 C. The C-horizon consist partly weathered mica schist or “saprolite”. The organic content of the ochric horizon is only 8%. The depth of the horizon is 21 cm. The clay content is low and is varies 4-8%. The Bw1 has a neutral soil reaction of 7. The clay content is higher than the A horizon and is measured at 17%. The horizon is having an effective depth of 42 cm. Below the Bw1 is a hard mica schist.

The leptic-arenic Regosols (RG-ar/le) has an effective depth of 66 cm. The ochric horizon is 12 cm thick. The colour of the horizon is brownish gray (10YR 4/1). The soil pH is 6. The clay content is 15% with an organic carbon of around 6-9%. The texture of the topsoil is fine sand with single grains or structureless. The total gravels was estimated at about 15-40% fine gravels (0.2-0.6 cm) and 15-20% coarse gravels (2-6 cm) respectively.
The Bw1 is having a lower organic carbon than the ochric horizon. It was measured at 9%. The colour of the horizon is dull yellowish brown (10YR 4/3). The texture is loamy sand. The effective depth of the horizon is 48. The structure is weak subangular blocky. The gravels content is about 15-40% fine gravel (0.2-0.6 cm) and 15-20% coarse gravels (2-6 cm). The horizon is 20-26 cm thick.
Just below the Bw1 is the C horizon or the partly weathered parent material of mica schist. It is highly weathered horizon and it is why it qualifies for the C horizon. The soil reaction (pH) was measured at 6 with a high organic content of 5%. The high content organic carbon is as result of the high accumulation of organic matter. The effective depth was measured at 66 cm. The texture is loamy sand and feels very gritty due to the high gravel content of mica schist and quartz. For chemical and physical characteristics of the leptic-arenic Regosols see Appendix I, table 2.6.

Arenic-skeletic Regosols (ar/skRG) is one of the few soil types within this pilot area with a high organic content. The organic carbon was measured at >5%. This show moderate organic matter and this is as the result of favourable climate and terrain conditions that contribute to the accumulation of fresh plant material. The ochric horizon colour is brownish gray (10YR 4/1). The clay content is very low and is around 4%. The soil pH is slightly acidic 6. The electrical conductivity is the highest compared to all the other Regosols. The EC is 53 um.
The Bw1 or subsoil horizon has dull yellowish brown (10YR 4/3, 7.5YR 4/3) to dull reddish brown (5YR 4/3) colour and have very weak to weak fine subangular blocky structure. The soil reaction is neutral and was measured at around 7. The texture varies from sandy loam to sandy clay loam and the depth varies 49-66 cm depth. The carbon content is in the range of 2-4%.
Throughout the profile there are skeletons or gravels of different shape and sizes. The skeleton materials of 20-50% consist of fine gravel (0.2-0.6 cm) and coarse gravel (2-6 cm) throughout the profile. Soft or weathered saprolite (so) mica schist and or hard rock of mica schist have been noticed in some profiles at 62-96 cm depth. The analytical data of the arenic-skeletic Regosols are shown in Appendix I, table 2.7.

JAN-1 is the soil profile representing this soil unit 6.

The haplic Luvisols (haLV) has been identified and described as soil associates in this soil unit 6. The soil is found mainly along the watercourses and lower positions within the landscape.
Luvisols has been classified as moderately deep soil with an effective soil depth of 72 cm. This soil type consists of three diagnostic horizons the A, Bw1 and Bw2.
The surface horizon is approximately 12-17 cm thick with brownish gray (10YR 4/1) colour. Many fine roots have been observed in the topsoil horizon due to the favourable environmental conditions. The horizon has weakly to moderately develop blocky structure with fine to medium sandy loam to loamy sand texture. Very few fine coarse fragments have been noticed in some profiles. The soil reaction was measured at 5. The ochric horizon has the highest EC than the Bw1 and Bw2. The EC in the ochric horizon is 74 um. The phosphorus content is very low at was measures at 2 ppm. The clay content is 15% with an organic carbon of 7%. The clay content is in

the range of minimal and leads the hard consistence. Hard consistence is not favourable conditions because it leads to runoff and poor germination.
The subsoil horizon (Bw1) has the same colour as the A horizon. The soil pH is measured at 6. The clay content is the same as the ochric horizon. The EC is lower than the ochric horizon and it is in the range of 10-11 um. The structure is moderate to strong, coarse subangular blocky. The texture is medium to fine sandy clay loam. The medium and coarse plants roots ends in this horizon and then they starts to grow parallel to the soil surface. The consistence is slightly hard to hard when dry and no coarse fragments has been noticed. The Bw1 depth ranges 29-35 cm.
Within the Bw2 the clay content and soil consistence or hardness increases depth. The effective depth of this horizon was measured at 72 cm deep. The soil texture is medium sandy loam to sandy clay loam. The structure is moderate to strong, coarse subangular blocky. The horizon is having a clay content of 19% with an organic carbon content of less than 7%. The phosphorus content is very low to none existing.
The fine to medium plant roots stops in this horizon due the hard consistence underneath. The consistence is hard to extremely hard when dry. There are no coarse fragments in the horizon. The Bw1 horizon depth varies 29-35 cm.

The Bw2 horizon is having an extremely hard consistence due to the high clay content. Very fine plant roots never grows in this horizon. During the wet season very few fine plant roots manage to penetrate this horizon and are being cut when the soil dries due to the swelling and shrinking characteristics of the clays.

Leptic-skeletic Leptosols (leLP) occur as inclusions in this soil unit 8. Leptic-skeletic Leptosols are very shallow to shallow soils having more than 80% of coarse fragments overlying a continuous hard rock of hard C-horizon or partly weathered calcrete within the maximum depth of 17 cm from the soil surface.
The leptic-skeletic Leptosols (le/skLP) of this mapping unit are very shallow (15-17 cm) grayish yellowish brown (10YR4/2) colour when moist. It is characterised by two distinct horizons namely the ochric and the C horizons overlying the parent material. The texture is loamy sand with weak subangular blocky structure. The pH is slightly acidic with very low clay of 3%. The EC is lower than the lithic Leptosols and was measured at 71 um. The organic content is considerable high of 21%. Just below the ochric horizon is the parent rock which consists of the mica schist.

Soil profiles representing this soil unit 6 are P 76, P 77, P 79, P 82, P 83, P 84, P 85, P 86, P 87 P 88 and NH 39.

7.10 Soil mapping unit 7: Shallow to moderatetly deep soils

The soil unit is located below the 1800 and 1500 m a.s.l.It is located at the foot of the Onganja- and Grimmrucken mountains respetively. The soil unit east of the Onganja mountain is characracterised by undulating to rolling topography. Many watercourses drain through this soil unit and causes extensive soil erosion.
While the soil unit east of the Grimmrucken mountain is characterised by gently to undulating topography. The isolated ridges and hills gives rise to the undulating topography. In general the topography is flat with low relief.
The soil associates are the haplic Regosols (haRG), leptic-arenic Regosols (le/arRG), eutric Cambisols (euCM) - and leptic Cambisols (leCM) while haplic Calcisols (haCL) and skeletic Leptosols (skLP) are occurring as inclusions in this soil unit. The Regosols has been classified as moderately deep soils.
The moderately deep soil has an effective depth of 68-80 cm.
The haplic Regosols (haRG) is characterised by three horizons. The ochric horizon is 8 cm thick. It is grayish yellowish brown (10YR 4/2), with weak fine to medium subangular blocky structure. The texture is fine to medium sandy to sandy loam. The pH is slightly acidic with EC of 37 um. The organic carbon content is 9%. Fine to medium quartz gravels have been noticed in the horizon.
The Bw1 horizon depth varies 35-37 cm. The texture is also sandy loam. The EC is lower than the ochric horizon and is estimated at 27 um. The organic matter is low than the ochric horizon. It is around 6% which means there is no inflow of organic matter from the ochric horizon.

The Bw2 horizon is having the lowest content of organic matter. The organic carbon was measured at only 5%. The colour of the horizon is dull yellowish gray (10YR 4/3). The soil reaction is slightly acidic with the least EC of around 18/24 um. The horizon structure is moderate fine to medium subangular blocky structure, fine to medium sandy loam texture. At the depth of 48-80 cm depth 10-20% fine gravel (2-25 mm) irregular to subrounded quartz gravels have been found.

The leptic-arenic Regosols (le/arRG) occur as soil associates. The soils are very shallow and overlying hard mica schist at depth. The soils are characterised by three prominent soil horizons. The soils horizon sequences are A-Bw-C. The effective depth of the ochric horizon ranges 11-18 cm. The colour is dull reddish brown (5YR 4/3) to brown (7.5YR 4/3). The structure is loose to weak fine subangular blocky structure. The texture is sandy loam. The clay content is very low and varies 3-4%. The organic carbon is slightly higher than haplic Regosols and varies from 4-9%. The Ca:Mg ratio in the ochric is low compare to the lower horizon. The Ca values were measured at 89-190 ppm while the Mg values vary 56-160 ppm. Ochric horizon or A horizon is having a higher EC than the lower horizon with values varying 11-38 um. The phosphorus is the highest in the pilot are with values ranging 3-19 ppm in the ochric horizon. The soil reaction is slightly acidic to neutral 6-7. There are many fine to coarse quartz gravels within the soil profile.

The Bw1 effective depth ranges 40-42 cm. Below, this horizon is skeletic horizon or gravely horizon or the C horizon. The moist colour of the horizon is dull reddish brown (5YR 4/3) to brown (7.5YR 4/3). The soil structure is very weak, fine subangular blocky with slightly hard consistence. The Ca:Mg ratio in the ochric is high compare to the ochric horizon. The Ca values are lower and were measured at 99-138 ppm while the Mg values are higher 178-298 ppm. The organic carbon is slightly humic 7-8%. The EC values were lower than the ochric horizon and ranges 7-21um. Within the soil profile rock fragment was estimated at 10-20% fine gravel (0.2-0.6 cm) and 15-50% coarse gravels on hard rock. The rock outcrops of mica schist and gneiss contribute 5-25% of the total soil surface.

Eutric Cambisols (euCM) and leptic-skeletic Cambisols (le/skCM) occur also as soil associates within soil mapping unit 9. The soil type is mainly found mainly in the flat to almost flood plains and old river valleys in the landscape.

The eutric Cambisols (euCM) shows a brownish black (10YR 3/2) colour when moist and have an average depth of 17 cm. The texture varies form sandy to sandy clay loam in the ochric horizon. This soil type is characterised by three distinctive horizons namely the A-Bw1-Bw2 horizontal sequences.

Ochric horizon is 17 cm thick. Within the soil unit at some places it is noticed the A-horizon is covered with fine, loose "aeolian" sand of approximately 5 cm thickness. The moist colour of the A-horizon ranges from very brownish black (10YR 3/2)). The content of the organic matter was measured at 9% that means a slightly humic and the phosphorus content shows very low values of 8 ppm.

The Bw1 horizon has a dull reddish brown (5YR 4/3) to brown (7.5YR 4/3) colour. The horizon thickness varies 52-63 cm. The texture of the horizon is fine to medium sand sandy loam. The structure is weak, coarse subangular blocky. The pH is slightly alkaline with a very low phosphorus content of little as 1 ppm. The cay content is higher in the Bw1 and was measured at 26%. The nitrogen (N) content is low and the phosphorus (P) content is also very low of 0.21 ppm.

The Bw2 horizon reaches to a depth of 65 cm with moderate, strong coarse sub-angular blocky structure. The horizon shows increases in the clay content with increases in depth and gives it sandy clay loam texture. The soil horizon is free from calcium carbonate salts. The soil reaction (pH) is slightly acidic with values of 6.83. The Bw2 horizon shows very low values of organic carbon content of less than 0.5 %, which is attributed by lack of organic matter in the upper horizons. The nitrogen (N) value of 0.03% and phosphorus (P) scores of 0.5% ranges around zero indicating low biological activity and poor soil conditions.

Leptic-skeletic Cambisols (le/skCM) as the name implies it is limited by depth. Skeleton occurs throughout the whole profile. The ochric is having brown (7.5YR 4/3)) colour when moist with a thickness of 22 cm. The texture of the ochric horizon is sandy loam. This soil type is characterised by three distinctive horizons namely the A-Bw1-Bw2 horizontal sequences.
The ochric horizon is 22 cm thick. The texture is sandy with lose or single grains structure. The ochric horizon is having brown (7.5YR 4/3) colour when moist. The clay content is low 8% with phosphorus content of 37 ppm. This soil is having the highest P content of all soils within the pilot are. The organic carbon is 8%. Within the soil unit at some places it is noticed the A-horizon is covered with fine, loose "aeolian" sand of approximately 3 cm thickness. Fine to medium gravels of quartz occur within the horizon.
The Bw1 horizon has brown (7.5YR 4/3) colour when moist. The horizon thickness is 51 cm. The texture of the horizon is sand sandy loam. The organic carbon is 5% with very low phosphorus content of 2 ppm. The soil structure is moderate to strong subangular blocky. The structure is as a result of high cay content of 27%. The horizon is having a neutral soil reaction. Most plants prefer neutral soil pH. Apart from the hard consistence there are few fine to medium quartz gravels.
The Bw2 horizon has an effective depth of 56 cm. The structure is moderate, medium to coarse sub-angular block structure. The clay content is higher than the ochric and Bw1 horizons and was measured in the range of 30%. Due to the high clay content clay content in the horizon the texture is sandy clay loam. It is free of the calcium carbonate salts. The soil reaction (pH) is slightly acidic to neutral (6.83-7). No samples were taken from this horizon. It is assumed that the organic content is less than 0.5%, this can be clearly explained by the hard layer were no plants roots can grow or penetrates.

Haplic Calcisols (haCL) occur on the lower position within the landscape. The soil has been classified as inclusion. The soils are very shallow to moderately deep, poorly drained and coarse textured with common calcrete rock fragments.
For more detail on soil profile description of the haplic Calcisols see Appendix I, table 2.9. The typical sequence of layers in the soil are the A-(or Bw) and C (calcrete).
The ochric horizon is only 17 cm thick. The structure of the ochric horizon is loose with very weak subangular blocky structure. The pH is slightly alkaline (7.5-8), with medium calcium carbonate of 994 ppm and slightly high organic content of 9%. Its wet colour is brown (7.5 YR 4/4). The texture is loam sand. The clay content is 12%. The EC content is 62 ppm.
The Bw1 horizon reaches to a depth of 42-53 cm. The moist colour is also grayish brown (7.5YR 4/2). The clay content is higher than the ochric horizon and was measured at 26%. The structure is weak to medium, coarse subangular blocky. The soil pH is moderately alkaline 9. The texture is sandy clay loam. The horizon is having a higher EC content than the ochric horizon and was measured at 87 um. The organic carbon content is in the range of 7%.
The C-horizon or petric horizon occurs at the depth of >53cm. The horizon is highly calcareous and slightly acidic. Appendix III, Table 10 shows a typical petric Calcisols with a petric horizon.

The Calcisols occurs mainly along the watercourses. Haplic Calcisols are shallow to moderately deep soils overlying byhard calcrete at depth. The profile are slightly calcareous throughtout but highly calcareous in the C horizon.The hard calcrete are impermeable and result in the formation of depression and pans. Acacia reficiens and Acacia mellifera are often associated with the soils of calcrete plains. (See Appendix III: Plate 7 B).

Skeletic Leptosols (skLP) occurs as inclusion within this soil mapping unit. The soil has very shallow depth 19 cm with dull reddish brown (5YR 5/3) colour. The ochric horizon has sandy loam texture. The soil reaction is neutral. The EC was measured at 68 um with very low phosphorus content of less than 1ppm. The Ca:Mg ratio is high and was measured at 3622 ppm and 534 ppm respectively. The horizon shows slight structural development. The structure is medium, coarse to strong subangular blocky. Underneath, the ochric is a partly weather to hard mica schist parent rock. The skeleton content within profile varies 10-50% fine and medium gravels and 5-15% stones. Boulders are also found on the soil surface and makes 5%.

The haplic Regosols (haRG) have been classified in this soil unit as shallow to moderately deep soil with mean depth of 34-82 cm.

The colour ranges from grayish yellowish brown (10YR 4/2) to brown (10YR 4/4 of the ochric or A-horizon. The horizon is structureless to weak, fine subangular blocky structure. The ochric horizon texture is fine sand, loam sand to sandy clay loam. The soil reaction is slightly acidic 6 very high EC of 37. The organic carbon shows slightly humic to humic characters of 9%. The skeletic content is 20-50% fine gravel (2-25 mm) to coarse gravel (25-75 mm). The horizon is 17-42 cm thick.
The Bw1 horizon is characterised by a lower EC of 18-27 ppm. This can be attributed by the low organic carbon of 28%. The soil contains a high organic matter which makes it highly fertile. The moist colour is grayish yellowish brown (10YR 4/2) to dull yellowish brown (10YR 4/3, 7.5YR 4/3) colour when moist with single grain structure to weak fine subangular blocky. The texture of the horizon is sand to sandy loam. The skeletic content ranges from 10-20% fine gravel (0.2-0.6 cm) and 20-40% coarse gravel (6-20 cm). The effective depth of the horizon varies from 36-82 cm.
In some profiles about 40-50% stones (6-20 cm) were recorded over a soft weathered parent material (saprolite) of mica schist or calcrete was observed at the depth of 34-42 cm.

7.11 Soil mapping unit 8: Shallow to moderately deep gravely soils

Soil unit runs parallel with the gravel road D 2102 from Neudamn Experiemental farm. It covers the following farms Ongombo-ost no. 140, Ongombo-west no. 54 and Frauenstein no. 227 farms. The soil unit extends southwards and covers the following farms Ondekerembe 78 and Oupembameva 79. Both farms are found north of the Bismarck mountain.
The soil unit 8 is on a slightly receiving edge within the central plateau region. The water that flows from the higher parts accumulates in this unit and drains away into Nossob river. The topography is flat to gently undulating with broad river channels or valleys.
This soil mapping unit is characterised by leptic-skeletic Regosols (le/skRG), haplic Regosols (haRG), arenic Regosols (arRG), lithic Leptosols (liLP) as soil associates with eutric Cambisols (euCM) and haplic Luvisols (haLV) as inclusions. The inclusion are located in flat to intermediate parts, were the solum mainly developed "in situ" and some soil material is washed in from surrounding hills. In contrast the Regosols and Leptosols are located at the higher relief or position.

The arenic Regosols (arRG), skeletic Regosols (skRG) and leptic Regosols (leRG) are soil associates.

The arenic Regosols (arRG) have grayish yellowsh brown (10YR 4/2) colour when moist. The horizon maximum depth is 21 cm. The soil clay content is 8% which makes it loam sand. The ochric horizon is having moderate to high organic content of 8%.
The Bw1 texture is also loamy sand. The organic content is lower than the ochric and was measured at 5%. The clay content is higher than the ochric with the value of around 17%. The effective depth is 42 cm. The moist colour is grayish yellowish brown (10YR 4/2). Partly weathered coarse gravels and stones of quartz cover more than eighty (80) percent of the fine earth.

The leptic-skeletic Regosols (le/skRG) main character is the presence of the many to abundant coarse fragments throughout the soil profile.
The soils are shallow to moderately deep (34-82 cm). The texture of the topsoil is fine sand loam sand to sandy clay loam topsoil and structureless. The clay content is only 4% with soil reaction of around neutral 7. Fine (0.2-0.6 cm) - and coarse (2-6 cm) contribute 20-40% of the soil. The ochric horizon is 7-22 cm thick.
The Bw1 or subsoil horizon is grayish yellowish brown (10YR 4/2) to dull yellowish brown (10YR 4/3, 7.5YR 4/3) in colour, structureless to weak fine subangular blocky structure. The texture is sand to sandy loam subsoil with skeleton content of about 10-50% fine gravel (0.2-0.6 cm) to coarse gravel (2-6 cm). The pH (H_2O) measured at 6 shows that the soil is slightly acidic. The C horizon is 36-82 cm deep with approximately 10% of quartzitic stone (6-20 cm) in the lower parts of the profile deposited on soft weathered parent material or saprolite (so).

The haplic Regosols (haRG) has mean depth of 31-34 cm. The moist colour of the ochric horizon is dark brown (7.5YR 3/4). The texture of the ochric horizon is fine to medium loamy sand to sandy loam with weakly developed subangular structure. The ochric horizon is 10-12 cm thick. The EC

content is lower in the ochric horizon than in the Bw1. The values are 28 and 31 um respectively. The phosphorus is low to none existing and is indicated by the value of less 2 ppm. The horizon does not have organic matter and the values are 1%.The skeleton content is about 10-20% fine (0.2-0.6 cm) to medium gravels (06-2.0 cm) in the ochric horizon and is only 10 cm thick. The soil reaction is slightly acidic with values of 6.
The Bw1 is dark brown (7.5YR 3/4) to reddish brown (5YR 4/4) when moist. The structure is weak fine subangular blocky. The texture is fine to medium loamy sand to sandy loam. The phosphorus content is none existing with no organic carbon. The clay content was measured at 18%. The skeleton material consisting of fine-, medium- and coarse gravels occurs throughout the profiles and it is estimated at 30-55%. The effective depth of Bw1 horizon is 38 cm deep. The C horizon comprise of partly weathered parent material of mica schist.

The mean depth of the lithic Leptosols (liLP) in the soil mapping unit 28 ranges 9-17 cm. The grayish yellowish brown (10YR 4/2) to dark reddish brown (5YR 3/3) soils are structureless and have fine loamy sand, sandy loam to sandy clay loam topsoil. The pH of the ochric horizon is strongly acidic 5. The soil horizon has a very phosphorus content of 38 ppm and an EC of 7um. The soil is humic with high to very organic carbon of 14%.The skeleton material content estimated at 5-20% coarse gravel (2-6 cm), 25-30% stones (6-20 cm) and boulders (20-60 cm). The horizon is approximately 9-17 cm thick.
Underneath, the ochric horizon is Bw1 horizon with a dark reddish brown (5YR 3/3) colour. The structure is weak fine to medium subanguar blocky with fine sandy loam texture. The soil reaction is slightly acidic 6. The EC content ranges 13-17% which is lower than the top soil horizon. The skeleton material content in the Bw1 are more than the ochric. It is estimated at 50-70% fine gravel (0.6-2 cm), 60-90% medium and coarse gravels. The effective depth of this horizon is 45 cm. The saprolite or weathered mica schist forms the C horizon. In some profiles the mica schist is so hard that it can not be broken with a spade. Rock outcrops of mainly mica schist makes 40%.

eutric Cambisols (euCM)

This soil type occurs as inclusion within the soil unit. It is patchy distributed and occurs as small isolated soil units.

Eutric Cambisols (CM-eu) is a shallow to moderately deep, dark grayish brown (10YR 4/2) colour soil with fine to medium loamy sand texture. There are some coarse fragments within the Bw2 horizon.
The soils is characterised by three distinctive horizons the A-Bw1-Bw2 (gravely) horizontal sequence. Typically the ochric horizon texture is fine loamy sand without coarse fragments and is 16 cm thick. In some profiles there is a very thin cover of +/- 5 cm of fine aeolian sand on top of the ochric horizon. The moist colour of the ochric horizon is dark grayish brown (10YR 4/2). The ochric pH value is neutral. The phosphorus content is in the range of 8 ppm. The soil horizon is being regard as slightly humic because it is having an organic carbon content of 9%. It is free of calcium carbonate salts or none calcareous.
The Bw1 horizon has dark grayish yellowish brown (10YR 4/2) to dull yellowish brown (10YR 4/3) colour when moist. The Bw1 - or subsoil horizon reaches to a depth of more than 75 cm and has very weak to weak, medium sub-angular blocky structure. The texture is fine sandy loam to sandy clay loam. The pH is higher than in the ochric with values of about 8. The soil pH is slightly alkaline. The phosphorus content is very low to none existing and was measured at 1 ppm.
The Bw2 occurs at the depth of 75 cm. It is characterised by common coarse irregular quartzitic gravels. It has an extremely hard consistence when dry. The Bw2 horizon is non-calcareous.
At the depth of 82 cm the horizon under went abrupt textural changes. It is having an extremely hard consistence. The consistence of the Bw2 is so extremely hard that even the finer plant roots can not penetrate.
These soils are not developed in situ, from weathered quartzite but have formed in reworked colluvial sediments (Kempf, 2000).

Haplic Luvisols (haLV) occurs as inclusion within this soil mapping unit. It is confined along the drainage lines and lower positions within the landscape such as pans and “waterholes”. The haplic

Luvisols (LV-ha) is being regard as moderately deep soil because it is having an effective depth 72 cm.
The pH of the ochric horizon is slightly acidic 6. The grayish yellowish brown (10YR 4/2) soil have a very weak medium subangular blocky structure. The EC increases with depth. The EC content in the ochric horizon is 46 um. The ochric horizon texture is fine to medium sand with no coarse fragments. Due to the sandy nature of the horizon the clay content is very low with values of less 1%. The ochric horizon is 17 cm thick.
The Bw1 horizon have a grayish yellowish brown (10YR 4/2) colour with weak medium subangular blocky structure. The texture of the subsoil is fine sandy loam and no skeleton material has been observed. The soil reaction is also slightly acidic 6. The EC is higher than in the ochric horizon and it is around 87 um. There is a slight increase in the clay content with values of 7% recorded. The organic carbon is very low to low and was measured at 2%. The horizon is 29 cm deep.
The Bw2 horizon has an effective depth of 48 cm. There is no colour between the ochric- and the Bw1 horizon. The colour is grayish yellowish brown (10YR 4/3) when moist with moderate to strong coarse subangular blocky structure. The consistence is hard to extremely hard when dry. The Bw1 is having a higher EC than the ochric horizons. It was measured at 58 um. The horizon shows high content of soluble mainly Na which may affect the normal growth of plants. The organic content is very low 1% with a high clay content of 28%. The high clay content results in the hard to extreme soil consistence. It is also affecting the free movement of water and roots grow negatively.

Profiles representing soil unit 8 are P 80, P 81, P 82, P 89, P 90, P 91, P 92, P 93, P 94, P 95, P 96, P 97, P 101, P 105, NH 16 and NH 17.

7.12 Soil mapping unit 9: Shallow to moderately deep sandy loamy textured soils

The relief of this soil unit is flat to gently undulating with some shallow river valleys and pans. The soil unit is found in the central plateau with Kalahari sand deposited over the parent material. The soil unit 9 is found east of Omieveberge and north of the Ozombahe- and Omitaraberge. The soil unit is just covering a small part which occurs east of the gravel road D-70 from Omitara to Steinhausen. The soil unit lies above the 1,600 meter contour line which is minimum natural southern and eastern boundary. While the 1.650 meter contour line forms the western border of this soil unit. The calcrete outcrops can be clearly seen along the pans and the dry omiramba. The hard petro-calcic rocks outcrops in the landscape is refers to as the “Hardeveld”. Another soil unit occurs east of the Humans- and Elisonhohe mountains at an elevation of 1650 m a.s.l. The unit is covering the Kaonus 121, Stolzenfeld 89 and Stolzenfeld 283.

The soils occupying the higher parts (ridges and hummock) in the landscape are very shallow to shallow gravely soils. The moderately deep soils occur as inclusions and are mainly confined to the flat plains. The poorly defined depressions and omiramba are dominated by Calcisols.

The soil unit 9 is characterised by nearly level to gently undulating topography with skeletic Regosols (skRG) and haplic Cambisols (haCM) as dominant and leptic-petric Calcisols (le/ptCL) as inclusions.

Skeletic Regosols (skRG) occur on slightly higher positions with haplic Cambisols (haCM) and leptic-petric Calcisols (le/ptCL) is confined to lower position within the landscape such as drainage lines, pans and depressions.

Skeletic Regosols (skRG) are the soil associates while haplic Cambisols (haCM) and leptic Calcisols (leCL) occurs as soil inclusions.

Skeletic Regosols (skRG) are characterised by loamy sand textured with fine to medium coarse subrounded quartz gravel in the lower horizons. The soil occurs on the sand ridge and higher positions within the landscape.
The dark reddish brown (5YR 3/3) to dull reddish brown (5YR 4/3) loamy sandy soil profiles have an A-Bw1 over C-horizons.

The A-horizon is 7-9 cm thick. The loamy sandy textured ochric or topsoil horizon has a loose to very weak, fine to medium subangular blocky structure. The colour is dark reddish brown (5YR 3/3). The soil reaction (pH) in the upper horizon is slightly alkaline and varies 6.32-6.0. It is carbonate free and the organic content varies between 1-5%, which is quite low. The fertility status in general low with the cation exchange capacity (CEC) of about 2.8 me/ 100g soil. Very few to few fine rock fragments occur within this horizon.

The Bw1 horizon thickness ranges 18-25 cm. The subsoil horizon has sandy loam to loamy sand texture and is free from calcium carbonate. The soil reaction (pH) is slightly alkaline to slightly acidic and varies 6-7. The soluble salts content within the horizon are very low to low. The nitrogen (N) content is very low and the phosphorus content values are also very low to non existence.
The Bw2 is having a high clay content than the Bw1 horizon. The texture is sand loam with dark reddish brown (5YR 3/3) colour. The pH is similar to the Bw1 and is slightly alkaline 6. The horizon is approximately 45-53 cm thick. The structure is moderately, medium to coarse subangular blocky with slightly hard consistence when dry. The drainageability of this horizon is moderately well due the slightly high clay content. The organic carbon is moderate with values ranging 3-5%.
The C horizon or the partly weathered horizon is characterised by many to abundant (40-80%), medium to coarse subrounded quartz gravel's. Fine soil particles fill the gap between the fragments. The coarse gravel's hinder or block the free movement of plant roots and water and this leads to the growth of sparsely and shrubby woody species of the acacia plant species.

Representative soil profiles for the leptic-arenic (skeletic) Regosols are profiles Mar-25 and Mar-26 (See Appendix I, table 2.7 for soil profile description). These soil types occur as dominant in this mapping unit.

Within this mapping unit haplic Cambisols (haCM) and leptic-petric Calcisols (le/ptCL) occurs as inclusions. Both soil types are found in the lower positions of the landscape.

Haplic Cambisols (haCM) occur as inclusion soil type within soil mapping unit 12. This soil type is mainly found in the flat to almost flood plains and old river valleys within the landscape.

The soil shows dark reddish brown (5YR 3/3) to dull reddish brown (5YR 4/3) colour and have an average depth of 122 cm. The texture varies form sandy in the ochric horizon to sandy clay loam in the lower horizons. This soil type is characterised by three distinctive horizons namely the A-Bw1-Bw2 horizontal sequences.
Ochric horizon depth varies betwen12-16 cm thick. Within the soil unit at some places it is noticed the ochric horizon is covered with fine, loose "aeolian" sand of approximately 5 cm thickness.
The moist colour of the A-horizon ranges from dark reddish brown (5YR 3/3) to brown (7.5YR 4/3). The content of the organic matter was measured at 0.94% that means a slightly humic and the phosphorus content shows very low values of 1-2 ppm. The texture is sandy to sandy loam. The pH is strongly acidic to slightly alkaline and varies 5-6. The EC is higher than of the chromic Cambisols. The EC values were measured at 46-76 um. The EC correlate quite well with the moderate organic carbon. The organic carbon values are high with values of 5-7%.
The Bw1 horizon has a dull reddish brown (5YR 4/3) to brown (7.5YR 4/3) colour. The horizon thickness varies 16-51 cm. The texture of the horizon is fine to medium sand sandy loam. The pH is slightly alkaline 6. The horizon is having a high amount of EC which varies 23-87 um. The nitrogen (N) content is low and the phosphorus (P) content is also very low of 0.21 ppm. The organic carbon was measured at 2-6%.
The Bw2 horizon reaches to a depth of more than 100 cm with moderate, medium sub-angular block structure. The soil horizon shows increases in the clay content with increases in depth and gives it sandy clay loam structure. The soil horizon contains no calcium carbonate salts. The soil reaction (pH) is slightly alkaline to neutral with values of 6-7. The Bw2 shows very low sign of organic content of less than 1%, which is attributed by lack of organic matter in the upper horizons. The nitrogen (N) value of 0.03% is very low with very high phosphorus values of 19-28% indicating low to high biological activity and moderate soil conditions.

In soil mapping unit 9, leptic-petric Calcisols (le/ptCL) occurs also as inclusion. The calcareous soil is largely determined by the accumulation of a large amount of calcium carbonate and other secondary carbonates. The soil type occurs mainly in the lower positions such as river valleys, closed pans and small depression in the landscape.

The calcareous soil (le/ptCL) profiles is characterised by the A-Bw1-C-horizons or A –C horizon. In this soil mapping unit A-horizon is only 8 cm thick. The surface horizon (A-horizon) had slightly acidic soil reaction (pH) varying 5.84-6.07. The horizon is free of calcium carbonate salts and the organic content is very low. The drainageability of the upper horizon somewhat poorly drained to well drained. The structure is very weak to weak grade with fine to medium sub angular blocky. The horizon is becoming compacted with the increasing in depth as the clay content increase. Wind- and water erodes the loose, fine textured topsoil at some places which resulted in the exposure of the petric horizon to the soil surface. With very thin fine particles over a hard petric horizon the horizon are now A-C horizons.
The subsoil horizon is having brownish black (10YR 3/2) to brown (7.5YR 3/4) colour. The texture of the surface horizon is sandy to loamy sand. The horizon has slightly acidic pH of 5.84-6.07. Interesting there horizon does not contain any calcium carbonate salts and the organic content is very low. The drainage class is moderately well.
In some instances, calcrete is extremely hard when dry and roots and water found it difficult to percolate or penetrate which causes lateral growth of plant root waterlogged conditions. It is only during the wet conditions that fine and very fine roots of annual plants managed to grow deeper, but perennial found it difficult. Thus is why these soils are prone or subject to soil- and wind erosion. The soil type in many cases it is covered with annual plants because they take advantage of the favourable water storage capacity of the soil during the rainy season.

The profiles representing the leptic-petric Calcisols are: P 240, P 243, P 242, P 244, P 191, P 189, P 188, P 187 (See Appendix I, table 2.10 for soil profile description). The petric Calcisols occur as inclusion as they are patchy distributed within the soil unit 12.
Open to closed Catophractus alexandrii shrubs indicate the presences of the petrocalcic horizon. The soil is also confined to the interdunal depressions, fossil drainages and pans in this soil mapping unit. (See Plate 4 B for vegetation).

7.13 Soil mapping unit 10: Moderately deep to deep sandy textured soils

Soil unit 10 is characterized by flat to gently undulating plains with low to moderate ridges with isolated hills, ridges and rocks outcrops (A1d). This soil unit is located at three different localities within the pilot area.
The one soil unit is located northeast of Bismark - and north of Seeis mountain and covers the area around Hosea Kutako International Airport and stretches northwards to the White Nossob river. The general relief of this soil unit 10 is flat to gently undulating with low relief. The other unit occur south of Omitara settlement and the main road from Windhoek to Gobabis cut this soil unit into two almost equal parts. The White Nossob river forms the northern border while the Groot Kleeberge the southern border. The Okahe mountain and the Losberge the eastern border. It general relief is flat to gently undulating with moderate relief.
The other soil unit which is covered by thick Kalahari sands is located north of the Otjihua river. It is covering the area between Onganjaberge and Omieveberge and stretches towards the northern boundary of the pilot area. The topography of this soil mapping unit is flat to gently undulating.

Soil unit 10 ocur south of Ozona military base near Okahandja in the Otjozondjupa region. The dunes are prominent features of thi soil mapping unit. The dunes are well established and are divided by the main road to Okahandja. The soils are moderately deep to deep reddish Kalahari sand (haplic Arenosols) with tall open Acacia erioloba tree and open to close acacia mellifera shrub and bushes. As a result of overgrazing the acacia mellifera tend to form thickets.
The sand fragments are predominantly of finer texture with low water holding capacity and low nutrients status which result in low agricultural potentials. The soil unit is characterised by flat to almost flat topography. The presence of the ridges gives the landscape the moderate relief.

The deep ferralic Arenosols (flAR) is the dominant soil type with moderately deep soils arenic Regosols (arRG) as inclusion. The deep sandy soils occur mainly on the flat to nearly level sand plains while the Regosols are found on the slightly hummocky areas and ridges.

The ferralic Arenosols (flAR) in this soil mapping unit 13 is brown (7.5YR 4/4-4/3) in colour and approximately 120 cm deep. The sandy textured soils (flAR) is characterised by A-Bw1 and Bw2 horizon sequences.
The ochric horizon is 21-23 cm thick. It consist of loose ochric with single grains and the colour is brown (7.5YR 4/4). The texture is sandy to loamy sand. The pH is slightly alkaline and varies 6. The horizon has an average organic matter content of 0.5-1% and it is calcium carbonate free with very low phosphorus values 1-3 ppm.
The Bw1 horizon is 47 –69 cm thick with brown (7.5YR 4/4) colour when moist. The texture is loamy sand with no calcium carbonate. The soil reaction (pH) is strongly acidic to slightly alkaline and varies 5-6. The phosphorus content is also very low to non-existing. The organic carbon content is also very low to none existing. The horizon is also having a low waterholding capacity (LWHC) and low cation exchange capacity (LCEC) within the range of 2-5 me/ 100 gram. The drainage is extremely well.

The Bw2 horizon has a loamy textured sand fraction and is generally moderately alkaline. Soil colour when moist is brown (7.5YR 4/4). The structure is very weak, fine to medium subangular blocky with slightly soft consistence when dry. No trace of phosphorus has been found in the horizon. The organic carbon ranges 0-2% which indicate very low soil fertility. Due to the extremely well drainage of the horizon no signs of mottle have been found throughout the profile.

Representative soil profiles for the ferralic Arenosols in the soil unit are NH43 and NH42 (See Appendix 2 F for the soil profile description).

The arenic Regosols (arRG) in soil unit 10 occur as inclusion and it covers the ridges or higher positions in the landscape. Arenic Regosols (RG-ar) soil profiles are characterised by A-Bw1 and C horizons.
As the name implies the soil contain a large amount of coarse gravels throughout the profile. The arenic Regosols is characterised by moderately depth of 70 cm. The moist colour of the ochric horizon or A-horizon is brown (7.5YR 4/3). Fine-, medium- and coarse gravels occur throughout the soil horizons.
The ochric horizon or A-horizon has sandy to sandy loam with fine to medium coarse gravels of quartz. The horizon is approximately 15-19 cm thick. The pH is neutral with very low organic carbon. The low carbon shows indicate that the soils are poor in nutrients meaning poor soil fertility. Very little organic matter has accumulated on top of the ochric horizon which contributes significantly to the organic carbon of slightly higher than 1%.
The Bw1 has sandy loamy texture with loose to very weak, fine to medium subangular blocky structure. The colour of the subsoil horizon is brown (7.5YR 4/3) with slightly alkaline soil reaction (pH) of about 8. The phosphorus and organic carbon are totally absent from this horizon. The clay content was measured at 10-14%. The scores of electrical conductivity range 15-17 um, which indicates there are slight salinity problems. The CEC was measured at 12.4 me/ 100g soil indicating low fertility. The texture is sandy to sandy loam.
The C horizon contains a large volume of coarse gravels and stones of subrounded and irregular quartz. The skeletic material is increasing with depth. The arenic Regosols effective depth is in the range of 65- 70 cm.
The low AFC of 79 mm and the TPS about 50 Volume %, give values that shows that the water holding capacity and the internal drainage of the Regosols in this soil unit is sufficient (Buch, 2001).

Representative soil profile for the arenic Regosols is FEB-33 (See Appendix I, Table 7): for soil profile description).

7.14 Soils mapping unit 11: Moderately deep to deep sandy soils of the Kalahari (Arenosols)

The topography of soil mapping unit is nearly level to gently undulating plain with low relief (A2d). This soil unit begin south of Ombuerendende mountain (north of Otjivero mountain) and extend towards the sourthern border of the pilot are. The Seeis- and the Olifant river forms the western boundary of this soil unit. While the Hartebeest-Rucken Kuppe mountain range, Groot Klee- and Okambara mountain forms the western borber of this soil unit. In the south the soil unit is bordering the southern boundary of this soil mapping unit.

Different soil types occur within the soil unit 11 due to various pedogenic processes that sharpen the landforms, geological activities, climatic change and drainage system.

The haplic Cambisols (haCM) and the ferralic Arenosols (flAR) are soil associates and found on the lower positions in the landscape. The soil colour is predominantly red. Lithic Leptosols (liLP), haplic Regosols (haRG) and skeletic Regosols (skRG) occur as inclusion on the higher positions or ridges in the landscape and have reddish brown to brown colour.
The soils of this mapping unit can be regard as of medium to high for dryland agricultural due to the favourable environmental conditions, level to nearly level topography and physical soil properties. The physical and chemical properties of importance are soil fertility, soil texture, nutrient status, the moderate to high water holding capacity, the moderate soil-water ratio content in some soils, the good drainageability and the level topography.
To some extend the reddish sandy soil (ferralic Arenosols) produces low quality fodder for animal grazing due to the very low phosphorus-nitrogen content and nutrient content within the grasses (Hines, 1993).

Haplic Cambisols (haCM) has been classified as dominant in soil unit 11. The soil type is characterised by the A-Bw1 or Bw2 horizons, and it differ from sandy texture soils because it has a well defined structural development and a higher clay content in the Bw1.
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The haplic Cambisols have a dark brown (7.5YR 3/3-4) to dark reddish brown (5YR 3/4) colour when moist with an average depth of 41-113 cm. The soil pH of the ochric horizon is moderate alkaline and varies 8-9. It is getting strongly alkaline with increases in soil depth.
The texture of the ochric horizon or A horizon is fine to medium loamy sand to sandy loam with a weak fine subangular blocky structure. The soil ph is slightly alkaline with values of 8. The ochric is having the highest phosphorus content than the Bw1 and Bw1 with values of 2%. The EC varies 30-36 ppm. The ochric is having the least clay content of 6%. The organic content is high in the ochric with values of 6-8%. No fine, medium or coarse gravels have been observed throughout the profile. The ochric horizon (A horizon) depth varies 9-14 cm. The Ca: Mg ratio is 5:1.
The subsoil horizon or Bw1 is characterised by a dark brown (10YR 3/3, 7.5YR 3/4) to dark reddish brown (5YR 3/4-4) colour when moist with weak to moderate fine, medium subangular blocky structure. The texture is fine to medium loamy sand to sandy clay loam. There is a clay increase with depth. In this horizon was measured at around 10%. The Ca: Mg ratio is 5:1. The subsoil horizon contains some calcareous unconsolidated material between depth of 41-113 cm. The EC content was measured at 83 um which is slightly higher than the ochric and the Bw2 horizons.
The Bw2 moist colour is having dark brown (10YR 3/3, 7.5YR 3/4) to brown (7.5YR 4/3-4). The structure grade is very strong. The size is strong (20-50 mm) to very coarse (>50 mm) which qualify as “coarse subangular blocky structure”. The texture is loamy sand to sandy clay loam. Some sign of calcaric unconsolidated material have been notice at the depth of 41 cm and below. The calcium is the highest in this horizon and was measured at 3028 ppm. The organic content is at around 7% lower than the upper two horizons.

The profiles representing haplic Cambisols are DOR-11B. In other cases, some profiles have hard to extremely hard consistence in B horizon (Bw2) when dry (yp) and they are DOR-29, DOR-38B, DOR-39.
Hard rock or parent rocks consisting of Gariep complex and Nama group rocks such as mica schist, conglomerate, shale and black has been recorded at 47-56 cm. The profiles representing these are DOR-44 and DOR-44B.

The ferralic Arenosols (flAR) or sandy textured soils are characterised by a reddish brown (2.5YR 4/4) colour with an average depth of 109 cm. The soils are slightly humic with organic matter content of contain low to medium bases, but are poor in organic matter and phosphorus. They are of low production value for livestock and dryland or irrigation production, because of the low micro- and macro-nutrient contents.

The ochric or A-horizon ranges 11-15 cm thick with loose, single grain structure. The ochric horizon has different colours which ranges from dull reddish brown (2.5YR 4/4) to bright brown (7.5YR 5/6). The texture of the ochric horizon or A horizon varies between sandy to sandy loam. The organic carbon within the upper horizon ranges 0-1%. The phosphorus content is very low in the ochric horizon and is in the range of 1-3%. Potassium content is slightly higher than other macro-nutrients and varies 124-170 ppm. The ochric horizon or A-horizon is having a slightly alkaline varies 6.0-6.30. The horizon is calcium carbonate free. The organic carbon is very low which indicates a very low organic content. There are no coarse gravels but fine and medium gravels within the whole profile. The clay content was measured at 4-5%.
Ferralic Arenosols soil profiles shows very weak to weak horizontal differentiation development. Soil colour is the criteria used to differentiate between the horizons soil horizons. Due the high content of fine and medium sand within the ochric or A-horizon the horizon is excessively well drained.

Below, the ochric horizon is the Bw1 horizon. The Bw1 horizon reaches to a depth of 15-55 cm. The fine to medium sand texture dominates the horizon and no trace of calcium carbonate has been found. The Bw1 horizon contains very low soluble salts content and this due to the good hydraulic properties. The pH is slightly alkaline and ranges 6-6.5. The phosphorus content is very low to none existing with values of 0-1-6 ppm. There is a slight decrease in the potassium content from the ochric to the Bw1. The potassium value varies 88-131. The Bw1 horizon texture ranges between sand to loamy sand. The horizon is well drained to well drained with dark brown (10YR 3/3) to bright brown (7.5YR 5/6) colour when moist.

There is a slight increase in clay content in the Bw2 horizon. The clay content is 19%. The other factor that differentiates the Bw1 from Bw2 is the colour. The soil colour of Bw2 ranges from greyish yellowish brown (10YR 4/2) to bright brown (7.5YR 5/8). Although, the texture is dominated by the fine sand particles the texture of this horizon is sandy clay loam. The structure is very weak to weak with fine to medium subangular blocky. The soil consistence is slightly hard meaning that soil clod broke easily when pressure with thumb and forefinger. Bw2 has an excessively well drainage capacity, because of the good hydraulic properties. The ferralic Arenosols have been described as fossil soils of the Kalahari sand dunes (Kempf, 2000).
The representative profile for the sandy textured soils (ferralic Arenosols) in this mapping unit is profile MAR-15. At the depth of 109 cm and deeper coarse gravels and stones of quartz making 10-20 % of the earth content were observed. A good stand of dense distribution medium to tall Acacia erioloba and Acacia mellifera vegetation dominate the sand plains with deep sands. On the sand ridges and along drainage lines species such as Grewia flava, Acacia mellifera, Driedoring bossies occur as typical community.

Skeletic Regosols (skRG), haplic Leptosols (haLP) and leptic Leptosols (leLP) occurs as inclusions within soil unit 14 and makes less than 20% of the total area. The soils depth varies from shallow to moderately deep.
The skeletic Regosols (skRG) is characterised by moderately depth (63-67 cm) with dull reddish brown (5YR 4/3, 2.5YR 4/3) colour moist colour. The medium depth of 65 cm of the soil and thus it being classified as moderately deep with organic carbon contents between 5% and 10%.
The texture of the ochric horizon is fine to medium sand to loamy sand and the structure is weak fine subangular blocky. The pH of the ochric horizon is slightly alkaline 6. The organic carbon is moderate to high with values 8-10%, indicating a moderate soil fertility meaning good store for plant nutrients. The skeleton content ranges around 25-40 % fine gravel (2-25 mm). The horizon is 8 cm thick and the representative profile is MAR-18.

The subsoil horizon is having a dull reddish brown (5YR 4/4, 2.5YR 4/3 and 2.5YR 4/4) colour when moist with weak to moderate subangular blocky structure. The organic carbon is lower with values of less than 5%. It is having a clay content of 17% which gives a fine to medium sandy to loamy texture. The EC content was measured at 16%. The total fragments (fine-, medium-, and coarse gravels) were estimated to be around 40% throughout the profiles. The consistence is hard to extremely hard when dry. The subsoil horizon is 63-67 cm deep.

The haplic Regosols (haRG) show a mean depth of 37 cm and is brown (7.5YR 3/4) in colour. The texture of the topsoil is fine to medium loamy sand to sandy loam with weakly developed subangular structure. The pH is strongly acidic to slightly alkaline and ranges 5-8%. The ochric horizon is having EC values that range from 18-54 cm with moderate phosphorus content 3-8 um. The organic carbon in turn is very low and ranges 0-1%. The low carbon shows poor soil fertility. The ochric horizon is having clay content of 5-9%. The skeleton content is about 10-20% fine (0.2-0.6 cm) to medium gravels (06-2.0 cm)) in the ochric horizon and is only 10 cm thick. The soil reaction is slightly acidic (6).
Below is a brown (7.5YR 3/4) to dull reddish brown (5YR 4/4) subsoil with a weak fine subangular blocky structure, Bw1 horizon. The EC is higher in the Bw1 horizon with values ranging 11-105 um. The phosphorus content is very low to none existing. The texture is fine to medium loamy sand to sandy loam. The clay is in the ranges of moderate to and was measured at 12-16%. The skeleton content 30-55% consist of medium (0.6-2.0 cm) and coarse gravel (2-6 cm). The effective depth of Bw1 horizon is 38 cm deep. The C horizon comprise of partly weathered parent material. No samples have been taken from the C horizon due to the high content of coarse gravels.

The leptic Leptosols (leLP) as the name implies are very shallow soils with very poor drainageability and permeability. The soil is characterised by a thin loose fine earth particles over the parent material. The soil colour is brown (7.5YR 4/4) with an effective soil depth of 6 cm. The soil pH is slightly acidic 6. The texture is fine to medium loamy sand with a weakly developed soil structure. The electrical conductivity was measured at around 12-21 um. The soil is having the phosphorus content of 8-11 ppm. The organic carbon was measured at 3% with the clay content of about 3-5%. The skeleton content is about 50-60% quartzitic stones and conglomerate (6-20 cm). Underneath, the ochric horizon is a soft to hard parent material of mica-schist, marble and conglomerate. The soft mica schist results in the improvement of the drainageability and waterholding capacity of the soil, because it serves as a sponge that absorbs the water. Haplic Leptosols in general is characterised by good internal drainage conditions and insufficient water holding capacity. In some profiles the ochric horizon A horizon is found directly on top of hard rock or partly weathered (know as saprolite) of mica schist. It is estimated that the rocks outcrops makes 5-25%.

Profiles describing the different soil mapping unit 11 are P 44, P 58, P 56, P 61, P 62, P 59, P 54, P 45, P 60, P 49, P 47, P 51, P 56 and P 52.

7.15 Soil unit 12: Moderately deep to deep sandy loam to sandy clay loam soils

The topography of this soil mapping unit varies from flat to gently undulating. The different geological formation gives rise to the undulating or different meso- and micro relief topography. The topography of the unit have been described and classified as flat to gently undulating with isolated sand ridges and hills (B1c and B2d).
The soil unit is located south of the Seeis river and north of the Grimmrucken mountain. The Humans- and the Ziegen mountain form the western border of this soil unit. The parts adjacent to the central highlands and the rivers are slightly undulating and highly eroded by water. The plains are characterised by flat to almost flat relief. The soil unit is characterised by few watercourses. Two master drainage lines that drain this are the Seeis- and the White Nossob river.

In this soil unit arenic Regosols (arRG), ferralic Arenosols (flAR) and haplic Cambisols (haCM) are found to be soil associates. Lithic Leptosols (liLP) and haplic Regosols (haRG) have been classified as soil inclusions.

The arenic Regosols (arRG) in soil unit 15 occur as soil associates. The arenic Regosols (arRG) soil profiles are characterised by A-Bw1 and C horizons.
As the name implies the soil contain a large amount of coarse gravels throughout the profile. The arenic Regosols is characterised by moderately depth of 56 cm. The moist colour of the ochric horizon (A-horizon) is brown (7.5YR 4/3). Fine-, medium- and coarse gravels occur throughout the soil horizons.
The ochric horizon (A-horizon) has sandy to sandy loam with fine to medium coarse gravels of quartz. The horizon is approximately 15-19 cm thick. The pH is neutral with very low organic carbon. The low carbon shows indicate that the soils are poor in nutrients meaning poor soil fertility. Very little organic matter has accumulated on top of the ochric horizon which contributes significantly to the organic carbon of slightly higher than 1%.
The Bw1 has sandy loamy texture with loose to very weak, fine to medium subangular blocky structure. The colour of the subsoil horizon is brown (7.5YR 4/3) with slightly alkaline soil reaction (pH) of about 8. The phosphorus and organic carbon are totally absent from this horizon. The clay content was measured at 10-14%. The scores of electrical conductivity range 15-17 um, which indicates there are slight salinity problems. The CEC was measured at 12.4 me/ 100g soil indicating low fertility. The texture is sandy to sandy loam.

The ferralic Arenosols (flAR) in this soil unit has different colours such as dull reddish brown (2.5YR 4/4), dark brown (7.5YR 3/3), brown (7.5YR 4/4), strong brown (7.5YR 4/6), reddish brown (5YR 4/3-4, 5YR 5/4). It is approximately 126 cm deep. Sandy textured soils (flAR) are having three A-Bw1 and Bw2 horizon sequence. The ohric horizon contain less than 5% gravels of subrounded quartz is 10-13 cm thick. The ochric horizon has loose, single sand grains and the grains are coated with dull reddish brown (2.5YR 4/4) colour. The texture is sandy to loamy sand. The soil reaction (pH) is neutral to slightly alkaline of 7-8. The horizon has an average organic matter content of less than 1% and it is calcium carbonate free. The phosphorus content is very low with values ranging from 1-3 ppm. The clay content is the lowest in the ochric horizon and is increasing further down and varies between 4-5% in the ochric horizon.
The Bw1 horizon is 15-38 cm thick with dull reddish brown (2.5YR 4/4), dull reddish brown (5YR 4/4) to bright brown (5YR 4/6) colour when moist. The texture is medium sand without calcium carbonate. The soil reaction (pH) is strongly acidic to slightly alkaline with values of 5-6. The phosphorus content is also very low to non-existing. There are no signs of organic carbon. The clay content is slightly higher than in the ochric with values of 5-6%.The horizon is also having low waterholding capacity (LWHC) and low cation exchange capacity (LCEC) within the range of 2-5 me/100 gram.
The Bw2 horizon which is below the Bw1 horizon has medium sand texture. It has moderately alkaline soil reaction (pH) of about 8. Soil colour is brown (7.5 YR 4/4) when moist. The soil structure is very weak, fine to medium subangular blocky with loose to soft consistence when dry. The organic carbon varies from zero to 1% which indicates very low soil fertility. The phosphorus content is very low to none existing in the soil profile. There is a slight clay increase with depth. This is a result as down wash of clay particle within the soil solum. The effective soil depth is 126 cm and no coarse gravels or stones have been seen in the profile.

The haplic Cambisols (haCM) has dark brown (10YR 3/2) to dull reddish brown (5YR 4/4) colour with a moderate depth of 62-120 cm. The soil has been classified as moderately deep. The structure of the topsoil is single grain or structureless, fine to medium sand to sandy clay loam texture without coarse fragments. It is 17-30 cm thick. The pH of the ochric horizon varies from slightly acidic to neutral 6-7. In the topsoil the phosphorus is low to moderate and varies from 2-21 ppm which is significantly high. The organic carbon is very low to none existing and was measured at 0-1%. The clay content ranges from 6-8% in the ochric horizon.
The depth of Bw1 starts at 56-78 cm. The subsoil horizon has brownish black (10YR 3/2) to brown (7.5YR 4/3-4) colour with weak medium subangular blocky structure. The texture is fine to medium sand loam to sandy clay loam without coarse fragments. The clay percent in the Bw1 is quite high with values ranging 11-24. The organic carbon is very low to low. The pH of the Bw1 is the same as the ochric. In some instance the consistence is extremely hard when dry and the profiles representing this soils type is JAN-23.

The Bw2 horizon has brown (7.5YR 4/3-4) colour with an effective depth of 82-96 cm. The Bw2 is having a moderate, medium to coarse subangular blocky structure. The texture is fine to medium sand loam to sandy clay loam without coarse fragments. The clay percent is quite high with values ranging 21-28. The pH is neutral with no organic carbon. The EC in the horizon was lower in the horizon with values of 35 um. Due to the high clay content the horizon is having an extremely hard consistence when dry.
The profiles representing the haplic Cambisols are the following and they are: DOR-19, DOR-29, DOR-39, DOR-44, JAN-23.

The very shallow to shallow soil in this soil mapping makes a small percentage of the total area and this has been classified as inclusions. The soils are the lithic Leptosols and the haplic Regosols.

The haplic Regosols (haRG) is characterised by three horizons. The ochric horizon is 8 cm thick. It is having a dark gray (10YR 4/2) colour, with weak fine to medium subangular blocky structure. The texture is fine to medium sandy to sandy loam. The pH is slightly acidic with EC of around 37 um. The organic carbon content is 9%. Fine to medium quartz gravels have been noticed in the horizon.
The Bw1 horizon depth varies 35-37 cm. The texture is also sandy loam. The EC is lower than the ochric horizon and is estimated at 27 um. The organic matter is low than the ochric horizon. It is around 6% which means there is no inflow of organic matter from the ochric horizon.
The Bw2 horizon is having the lowest content of organic matter. The organic carbon was measured at only 5%. The colour of the horizon is dark gray (10YR 4/3). The soil reaction is slightly acidic with the least EC of around 18/24 um. The horizon structure is moderate fine to medium subangular blocky structure, fine to medium sandy loam texture.
At the depth of 48-80 cm depth 10-20% fine gravel (2-25 mm) irregular to subrounded quartz gravels have been found.

The lithic-skeletic Leptosols (li/skLP) are very shallow soils, 3-16 cm deep with hard rock or of sandstone below. The colour of the ochric horizon varies markedly due to the different parent materials, the presence of organic matter and the deposition fresh fine sand particles from neighbouring areas.
The common colours observed are grayish brown (10YR 5/2), brown (7.5YR 4/2) and reddish brown (5YR 4/3, 2.5YR 4/4) colour when moist. In many cases the ochric horizon has single grain to very weakly developed structure with fine to medium sand to loamy sand texture. Coarse gravel (2.0-6 cm) and stones (6-20 cm) are many to abundant (40-70%). Lithic Leptosols are overlying hard sandstone with 30-60 % rock outcrops of conglomerate, marble and mica-schist.

Representative soil profiles for the different soils are follows: ferralic Arenosols P 235, NAM 944, NAM 943, NH 36, NH 37; Cambisols P 18, P 65, P 221; Leptosols P 66, NH 44, Calcisols NAM 941, P 100 and Regosols NAM 942, NAM 940.

7.16 Soil mapping unit 13: Shallow gravely to moderately deep on calcrete.

The general topography of soil unit is gently undulating to undulating (A5c) with shallow incised river valleys. The soil unit covers the lower hills, ridges, calcrete gravel plains or the “Hardeveld” within the study area. The dominant soils on the higher parts (ridges and hummock) in the landscape are shallow soils. While moderately deep soils occurs as inclusions and are found in the flat plains. The rounded ridges were formed way back during the Molokian area. The geology is of the Damara Sequence which consists of conglomerate, mica schist and sandstone.

Soil unit 13 is found in the central plateau of Namibia. It is just below the 1,600 meter contour and above the 1,450 meter contour line. The unit starts east of the Ozombahe mountain or hills which is northwest of Omitara settlement and extend towards the Witvleiberge in the south. The 1,450 m contour line south of Witvlei serves as the natural boundary between the calcrete ridges and the Kalhari sand plains. The soil unit 16 is overlying by soft powdery to hard calcrete at depth which makes it a “hardveld”. In some parts it is overlying by conglomerate at shallow depth. Some of the ridges within this soil unit consist mainly of calcrete. The Black Nossob river forms the eastern border. This soil unit extends towards the northern boundary of the pilot area.

Skeletic Regosols (skRG), arenic Regosols (arRG), haplic Leptosols (haLP), lithic Leptosols (liLP) occurs as soil associates while haplic Cambisols (haCM) and ferralic Arenosols (flAR) as inclusions.

Skeletic Regosols (skRG) has been described as moderately deep (26-82 cm) soils with fine to medium sandy to sandy texture. The ochric or A horizon colours ranges from brown (7.5YR 4/3, 7.5YR 5/4), graysh brown (5YR 4/2) to brown (5YR 4/3). Due to the low physical and chemical weathering the soils have single grain or structureless to weak fine subangular blocky structure. The topsoil thickness ranges 9-44 cm thick. The soil reaction of the ochric horizon is slightly alkaline (6). The organic content high as was measured at 9%. This makes the horizon humic. The ochric texture is fine to medium sand to sandy loam. The sandy loam has a very low to low clay content which is less than 5%.
The Bw1 horizon depth varies 26-82 cm with many to abundant (50-80%) irregular quartz coarse gravels (2-6 cm) and stones (6-20 cm). The brown (7.5YR 4/4) to dull yellowish brown (5YR 4/3-4) subsoil horizon is structureless with weak to moderate subangular blocky structure. The texture is medium to fine sandy loam to loamy sand. The clay content was measured at 6%. The EC content varies 12-17um. The sub horizon is having high organic carbon that indicates a high soil fertility status.
Some profiles the horizon has hard to extremely hard consistence when dry that hinder plants roots and from entering the horizon. In others the Bw1 occurs directly on top of parent material of mica-schist and graphitic schist.

The arenic Regosols (arRG) in soil unit 13 occur as associates. Arenic Regosols (arRG) profiles are being characterised in this soil unit by three horizons: the A-Bw1 and the C.
The word “Arenic” refers to large amount of coarse gravels and stones within the whole profile. The gravels and stones consist mainly of subrounded and irregular quartz. The arenic Regosols is characterised by moderately depth of 70 cm. The moist colour of the ochric horizon (A-horizon) is brown (7.5YR 4/3). Fine-, medium- and coarse gravels occur throughout the soil horizons.
The ochric horizon (A-horizon) has sandy to sandy loam with fine to medium coarse gravels of quartz. The horizon is approximately 15-19 cm thick. The pH is neutral with very low organic carbon. The low carbon shows that the soils are poor in nutrients meaning poor soil fertility. Very little organic matter has accumulated on top of the soil horizon which contributes significantly to the organic carbon of less than 1%.

The Bw1 has sandy loamy texture with loose to very weak, fine to medium subangular blocky structure. The colour of the subsoil horizon is brown (7.5YR 4/3) with slightly alkaline soil reaction (pH) of about 8. The phosphorus and organic carbon are totally absent from this horizon. The clay content was measured at 10-14%. The scores of electrical conductivity ranges from 15-17 um, which indicates there is slight salinity problem. The CEC was measured at 12.4 me/ 100g soil indicating that the soil fertility is low. The texture is sandy to sandy loam.
The C horizon contains a large volume of coarse gravels and stones of subrounded and irregular quartz. The skeletic material is increasing with the increases in depth. The arenic Regosols effective depth is in the range of 65-70 cm.
The low AFC of 79 mm and the TPS about 50 Volume %, give values that shows that the water holding capacity and the internal drainage of the Regosols in this soil unit is sufficient (Buch M, 2001).

Another soil associates in the soil mapping unit 13 is the lithic Leptosols (liLP). Lithic Leptosols is the shallowest soil types within the whole pilot area. The soil is associated with higher part in the landscape.
The dark brown (7.5YR 3/2) to brown (7.5YR 4/4) soil is characterised by very shallow (9 cm) depth. Due to unfavourable environmental conditions (climate and relief) coupled with shallow depth the soils tend to have a single grain or structureless structure. The topsoil texture is fine to medium sand to loamy sand. Lithic Leptosols is having strong soil reaction with EC of more than

89 um. The ochric as usual is high in organic carbon which contributes to high organic matter. The organic is higher than 10%. The clay content was measured at 27% which contribute significantly to high absorption and WHC of water.
In some profiles many to abundant coarse gravels (50-80%) have been found. The top depth varies 3-9 cm and is overlying hard rock mica-schist of the Khomas Formation.

The haplic Cambisols (haCM) and ferralic Arenosols (flAR) are soil inclusions in this soil mapping unit. These soils types are found mainly in the flatter and lower position landscapes. They tend to be deep, due to the regular accumulation of soil particles and organic matter from other regions by water and wind.

Haplic Cambisols (haCM) is characterised by moderately depth of 56 cm with brownish black (7.5YR 3/2) to brown (7.5YR 4/3) topsoil. The topsoil thickness is 19 cm with single grain texture. The pH is slightly alkaline to neutral and varies 6-7 in the ochric horizon. The phosphorus content is significantly low with values of 0-2 ppm. The EC of the horizon was quite high and the values 30-64 um have been recorded. The soil structure grade is weak with fine subangular blocky structure. The clay content was measured at 11-28% which gives the horizon a sandy loam texture. Very few (0-2%) to few (2-5%) fine (0.2-0.6 cm), medium (0.6-2 cm) and coarse gravels (2-6 cm) has been found in the horizon.
The Bw1 (subsoil horizon) colour is brownish brown (7.5YR 3/2) with moderate to coarse subangular blocky structure. The texture is fine sandy loam with an extremely hard consistence when dry (yp) which hinder full expansion of plant roots and water infiltration. The plants on these soils tend to have bushy and shrub form. The clay content is high with values of 25-24%. The ph varies 6-7. The organic carbon is very low to none existing. The consistence of the Bw2 soil horizon is extremely hard.
The Bw2 soil horizon has an extremely hard consistence. As a result the structure is strong, coarse subangular blocky. The colour is brownish brown (7.5YR 3/2). The very fine plants roots penetrate this horizon during the wet season and when the soils dry out they are being cut off. Few medium and coarse gravels have been noticed and they are of not great significant. The effective horizon depth of the profile was measured at 56 cm. The EC was measured in the range of 36-37 um and the phosphorus is moderate (6).

Ferralic Arenosols (flAR). The soil is covered with loose thin layer of “aeolian” sand of medium sizes. The finer soil particles have been blown away by the wind. The fine sand has been trapped by the short shrub and bushes. These features give the landscape a hummocky shape to this soil mapping unit.
The mean depth is 110 cm with dull reddish brown (5YR 4/3) colour. The structure the ochric (A horizon) is loose with single grains. The thickness of the A-horizon ranges from 12-16 cm and the colour is dull reddish brown (5YR 4/4) colour. Due to sandy nature of the soil it has a very low phosphorus and organic content. The values were measured at zero and 1% respectively. During rainy season the ochric is tend to form soil crusts which inhibits water infiltration and plants germination. The CE in the horizon is around 1-20 um. The water infiltration in the ochric is very rapid with a low water holding capacity.
Bw1 horizon has single grains or structureless. The texture is fine loamy sand. There are no coarse, stones or even boulders throughout the profile. The subsoil horizons has dull reddish brown (2.5YR 4/4) to reddish brown (2.5YR 4/6) in colour and structureless. The pH was strongly acidic to slightly alkaline with values of 5-6. There are no phosphorus in the sub horizon as a result the organic carbon is absent of none existing. The clay content is quite with values ranging from 5-6%. Coarse gravels, stones or boulders have not been observed in the horizon. It is also free of any hazardous salts such as calcium carbonate and potassium.
The Bw2 horizon is having a dull reddish brown (5YR 4/3) colour, with a fine loamy sand texture. The structure has a very weak grade, with very fine to subangular blocky. The Bw2 is almost having the same chemical characteristics as the Bw1. The pH is neutral with values of 7 classified it as slight alkaline. It is lacking phosphorus which leads to very low to low organic carbon content. The clay content is also quite very low to low and was measured at 0-2%. The horizon is free from any coarse gravels, stones or boulders that are becoming obstacles when one is ploughing the field. The Bw2 reaches up to an effective depth is approximately 93 cm.

The profiles representing for the soils of this soil unit are: P 241, P 247, P 168, P 172, P 192 P 194. MAR-24 represent soil profiles with 40-70% coarse gravel (6-20 cm) and MAR-29 represent profiles with hard rock at depth.

7.17 Soil mapping unit 14: Deep to very deep sandy soils of the Kalahari sand plateau.

Soil unit 14 is located at the eastern foot of the Okambara mountain and Hartebeest rucken. The White Nossob river south Witvlei settlement forms the eastern border of this soil unit. This soil unit stretch further down towards the southern border of the pilot area. The geology consists of the “Kalahari sand” underlying by the Damara sequence of the Kamtsas formation. The topography is flat to gently undulating topography with low relief. Very few river courses cut through this unit and gives it a gently undulating landform. Very few sandstone and shale rock outcrop exposed to the surface have been noticed especially along the eroded areas such rivers and depression.
There are two major soils types within this soil unit namely the Arenosols. The dominant is the haplic Arenosols (haAR) while ferralic Arenosols (flAR) occurs as inclusion. The first mention soil type is covering the lower positions such as the slopes and foot of the hills, while the ferralic Arenosols is found on the higher positions such as the crest and ridges.

The haplic Arenosols (haAR) occur as soil associates within this soil unit. The soils are predominantly of medium to coarse sandy texture. The soils have been classified as deep to very with maximum depth of 120 cm.
The structure of the topsoil is characterised as loose with single grains. The texture is predominantly of medium sandy texture. Because of the arid conditions and the prevailing winds the finer sand particles have blown away by the wind. The moist colour is dark grayish brown (10YR 4/2) to brown (7.5YR 4/3). The organic content is very to low values of less than 0.8%. The nitrogen as well as plant available phosphate content are also very low to none existing within the soil horizon. Few fine roots of grasses and other plants have been recorded.
The structure of the Bw1 horizon is weak fine subangular blocky structure with fine to medium sandy texture. The horizon is grayish brown (10YR 5/2). No coarse fragments have been observed and it is 11-36 cm thick. There are some medium to coarse plant roots within this horizon. The nitrogen and the phosphorus content s less than 1%.
The Bw2 horizon is dull yellowish brown (10YR 5/3, 7.5YR 4/3-4) to yellowish brown (7.5YR 5/6). The subsoil horizon shows slight sign of structural development which is very weak fine subangular blocky structure. The texture is fine to medium sandy loam. The high clay content is a result of the release of the clay from the parent rock. The effective soil depth was measured at 120 cm. In some profiles 40-50% coarse gravel (25-75 mm) has been observed while in others stones (75-250 mm) making between 20-30% of the soil volume weight has been noticed at the 95-120 cm soil depth. In some soil profiles which are located at the foot of the ridges the parent material of gneiss has been recorded at 100 cm depth.

Ferralic Arenosols (flAR) occur as an inclusion and is found at the higher position within this soil unit. The places were it is found are the ridges and crests. The soil profile is characterised by three sequences namely the A-Bw1 and Bw2.
The upper horizon has a loose structure with sandy texture. The thickness of the A-horizon ranges from 12-16 cm and the colour is dull reddish brown (5YR 4/4) colour. Due to sandy nature of the soil it has a very low phosphorus and organic content. The values were measured at zero and 1% respectively. During rainy season the ochric is subjected to form crust which inhibits water infiltration and plants germination. The EC in the horizon is around 1-20 um. The water infiltration in the ochric is very rapid with a low water holding capacity.
The Bw1 horizons are normally dull reddish brown (2.5YR 4/4) to bright reddish brown (2.5YR 5/6) in colour and structureless. The pH was strongly acidic to slightly alkaline with values of 5-6. There are no phosphorus in the sub horizon as a result the organic carbon is absent of none existing. The clay content is quite with values ranging from 5-6%. Coarse gravels, stones or boulders have not been observed in the horizon. It is also free of any hazardous salts such as calcium carbonate and potassium.

The Bw2 horizons are normally dull reddish brown (2.5YR 4/4) to bright reddish brown (2.5YR 5/6) in colour and structureless. The horizon is having an almost the same chemical characteristics as the Bw1. The pH is neutral with values of 7 classified it as slight alkaline. It is lacking phosphorus which leads to very low to low organic carbon content. The clay content is also quite very low to low and was measured at 0-2%. The horizon is free from any coarse gravels, stones or boulders that are becoming obstacles when one is ploughing the field. The Bw2 reaches up to an effective depth is approximately 115 cm.

The following soil profiles are representing the soils of soil unit 14 are P 154, P 226, P 219, P 221 and P 209.

7.18 Soil mapping unit 15: Shallow to moderately deep soils on highly eroded river terrace

The soil unit 15 is being found on the eroded river banks of the White Nossob south of Witvlei settlemnt in the Omaheke region. The unit lies between the Witvlei mountain, Langer Forst mountain and the Nicodemus mountain.A larger part of this unit of this unit is located north of the White Nossob rive. The topography is gently undulating to undulating topography with moderate relief. The undulating topography is as a result of the incised water channels due to water erosion. Three major soil types were identified in this unit namely the ferralic Arenosols (flAR) the associates with skeletic Regosols (skRG) and leptic-skeletic Leptosols (le/skLP) occur as inclusion.

The ferralic Arenosols (flAR) topsoil horizon is having a dull reddish brown (2.5YR 4/4) to dark brown (7.5YR 3/3) colour when moist. The texture of the topsoil is characterised as medium to coarse sandy to loamy sand. The ochric horizon (A horizon) contain less than 5% gravels of subrounded quartz is 10-13 cm thick. The ochric horizon (A horizon) has a loose, single sand grains and the grains are coated with dull reddish brown (2.5YR 4/4) colour. The soil reaction (pH) is neutral to slightly alkaline of 7-8. The horizon has an average organic matter content of less than 1% and it is calcium carbonate free. The phosphorus content is very low with values ranging from 1-3 ppm. The clay content is the lowest in the ochric horizon and is increasing downwards. It varies 4-5% in the ochric horizon.
The subsoil horizon is characterised by dull brown (7.5YR 5/4) to bright brown (7.5YR 5/6) colour. The weak subangular blocky structure with medium sandy texture is common. The Bw1 horizon is 15-38 cm. The texture is medium sand without calcium carbonate. The soil reaction (pH) is strongly acidic to slightly alkaline with values of 5-6. The phosphorus content is also very low to non-existing. There are no signs of organic carbon. The clay content is slightly higher than in the ochric with values of 5-6%.The horizon is also having low waterholding capacity (LWHC) and low cation exchange capacity (LCEC) within the range of 2-5 me/100 gram.
The Bw2 horizon which is below the Bw1 horizon has medium sand texture. It has moderately alkaline soil reaction (pH) of about 8. Soil colour is brown (7.5YR 4/4) when moist. The soil structure is very weak, fine to medium subangular blocky with loose to soft consistence when dry. The organic carbon varies from zero to 1% which indicates very low soil fertility. The phosphorus content is very low to none existing in the soil profile. There is a slight clay increase with increases in depth. The clay increases with depth is as a result of down wash of finer clay particle within the soil profile. The effective soil depth is 126 cm and no coarse gravels or stones have been notice in the profile.

Skeletic Regosols (skRG) occupy mainly the higher parts landscape namely the ridges and hills. The prominent character of the skeletic Regosols is the presence of the irregular subrounded quartz medium and coarse gravels in the lower horizon.
The shallow soil has a maximum depth of 28 cm and has grayish brown colour (7.5YR 4/2) to brown 7.5YR 4/3). The ochric horizon shows very weak structural development. The structure is fine subangular blocky structure and the texture is fine to medium sand to loamy sand. The soil reaction of the ochric horizon is slightly acidic with values of around 6. The horizon is only 4-28 cm thick. The phosphorus content is vary to none existing and was measured at less than 1%.
The (Bw1) subsoil horizon is dull yellowish brown (10YR 5/4) with weak, fine subangular blocky structure. The texture is of medium sandy loam. There are no coarse fragments in this horizon.

The horizon is slightly humic to humic with organic carbon content of 5%. The soil reaction is slightly acidic to neutral with values of 6-7.
Underneath the Bw1 occurs the partly weathered horizon or C horizon. The C-horizon comprises of the mixture of 30-60% medium (0.6-2 cm) to coarse gravel (2-6 cm) and stones (6-20 cm) of sandstone, quartz and conglomerate at the depth of 28 cm.
Within this soil mapping unit very few to common (2-15%) sandstone rock outcrops of conglomerate have been seen.

The lithic-skeletic Leptosols (li/skLP) is characterised as very shallow soils with high content of coarse fragments. The maximum soil depth of this soil ranges 3-16 cm. At shallow depth the parent material of sandstone have been recorded. The colour of the ochric horizon varies from grayish brown to brown to the different geological formation. Fine to medium coarse fragments ies scattered on the soil surface. A large amount of the loose soil particles have been washed away. The moist colour of the topsoil or horizon is grayish yellowish brown (10YR 5/2) to dull reddish brown (5YR 4/3, 2.5YR 4/4). The ochric horizon is characterised by single grain to very weakly developed structure with fine to medium sand to loamy sand texture. The pH is strongly acidic with values of less than 5. The low pH is attributed by the acidic parent material. The soil horizon is rich in organic matter as a result it is having a high organic carbon content. The clay content is also high to very high with values exceeding 30%.
Coarse gravel (2.0-6 cm) and stones (6-20 cm) makes more than 40-70% of the fine earth. Lithic-skeletic Leptosols are overlying by hard sandstone at maximum depth of 16 cm. The coarses fragments were estimated in the range of 30-60% consisting of quartz and conglomerate.

Profiles representing the soils of soil mapping unit 15 are P 224, P 135, P 133 and P 132.

7.19 Soil mapping unit 16: Moderately deep to deep loamy sand soils

Soil unit 16 covers the soils of the larger rivers or omiramba and some pans or depressions in the pilot area. The three large rivers or omiramba are the Seeis, the White - and the Black Nossob.The rivers are the soil unit with different soil types. This can be attributed by different factors such as the steepness of the slopes, the The soil unit is dominated by haplic Regosols (haRG), skeletic Regosols (skRG), leptic Regosols (leRG) and ferralic Arenosols (flAR) and lithic Leptosols (liLP) that along the drainage lines and watercourses.

Haplic Regosols (haRG), skeletic Regosols (skRG) and leptic Regosols (leRG) are the dominant soils while ferralic Arenosols (flAR) and lithic Leptosols (liLP) occur as inclusions. The Regosols as major soils of this mapping unit can be distinguished into different units and groups as there are haplic Regosols, skeletic Regosols, leptic Regosols.

The leptic Regosols (leRG) is being found on the upper and middle slopes of the rivers. Leptic Regosols refers to shallow to moderately deep soils. The Regosols in the soil unit 19 have a brown (7.5YR 4/3-4) to dull reddish brown (5YR 4/3-4) colour, depths ranges from 64-82 cm, what classifies these soils as moderately deep.
The topsoil structure is single grain or structureless to weak fine subangular blocky without coarse fragments. It is 9-30 cm thick. The texture is sandy loam with 8% clay content. The soil reaction is slightly acidic in the ochric horizon. The EC is high in the ochric horizon than the lower horizon and was measured at 43 um. The ochric horizon is having a low potassium content of 3 ppm. The organic carbon is high with values of 9%. The ph is neutral 7. The EC in the ochric horizon is higher and was measured at 27-150 um. The organic carbon is very low to none existing in this horizon.
At the depth of 42 cm start the Bw1 horizon. The horizon have grayish brown (7.5YR 4/2), brown (7.5YR 4/4) to dull reddish brown (5YR 4/3-4) colour with weak to moderate subangular blocky structure subsoil horizon. The texture is medium loamy sand to sandy clay loam. The soil reaction is also neutral 7. The EC was measured at 15um. The phosphorus and the organic carbon is zero in the Bw1 horizon. Due to the high clay content the horizon is having an extremely hard consistence when dry (yp).

The Bw2 is having the same clay content as the ochric horizon. The value was in the range 10-12%. The phosphorus and the organic carbon content are very low and were measured at less than 1%. The average content skeleton content ranges from 40-60% fine- (0.2-0.6 cm) to coarse gravel (0.6-20 cm) and stones (6-20 cm) at a depth of 72-82 cm.

The skeletic Regosols (skRG) is characterised by moderately depth (63-67 cm) with dull reddish brown (5YR 4/3, 2.5YR 4/3) colour when moist. The medium depth of 65 cm of the soil and thus it being classified as moderately deep with organic carbon contents between 5% and 10%.
The texture of the topsoil (ochric) is fine to medium sand to loamy sand and the structure is weak fine subangular blocky. The pH of the ochric horizon is slightly alkaline 6. The organic carbon is moderate to high with values 8-10%, indicating a high soil fertility meaning good store for plant nutrients. The skeleton content ranges around 25-40 % fine gravel (2-25 mm). The horizon is 8 cm thick.
The subsoil horizon is dull reddish brown (5YR 4/4, 2.5YR 4/3 and 2.5YR 4/4) with weak to moderate subangular blocky structure. The organic carbon is lower with values of less than 5%. The clay percent is 17%. It gives the texture it fine to medium sandy to loamy appearance. The EC content was measured at 16 percent. The total fragments (fine-, medium-, and coarse gravels) was estimated approximately 40% throughout the profiles. The consistence is hard to extremely hard when dry. The subsoil horizon is 63-67 cm deep.

The haplic Regosols (haRG) show a mean depth of 37 cm and is dark brown (7.5YR 3/4) in colour. The texture of the topsoil is fine to medium loamy sand to sandy loam with weakly developed subangular structure. The pH is strongly acidic to slightly alkaline and ranges 5-8%. The ochric horizon is having EC values that range from 18-54 cm with moderate phosphorus content 3-8 um. The organic carbon in turn is very low and ranges 0-1%. The low carbon shows poor soil fertility. The ochric horizon is having clay content of 5-9%. The skeleton content is about 10-20% fine (0.2-0.6 cm) to medium gravels (06-2.0 cm)) in the ochric horizon and is only 10 cm thick. The soil reaction is slightly acidic (6).
Below is a dark brown (7.5YR 3/4) to dull reddish brown (5YR 4/4) subsoil with a weak fine subangular blocky structure, Bw1 horizon. The EC is higher in the Bw1 horizon with values ranging 11-105 um. The phosphorus content is very low to none existing. The texture is fine to medium loamy sand to sandy loam. The clay is in the ranges of moderate to and was measured at 12-16%. The skeleton content 30-55% consist of medium (0.6-2.0 cm) and coarse gravel (2-6 cm). The effective depth of Bw1 horizon is 38 cm deep. The C horizon comprise of partly weathered parent material. No samples were taken from the C horizon because it is containing a high content of gravels.

Ferralic Arenosols (flAR) is rated as soil associates and occur at the bottom of the river valleys. Ferralic Arenosols (flAR) is rated as a deep to very deep sandy textured soil. The maximum depth ranges from 102-140 cm.
The mean depth of this dull reddish brown (5YR 4/3, 2.5YR 4/4) to dark reddish brown (2.5YR 3/4) soils varies around 118-120cm. The texture of soil of this mapping unit is medium sand to loamy sand, with a single grained structure in the topsoil to weak, fine medium subangular blocky structure in the subsoil. In general the available field capacity of the ferralic Arenosols of the mapping unit is high with values around 275 mm (Buch, 2000). The total pore space ranges around 55 volume.-%. The ochric horizon (A horizon) thickness varies from 13-19 cm without coarse fragments. The pH is strongly acidic to slightly acidic with values of 5-6. The phosphorus content is very low to none existing. The values were measured at 0-1 ppm. The horizon is very low in organic carbon meaning that it is poor in soil fertility.
Underneath the ochric horizon is the Bw1 subsoil. The subsoil horizon have dull reddish brown (5YR 4/3-4, 2.5YR 4/4) to dark reddish brown (2.5YR 3/4) colour and an average depth of 121 cm, with a slightly hard consistence when dry. The texture is loamy sand with single grain or structureless to very weak fine subangular blocky structure. The Bw1 horizon has an EC of 11-20 um. The ochric horizon pH is slightly acidic and varies 6-7.
The depth of the Bw2 ranges 44-52 cm. The soil colour 5YR 4/3 when moist. The soil reaction is strongly acidic to slightly acidic 5-6. The phosphorus and the organic carbon are totally absent. The texture is sandy to loamy sand with clay content of 5-6%.

The effective depth of the Bw2 horizon varies markedly. The maximum depth of the subsoil horizon was measured at 140cm with no coarse fragments and stones. The texture is loamy sand with very weak to weak sub angular blocky structure. The clay content is slightly higher the upper horizon. The clay pecentage was measured at 5-10.

The lithic Leptosols (liLP) has been identified as an inclusion in this mapping unit. It is found on the upper slopes and middle slopes. The soils are shallow because they subjected to continuous erosion by water and wind.
"Lithic" horizon is approximately 5 cm thick with sandy to loam sand texture. The soil effective depth of the soil is 15 cm deep. They are characterised by only two distinctive horizons namely the A-C horizons or R (parent material). The dull reddish brown (5YR 4/4) ochric horizon has a single grain or structureless sandy texture. Few to abundant (5-40%) coarse fragments of different sizes and shapes occur in this soil mapping unit. The effective of the horizon is 9-13 cm. The pH is slightly acidic with values of 5. The horizon is highly humic with organic carbon values 12-16%. The EC content in the horizon is around 7. Lithic Leptosols is having the highest phosphorus content. This is a result of the high organic matter from dead plants roots. The horizon is also rich in the clay. The clay content was measured at 27%. Because of the rough terrain and steep terrain the soils are continuously removed by water and wind and thus result in the exposure of the parent material on the surface. Partly weathered or hard mica-schist outcrops give the landscape zig-zags form.
It is advisable that this soil should be left under natural vegetation. The Leptosols have too low water holding capacity for agronomic applications, and the gravel soils are too difficult to cultivate. Therefore they are suitable for livestock grazing. Lithic Leptosols soil occurs mainly on the middle- and upper slopes, crest of the hills and steeply dissected landscape.

The following profiles P 205, P 207, P 204, P 203, P 201, P 180 and P 181 are representing the soil unit 16.

7.20 Soil mapping unit 17: Very deep red sands of the Kalahari

The soil unit 17 characterised by deep to very deep sandy soils and are patchly distributed within the northern and eastern parts of the pilot area. The soil unit is covering a large part of the Kalahari sand plains. Area around Spinosa 138, Riviera 1139, Marigold 136 and Iowa 133 farms are covered with very deep of the Kalahari deposited on Damara sequence. The dykes around Vergelegen 162 and Ombujondana 165 are also covered with deep sandy soils. The sand plains east of the Black Nossob are characterised by very deep sandy soils of the Kalahari. They are overlaid by the Damara sequence (Khomas formation) and the geology consist of quartzite, marble and schist.

In this soil unit 17, ferralic Arenosols (flAR) occur as a soil associates while haplic Arenosols (haAR) occur as an inclusions.

Ferralic Arenosols (flAR)

The ferralic Arenosols occupy mainly Kalahari sand plains. Very deep sandy covers a larger part east of the Black Nossob and extend to the eastern border of the pilot area. The effective depth of this grayish brown (5YR 4/2) to dull reddish brown (5YR4/4) soil varies around 100-135 cm. The texture is predominantly of fine to medium sandy. The structure of the topsoil is single grain or loose to very weak fine subangular blocky structure. The thickness of the topsoil horizon varies 13-54 cm. The ph is strongly acidic to slightly alkaline 5-6. The phosphorus content varies from 1-4 ppm and the organic carbon none exists.

The sub horizons consist of Bw1 and Bw2. The subsoil horizon is brown (7.5YR 4/3-4) to dark reddish brown (2.5YR 3/4) in colour when moist. The structure is single grain with a sandy texture. The EC ranges 7-23 um with very low organic carbon. The clay content is also low with values 4-10% in the subsoil. The effective depth is around 123 cm and the coarse fragments are absent.

Haplic Arenosols

The haplic Arenosols (haAR) are predominantly of medium sandy textured. The soil is characterisedby three main horizons namely the ochric-, Bw1- and the Bw2 horizon. The moist colour is dark grayish yellowish brown (10YR 4/2) to brown (7.5YR 4/3). The soil is moderately to deep soil with an effective of 95-120 cm. The organic content is very to low values of less than 0.8%. The nitrogen as well as plant available phosphate content are also very low to none existing throughout the soil profile.
The structure is single grain or structureless or weak fine subangular blocky structure with fine to medium sandy ochric horizon. No coarse fragments have been observed and the horizon is 11-36 cm thick.
The subsoil horizon is grayish brown (10YR 5/2) to brown (7.5YR 4/3-4) colour when moist. The subsoil horizon has a structureless to very weak fine subangular blocky structure. The texture is medium to fine sandy loam. The effective depth is 120 cm. At place 40-50% coarse gravel (25-75 mm) has been observed while the stones (75-250 mm) contribute 20-30% has been noticed at the 95-120 cm depth. In some profiles hard rock occur at 100 cm.

7.21 Soil mapping unit 18: Unit between the Kalahari sand plain and ridge with shallow to moderately deep sandy loamy textured soils.

It is a small soil unit occurring east of the Black Nossob river is located in the extreme southern region of the pilot area. The soil unit serves as a transition between the granitic rock ridge and the Kalahari sand plains. The topography is almost flat to flat with low relief of less than 50 m. Due to its unique position in the landscape this soil unit is characterised by two soilo types namely the Calcisols and Regosols. The Regosols is being regard as the associates while the Calcisols occur as an inclusion.

Arenic skeletic Regosols (ar/skRG) are having a dull brown (7.5YR 5/4) to dull reddish brown (5YR 4/4) colour when moist with an average soil depth of between 38-84 cm. The ochric or topsoil horizon has single grain structure with fine to medium sandy texture. The petric horizon is having single or structureless to weak medium subangular blocky structure. The pH is neutral with very low organic carbon. The low carbon shows that the soils are poor in nutrients meaning poor soil fertility. Very little organic matter has accumulated on top of the soil horizon which contributes significantly to the organic carbon of less than 1%.

The Bw1 has sandy loamy texture with loose to very weak, fine to medium subangular blocky structure. The soil colour is dull reddish brown (5YR 4/4) when moist with medium sand to loamy sand texture. At the depth of 48-84 cm fine (2-25 mm) to coarse gravels (25-75 mm) makes 40-50% of the soil volume. The soil reaction is slightly alkaline of about 8. The phosphorus and organic carbon are totally absent from this horizon. The clay content was measured at 10-14%. The scores of electrical conductivity range 15-17 um, that indicates there is a slight salinity problem. The CEC was measured at 11 me/ 100g soil indicating low fertility. The texture is sandy to sandy loam.
The C horizon contains a large volume of coarse gravels and stones of subrounded and irregular quartz. The skeletic material is increasing with depth. The arenic Regosols effective depth is in the range of 65- 70 cm.
The low AFC of 79 mm and the TPS about 50 Volume %, give values that shows that the water holding capacity and the internal drainage of the Regosols in this soil unit is sufficient (Buch, 2001).

The brown (7.5YR 4/3) petric Calcisols (ptCL) have an effective depth of 32 cm underlying by a hard calcrete. It is occurring in the lower depression and pans within the unit. The lower position serves also as drainage and drains the water to the main channel. Fine, loose sand particles are being removed annually by water and strong wind prevailing in the area.
The structure of the A-horizon is moderate fine to medium subangular blocky. The texture is fine clay which gives a powdery appearance to the soil. The soil is highly calciferous with values of up to 55% calcium carbonate throughout the profile. The A-horizon is only 9 cm.

The subsoil horizon or B-horizon is brown (7.5YR 4/3). The structure of the subsoil horizon have moderate grade with fine to medium granular structure. The texture is of fine clay.
The C-horizon consists of whitish powder followed by hard horizon of calcrete. This is sometimes refers to as the “petro-calcic horizon”. Due to the hardness of the subsoil the vegetation shows shrubby or bushy appearance and the water stagnate on the soil surface. In some instances, the petro-calcic horizon is exposed to the surface because the fine sand particles and powdery clay are being blown away.

7.22 Soil mapping unit 19: Moderately deep to deep sandy soils

This unit is found on the Kalahari sand plain, between the White- and Black Nossob Rivers and north of the Langer Forst Mountain. The 1500 m contour just north of the main road from Gobabis to Witvlei forms the northern boundary, while the Witvlei Mountain forms the northwestern boundary. Another unit lies in the southern part of the pilot area, east of the Black Nossob River and west of the Gobabis-Leonardville main road. The topography is flat to almost flat with low to moderate relief. The elevation ranges between 1500 and 1400 m above sea level. This soil unit is characterised by ferralic Arenosol and skeletic Regosol assiciations, with Calcisol and Leptosol inclusions. The Calcisols are found in flat to medium deep depressions, were the solum mainly developed *in situ,* though some parent material was washed in from the surrounding land. Leptosols and Regosols are found higher in the landscape, on top of low ridges and hills.

Ferralic Arenosols (flAR) are characterised by a grayish brown (7.5YR 4/2-4), dark reddish brown (5YR 3/4) and reddish brown (5YR 4/4) colour when has an average depth of 145 cm. It is poor in organic matter. The ochric (topsoil horizon) consist of single grains or structureless to very weak fine subangular blocky. The texture is of fine to medium sand. There are no coarse fragments and it is 7-49 cm thick. The soil reaction is strongly acidic with values of 5 and lower.
The Bw1 horizons is dull reddish brown (5YR 4/3-4, 2.5YR 4/4) to bright reddish brown (5YR 5/6) with structureless to weak fine to medium subangular. The pH of the Bw1 horizon is strongly acidic to neutral. The organic carbon content is very low to none existing. The Bw2 (subsoil horizons) have medium sandy texture with no coarse fragments and are 160 cm deep.

The skeletic Regosols (skRG) is moderately 52-97 cm deep with brown (7.5YR 4/3) to reddish brown (5YR 4/4) colour. The ochric (A horizon) is structureless to weak fine subangular blocky structure. The texture is medium sand to sandy loam with no coarse fragments. The horizon is 15-55 cm thick. The pH value is slightly acidic and was measured at around 6. The EC was measured at 21 um.
The Bw1 horizon is brown (7.5YR 4/3) to reddish brown (5YR 4/4), structureless to weak fine subangular blocky structure. The texture is medium sand to sandy loam and 52-97 cm deep. The organic carbon content is in the ranges of 5-8%. This indicates moderate to high organic matter content.
In some instances 40-50% stones have been observed at 52 cm, the representative profile is FEB-70.
Other profiles representing Regosols with hard rock at depth are FEB-87 and FEB-89.

Lithic Leptosols (liLP) is a very shallow soil. The mean depth of the Leptosols in the soil unit ranges 5-7 cm and the soil has brown (7.5YR 4/4) to reddish brown (5YR 4/3) colour when moist. The texture is fine to medium sand to loamy sand with single fine to medium grains of quartz. The ochric or Ahorizon is having a weak fine subangular structure. The Leptosols have high content of coarse gravels with a mean share of 40-50% stones (6-20 cm) to boulders (20-60 cm) over hard mica-schist rock. The horizon is having a high phosphorus content of 38 ppm with also high organic content of 14%. The clay content is also very high with values of 27%. Throughout the soil mapping unit the rocks makes 25-50 percent.

The petric Calcisols (ptCL) is mainly confined to the flat watercourses at the foot of the hills, the broad flat drainages lines and depressions. This soil type is characterised by the grayish soft powdery or hard calcrete horizon at depth.

Petric Calcisols has a mean depth of 59 cm. The topsoil horizon is dark grayish yellowish brown (10YR 4/2) to dull yellowish brown (10YR 5/3) colour when moist. The texture is fine to medium loamy sand to sandy loam with very weak to weak fine subangular blocky structure. It is 38 cm thick.
Underneath is a dull yellowish orange (10YR 6/3), weak medium subangular blocky structure, fine to medium sandy clay Bw1 horizon. At the depth of 59 cm a soft powdery of calcium carbonate horizon were noticed in some profiles. The hard petric horizon is impermeable and hinders the free movement of plant roots and water. Roots are thus force to grow parallel to the soil surface while the water tend to stagnate and causes pans and depressions.

Profiles describing the different soils types within this soil mapping unit 19 are P 44, P 58, P 56, P 61, P 62, P 59, P 54, P 45, P 60, P 49, P 47, P 51, P 56 and P 52.

7.23 Soil mapping unit 20: Shallow to moderately deep soils

This unit is found on the Kalahari sand plateau, south of the See- and Xabpoort (Nolte- and Langer Forst Mountains), covering the southern area between the White– and Black Nossob Rivers. The topography is flat to almost flat, consisting of broad interdunal valleys and low sand dunes / sand ridges, with very low relief of less the 50 m. The dune crests are still active and unvegetated. The linear dunes are oriented north-north-west (NNW) to south-south-east (SSE). A small number of pans are found. The soils of the covering the dune streets are very shallow, being underlain by hard calcrete. The soils consist of an association of haplic Arenosols (haAR) and chromic Cambisols (crCM), with inclusions of lithic Leptosols (liLP) and lepti-petric Calcisols (le/ptCL).

The haplic Arenosols (haAR) are predominantly sandy textured soils. The moist colour is dark grayish yellowish brown (10YR 4/2) to brown (7.5YR 4/3). The soil is moderately to deep soil with an effective of 95-120 cm. The organic content is very to low values of less than 0.8%. The nitrogen as well as plant available phosphate content are also very low to none existing throughout the soil profile.
The structure is single grain or structureless or weak fine subangular blocky structure with fine to medium sandy A horizon. No coarse fragments have been observed and the horizon is 11-36 cm thick.
The subsoil horizon is grayish brown (10YR 5/2) to brown (7.5YR 4/3-4) colour when moist. The subsoil horizon has a structureless to very weak fine subangular blocky structure. The texture is medium to fine sandy loam. The effective depth is 120 cm. At place 40-50% coarse gravel (25-75 mm) has been observed while the stones (75-250 mm) contribute 20-30% has been noticed at the 95-120 cm depth. In some profiles hard rock occur at 100 cm.

The chromic Cambisols (haCM) is shallow to moderately deep (33-77 cm) grayish yellowish brown (10YR4/2) to dull reddish brown (5YR 4/3-4) soil and roughly 77 cm deep and this is why it has classified as shallow to moderately deep soil. The chromic Cambisols is free of skeleton material and the texture has been described as medium to fine sand to sandy loam. The topsoil structure varies from loose to weak medium subangular blocky structure.
The subsoil horizon is brown (7.5YR 4/4) to dull reddish brown (5YR 4/3, 2.5YR 4/4). The structure is moderate medium to coarse subangular blocky structure with medium to fine sandy loam sandy clay loam to clay texture. The consistence is hard to extremely hard when dry. In some cases 40-50% coarse gravel (25-75 mm) at 42 cm and 77 cm respectively has been recorded.
Profile FEB-49 has been identified as the representative profile for the chromic Cambisols within the pilot area.

Lithic Leptosols (liLP) and petric Calcisols (ptCL) are the inclusions and make less than 15% of the total area.

The lithic Leptosols (liLP) is brown (7.5YR 4/3-4) to dull reddish brown (5YR 4/3) with a mean depth of 7 cm. The texture is medium sandy and structureless. In the profiles the coarse fragments were estimated at 10-25%, the stones contribute 40-50% to soil volume. The topsoil horizon is 5-7 cm thick. It is overlying a hard rock or petrocalcic horizon at the depth of 5-7 cm. Sandstone, petrocalcic and granite rocks outcrops makes 25-50% in the soil unit.

The brown (7.5YR 4/3) petric Calcisols (ptCL) have an effective depth of 42 cm underlying by a hard calcrete. The structure is moderate fine to medium subangular blocky. The texture is fine clay. The soil type is very highly calciferous with values of up to 65% calcium carbonate throughout. The horizon is 8 cm.
The subsoil horizon is brown (7.5YR 4/3) in colour. The structure is moderate, fine to medium granular with fine textured clay.
The C-horizon consists of pure white hard petro-calcic horizon or calcrete. Due to the hardness of the this layer the vegetation grows dwarf with shrubby or bushy appearance.

Leptic Regosols (leRG), skeletic Regosols (skRG), haplic Arenosols (haAR), lithic Leptosols (liLP), chromic Cambisols (crCM), petric- leptic Calcisols (pt/leCL) are represented by the following profiles: P 148, P 142, P 143, P 140, P 139, P 141 and 170.

7.24 Soil mapping unit 21: Shallow to moderately deep soils

Soil unit 21 forms the margin between the central plateau and the Kalahari sand plateau. It covers the farms Suliman 215, Weshof 585, Okasewa 103, Okasewa 102, Held 84 and Okatjirute 155 in the Witvlei district, and the intermontane valleys between the Okambara-, Buschmann-, Groot Klee- and Hartebeest Rucken Mountains. The unit is located south of the 1500 m and north of the 1450 m contour. The topography is flat to gently undulating, with low relief.
On the flat plains, an association of lepti-skeletic Cambisols (le/skCM) and haplic Cambisols (haCM) are found, while lithic Leptosols (liLP), with many coarse sandstone fragments, occur as inclusions on the foot slopes of hills and ridges. Skeletic Cambisols are found the flat to almost plain middle slope of the omiramba.

Leptic-skeletic Cambisols (le/skCM) as the name implies it is limited by depth. Skeleton occurs throughout the whole profile. The soils is having brown (10YR 4/3)) colour with a thickness of 27 cm. The texture of the ochric horizon is sandy clay loam. This soil type is characterised by three distinctive horizons namely the A-Bw1-Bw2 horizontal sequences.
The ochric horizon is 22 cm thick. The texture is medium sandy with loose or single grains structure. The ochric horizon is having brown (7.5YR 4/3) colour when moist. The ochric horizon is 16 cm thick. The clay content is low 8% with phosphorus content of 37 ppm. The consistence is slightly hard when dry. The pH of the ochric horizon is acidic to neutral with values of 6-7. This soil is having the highest P content of all soils within the pilot are. The organic carbon is 8%. Within the soil unit at some places it is noticed the A-horizon is covered with fine, loose “aeolian” sand of approximately 3 cm thickness. Fine to medium gravels of quartz occur within the horizon.
The Bw1 horizon has brown (7.5YR 4/3) colour when moist. The horizon thickness is 51 cm. The texture of the horizon is sand sandy loam. The Bw1 is brown (7.5YR 4/3) in colour when moist with a weak to moderate, medium to coarse subangular blocky structure. The organic carbon is 5% with very low phosphorus content of 2 ppm. The soil structure is moderate to strong subangular blocky. The structure is as a result of high cay content of 27%. The horizon is having a neutral soil reaction. Most plants prefer neutral soil pH. Apart from the hard consistence there are few fine to medium quartz gravels.
The Bw2 horizon has an effective depth of 56 cm. The structure is moderate, medium to coarse sub-angular block structure. The clay content is higher than the ochric and Bw1 horizons and was measured in the range of 30%. Due to the high clay content clay content in the horizon the texture is sandy clay loam. It is free of the calcium carbonate salts. The soil reaction (pH) is slightly acidic to neutral (6.83-7). No samples were taken from this horizon. It is assumed that the organic content is less than 0.5%, this can be clearly explain by the hard layer were no plants roots can penetrate.

The haplic Cambisols (haCM) has brown (7.5YR 4/3) colour when moist with a moderate depth of 62-90 cm. The soil has been classified as moderately deep. The structure of the topsoil is weak subangular blocky with fine to medium sand to sandy clay loam texture without coarse fragments.

It is 12-23 cm thick. The pH of the ochric horizon varies from slightly acidic to neutral 6-7. In the topsoil the phosphorus is low to moderate and varies from 2-21 ppm which is significantly high. The organic carbon is very low to none existing and was measured at 0-1%. The clay content ranges from 6-8% in the ochric horizon.
The depth of Bw1 starts at 56-78 cm. The subsoil horizon has brownish black (10YR 3/2) to brown (7.5YR 4/3) colour with weak medium subangular blocky structure. The texture is fine to medium sand loam to sandy clay loam without coarse fragments. The clay percent in the Bw1 is quite high with values ranging 11-24%. The organic carbon is very low to low. The pH of the Bw1 is the same as the ochric. In some instance the consistence is extremely hard when dry (yp) and the profiles representing this soils type is JAN-23.
The Bw2 horizon has dull yellowish brown (7.5YR 4/3-5/4) colour with an effective depth of 82-96 cm. The Bw2 is having a moderate, medium to coarse subangular blocky structure. The texture is fine to medium sand loam to sandy clay loam without coarse fragments. The clay percent is quite high with values ranging 21-28. The pH is neutral with no organic carbon. The EC in the horizon was lower in the horizon with values of 35 um. Due to the high clay content the horizon is having an extremely hard consistence when dry.

The lithic Leptosols (liLP) has been identified as an inclusion in this mapping unit. It is found on the upper slopes and middle slopes. The soils are shallow because they subjected to continuous erosion by water and wind.
"Lithic" horizon is approximately 5 cm thick with sandy to loam sand texture. The soil effective depth of the soil is 15 cm deep. They are characterised by only two distinctive horizons namely the A-C horizons or R (parent material). The dull reddish brown (5YR 4/4) ochric horizon has a single grain or structureless sandy texture. Few to abundant (5-40%) coarse fragments of different sizes and shapes occur in this soil mapping unit. The effective of the horizon is 9-13 cm. The pH is slightly acidic with values of 5. The horizon is highly humic with organic carbon values 12-16%. The EC content in the horizon is around 7. Lithic Leptosols is having the highest phosphorus content. This is a result of the high organic matter from dead plants roots. The horizon is also rich in the clay. The clay content was measured at 27%. Because of the rough terrain and steep terrain the soils are continuously removed by water and wind and thus result in the exposure of the parent material on the surface. Partly weathered or hard mica-schist outcrops give the landscape zig-zags form.
It is advisable that this soil should be left under natural vegetation. The Leptosols have too low water holding capacity for agronomic applications, and the gravel soils are too difficult to cultivate. Therefore they are suitable for livestock grazing. Lithic Leptosols soil occurs mainly on the middle- and upper slopes, crest of the hills and steeply dissected landscape.

7.25 Soil mapping unit 22: Shallow to moderately deep sandy soils of the dunes, dunefields and interdunal depressions

Soil unit 22 is found in the extreme xxx part of the pilot area, on both sides of the White Nossob River, south of Witvlei settlement, from the southern foot of the Langer Forst Mountain towards the southern edge of the pilot area. The topography is flat to gently undulating with moderate relief, ascribed to linear dunes. Dune streets (interdunal depressions) are flat to almost flat. Dune crests are still active unvegetated. The sois are mainly an association of ferralic Arenosols (flAR) and haplic Calcisols (haCL), with petric Calcisols (ptCL) inclusions.

The ferralic Arenosols (flAR) topsoil horizon is having a dull reddish brown (2.5YR 4/4) to dark brown (7.5YR 3/3) colour when moist. The texture of the topsoil is characterised as medium to coarse sandy to loamy sand. The ochric horizon contains less than 10% gravels of subrounded quartz and it is 1-5 cm thick. The upper horizon is highly sujbjected to wind erosion and that is why it is varies in thickness.
The ochric horizon (A horizon) has a loose, single sand grains and the grains are coated with dull reddish brown (2.5YR 4/4) colour. The soil reaction (pH) is neutral to slightly alkaline of 7-8. The horizon has an average organic matter content of less than 1% and it contain a bit of calcium carbonate. The calcium carbonate can be as the reslut of the dust from the interdunal depressions.

The phosphorus content is very low with values ranging from 1-3 ppm. The clay content is the lowest in the ochric horizon and is increasing with soil depth. It varies 4-5% in the ochric horizon. The subsoil horizon is characterised by dull brown (7.5YR 5/4) to bright brown (7.5YR 5/6) colour. The weak subangular blocky structure with medium sandy texture is common. The Bw1 horizon is 15-38 cm. The texture is medium sand without calcium carbonate. The soil reaction (pH) is strongly acidic to slightly alkaline with values of 5-6. The phosphorus content is also very low to non-existing. There are no signs of organic carbon. The clay content is slightly higher than in the ochric with values of 5-6%.The horizon is also having low waterholding capacity (LWHC) and low cation exchange capacity (LCEC) within the range of 2-5 me/100 gram.
The Bw2 horizon which is below the Bw1 horizon has medium sand texture. It has moderately alkaline soil reaction (pH) of about 8. Soil colour is brown (7.5YR 4/4) when moist. The soil structure is very weak, fine to medium subangular blocky with loose to soft consistence when dry. The organic carbon varies from zero to 1% which indicates very low soil fertility. The phosphorus content is very low to none existing in the soil profile. There is a slight clay increase with increases in depth. The clay increases with depth is as a result of down wash of finer clay particle within the soil profile. The effective soil depth is 126 cm and no coarse gravels or stones have been notice in the profile.

Haplic Calcisols (haCL) occur on the lower position of the landscape or the interdunal depressions. The soil has been classified as inclusion. The soils are very shallow to moderately deep, poorly drained and coarse textured with common calcrete rock fragments.
For more detail on soil profile description of the haplic Calcisols see Appendix I, table 2.9. The typical sequence of layers in the soil are the A-(or Bw) and C (calcrete).
The ochric horizon is only 7 cm thick. The structure of the ochric horizon is loose with very weak subangular blocky structure. The pH is slightly alkaline (7.5-8), with medium calcium carbonate of 994 ppm and slightly high organic content of 9%. Its wet colour is brown (7.5 YR 4/4). The texture is loam sand. The clay content is 12%. The EC content is 62 ppm.
The Bw1 horizon reaches to a depth of 25-36 cm. The moist colour is also grayish brown (7.5YR 4/2). The clay content is higher than the ochric horizon and was measured at 26%. The structure is weak to medium, coarse subangular blocky. The soil pH is moderately alkaline 9. The texture is sandy clay loam. The horizon is having a higher EC content than the ochric horizon and was measured at 87 um. The organic carbon content is in the range of 7%.
The C-horizon or petric horizon occurs at the depth of >53cm. The horizon is highly calcareous and slightly acidic. Appendix III, Table 10 shows a typical petric Calcisols with a petric horizon.

The petric Calcisols

The petric Calcsols in this soil unit is characterised by two main horizons the ochric and the petric horizon. The ochric horizon consist predominatly of fine, loose Kalahari sand which is deposited on top of the hard calcrete layer. The ochric horizon varies markedly in depth pending on the presence of the petro-calcic horizon. The horizon depth varies between 3-7 cm thick. The pH is slightly alkaline to alkaline (7.5-8). Calcium carbonate is present within the top soil horizon although it was reacting very slow. The organic content of the topsoil was measured at <3%. The ochric horizon wet colour is brown (7.5 YR 4/4). The texture is pure sand.
Below the ochric horizon is the C horizon which consists of hard clacium carbonate. Because of the hardness of this layer rain water tend to accumulate on the surface and forms waterpools. The waterpools are called pans or depressions. The pans and depressions forms favourable environment for many plants roots expecially the annual grasses and trees. Tree such as the Acaica erioloba are highly adaptable to this environment and forms circles around the pans.

CHAPTER 8. DESCRIPTION OF THE PHYSICAL- , CHEMICAL CHARACTERISTIC AND USE OF THE DOMINANT SOIL WITHIN THE PILOT AREA.

8.1 Arenosols

In simple terms Arenosol are sandy textured soils. Arenosols covers the Kalahari sand plateau of the pilot area. The sand plains covered with thick sand in the pilot area stretches from east of the Omitara settlement towards eastern border. The dominant sand fractions are of fine to medium size.

8.1.1 Physical characteristics of the Arenosols

Arenosols have relatively high bulk density values that are typically between 1.5 and 1.7 kg dm3; somewhat lower or higher values are not uncommon. With the specific gravity of quartz close to 2.65 g dm3, the calculated total porosity of Arenosols amounts to 36 to 46 volume-percent, less than that of most finely textured soils. Arenosols have a high proportion of large pores that account for their good aeration, rapid drainage and low moisture holding capacity.
Kalahari sands are non-coherent, `single grain' materials, especially in the absence of organic matter or other cementing agents. Arenosols are predominantly `structureless'; they are `non-sticky' and `non-plastic' when wet and `loose' when dry. A cemented or indurated layer may occur at some depth.
Static loads produce very little compaction of Arenosols but vibration does; fine sand in a loose state and saturated with water is a very unstable material, especially in embankments.

8.1.2 Chemical characteristics of the sandy textured soils

Most Arenosols in the pilot area are deeply leached and decalcified soils with a low capacity to store bases. Their ochric or A-horizons are shallow and/or contain little or poorly decomposed organic matter. The natural vegetation survives on cycling nutrients and roots almost exclusively in the very thin O-horizon and in a shallow ochric or A-horizon.

Rooting is deeper and nutrient cycling less vital to the vegetation in Arenosols in semi arid regions, particularly those in loamy sands. The organic carbon content of well-drained Arenosols is normally less than 1 percent; 2 to 3 percent may be present in the upper 10 to 20 cm of soil. The CEC is typically low except in the upper 10 to 20 cm layer. The effective CEC (ECEC) is normally less than 4 cmol (+) kg-1 soil but may reach somewhat higher values in the topsoil.

Arenosols in the pilot area are normally rich in bases. Moderate leaching and shallow decalcification may still occur. The organic carbon contents of most surface horizons are normally less than 0.5 percent (less than 0.2 percent in the subsoil). CEC and ECEC values are also very low.

8.1.3 Hydrological characteristics of the sandy soils

Coarsely textured sandy soils hold a much greater proportion of their `available' water at low suctions than finer soils. Since most of the pores are relatively large, much of the retained moisture is lost at a soil suction of only 100 kPa. Depending on the grain size distribution and organic matter content, the `Available Water (storage) Capacity' (AWC) may be as low as 3 to 4 percent or as high as 15 to 17 percent.
Arenosols are permeable to water; saturated hydraulic conductivity varies with the packing density of the sand and can assume any value between 300 and 30,000 cm/day. Infiltration of water in sandy soils varies between 2.5 and 25 cm/hour and may be 250 times faster than in clay soils (0.01 - 0.1 cm/hr).
Note that under unsaturated flow conditions water moves more slowly in sandy soils than in clayey soils on account of their lower moisture content and lower unsaturated hydraulic conductivity. Understanding these relations is important for proper irrigation and drainage practices.

8.1.4 Limitations in terms of the use of Arenosols

Uses of Arenosols

Arenosols within the pilot area are commonly used for extensive grazing (cattle and game farming) but they could be used on a small scale for dry land or arable cropping if irrigated.

Arenosols are very permeable soils and their storage of available water is generally low within the normal rooting depths of crops. Their surface horizon is often pale and poor in organic matter. Their inherent fertility status is low but they are easy to till and tend to form a dry surface quickly, which protects soil moisture against evaporation. For these reasons they are often preferred over more heavy soils for agriculture in semi-arid regions.
Arenosols is the most extensive soils in the pilot area with a total area estimated at 35 %. Arenosols are mainly used in the pilot area for extensive grazing but in the northern regions of Namibia it is used for dryland and irrigated farming.

Arenosols have a fine to medium texture, accountable for the generally moderate permeability and low water and nutrient storage capacity. Arenosols are further marked by ease of cultivation, rooting and harvesting of root and tuber crops.

Low coherence, low nutrient storage capacity and high sensitivity to erosion are serious limitations of Arenosols in the pilot area. Good yields of small grains, cabbages, sorghum and fodder crops can been realized on irrigated Arenosols but high percolation losses may make surface irrigation impracticable. Drip or trickle irrigation, combined with careful dosage of fertilizers, may remedy the situation.

Large area of the pilot with sand is covered with sparse dense vegetation. Uncontrolled grazing and clearing for cultivation without appropriate soil conservation measures can easily make these soils unstable and revert the land to shifting dune areas.

8.2 Calcisols

Soils with calcium carbonate accumulation. Calcisols accommodates soils in which there is substantial secondary accumulation of lime. Calcisols are common in calcareous parent materials and widespread in arid and semi-arid environments. The most prominent feature of Calcisols is the translocation of calcium carbonate from the surface horizons to an accumulation layer at some

depth. This layer may be soft and powdery, or consist of hard concretions or calcite pendants, and can eventually become indurated and cemented.
Calcisols are estimated at approximately 10 percent, mainly concentrated in lower and flat topography of the pilot area.

8.2.1 Physical characteristics of the Calcisols

Most Calcisols have a medium or fine texture and good water holding properties. Slaking and crust formation may hinder the infiltration of rain and irrigation water, particularly where surface soils are silty. Surface run-off over the bare soil causes sheet wash and gully erosion and, in places, exposure of a petrocalcic horizon to the soil surface.

8.2.2 Chemical characteristics of the Calcisols

Most Calcisols in the pilot area contain only 1 or 2 percent organic matter but many are rich in plant nutrients. The pH(w) is near-neutral in the surface soil and slightly higher at a depth of 80 to 100 cm where the carbonate content may be 25 percent or more. The nominal cation exchange capacity of typical Calcisols is highest in the surface soil (10 to 25 cmol (+)/kg) and slightly less at some depth. The exchange complex is completely saturated with bases; Ca2+ and Mg2+ make up more than 90 percent of all adsorbed cations.

8.2.3 Limitations in terms of the use of Calcisols

Use of Calcisols

Most Calcisols have a medium to fine texture and a good water holding capacity. They are generally well drained. They are also potentially fertile soils, as they are rich in mineral nutrients, but the high calcium contents are not favourable for many crops, and the high Ca content may also result in iron and zinc deficiency.
The dryness, and in places also stoniness and/or the presence of a shallow petro-calcic horizon, limit the suitability of Calcisols for agriculture. If irrigated, drained (to prevent salinization) and fertilised, Calcisols can be highly productive under a wide variety of crops. Hilly areas with Calcisols are predominantly used for low volume grazing of cattle, sheep and goats unlike in the mountainous area of former Kaokoland.
Calcisols are mainly used for extensive grazing, but may yield well when carefully irrigated for fodder crops, sunflower, sorghum or cotton, amongst others.

8.3 Cambisols

Soils conditioned by their limited age. Cambisols are moderately developed soils characterized by slight or moderate weathering of the parent material and by absence of appreciable quantities of accumulated clay, organic matter, and aluminium or iron compounds. Cambisols develop on medium and fine textured materials derived from a wide range of rocks, under different climates, different topography and a wide range of vegetation.

Profile development: ABC profiles. Cambisols are characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay, organic matter, aluminium and/or iron compounds.

8.3.1 Mineralogical, physical and chemical characteristics of Cambisols

It is not well possible to sum up all mineralogical, physical and chemical characteristics of Cambisols in one generalised account because Cambisols occur in such widely differing environments. However:
The Cambisols contain at least some weatherable minerals in the silt and sand fractions.
Cambisols in the pilot area are medium-textured and have a good structural stability, a high

porosity, a good water holding capacity and good internal drainage. Cambisols have a neutral to weakly acid soil reaction, a satisfactory chemical fertility and an active soil fauna.

Cambisols are the least extensive soils in the pilot area, with an estimated 5 percent. Cambisols are particularly extensive in the mountainous valleys and sloping terrain, partly because the parent material is still young and partly because soil formation is slowed by the low drainage. Erosion and deposition cycles are the main reason why Cambisols occur frequently in mountainous areas (Auas and Grimmruckenberge footslopes).

These soils are also quite frequent in semi-arid climates, where they are closely associated with Calcisols.
Although their soil properties may vary widely, they generally have good structural stability, high porosity, good water holding capacity and good internal drainage. Most Cambisols have a moderate to high natural fertility and an active soil fauna.

8.3.2 Limitations in terms of management and use of Cambisols

Management and use of Cambisols

By and large, Cambisols make good agricultural land and are intensively used. The eutric Cambisols in the pilot are among the most productive soils in the Namibia. The dystric Cambisols, though less fertile, are used for (mixed) arable farming and as extensive grazing land.
Eutric, Calcaric and Chromic Cambisols in undulating or hilly (mainly colluvial) terrain in the pilot area are used as grazing land and a small scale for planting of annual and perennial crops.

On the whole, Cambisols make good agricultural lands and are intensively used for a wide range of crops, depending on the relief and the climate in which they occur.

8.4 Leptosols

Soils of eroding landscapes. Leptosols are genetically young soils and evidence of soil formation is normally limited to a thin A-horizon over an incipient B-horizon or directly over the unaltered parent material.

Leptosols are characterized by their shallow depth (less than 30 cm of soil over hard rock or partially rock) or by their very high gravel content. The limited soil volume makes them subject to drought, but also to waterlogging and run-off. They constitute the second extensive soils in the pilot area with an estimated total area of about 25 percent, mostly concentrated in mountainous and hilly areas

Profile development: A(B)R or A(B)C profiles with a very thin or no A-horizon. Leptosols in non calcareous weathering material have an ochric A-horizon that shows signs of intensive biological activity.

Eroding uplands or highlands are marked by the occurrence of the unstable rocky slopes and outcrops of bedrock which are particularly common in mountainous and hilly areas, moderate mountains and undulating areas. In these landscapes, Leptosols and Regosols dominate. Both are characterized by a very limited amount of soil forming processes, due to constant wind or water erosion and climatic conditions which retard soil formation, such as dry and hot desert arid climates.
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8.4.1 Physical, chemical and biological properties of Leptosols

The physical, chemical and biological properties of Leptosols are largely conditioned by the characteristics of the parent material and the climate. Most Leptosols in the pilot area are non-calcareous have generally better physical and chemical properties than Regosols and are also less diverse. Leptosols are normally free from noxious levels of soluble salts. However, their

shallowness and/or stoniness, and implicit low water holding capacity, are serious limitations. The natural vegetation on Leptosols varies with the climate, parent material and steepness of the slope. On steeper slopes and partially weathered parent material the vegetation distribution is generally poor than on lower and slightly weathered parent material.
The parent material for Leptosols is derived from unconsolidated material weathered from the nearby mica and quartz of the PRECABIUM ERA. Due to the high quartz content of these weathered material the soils from them have not be able to developed a significant amount of clay. This result in a loamy sand texture with high permeability (i.e. low water holding capacity) which leads to limited plant grow and mineral organic accumulation.

8.4.2 Limitations in terms of use of the shallow soils:

Use of Leptosols

Leptosols in the pilot area remain under natural vegetation and as such have a potential for extensive grazing and natural vegetation. If exploited, be it for agriculture or for tourism, their fragility and susceptibility to erosion necessitate protective management.
Erosion is the greatest threat to Leptosol areas, particularly in mountain and hills regions where high animal pressure (overgrazing), overexploitation and increasing environmental pollution lead to increasing deterioration of natural resources and threaten large areas of vulnerable Leptosols. Leptosols on lower hills and mountainous slopes are generally more fertile than their counterparts on more level land. The excessive internal drainage of many Leptosols can cause drought.

8.5 Luvisols

These soils are characterized by clay migration from the surface soil to an accumulation horizon at some depth. They are common in flat or gently sloping land.
Luvisols extend over an estimated 1%, concentrated in the central and eastern region of the pilot area. They are often associated with Cambisols.

8.5.1 Physical characteristics

Luvisols have favourable physical properties; they have granular or crumb surface soils that are porous and well aerated. The `available' moisture storage capacity is highest in the argic horizon (15 to 20 volume percent). The Bw2 horizon has a stable blocky structure but surface soils with high silt content may be sensitive to water stagnation and erosion.
Luvisols are well drained but Luvisols in depression areas tend to stagnate and form pools of water. Stagnic properties were found where a dense illuviation horizon obstructs downward percolation and the surface soil becomes saturated with water for extended periods of time

8.5.2 Chemical characteristics

The chemical properties of Luvisols vary with parent material and pedogenetic history. Surface soils are normally wholly or partly de-calcified and slightly acid in reaction; they contain a few percent organic matter with a C/N ratio of 10 to 15. Subsurface soils tend to have a neutral reaction and may contain some calcium carbonate.

They are, in general, fertile soils because of their mixed mineralogy, relatively high nutrient content and the presence of weatherable minerals. Their physical characteristics are also favourable. They are well drained (unless a dense clay accumulation layer develops over time), porous and well aerated and have a moderate to high moisture storage capacity.

8.5.3 Limitations

Use of Luvisols

Most Luvisols are suitable for extensive and arable farming. In the flat to nearly level terrain they are widely used for irrigation. On sloping lands they are used for orchards or extensive grazing.

8.6 Regosols

Regosols has been identified as the dominant soil types within the pilot are. The central concept of a Regosol is a deep, well-drained, medium-textured, non-differentiated mineral soil that has minimal expression of diagnostic horizons (other than an ochric surface horizon), properties or materials.

In practice, Regosols are very weakly developed mineral soils in unconsolidated materials that have only an ochric surface horizon and that are not very shallow (Leptosols), sandy (Arenosols) or with fluvic properties (Fluvisols)

Profile development: AC-profiles with no other diagnostic horizon than an ochric surface horizon. Profile development is minimal as a consequence of young age and/or slow soil formation e.g. because of prolonged drought. Profile development is limited to formation of a thin ochric surface horizon over (almost) unaltered parent material.

8.6.1 Physical and chemical characteristics

Regosols have a morphology determined by the type of parent material and the climate in which they occur. In the pilot area, surface horizons of Regosols are very thin to non existing and low in organic matter. Soil horizon formation remains limited, and the subsurface reflects generally the weathered rocks on which the Regosols developed. Regosols are soils that are mainly associated with Leptosols. The total area of Regosols is estimated at about 10 percent.

8.6.2 Limitations

Use

Land use and management of Regosols depends mainly on the climate and the relief. The soils within the arid climates can be used for extensive grazing and dryland farming, but often need supplementary irrigation. Most Regosols in the pilot area remain under their natural vegetation.

Regosols in desert areas have minimal agricultural significance. The low moisture holding capacity of these soils calls for frequent applications of irrigation water; sprinkler or trickle irrigation solves the problem but is rarely economic.
Many Regosols are used for extensive grazing. Regosols in mountain regions are best suited for natural vegetation.

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APPENDIX I:
DESCRIPTIONS AND CLASSIFCATION OF MODULE PROFILES WITH THEIR CHEMICAL AND PHYSICAL PROPERTIES.

Table 2.1: Haplic Arenosols

PROFILE	JAN – 37 (haplic Arenosols)			
0-9 cm Dull yellowish brown (7.5YR 4/3) moist, single grain sand or loose structure none sticky and none plastic, none calcareous and sand. No coarse fragments or stones in the horizon (A1). 10-34 cm Brown (7.5YR 4/4) moist, loose to very weak fine subangular blocky structure with slightly hard consistence when dry, no rock fragments and none calcareous (A2). 35-80 cm Brown (7.5YR 4/4) moist, moderate, coarse to medium subangular blocky structure with slightly hard consistence when dry, no coarse or stones have been noticed none calcareous (Bw1). 80+ cm Brown (7.5YR 4/4) when moist, moderate, coarse to medium subangular blocky structure. The texture is sand loamy to sandy clay loam (Bw2).				
Soil group Soil phase				
Generic horizon	A1	A2	B1	B2
Horizon boundary	Clear	Clear	Clear	
Depth (cm)	0-9	10-34	35-80	80+
Colour (dry)	7.5YR 5/4	7.5YR 5/4	7.5YR 5/4	7.5YR 5/4
Colour (moist)	7.5YR 4/3	7.5YR 4/4	7.5YR 4/4	7.5YR 4/4
Textural class	Sand	Sand	Loamy Sand	Sandy Loam
Clay (%)	8	4	19	
Silt (%)	15	8	8	
Sand (%)	77	88	73	
Rock fragments	None	None	None	None
Grade	Very weak	Very weak	Very weak	Very weak
Size	Very Fine	Very Fine	Very Fine	Fine
Type of structure	Single grains	Subangular blocky	Subangular blocky	Subangular blocky
Mottling	None	None	None	None
Consistence	None	None	None	None
Permeability				
Cutans				
Extractable P (me/100g soil)	2	6	7	
Extractable K (me/100g soil)	170	131	186	
Extractable Ca (me/100g soil)	318	160	752	
Extractable Mg (me/100g soil)	86	34	218	
Extractable Na (me/100g soil)	27	33	41	
CEC (me/100g soil)				
Base saturation (%)				
PH.H2O	6	6	7	
Electrical conductivity	16	17	15	

(mS/m)				

Table 2.2: Calcaric Cambisols

PROFILE	JAN- 36 (calcaric Cambisols)			
0-35 cm Dull yellowish brown (10YR 5/3) moist, very weak, fine subangular blocky structure none sticky and none plastic, slightly calcareous. Without coarse fragments (A1). 36-78 cm Dull yellowish brown (10YR 5/3) moist, weak fine subangular blocky structure with slightly hard consistence when dry, no rock fragments, strongly calcareous (A2). 79-121 cm Dull yellowish brown (10YR 5/3) moist, weak fine subangular blocky structure with slightly hard consistence when dry, no rock fragments and extreme effluence (strongly calcareous) (Bw1). 122+ cm Extermely hard compact layer				
Soil group Soil phase				
Generic horizon	A1	A2	Bw1	C
Horizon boundary	Clear	Diffuse	Abrupt	
Depth (cm)	0-35	36-78	79-121	122+
Colour (dry)	No	No	No	
Colour (moist)	10YR 5/3	10YR 5/3	10YR 5/3	
Textural class	Loamy Sand	Sandy Loam	Sandy Loam	
Clay (%)	6	10	11	
Silt (%)	15	20	28	
Sand (%)	79	69	61	
Rock fragments	None	None	None	Compact layer
Grade	Very weak	Very weak	Very weak	
Size	Fine	Fine	Fine	
Type of structure	Subangular blocky	Subangular blocky	Subangular blocky	
Mottling	None	None	None	
Consistence				
Permeability				
Cutans				
Extractable P (me/100g soil)	2	0	0	
Extractable K (me/100g soil)	152	139	114	
Extractable Ca (me/100g soil)	626	3028	2948	
Extractable Mg (me/100g soil)	92	266	516	
Extractable Na (me/100g soil)	39	43	40	
CEC (me/100g soil)				
Base saturation (%)				
PH.H2O	8	9	9	
Electrical conductivity (mS/m)	36	83	90	

Table 2.3: Haplic Leptosols

PROFILE	JAN- 36 (haplic Leptosols)		
0-5 cm	Dull brown (7.5YR 5/4) moist, single grains, slightly hard consistence with no reaction with few fine irregular quartzitic gravels (A).		
6-21 cm	Dull brown (7.5YR 5/4) moist colour, weak fine subangular blocky structure (Bw1), slightly hard consistence when dry, common fine to medium gravels of quartz.		
22 + cm	Hard impermeable sandstone (R).		
Soil group Soil phase			
Generic horizon	A	Bw1	R
Horizon boundary	Clear	Abrupt	
Depth (cm)	0-5	6-21+	
Colour (dry)	7.5YR 5/3	7.5YR 5/3-	
Colour (moist)	7.5YR 5/4	7.5YR 5/4	
Textural class	Loamy sand	Loamy sand	
Clay (%)	5-6	-	
Silt (%)	16	-	
Sand (%)	78	-	
Rock fragments	Few , medium gravels Common, coarse gravels	Common to many, medium gravels Many, medium to coarse gravels	
Type of rock	Quartz	Quartz	
Grade	Very weak	Very weak	
Size	Very fine	Fine	
Type of strucutre	Subangular blocky	Subangular blocky	
Mottling	None	None	
Consistence			
Permeability			
Cutans			
Extractable P (me/100g soil)	8	None	
Extractable K (me/100g soil)	88	None	
Extractable Ca (me/100g soil)	390	None	
Extractable Mg (me/100g soil)	25	None	
Extractable Na (me/100g soil)	22	None	
CEC (me/100g soil)	-	-	
Base saturation (%)	-	-	
PH.H2O	6	None	
Electrical conductivity (mS/m)	12	None	

Table 2.4: Leptic-skeletic Leptosols

PROFILE	JAN – 17 (Leptic-skeletic Leptosols)	
0-17 cm Dark brown (10YR 3/4) when moist, loose to very weak, fine subangular blocky structure, many to abundant irregular and platy quartzitic gravels, with slightly hard consistence with no reaction (A). 18+ cm Abundant irregular quartz coarse gravel's and stones (C).		
Soil group Soil phase		
Generic horizon	A	C
Horizon boundary	Abrupt	None
Depth (cm)	0-17	18+
Colour (dry)	None	None
Colour (moist)	10YR 3/4	None
Textural class	Loamy sand	None
Clay (%)	3	None
Silt (%)	15	None
Sand (%)	82	None
Rock fragments	Many to abundant, medium to coarse quartz gravels	Abundant, coarse and stone quartz
Grade	Loose	None
Size	Very to fine	None
Type	Subangular blocky	None
Mottling	None	None
Consistence	None	None
Permeability		
Cutans		
Extractable P (me/100g soil)	6	None
Extractable K (me/100g soil)	83	None
Extractable Ca (me/100g soil)	740	None
Extractable Mg (me/100g soil)	204	None
Extractable Na (me/100g soil)	33	
CEC (me/100g soil)		
Base saturation (%)		
PH.H2O	6	None
Electrical conductivity (mS/m)	71	None

Table 2.5: Hyperskeletic Leptosols

PROFILE	JAN-2 (hyperskeletic Leptosols)		
0-26 cm Dull yellowish brown (10YR 4/3) moist colour, loose or single grains, with many to abundant medium to coarse irregular quartz gravels. None calcareous. None plastic and none sticky sand (A). 27-42 cm Dull yellowish brown (10YR 4/3) moist colour and dull yellowish brown (10YR 5/4) when dry, loose or single grains, with common to many fine quartz gravels. It is non-calcareous. None plastic and none sticky sand (Bw1). 43-62 cm Partly weathered mica-schist, flat to platy shape mica schist (C).			
Soil group Soil phase			
Generic horizon	A	Bw1	C
Horizon boundary	Clear	Abrupt	
Depth (cm)	0-9	9-41	41-113
Colour (dry)	10YR 5/4	10YR 5/4	None
Colour (moist)	10YR 4/3	10YR 4/3	
Textural class	Sandy loam	Sandy loam	None
Clay (%)	17	13	None
Silt (%)	13	12	None
Sand (%)	70	75	
Rock fragments	Many, medium to coarse quartz subrounded gravels	Few to common, medium to coarse subrounded quartz gravels	Abundant to dominant, medium to coarse mica-schist gravels
Grade	Weak to moderate	Weak to moderate	
Size	Fine to medium	Fine to medium	
Type of strucutre	Subangular blocky	Subangular blocky	
Mottling	None	None	
Consistence			
Permeability			
Cutans			
Extractable P (me/100g soil)	4	0-1	
Extractable K (me/100g soil)	112	62	
Extractable Ca (me/100g soil)	758	1220	
Extractable Mg (me/100g soil)	228	294	
Extractable Na (me/100g soil)	61	38	
CEC (me/100g soil)			
Base saturation (%)			
PH.H2O	5	7	
Electrical conductivity (mS/m)	76	10	

Table 2.6: Leptic-arenic Regosols

PROFILE	JAN 50 (Leptic-arenic Regosols)		
0-17 cm	Brown (7.5YR 4/3) when dry and dull reddish brown (5YR 4/3) moist, structureless, very few to few medium and gravel of quartz. Consistencies is slightly hard when dry, none calcareous. (A).		
18-42 cm	Brown (7.5YR 4/3) when dry and turns dull dark brown (7.5YR3/4) when moist, very weak fine subangular blocky structure, slightly hard when dry, none calcareous and many rock fragments (C).		
43+ cm	Parent material mica-schist. With many to abundant subrounded and irregular quartzitic gravels (R).		
Soil group Soil phase			
Generic horizon	A	C	R
Horizon boundary	Clear	Abrupt	
Depth (cm)	0-17	18-42	
Colour (dry)	7.5YR 4/3	7.5YR 4/3	
Colour (moist)	5YR 4/3	5YR 4/3	
Textural class	Loamy sand	Loamy sand	
Clay (%)	3	6	
Silt (%)	16	11	
Sand (%)	80	82	
Rock fragments	Very few to few, medium to coarse gravel.	Many, fine to medium rounded quartz gravles	Abundant, Fine to medium Subrounded quartz gravels
Grade	Weak	Weak	None
Size	Fine to medium	Fine to medium	
Type of structure	Subangular blocky	Slightly hard	
Mottling	None	None	
Consistence	None	None	
Permeability	None	None	
Cutans	None	None	
Extractable P (me/100g soil)	19	7	
Extractable K (me/100g soil)	190	139	
Extractable Ca (me/100g soil)	160	298	
Extractable Mg (me/100g soil)	15	24	
Extractable Na (me/100g soil)	27	63	
CEC (me/100g soil)			
Base saturation (%)			
PH.H2O	7	7	
Electrical conductivity (mS/m)	38	21	

Table 2.7: Arenic-skeletic Regosols

PROFILE	FEB – 55 (arenic-skeletic Regosols)			
0-15 cm: Dull reddish brown (5YR 4/4) moist colour, loose or single grains. Slightly hard consistence when dry, none sticky, none plastic, none calcareous. Very few to few fine roots have been noticed in the horizon (A). 16-48 cm: Dull reddish brown (5YR 4/4) moist colour, loose structure with slightly hard consistence when dry, no medium or coarse fragments, none calcareous. Fine few plant roots (Bw1). 49-85 cm: Dull reddish brown (5YR 4/4) moist, weak fine subangular blocky structure, hard to extremely hard consistence when dry, no rock fragments and none calcareous (Bw2). 86+ cm: Many to abundant rounded quartzitic coarse gravels and stones (C).				
Soil group Soil phase				
Generic horizon	A	Bw1	Bw2	C
Horizon boundary	Clear	Clear	Abrupt	
Depth (cm)	0-15	15-48	49-85	86+
Colour (dry)	No	No	5YR 4/6	
Colour (moist)	5YR 4/4	5YR 4/4	5YR 4/4	
Textural class	Sand	Loamy Sand	Loamy sand	No samples
Clay (%)	5	7	10	
Silt (%)	6	6	5	
Sand (%)	89	87	84	
Rock fragments	Very few, medium gravel	Very few, medium gravels	Very few	Many, medium to stones of quartz
Grade	Very weak	Very weak	Very weak	
Size	Very fine	Fine	Fine	
Type of structure	Single grains	Subangular blocky	Subangular blocky	
Mottling	None	None	None	
Consistence	Soft	Soft	Slightly hard	
Permeability	None	None	None	
Cutans	None	None	None	
Extractable P (me/100g soil)	0	0	0	
Extractable K (me/100g soil)	102	186	199	
Extractable Ca (me/100g soil)	228	324	446	
Extractable Mg (me/100g soil)	14	22	40	
Extractable Na (me/100g soil)	6	32	24	
CEC (me/100g soil)				
Base saturation (%)				
PH.H2O	6	7	7	
Electrical conductivity (mS/m)	16	28	22	

Table 2.8: Ferralic Arenosols

PROFILE	MARCH – 13 (ferralic Arenosols)		
0-12 cm	Dull reddish brown (2.5YR 4/3) moist, single grain sand, loose dry, loose moist none sticky and none plastic, none calcareous sand with no rock fragments. Fine roots (A).		
13-56 cm	Dull reddish brown (2.5YR 4/4) moist, loose to very weak fine subangular blocky structure with slightly soft consistence when dry, no rock fragments, none calcareous. Very few fine roots (Bw1).		
57-120 cm	Reddish brown (2.5YR 4/6) moist, loose to weak fine subangular blocky structure with slightly hard consistence when dry, no rock fragments. No plant roots. None calcareous (Bw2).		
Soil group Soil phase			
Generic horizon	A	Bw1	Bw2
Horizon boundary	Clear	Clear	Clear
Depth (cm)	0-12	13-56	57-120
Colour (dry)	5YR 5/6	5YR 5/6	5YR 5/6
Colour (moist)	2.5YR 4/3	2.5YR 4/4	2.5YR 4/6
Textural class	Sand	Sand	Sand
Clay (%)	3	4	4
Silt (%)	6	4	3
Sand (%)	90	92	93
Rock fragments	None	None	None
Grade	Very weak	Very weak	Very weak
Size	Very fine	Very fine	Very fine
Type of structure	Single grains or loose	Single grains or loose	Single grains or loose
Mottling	None	None	None
Consistence	None	None	None
Permeability	None	None	None
Cutans	None	None	None
Extractable P (me/100g soil)	2	1	0
Extractable K (me/100g soil)	44	47	43
Extractable Ca (me/100g soil)	155	127	153
Extractable Mg (me/100g soil)	33	27	28
Extractable Na (me/100g soil)	14	68	72
CEC (me/100g soil)	15	32	42
Base saturation (%)			
PH.H2O	6	5	6
Electrical conductivity (mS/m)	12	11	9

Table 2.9: Haplic Cambisols

PROFILE	DOR-19 (haplic Cambisols)			
0-30 cm	Dull reddish brown (5YR 4/4) moist, weak, medium subangular blocky structure, none sticky and none plastic, none calcareous. Slightly hard consistence (A).			
31-81 cm	Brown (7.5YR 4/4) moist, moderate, medium subangular blocky structure with extreme hard consistence when dry, no rock fragments. None calcareous (Bw1).			
82-120 cm	Brown (7.5YR 4/3) moist, moderate, medium to coarse subangular blocky structure with extreme hard consistence when dry, no rock fragments. None calcareous (Bw2).			
120+ cm	A C-horizon consisting of coarse gravels and stones (C).			
Soil group Soil phase				
Generic horizon	A	Bw1	Bw2	C
Horizon boundary	Clear	Clear	Abrupt	
Depth (cm)	0-30	31-81	82-121	122+
Colour (dry)	5YR 4/4	5YR 4/4	5YR 4/4	
Colour (moist)	5YR 4/4	7.5Y R4/4	7.5YR 4/3	
Textural class	Loamy Sand	Sandy Loam	Sand loam	
Clay (%)	6	11	20	
Silt (%)	17	19	13	
Sand (%)	77	70	66	
Rock fragments	None	None	None	Abundant, coarse quartz gravles
Grade	Very fine	Very fine	Fine	
Size	Fine	Fine	Fine to medium	
Type of structure	Subangular blocky	Subangular blocky	Subanguar blocky	
Mottling	None	None	None	
Consistence				
Permeability				
Cutans				
Extractable P (me/100g soil)	2	2	6	
Extractable K (me/100g soil)	170	161	110	
Extractable Ca (me/100g soil)	314	388	690	
Extractable Mg (me/100g soil)	76	108	234	
Extractable Na (me/100g soil)	25	45	49	
CEC (me/100g soil)				
Base saturation (%)				
PH.H2O	7	6	7	
Electrical conductivity (mS/m)	29	30	35	

Table 2.10: Petric Calcisols

PROFILE	DOR- 48 (petric Calcisols)		
0-8 cm Dull reddish brown (5YR 3/4) moist, weak fine subangular blocky structure, with slightly hard to hard consistence, none sticky and none plastic, slightly calcareous and no coarse gravels (A). 9-31 cm Dull reddish brown (5YR 4/4) moist, moderate fine to medium subangular blocky structure with slightly hard to hard consistence when dry, no rock fragments. Showing slight effluence (Bw1). 32+ cm Petro-calcic horizon. Extremely hard calcareous horizon. Extremely calcareous (C).			
Soil group Soil phase			
Generic horizon	A	Bw1	C
Horizon boundary	Clear	Abrupt	None
Depth (cm)	0-8	9-31	32+
Colour (dry)	No	No	No
Colour (moist)	5YR 3/4	5YR 4/4	None
Textural class	Sandy Loam	Sandy Loam	None
Clay (%)	20	6	None
Silt (%)	17	23	None
Sand (%)	64	71	None
Rock fragments	None	None	None
Grade	Weak	Moderate	None
Size	Fine	Medium/ Fine	None
Type of structure	Subangular blocky	Subangular blocky	None
Mottling	None	None	None
Consistence	None	None	None
Permeability			
Cutans			
Extractable P (me/100g soil)	1	15	None
Extractable K (me/100g soil)	318	438	None
Extractable Ca (me/100g soil)	3722	2318	None
Extractable Mg (me/100g soil)	420	508	None
Extractable Na (me/100g soil)	0	0	None
CEC (me/100g soil)			
Base saturation (%)			
PH.H2O	9	8	None
Electrical conductivity (mS/m)	100	123	None

Table 2.11: skeletic Leptosols

PROFILE	DOR- 70B (skeletic Leptosols)		
0-5 cm Dark reddish brown (5YR 3/6) moist, very weak fine subangular blocky structure. Very thin layer of sand covers the surface (A). 5-26 cm Dark reddish brown (5YR 3/6) moist, very weak fine subangular blocky structure. The sand is none sticky, none plastic and none calcareous (C). 26+ cm Flat platty like, shiny partly weathered mica-schist gravels. Overlying a extremely hard mica-schist parent material (R).			
Soil group Soil phase			
Generic horizon	A	C	R
Horizon boundary	Clear	Diffuse	
Depth (cm)	0-5	5-26	
Colour (dry)	No	No	
Colour (moist)	5YR 3/6	5YR 3/6	
Textural class	Sand	Sandy loam	
Clay (%)	4	4	
Silt (%)	7	7	
Sand (%)	90	90	
Rock fragments	None	None	
Grade	Weak	Weak	
Size	Fine	Fine	
Type of structure	Subangular blocky	Subangular blocky	
Mottling	None	None	
Consistence			
Permeability			
Cutans			
Extractable P (me/100g soil)	1	6	
Extractable K (me/100g soil)	78	140	
Extractable Ca (me/100g soil)	196	712	
Extractable Mg (me/100g soil)	40	153	
Extractable Na (me/100g soil)	23	23	
CEC (me/100g soil)		6	
Base saturation (%)			
PH.H2O	6	7	
Electrical conductivity (mS/m)	7	7	

Table 2.12: Haplic Regosols

PROFILE	MARCH-24 (haplic Regosols)			
0-16 cm Brown (7.5YR 4/3) moist, single grain sand, none sticky and none plastic, none calcareous and no medium to coarse gravels fragments. Common fine roots and very few coarse roots (A). 17-48 cm Brown (7.5YR 4/4) moist, weak fine subangular blocky structure with slightly hard consistence when dry, no rock fragments none calcareous. No roots (Bw1) 49-82 cm Brown (7.5YR 4/4) moist, moderate, medium to coarse subangular blocky structure with hard to extremely hard consistence when dry, no rock fragments and none calcareous. No roots (Bw2).				
Soil group Soil phase				
Generic horizon	A	Bw1	Bw2	
Horizon boundary	Clear	Abrupt		
Depth (cm)	0-16	17-48	49-82	
Colour (dry)	7.5YR 5/4	7.5YR 5/4	7.5YR 5/4	
Colour (moist)	7.5YR 4/3	7.5YR 4/4	7.5YR 4/4	
Textural class	Loamy Sand	Sand Loam	Sandy Loam	
Clay (%)	6	10	18	
Silt (%)	11	14	10	
Sand (%)	84	76	72	
Rock fragments	None	None	None	
Grade	Very fine to fine	Weak	Moderate	
Size	Fine	Fine	Medium/ Coarse	
Type of structure	Subangular blocky	Subangular blocky	Subangular blocky	
Mottling	None	None	None	
Consistence				
Permeability				
Cutans				
Extractable P (me/100g soil)	1	0	0	
Extractable K (me/100g soil)				
Extractable Ca (me/100g soil)				
Extractable Mg (me/100g soil)				
Extractable Na (me/100g soil)				
CEC (me/100g soil)				
Base saturation (%)				
PH.H2O	8	8	8	
Electrical conductivity (mS/m)				

Table 2.13: Lithic Leptosols

PROFILE	KH 37 (lithic Leptosols)		
0 cm Surface covered with coarse quartzitic gravels (surface horizon)). 0-8 cm Brown (10YR 4/4) moist colour, very weak fine subangular blocky structure, with medium to large pores. Horison boundary is clear (A). >8 cm Partly weathered mica schist (C).			
Soil group Soil phase			
Generic horizon	Surface	Ah	C
Horizon boundary	Clear	Clear	Abrupt
Depth (cm)	0	0-8	>8
Colour (dry)	None	No	
Colour (moist)	None	10YR 4/4	
Textural class	None	Loamy sand 5-5-17	
Clay (%)	None	0-10	
Silt (%)	None	73-95	
Sand (%)	None	None	
Rock fragments	Medium to coarse quartz gravels	Medium to coarse quartz gravels	
Grade	None	Very weak	
Size	None	Fine	
Type of structure	None	Subangular blocky	
Mottling		None	
Consistence		None	
Permeability			
Cutans			
Extractable P (me/100g soil)		20	
Extractable K (me/100g soil)		88	
Extractable Ca (me/100g soil)		534	
Extractable Mg (me/100g soil)		60	
Extractable Na (me/100g soil)		31	
CEC (me/100g soil)		4.5	
Base saturation (%)		77.6	
PH.H2O		6	
Electrical conductivity (mS/m)		230	

Table 2.14: Saprolitic Leptosols

PROFILE	KH 52 (Saprolitic Leptosols)			
0	Surface is covered with coarse gravels and stone of quartz.			
0-1 cm	Brown (10YR 4/6) colour when moist, characterised by single grain structure to very weak fine subangular blocky structure. Large pores and well drained. Skeletons makes >80% of the soil volume (A).			
1-11 cm	Dull reddish brown (10YR 5/4) colour when moist, weak fine subangular blocky structure. Medium size pores and well drained soil (Bw1).			
11+ cm	Partly weathered mica schist parent material or the saprolite (C/R).			
Soil group Soil phase				
Generic horizon	Surface feature	A	Bw	C/R
Horizon boundary	Clear	Clear	Abrupt	
Depth (cm)	0	0-1	1-11	11+
Colour (dry)	None	None	None	
Colour (moist)	None	10YR 4/4	10YR 4/4	
Textural class	None	Loamy sand	Loamy sand	
Clay (%)	None	12-17	7.5	
Silt (%)	None	10-40	10.3	
Sand (%)	None	43-78	82.2	
Rock fragments	>80%	>80%	>80%	
Grade	None	Very weak		
Size	None	Fine		
Type of structure	None	Subanular blocky structure	Subanular blocky structure	
Mottling	None	None	None	
Consistence				
Permeability				
Cutans				
Extractable P (me/100g soil)		4		
Extractable K (me/100g soil)		63		
Extractable Ca (me/100g soil)		381		
Extractable Mg (me/100g soil)		46		
Extractable Na (me/100g soil)		18		
CEC (me/100g soil)		None		
Base saturation (%)		None		
PH.H2O		6.41	7.28	
Electrical conductivity (mS/m)		81	24	

APPENDIX II:
DETERMINATION OF DIFFERENT TERRAIN UNITS.

Table 3.1: How the different terrain units or landform types slopes wedges were determined.

Land Units	Highest point minus lowest point	Differences (meters)	Average	Criteria	Slope class	Profile type	General description of the unit	Highland or lowland	General description of the units
Unit 1	1675-1670	5	7	1	A	a	A2a	Highland	
	1655-1550	5	7	1	A	a	A2a	Highland	
	1654-1550	4	7	1	A	a	A2a	Highland	
	1675-1670	5	7	1	A	a	A2a	Highland	
	1679-11670	9	7	1	A	a	A2a	Highland	
	1592-1580	12	7	1	A	a	A2a	Highland	
Unit 2	1472-1420	72	71	2	C	c	C2c	Lowland	
	1476-1420	76	71	2	C	c	C2c	Lowland	
	1462-1420	42	71	2	C	c	C2c	Lowland	
	1562-1480	102	71	2	C	c	C2c	Lowland	
	1517-1450	67	71	2	C	c	C2c	Lowland	
Unit 3	1592-1580	12	6	1	A	a	A1a	Highland	
	1581-1580	1	6	1	A	a	A1a	Highland	
	1536-1530	6	6	1	A	a	A1a	Highland	
	1528-1520	8	6	1	A	a	A1a	Highland	
	1555-1550	5	6	1	A	a	A1a	Highland	
Unit 4	1513-1520	-7	-8	1	A	a	A1a	Highland	
	1520-1520	-8	-8	1	A	a	A1a	Highland	
	1509-1520	-11	-8	1	A	a	A1a	Highland	
	1508-1520	-12	-8	1	A	a	A1a	Highland	
	1516-1520	-4	-8	1	A	a	A1a	Highland	
Unit 5	1488-1480	8	8	1	A	a	A1a	Lowland	
	1459-1450	9	8	1	A	a	A1a	Lowland	
	1402-1400	2	8	1	A	a	A1a	Lowland	
	1278-1270	8	8	1	A	a	A1a	Lowland	
	1285-1270	15	8	1	A	a	A1a	Lowland	
Unit 6	1424-1400	24	37	2	B	b	B2b	Lowland	
	1439-1380	59	37	2	B	b	B2b	Lowland	
	1378-1340	38	37	2	B	b	B2b	Lowland	
	1425-1400	25	37	2	B	b	B2b	Lowland	
	1399-1360	39	37	2	B	b	B2b	Lowland	
Unit 7	1605-1500	105	157	3	C	d	C3d	Lowland	
	1674-1500	174	157	3	C	d	C3d	Lowland	
	1696-1500	196	157	3	C	d	C3d	Lowland	
	1705-1540	165	157	3	C	d	C3d	Lowland	
	1746-1500	246	157	3	C	d	C3d	Lowland	

	1746-1590	156	157	3	C	d	C3d	Lowland	
	1706-1610	96	157	3	C	d	C3d	Lowland	
	1741-1600	141	157	3	C	d	C3d	Lowland	
	1698-1560	138	157	3	C	d	C3d	Lowland	
Unit 8	1440-1420	20	15	1	B	b	B1b	Lowland	Valleys
	1340-1330	10	15	1	B	b	B1b	Lowland	Valleys
Unit 9	1536-1520	16	16	1	B	d	B1d	Highland	Dunes
	1536-1520	16	18	1	B	b	B1b	Lowland	Dunes
	1465-1440	26	18	1	B	b	B1b	Lowland	Dunes

Lanforms or terrain were manually calculated by calculating the slopes differences.

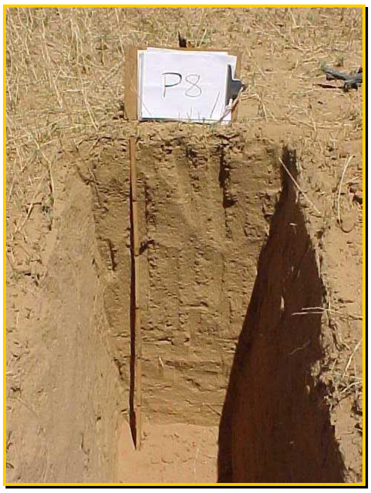
APPENDIX III:
THE DESCRIPTION OF THE TERRAIN TYPES OR LANDFORMS AND SOME OF MODULE PROFILES IN THE PILOT AREA.

Plate 1: The light blue mountain in the background is the “Auas Mountain” with >10% lithic Leptosols and <90% stones and rocks consisting of quartz, marble and mica-schist.

Auas Mountains (D5d) forms highest pick in the pilot area and the second highest pick in Namibia. The average slope is more than 35% with steep, straight slopes and deeply dissected. It forms part of the central plateau.

Representative profile of soil mapping unit CHa1: Leptic-skeletic Leptosols is very shallow to shallow soil with many to abundant medium, coarse gravels and stones of irregular quartz.

Plate 2: The Krumhuk-Oamites-Goachanas intermountain valley south of Aris which is covered by deep to very deep sand yextured soils the “aridic ferralic Arenosols”.



Flat to nearly level sand plain (B2a) with open tall Acacia erioloba and dense Ziziphus mucronata along the ephemeral rivers. The sand plain is having a flat topography with maximum slope 2%.

A typical representative profile in the soil mapping unit (B2a) for aridic ferralic Arenosols are very deep, somewhat excessively drained soil with fine to medium sandy textured, no rock fragments.

Plate 3: The Khomas Hochland west of Windhoek is a typical rolling upland in Namibia. The hills show rounded crests with concave slopes.

This landscape was created by the continuous removal of the loose fine soil by water. It is characterised by rounded tops and straight to concave slopes with well defined drainages. The slopes range is less than 15%.

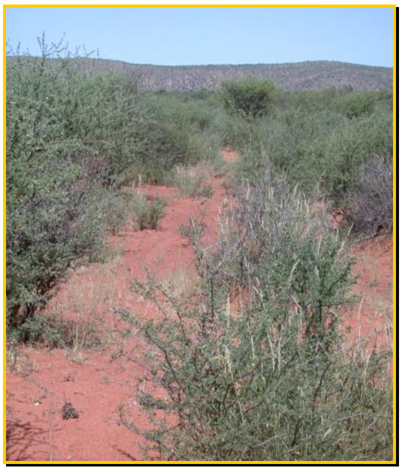
Skeletic Regosols is the dominant soil within this unit. The soils are shallow to moderately deep with many to abundant rock fragment in the profile.

Plate 4: The rolling upland is steeply dissected by drainage line that erode the fine loose soil particles and result in the exposure of hard mica-schist on the soil surface.

The rolling topography of the Khomas Hochland results in the fast removal of loose fine soil particles by water and wind erosion and leads to the formation of small islands of hard resistant mica-schist in the landscape.

On the hills slopes and crests fine sand particles have been washed and blown away and left heavy stones and fragments on top of the hard bedrock.

Plate 5: This flat plain with deep reddish loamy textured soil occurs east of Gimmrucken mountain and is covered with dense Acacia mellifera.



Grimmrucken Mountains (D4d) forms second highest point in the pilot. The average slope is more than 21% with steep, straight slopes and moderately dissected. It forms part of the central plateau.

Cambisols is the representative soil type in this mapping unit (C1c). Haplic Cambisols shows a structural development in the B-horizon.

Plate 6: Suliman 215 and Weshof 585 is covered by vast extensive plains with Cambisols and Calcisols as soil types.

Flat to nearly level plain (B2a) with open short Acacia mellifera and annual grasses. Sand plain with a flat topography maximum slope below 2%.

Crack formation result in the poor germination of plants and also low infiltration which leads to runoff and soil erosion.

Plate 7: Calcrete plains or a depression southeast of Dordabis at Skumok 167. Fine sand have blown in from neighboring regions and deposited on the petrocalcic horizon.

The average slope of the landform is >2%. The forbs in the back ground is adaptable to the calcaric and shallow soils of the pans or depressions.

The upper horizons are gray in colour which indicate highly fertility status and the deposition of other material from higher positions. The calcrete have a pale colour

Plate 8: The Kalahari sand plains are characterized by open tall Acacia erioloba trees on deep red sandy soil.

The topography of this unit is flat to nearly level sand plain (B2a) with open tall Acacia erioloba . Schmidtia sp (Suurgras) forms the basal cover.

Ferralic Arenosols are very deep, somewhat excessively drained soil with fine to medium sandy textured without rock fragments in the rooting zone.

Plate 9: Flat to nearly level sand plains south of Spandau 149. The mountain range in the background is Ottawaberge.

Nearly level landform with an average slope of >2% with a sparsely distributed Acacia erioloba tree and few “Driedoring bossies”. This unit is situated in the central plateau of Namibia.

This soil type have been blown in from neighbouring region and deposited on the irregular quartzitic fragments.

Plate 10: The absence of woody plants in this inset is having meaning for a farmer and soil scientist.

Plain (B2a) with dense annual and perennial grasses. From the extensive grazing point of view this is a good grazing land, but from an agronomic point this unit is not recommended at all.

The central plateau of Namibia is characterised by very shallow to shallow soils overlying by soft to hard impermeable layers.

Plate 11: This flat to gently undulating sand plain occurs east of the Bismarckberge one of the highest unit in the pilot area.

An extensive flat grass plain with isolated hill east of the Bismarck with a good stand of perennial grasses. The land use of this region is mainly livestock production.

Moderately deep, aridic ferralic Arenosols underlying by hard gneiss rock that restrict the down movement of plant roots and water.

Plate 12: Ovitoto communal land is characterized by a divers landscapes ranging from gently undulating gravels plains to isolated hills.

Gently undulating quartzitic gravel plain east of Okandjira with isolated hills in the background. The vegetation are sparse Acacia mellifera.

The gently undulating to undulating landforms of the central plateau is dominated by leptic-skeletic Regosols. The prominent character of this soils is the presence of 40-80% fragments.

Plate 13: The low hills covers a small portion of Ovitoto communal land with an average height of 1600 m a.s.l. The dominant soil type is "lithic Leptosols".

The low hills near Okomakuara settlement at Okomuakuara south of Okandjira are part of the central plateau.

The lithic Leptosols are very shallow soils above a hard mica-schist.

Plate 14: The peneplain with deeply dissected water channels that leads to the Swakopriver.

Undulating topography with steep concave slopes. The water erodes or washed away the fine soil particles and left the hard mica-schist rock outcrops and medium to course quartz gravels exposed to the surface.

This is a typical "saprolitic Leptosol". It consists of fine loose topsoil horizon over a partly soft, weathered mica-schist or hard mica-schist.

Plate 15: A typical "omuramba" meaning dry river valley with coarse quartzitic gravels at ovitoto in the Otjozondjupa region.

This is a typical weakly defined watercourse north of Oruua in the Ovitoto communal land with undulating to hilly terrains of the central plateau.

A Luvisols soil is being characterised by the moved of clay particles (migration) from the surface horizon to the horizons below. Meaning the B and C horizons are richer in clay as the A or ochric.

APPENDIX IV

TERRAIN MORPHOLOGICAL UNITS MAP

APPENDIX V

SOIL-TERRAIN UNITS MAP