SPATIAL ANALYSIS OF LAND SUITABILITY TO SUPPORT ALTERNATIVE LAND USES AT EXCELSIOR RESETTLEMENT PROJECT, OSHIKOTO REGION, NAMIBIA

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By

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Abstract

Since the year 1990 the government of the Republic of Namibia has embarked on a land reform programme which is a process of acquiring land, through the current system of willing seller – willing buyer, to the actual resettlement of individuals on the land purchased for such purpose. The main aim of the resettlement programme is to enhance the welfare of the people through improvement of productivity, and to develop destination areas where they are supposed to earn a decent living. However, the success of resettlement is constrained by a number of limitations during implementation such as shortage of land use planners, land evaluators and land managers.

The main aim of this study was land evaluation and land use and cover change analysis in space over time. The Excelsior Resettlement project in Oshikoto region is the object of study in this thesis. Interviews with settlers and experts took place during field work. Soil surveys were carried out to determine the land characteristics of each Land Evaluation Unit (LEU). Supporting secondary data were also collected. Actual land use types at the project are Livestock production (Cattle & Goats) Rain-fed maize and pearl millet.

Two approaches were used: a qualitative method based on expert knowledge and a quantitative model based approach, referred to as K2 & K4 level in Bouma (2000). Expert knowledge, secondary data and existing literature (K2 approach) were captured into the expert system Automated Land Evaluation System (ALES) to determine the physical suitability of each LEU for both current and potential land uses. Soil and climatic data were inserted into CropWat (K4 approach) to simulate crop water requirements, effective rainfall, and evapotranspiration and to assess the yield reductions in the given conditions. Each LEU (point/Post) was evaluated for its suitability of LUTs that included cowpea, maize, pearl millet, sorghum and rangeland (grazing). Most of these LUTs had moderate or marginal suitability for the different LEUs.

The method of land use and cover change detection by comparing classification was applied to identify land-use and land cover changes using difference satellite images (1990, 2000 & 2005). Normalized Difference Vegetation Index (NDVI) was also used for land use and cover change analysis of the project. Results of the change detection analysis reveals land use and cover changes in space over time, due to homestead construction, extra dryland needed for cropping and bush thickening as a result of woody plants invading the open areas. The overall changes are accounted for 43% while unchanged is 57%.

Dedicated to my lovely wife Isabel Lumba Mwazi and
my wonderful sons, Owen Mwazi and Nyambe Mwazi Jr.
for enduring my absence

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The success of this Thesis would not have been possible without various contributions and support from people I interacted with during my study period in The Netherlands. I thank all those who contributed to this work directly or indirectly.

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Love & Peace

Table of contents

List of figures

List of tables

1. INTRODUCTION

1.1. Resettlement in Namibia

Since the year 1990 the government of the Republic of Namibia has embarked on a land reform programme which is a process of acquiring land, through the current system of willing seller – willing buyer, to the actual resettlement of individuals on the land purchased for such purpose. The Agricultural (Commercial) Land Reform Act (Act No. 6 of 1995) also provides for compulsory acquisition of land for public interest, provided fair compensation is paid to the owner of such land (MLR, 2001a). The provision of the Act stipulates that after a farm has been purchased it should be demarcated into farming units which must be advertised for allotment.

The nature of resettlement is highly complex, because it requires rigorous application of social, agricultural as well as physical planning principles (MLR, 2001a). In Namibia, the resettlement process targets previously disadvantaged groups (the main target groups are members of the San Community, Ex-soldiers, and Returnees from exile and many more people in need of the land) of the population, and it is a popular and irreversible policy (MLR, 2001a).

The land evaluation is undertaken by the Directorate of Land Reform, under the Ministry of Lands and Resettlements. Its activities are based on the Act which provides the legislative basis for the acquisition and distribution of land in the communal and commercial farming area (MLR, 2001a). The main aim of the resettlement programme (MLR, 2001a) is to enhance the welfare of the people through improvement of productivity, and to develop destination areas where they are supposed to earn a decent living. Specific objectives as outlined by the Ministry of Lands and Resettlement on behalf of the Government of the Republic of Namibia are as follows: (MLR, 2001a)

- To redress past imbalances in the distribution of natural resources, particularly land.
- To give an opportunity to the target groups to produce their own food with a view towards self-sufficiency.
- To bring small-holder farmers into the mainstream of the Namibian economy by producing for the open market and to contribute to the country's Gross Domestic Product.
- To create employment through farming and other income generating activities.
- To alleviate human and livestock pressure in communal areas.
- To offer an opportunity to citizens to reintegrate into society after many years of displacement by colonialization process, war of liberation and other diverse circumstances.

Resettlement in Namibia has political, economic and social benefits in terms of returning land to the landless in order to alleviate poverty. However, the success of resettlement is constrained by a number of limitations during implementations. The shortage of qualified land use planners, land evaluators, land managers, resettlement officers and land economists within the ministry has made the implementation of the land reform process difficult (Werner, 2002). Werner explained that this has resulted in lack of proper land evaluation in the country; it is also regarded as a contributing factor to unsustainable use of the area's natural resources. According to Werner, redistributive land reform and the development of resettlement projects in both communal and acquired commercial areas were developed in some parts of the country.

Oshikoto region is one of the areas that benefited from the development of resettlement projects and also one of the places where currently settled farmers are faced with farming hardships. The Excelsior Resettlement project in Oshikoto region is the object of study in this thesis. Fourteen families are settled at this project. The project has been divided into five farm units (posts), excluding an extra post for community grazing. Each unit is shared between two to four families. The main Land Utilization Types (LUTs) in the area are Livestock production (cattle & goats) and Rain-fed maize and pearl millet. The farmers depend on rain-fed agriculture, but have no or few clues on land suitability for alternative land uses. Their establishment has also led to land use and land cover changes around the project. However, the extent of these changes is not known.

1.2. Research Objectives, Questions and Hypothesis

1.2.1. Objectives

The general objective of this study was to perform land evaluation and land use and cover change analysis in space over time (1990, 2000 & 2005). Two approaches were used: a qualitative method based on expert knowledge and a quantitative model based approach, referred to as K2 & K4 level in Bouma (2000). Expert knowledge, secondary data and existing literature (K2 approach) were captured into the expert system Automated Land Evaluation System (ALES) to determine the physical suitability of each LEU for both current and potential land uses. Soil and climatic data were inserted into CropWat (K4 approach) to simulate crop water requirements, effective rainfall, and evapotranspiration and to assess the yield reductions in the given conditions. Relevant Land Characteristics (LCs) and Land Qualities (LQs) corresponding to Land Use Requirements (LURs) were selected. Each LEU (point/Post) was evaluated for its suitability of LUTs that included cowpea, maize, pearl millet, sorghum and rangeland (grazing). Most of these LUTs had moderate or marginal suitability for the different LEUs.

The method of land use and cover change detection by comparing classification was applied to identify land-use/land cover changes using difference satellite images (1990, 2000 & 2005). Normalized Difference Vegetation Index (NDVI) was also used for land use and cover change analysis of the project. Results of the change detection analysis reveals land use and cover changes in space over time, due to homestead construction, extra dryland needed for cropping and bush thickening. The overall changes are accounted for 43 % while unchanged is 57%. The intended audience of the evaluation is the government, particularly the Ministry of Lands and Resettlement, Ministry of Agriculture & Forestry as well as the farm managers of the resettlement projects.

Specific objectives include the following:

a) To conduct a baseline field surveys of actual and potential land use types and interpret secondary information.
b) To perform land evaluation, based on selection and quantification of LCs and LQs using K2 & K4 knowledge level of complexity.
c) To determine land cover changes with satellite imagery using change detection methods.
d) To map land use and cover change of the Excelsior Resettlement Project.

1.2.2. Research Questions

a) What are the current and potential land use types?
b) How suitable are the current and potential LUTs for the area?
c) How can expert's knowledge for Automated Land Evaluation System be elicited?
d) How has land use/land cover changed in space over time in the area?
e) Can land use/land cover in resettlement areas be mapped using GIS & RS techniques?

1.2.3. Expected Outputs

a) Maps
b) Thesis

1.2.4. Hypothesis

The expected answers to questions were:

a) Both a qualitative and quantitative land evaluation provides tools that allow useful comparison of current and potential land uses.
b) The study of land use and cover change reveals that resettlement of people has impact on the land use and cover pattern in space over time.
c) Multi-temporal remote sensing data analysis is indispensable to understand land use and cover changes and should be used more often in land use monitoring.

1.3. Conceptual Framework of Land Suitability Evaluation (LSE)

In order to carry out the research tasks effectively a conceptual framework was developed to serve as a guiding tool. The framework (**fig. 1-1)** shows the data information flow during the study, towards the land suitability evaluation of Excelsior Resettlement Project. The framework is discussed in Chapter 4.

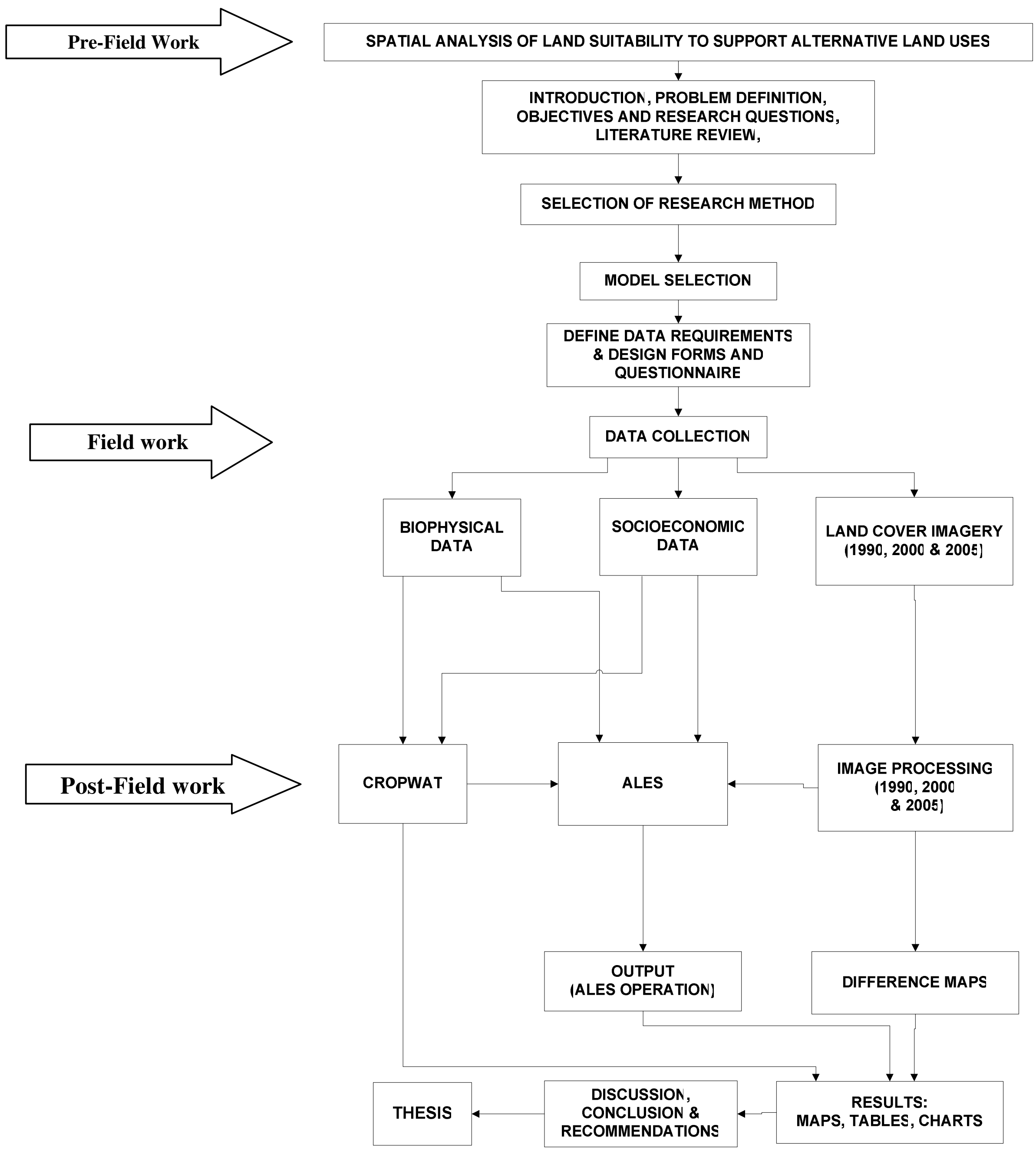


Figure 1-1: Illustration of a generalized research procedure that was followed

1.4. The Outline of this Thesis

- Chapter 1: provides a general introduction and problem definition, the objectives and research questions.
- Chapter 2: gives a general overview of the definitions on land evaluation and land use and cover change detection.
- Chapter 3: Introduces the study area, items of location, climate, soil, vegetation, infrastructure, population and Excelsior farm units/posts.
- Chapter 4: explains the study methods and materials used.
- Chapter 5: explains the results and discusses them.
- Chapter 6: provides conclusions and recommendations.

2. LITERATURE REVIEW

This chapter explains concepts and general overview for land evaluation. The first part deals with a list of definitions/ glossary used in this thesis. The second part gives a brief discussion of FAO Framework for land evaluation, Automated Land Evaluation System (ALES), CropWat, Levels of complexity, Eliciting of expert knowledge, and Land Use and Cover Change analysis (LUCC).

2.1. List of Definitions/ Glossary for Land Evaluation

Automated Land Evaluation System (ALES) – ALES is a computer program that allows land evaluators to build expert systems to evaluate land according to the method presented in the FAO Framework (1983) for Land Evaluation. It is intended for use in project or regional scale land evaluation (Rossiter, 1990). ALES has seven components (Rossiter and van Wambeke, 1995) which are:

- A framework for a knowledge base describing proposed land uses, in both physical and economic terms;
- A framework for a database describing the land areas to be evaluated;
- An inference mechanism to relate these two, thereby computing the physical and economic suitability of a set of map units for a set of proposed land uses;
- An explanation facility that allows model builders to understand and fine-tune their models;
- A consultation mode that allows a casual user to query the system about one land use at a time;
- A report generator (on-screen, to a printer, or to a disk files); and
- An import/export module that allow data to be exchanged with external databases, geographic information systems, and spreadsheets.

CropWat 4 Windows 4.3 software – is a decision support system developed by the Land and Water Development Division of FAO (FAO. et al., 1998). The program uses FAO (1992) Penman-Monteith methods for calculating reference crop evapotranspration (ETo), crop water requirements (CWR), irrigation requirements and scheme water supply, to develop irrigation schedules under various management conditions and effective rainfall. And also to evaluate rain-fed production and droughts effects (FAO and UNEP, 1999; FAO. et al., 1998).

Crop Water Requirements – is defined as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall or irrigation and does not limit plant growth and crop yield (FAO. et al., 1998; WCA, 2005).

Effective rainfall – is the amount of rainfall that enters the soil and is stored in the crop root zone (FAO. et al., 1998; UNL and USDA, 1996).

Land Characteristics (LC) – is an attribute of the land that can be measured or estimated and that can be used for distinguishing between land units of differing suitabilities for use and employed as a means of describing land qualities (FAO, 1983; Rossiter and van Wambeke, 1995). Examples are mean annual rainfall, pH and soil nitrogen percentage.

Land Evaluation – is the assessment of performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soil vegetation, climate and other aspects of in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (Bouma, 2000; de Bie, 2000; FAO, 1998a; FAO and UNEP, 1999; Huizing and Bronsveld, 1994; Rossiter and van Wambeke, 1997; van Lanen, 1991; Vink, 1975).

Land qualities (LQs) – Is an attribute of land which acts in a distinct manner in its influence on the suitability of the land for a specific kind of use (FAO, 1983; Rossiter and van Wambeke, 1995; Vink, 1975). These are properties of the land, but an essential feature is that they influence land use in a particular manner (FAO, 1983). Examples are temperature regime, moisture availability, nutrient supply and rooting conditions.

Land mapping units – Is an area of land, usually mapped, with specified characteristics, employed as a basis for land evaluation (FAO, 1983; Rossiter and van Wambeke, 1995). These are sets of map delineations designated by a single name, and representing a single legend category.

Land suitability concepts - There are four categories recognized for classification of land suitability (FAO, 1983):

a. Land Suitability Orders: suitability orders indicate in the simplest form whether land is suitability or not suitable, for specified use. Where as S = Suitable, N = Not suitable for the land use.
b. Land Suitability Classes: suitability classes show the degree of suitability within an order. The following are the land suitability classes:
    - S1 (highly suitable) – land having no significant limitations to sustained application of a given use.
    - S2 (moderately suitable) – land having limitations which in aggregate are moderately severe for a sustained application of a given use.
    - S3 (marginally suitable) - land having limitations which in aggregate are severe for sustained application of a given use and will reduce productivity or benefits.
    - N1 (currently not suitable) - land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.
    - N2 (permanently not suitable) – land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of a given land use.
c. Land Suitability Subclasses: subclasses reflect kinds of limitation or required improvements measures within classes.
d. Land Suitability Units: indicating differences in required management within subclasses.

Land use - is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO, 1998a; Nunes and Auge, 1999; Vink, 1975).

The selection of relevant land use alternatives is based primarily on the physical and socio-economic conditions prevailing in the area under consideration (Elsevier, 1989). This may refer to major kinds of land use or to land utilization types (LUTs).

Land Use Requirements (LUR) – these are requirements needed by the land utilization types for their successful operations. The group of land-use requirements are those related to the physiological requirements of the crops (crop requirements), management requirements and conservation requirements (FAO, 1983; Rossiter and van Wambeke, 1995).

Land Utilization Types (LUTs) – is a kind of land use defined in more detail, according to a set of technical specifications in a given physical, economic and social setting (FAO, 1983; Rossiter and van Wambeke, 1995; Sys et al., 1991).

Normalized Difference Vegetation Index (NDVI) is calculated from the visible and near-infrared light reflected by vegetation (NASA, 2005). According to NASA nearly all satellite Vegetation Indices employ this difference formula to quantify the density of plant growth on the Earth — near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. The result of this formula is called the Normalized Difference Vegetation Index (NDVI). Written mathematically, the formula is: NDVI = (NIR — VIS)/ (NIR + VIS). Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves (NASA, 2005).

Reference Crop Evapotranspiration – is the rate of evapotranspiration from a hypothetical reference crop with specific characteristics, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, not short of water (FAO. et al., 1998; UF, 1994).

2.2. Land Evaluation

2.2.1. FAO Framework for land evaluation

The major trends in land evaluation since 1950 have been a shift from broad to specific assessments, increasing use of nonsoil factors, and increasing quantification (Van Diepen et al., 1991). In response, the Framework for Land Evaluation (FAO, 1976) was developed jointly by FAO and a Dutch working group in consultation with a number of international experts (Van Diepen et al., 1991). According to Van Diepen, Van Keulen, Wolf and Berkhout modern land evaluation has gradually developed into an interdisciplinary field of study, aiming at the integration of knowledge of land resources and land use. The art of land evaluation is to predict the most important changes, to decide whether these are desirable or acceptable, and thus to categorize the proposed as a wise or unwise use of land (FAO, 1980). FAO stated that successful land evaluation is necessarily a multi-disciplinary process. And therefore the use of a standardized framework, i.e. FAO Framework (1983) for Land Evaluation, is essential to ensure logical and as far as possible, qualitative & quantitative analysis of the suitability of the land for a wide range of possible land uses. The Framework for Land Evaluation sets out basic concepts, principles and procedures for land evaluation which are universally valid, applicable in any part of the world and at any level, from global to single farm (Van Diepen et al., 1991). Van Diepen, Van Keulen, Wolf and Berkhout explained further that the framework as such does not constitute an evaluation system but is primarily designed to provide tools for the construction of local, national, or regional evaluation systems in support of rural land use planning.

The basic concepts of the Framework include land, land (mapping) unit, and major kind of land use, land utilization type, land characteristics, land quality, diagnostic criterion, land use requirement, and land improvement (Van Diepen et al., 1991). Based on the objectives of the evaluation, relevant land use types, land characteristics and land qualities are defined. FAO distinguishes simple land use type and compound land use type. A simple land use type is about one use at a time; in agricultural LUTs this means one crop species per cycle. A compound LUT means several uses at a time (intercropping) or more than one activity per cycle (multiple) (FAO, 1983).

The FAO framework does not allow the use of land characteristics directly to assess suitability. The framework recommends describing the land in terms of land qualities (Van Diepen et al., 1991). According to Van Diepen, Van Keulen, Wolf and Berkhout, this means a conversion of land LCs into LQs. Both are properties of the land, but the advantage of using LQs would have a distinct influence on land use and they constitute the integrating expression of a large number of interacting land characteristics (Driessen and Konijn, 1992; Van Diepen et al., 1991). Van Diepen, Van Keulen, Wolf and Berkhout explained that LQs are usually rated on a scale ranging from 1 (very good) to 5 (very poor) and ratings are compared with the requirements of a given land use. Therefore, land qualities are inferred from a set of diagnostic land characteristics.

The framework allows comparing or matches the requirements of each potential land use with the characteristics of each kind of land (FAO, 1983). Overall land suitability of a specific land area for a specific land use is evaluated from a set of more-or-less independent land qualities, which may each limit the land-use potential (Rossiter and van Wambeke, 1997). Rossiter and van Wambeke explained further that these evaluations almost always classify map units of natural resource inventories, such as the legend categories of soil survey, into suitability subclasses, based on the number and severity of limitations to land use. Hence ALES was developed within this tradition (Rossiter and van Wambeke, 1997).

2.2.2. Automated Land Evaluation System (ALES)

In ALES, expert users describe proposed land uses as well as the geographical areas to be evaluated; using their own set of criteria based on their knowledge and final allow the program to automatically do the matching (Rossiter, 1990). According to Rossiter, ALES is a shell which provides a reasoning mechanism and constrains the evaluator to express inferences using this mechanism. In ALES the interrelations of LCs to define a certain LQ and of LQs to eventually arrive at the physical suitability assessment have to be accounted for in the form of decision trees based on the FAO framework. The expert system allows the user to build decision trees, containing ratings for land qualities and requirements for land utilization types done in the form of matching. The matching procedure of land-use requirements and land qualities, including the sequence of steps is much clear when using decision trees, rather than matching tables (Bouma et al., 1993). It is important for the evaluators to construct decision trees to infer each land quality from its set of diagnostic land characteristics. These are hierarchy multiway keys in which the leaves are results (e.g. severity levels of land qualities), and the interior nodes of the tree are decision criteria (e.g. land characteristics values) (Rossiter, 1990).

ALES is able to evaluate land in physical terms only, or in both physical and economic terms. Each evaluation may include a set of land mapping units and land utilization types, i.e. proposed land uses. In physical evaluation, map units are assigned physical suitability classes, which indicate the relative suitability: s1, s2, s3/n1 and n2. ALES have been applied in several studies of Land Evaluation. For example, grazing or rangelands (Msuku, 1990), evaluate possibilities for injection of slurry from animal manure (van Lanen, 1991), land use planning (Funnpheng et al., 1994), land suitability, and erosion hazard (Noroozi, 1997), evaluating land evaluation (Habibi, 1998), soil and land use (Shepande, 2002). van Lanen (1991) explained that ALES allows the land units to be screened quickly for the requirements to be met. Therefore, at a later stage more detailed analysis could be carried out using a different knowledge level on the complexity scales.

2.2.3. CropWat 4 Windows 4.3 Software

CropWat uses monthly climate data to estimate evapotranspiration and the monthly ETo has to be distributed or smoothed into equivalent daily values. The monthly rainfall is divided into a number of rain storms per each month. CropWat 4 Windows does this in two steps (FAO. et al., 1998): Firstly the rainfall from month to month is smoothed into a continuous curve. The default curve is a polynomial curve. Secondly, it assumes that the monthly rainfalls in six separate rainstorms, one every in five days. It predicts crop yield reductions caused by water shortage based on climate data, soil data and planting date (Bronsveld et al., 1994; Kuneepong, 1994). This has been applied in several areas to simulate the crop water requirements and water use, with reference to Sub-Sahara Africa in the rain-fed agriculture. The aim was to show the historical trends of productivity of water (PW) for selected crops and identify the forces dictating PW (Igbadun et al., 2005). CropWat has also been applied as crop growth model to support land evaluation (Kuneepong, 1994).

2.2.4. Levels of complexity scales

In the older land evaluation work, attempts were made to find proxies for land quality (Land Characteristics) which are attributes of land that can be measured or estimated (Bouma, 2000). Bouma explained that land Evaluation is based on the Degree of Computation (Qualitative to Quantitative), Degree of Complexity (Empirical to Mechanistic) and Level in the Scale Hierarchy (Molecular Interaction to World) and different knowledge levels (fig 2-1). Different research approaches occur within the plane thus obtained: K1 represents user knowledge; K2 represents expert knowledge; K3 represents knowledge to be obtained through semi-quantitative models, in which real soil processes are not known; K4 represents knowledge through quantitative models where processes are characterized in general terms; and K5 represents the same, but processes are described in great detail which can imply that the entire soil/crop system cannot be characterized anymore and attention is focused on one aspect only. Bouma explained that its application has been facilitated by automated computer-driven decision support systems.

The use of expert knowledge, captured in a computer system such as Automated Land Evaluation System (ALES) (Rossiter, 1990), implies that the evaluation of all land units is carried out quickly (van Lanen, 1991). van Lanen explained that fast results can only be possible when expert knowledge captured in a computer system is linked to a geographical information system (GIS). Use of expert knowledge, a K2 level is a characteristic of qualitative methods (fig 2-1). Qualitative physical land evaluation methods indicate the degree of suitability of land for a particular land use in qualitative terms (e.g. well suited, marginally suited) (Driessen and Konijn, 1992; van Lanen, 1991). Experts determine which land use requirements are relevant to the functioning of a particular system, the adequacy of the corresponding land qualities, and the overall suitability (Driessen and Konijn, 1992).

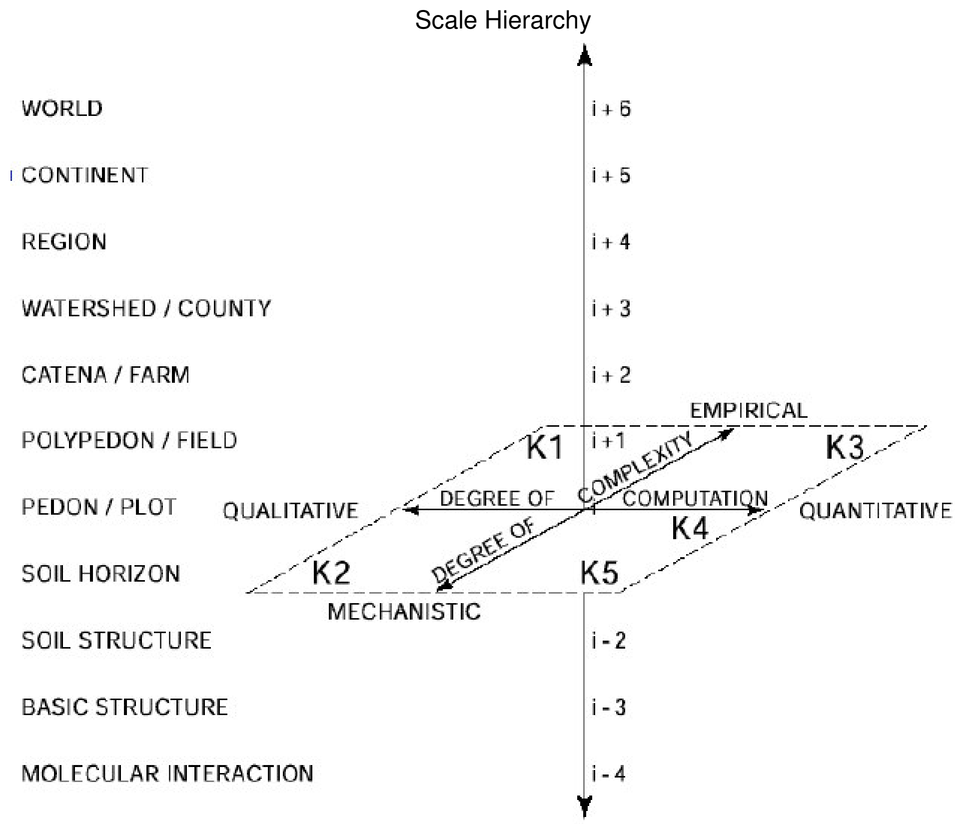


Figure 2-1: Scale diagram showing a series of hierarchy scales (i Levels) and modelling approaches expressed in terms of four characteristics, which are summarized in terms of knowledge levels K1-K5. Source: Bouma (2000)

The use of quantitative models a K4 level, such as CropWat 4 Windows 4.3 software is a characteristic of quantitative methods (fig 2-1). Quantitative physical land evaluation methods yield quantitative expressions for crop production, such as crop yield in kg dry matter per unit of area (van Lanen, 1991). Driessen and Konijn explained that the methods differ among applications but matching relevant land-use requirements against the corresponding land qualities or land characteristics in single-land-use systems forms the core of the procedure in all cases.

The level of complexity scales gives an option to select the right approach to address the problem to be investigated. In the Sahelian region, contradictory statements at the K1 level (Farmer's knowledge) indicated the need for K2 level (Expert knowledge) when investigating soil conditions and due to lack of data and complex, highly heterogeneous agro-ecological environment (Bouma, 2000). Sometimes a combination of approaches is required due to other land qualities that cannot be characterized well by one simulation modelling. Therefore, a mix can be obtained in a decision tree of branches based on qualitative data combined with branches using quantitative data obtained by simulation (Bouma et al., 1993). Hence in this study qualitative (ALES) and quantitative (CropWat) methods were applied.

2.2.5. Eliciting expert knowledge for land evaluation

Conducting interviews for land evaluation requires a good understanding of the subject and communication skills. Bouma, Wagenet, Hoosbeek and Hutson (1993) concluded that results obtained in their study after interviewing ten experts for land evaluation, showed distinctions based on the background of the experts. The performance of the expert system (i.e. ALES) in terms of the systems reliability, validity and utility depends on the reliability, validity and accuracy of the elicited knowledge (Boose and Gaines, 1988). However, Driessen and Konijn (1992) explained that as long as different experts interpret aspects of land use systems differently, reproducibility will be poor.

2.3. Land Use and Cover Change detection (LUCC)

Everywhere in the developing world, expanding population is having an impact on the vegetation (Meyer and Turner, 1994). Space is needed to grow food and to setup shelter for a living. The study of the land-use/ land cover patterns and the monitoring of changes are very important for economic planning and development. And also important for updating land use/ land cover maps, management of natural resources and improve understanding of, and gain new knowledge of interactive changes between land uses and covers (Lwin et al., 1997; Nunes and Auge, 1999). In order to understand recent changes in the earth system, the research community needs spatially-explicit data on how land use/land cover has changed as a result of human use (Nunes and Auge, 1999). Land cover changes may fall into two categories, conversion and modification. Conversion is the result of change from one class of land cover to another, e.g. grassland to cropland. Modification is the result of change of condition within a land cover, such as sparsely distributed bushes to thicket or bush encroachment, or change in its composition (Nunes and Auge, 1999). Land cover is used to infer land use which is rarely caught through the source data but rather through expert and user's knowledge, fieldwork and other secondary data (Compaore, 1998).

Measurements of past rates and spatial patterns of land-cover changes can be derived from: maps and indirect evidence on past land cover, for the historical period (past years to the present) and remote sensing-based data for the recent past (last 30 years) (Nunes and Auge, 1999). Satellite remote sensing, because of its temporal resolution, provides an excellent historical framework for estimating the spatial extent of land use and cover changes (Serra et al., 2002). Serra, Pons and Sauri explained that using satellite images, different types of LUCC changes have been monitored, for instance in urban development, in agricultural crop rotation or in deforestation assessment. The method of satellite images have also been applied in the identification of land cover and for detection of land use changes (Huising and Mulders, 1992; Jansen and Gregorio, 2002) and Biomass changes (Richters, 2005).

3. STUDY AREA

3.1. Location

The Republic of Namibia has a land surface of 824 268km^2 situated along the south Atlantic coast of Africa between 17 and 29 degrees south of the equator. This research was undertaken at local scale on the Excelsior Resettlement Project (fig.3-1). The project is 6234ha, found 40km north of Tsumeb town situated in the Guinas constituency, Oshikoto region, Namibia. Oshikoto region is one of the first places where resettlement projects began and is 26 607,162 km^2, in the north central part of Namibia. The area was selected given that the resettlement process, including the training of settled persons, is a current issue of national importance of which the Agriculture Department of the Polytechnic of Namibia wished to learn more and contribute towards. These farmers are trained the basics of farming, particularly crops and livestock handling. It has been done through a participatory rural appraisal approach coordinated by lecturers from the Department of Agriculture, where students & the communities do the role plays.

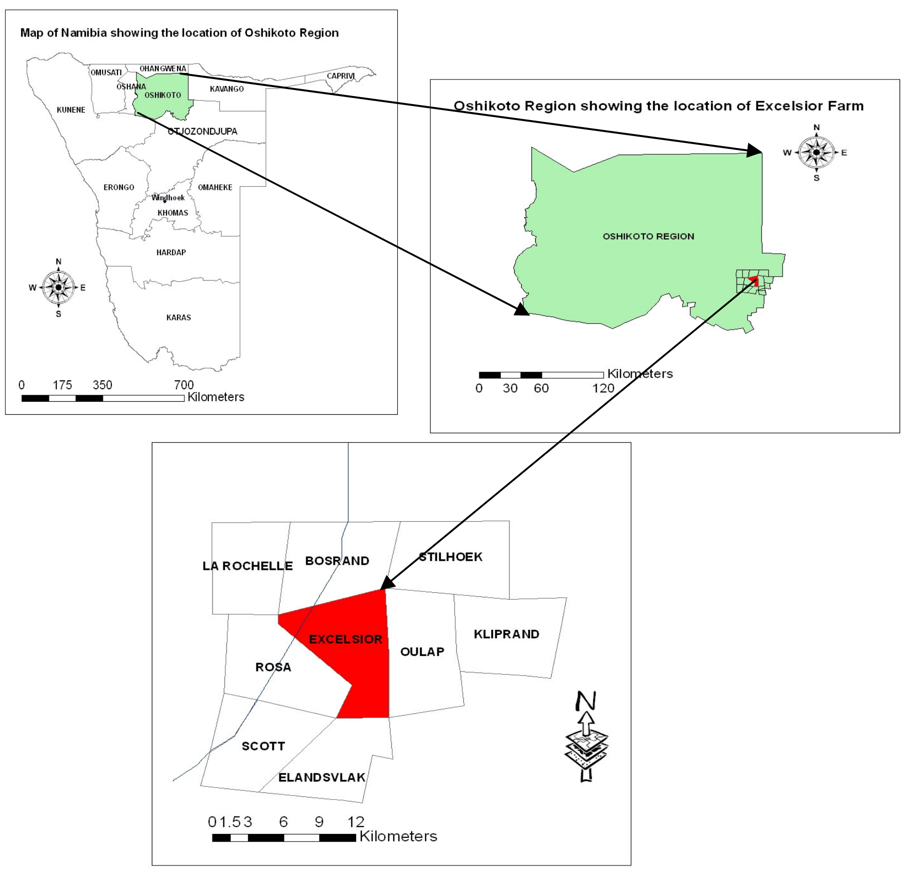


Figure 3-1: Location of the Excelsior Resettlement Farm the study area in Oshikoto Region, Namibia. Source: (UK, 2002)

3.2. Climate

Namibia is classed as the driest country in sub-Saharan Africa (du Pisani, 1997; Elsevier, 1989). It has a highly variable and unpredictable climate which is subject to great temporal and spatial perturbations in rainfall patterns. Tsumeb weather station is 40 km away from Excelsior project. The Longitude is 17. 43 degrees east and latitude is -19.14 degrees south. The Altitude is 1311 meter(s) above sea level (NMS, 2005). The climate of the study area is classified within semi-arid and sub-tropical areas (Moller, 1997), with mild winters and hot, dry summers (Appendix 1: Climate data). Rainfall ranges from 300 to 500mm per year. The annual evaporation exceeds annual precipitation.

3.2.1. Rainfall

In Namibia rainfall is highly seasonal. The mean annual rainfall of the Oshikoto region is 422mm, 90% of which occurs during the summer months of October to February (fig: 3-2) while there is no rainfall in the winter months. The rainfall is not only low, but also highly variable and unpredictable over time and space. Figure 3-3 shows the variations in rainfall over a period of 14 years. The highest rainfall amount was received in 1990 and the lowest in 1992 (Appendix 2: Rainfall data).

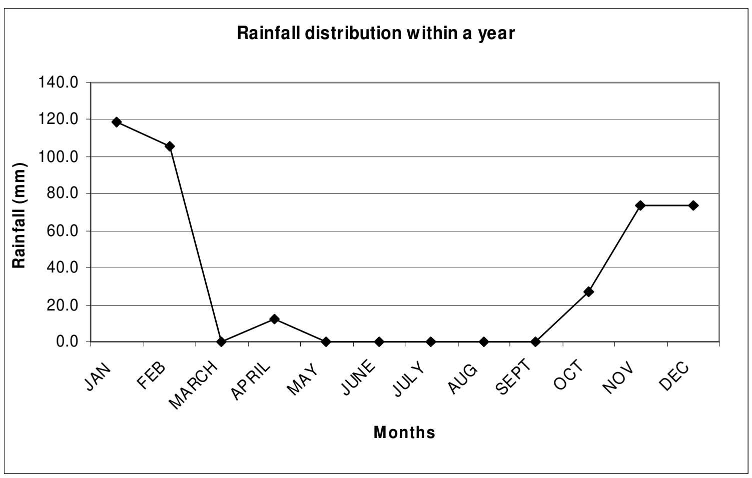


Figure 3-2: Monthly rainfall totals, 2003 (Tsumeb Station) Source: (NMS, 2005)

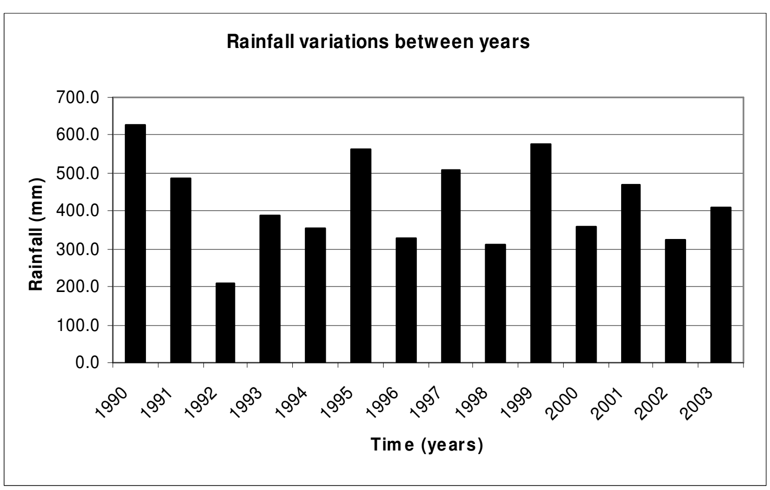


Figure 3-3: Rainfall totals (1990 – 2003) (Tsumeb Station) Source: (NMS, 2005)

Table 3-1: Descriptive statistics for monthly rainfall (mm) from 1990 to 2003

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
MIN	22	24	0	0	0	0	0	0	0	0	5	6	57
First Deciles	4	6	2	0	0	0	0	0	0	0	3	5	20
First Quartile	40	56	22	0	0	0	0	0	0	2	26	53	199
Median	114	89	48	12	0	0	0	0	0	20	32	63	378
MAX	216	185	233	89	29	0	0	0	20	96	95	158	1120
Mean	103	89	70	20	2	0	0	0	2	23	44	69	422
std. Deviation	62	46	66	28	8	0	0	0	5	26	30	43	313
Coefficiency	1.7	1.9	1.1	0.7	0.3	N/A	N/A	N/A	0.3	0.9	1.4	1.6	1.3

The descriptive statistics indicate that mean rainfall in January was the highest followed by February (table 3-1). The standard deviation is highest in March followed by January. To determine the reliability of the rain the first deciles & quartile of rain was calculated from the previous rainfall data over the past 14 years. The first deciles and quartile values are value of rainfall within 10% & 25% of the expected range in a season. (Calculation of deciles was based on quartile (40mm) by ten percent (10%), and first quartile is 25th percentile of rainfall data (appendix 2) for each month per year).

3.2.2. Temperature

Summer time is hot and dry with a maximum temperature of 33.1°C and highest in October (fig 3-4), the hottest month of the year. The winter time is mild, July being the coolest month with a daily minimum temperature of 8.1°C. High temperatures lead to high evaporation rates resulting in a net water deficit.

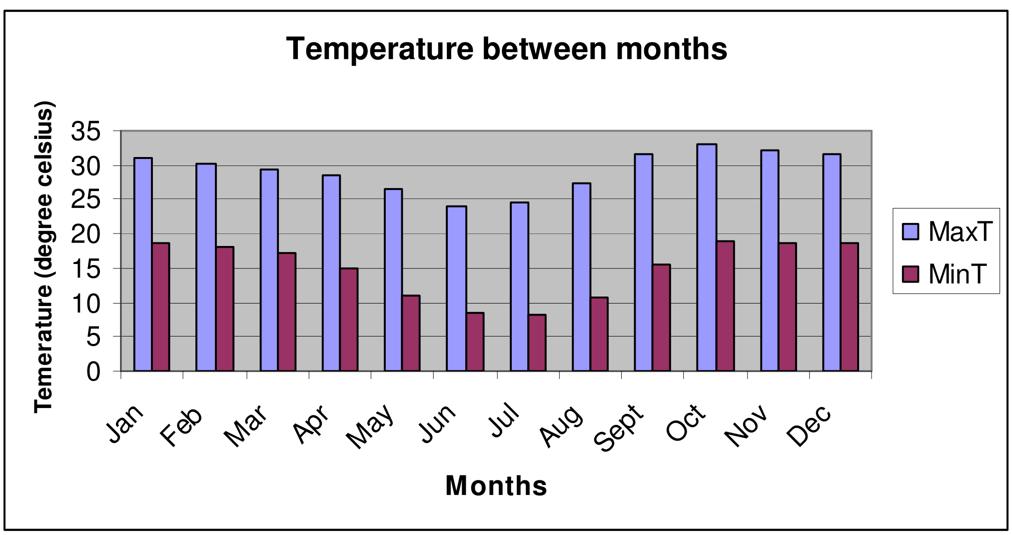


Figure 3-4: Minimum & Maximum temperature ranges per month (Oshikoto region, Tsumeb) Source: (FAO, 1998b)

3.2.3. Sunshine

The average sunshine (fig: 3-5) in Oshikoto region is between 8-9 hours per day per month. More hours per day are experienced from June to September at 10.8 hours/day. Few hours are experienced from January to May and October to December at 8 hours/day. More clouds cover during the rain season (October – March) may be the cause of fewer hours per day compared to the winter season.

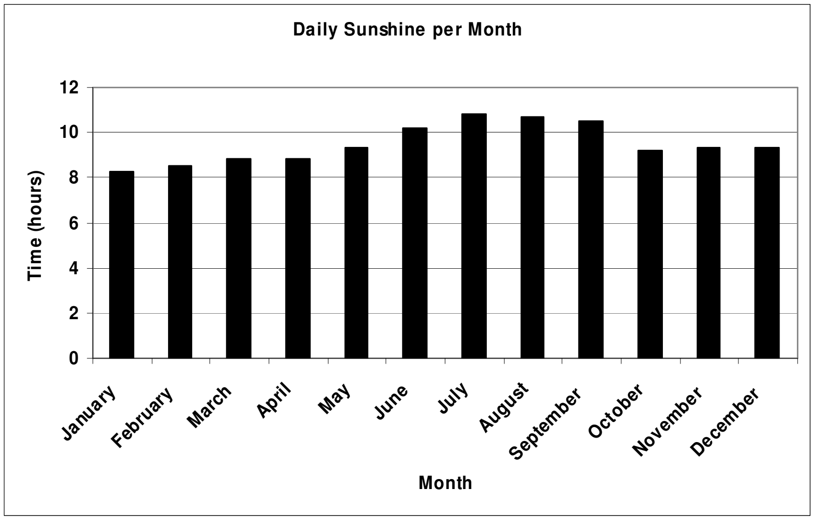


Figure 3-5: Average hours of sunshine per day per month (Oshikoto region, Tsumeb) Source: (FAO, 1998b)

3.2.4. Wind Speed

High wind speed is experienced in the area (fig. 3-6). The highest wind speeds has been experienced in June, August to November at 130 km/day. The lowest is experienced in March and April at 86 km/day.

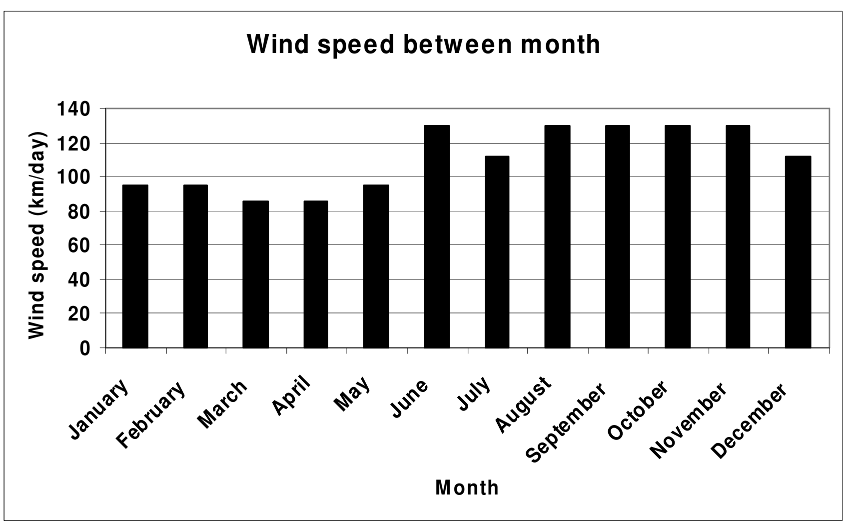


Figure 3-6: Daily wind speeds km/day per month (Oshikoto region, Tsumeb) Source: (FAO, 1998b)

3.2.5. Relative Humidity

The area experiences a high relative humidity during summers (October-March) fig.3-7. The maximum of 61% is experienced in March. It decreases from April to September with a minimum of 23%.

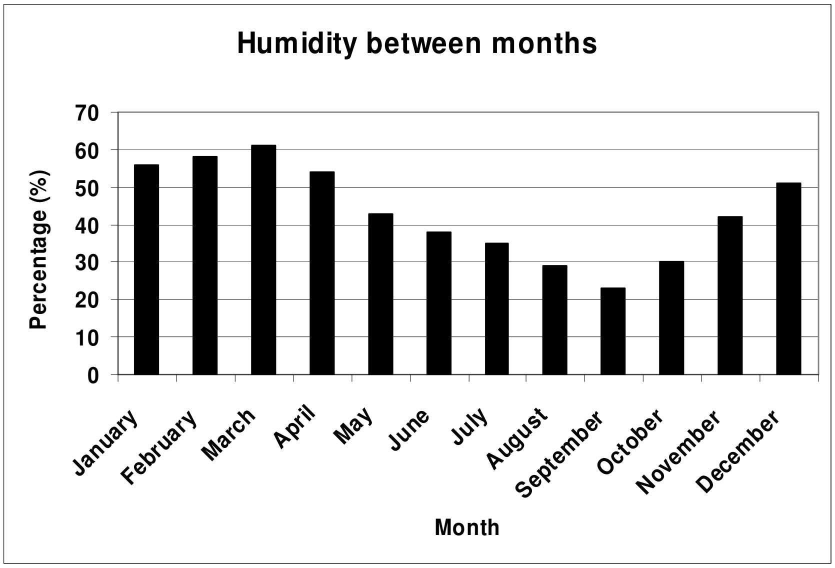


Figure 3-7: Relative Humidity between months. (Oshikoto region, Tsumeb) Source: (FAO, 1998b)

3.3. Soil

The Agro-Ecological Zones (AEZs) exercise of the whole country has been done at the scale of 1:1 million scale Map of the AEZs for Namibia (de Pauw et al., 2001). The growing period is the period of the year when both moisture and temperature conditions are suitable for production and the plant can complete its life cycle (FAO, 1998a). The project falls within Kalkveld (KALK-2) (figure 3-8) with an average growing period of 91 to 120 days with 80% of average as dependable growing period (de Pauw et al., 2001), (Appendix 3: AEZ, abbreviations).

The landform of the area is plain with a general altitude range of 1100m – 1400m. The project is within a regional slope of 0-2%, with a very low relative relief of <10m and a weakly oriented drainage pattern (de Pauw et al., 2001).

The soil in the Excelsior Project are according to the 1:1 million scale Soil Map of Namibia, 50% Petric Calcisols, with sandy to loamy topsoil, are with high lime concentrations in indurated form in the subsoil. The other 20% are Calcic Vertisols, dark cracking clays (>35 % clay) (Picture 5-1) with deficient drainage, calcium enrichment in the subsoil and 20% are Gleyic Solonetz sodic soils with poor drainage and evidence of periodic waterlogging. The remaining 10% are Haplic Arenosols: modal sandy soils with low nutrient status (de Pauw et al., 2001). This soil type has been classified through the AEZ (fig 3-8) as not suitable for cropping due to shallow soils on calcrete, but good grazing area for large livestock.

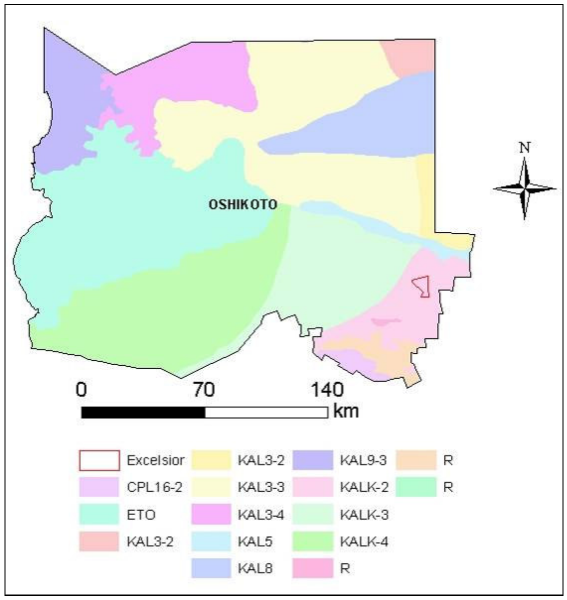


Figure 3-8: AEZs and soil units of the Oshikoto region. Source: (de Pauw et al., 2001)

3.4. Vegetation

The Oshikoto region is mainly covered by woody vegetation (MET, 2002). Almost 30% of the region is thicket bush. Thicket bush-land occupies almost the entire area of the project. Excelsior falls within the area dominated by *Dichrostachys cinerea* (Picture 3-1A) on the bush encroachment map of the Oshikoto region (appendix 4). Other plant species found are Acacia spp such as *A. mellifera,* and *A. Frekkii* which are labelled together with *Dichrostachys cinerea* as problem species in most parts of Namibia. Once open area become covered by dense layers of these woody plants resulting in areas where diverse and palatable grass species are replaced with unpalatable bush species. Then the area will have the problem of bush encroachment. It leads to the reduction in grazing capacity. As it leads to declining land productivity it is defined as a form of land degradation. The dominant grasses are *Stipagrostis uniplumis & Fingerhuthia Africana* (Picture 3-1B). These grasses are palatable to domestic animals (Muller, 1984). (See Appendix 5: other photographs taken at the project).

A) Vegetation dominated by Thicket bushes

B) Vegetation Dominated by grasses

Picture 3-1 Vegetations at Excelsior Project

3.5. Infrastructure

The project has good infrastructures such as boreholes; main road (gravel) to town, water pumps, school and concrete houses. The project is well fenced off. Each settled family has a house. There are seven boreholes around the farm for supplying water to livestock. Drinking water is supplied by water pumps which are provided to each farm unit.

3.6. Population size and size of Farm Units

Fourteen families are settled at the Excelsior Resettlement Project. At the time of the field-work, the total population on the project was 108. The farm is divided into six posts (farm units) including 1015 ha grazing area (fig: 3.9). Each post was allocated to two to four families. At the time of the visit to the area there were three dry-lands for cropping purposes. The families share the resources of the unit, including sharing the community grazing area and dryland for cropping.

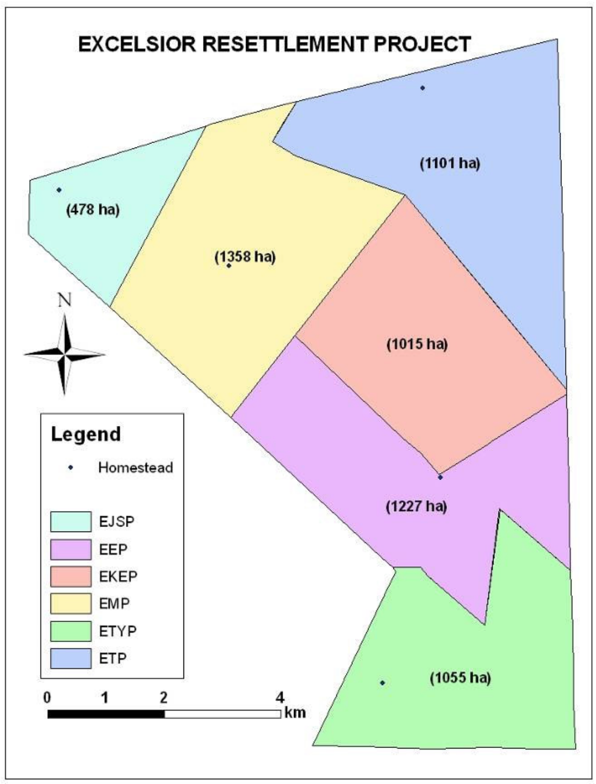


Figure 3-9: Excelsior Resettlement Project Map showing the farm units and centre or homestead location

<u>Abbreviation</u>

EJSP – Excelsior John Steel Post
EEP – Excelsior Excelsior Post
ETYP – Excelsior Thank You Post
EKEP – Excelsior Klein Excelsior Post
EMP – Excelsior Makalani Post
ETP – Excelsior Twewaadha Post

4. METHODS AND MATERIALS

4.1. Introduction

The research project was divided into three stages: Pre-fieldwork, Fieldwork and Post-fieldwork. The illustration of a generalized research procedure that was followed is shown in figure 1-1. The pre-fieldwork (first stage) included many activities such as proposal writing, literature search, selection of research methods, defining data requirements, acquiring of satellite imagery of 1990, 2000 & 2005 and perform unsupervised classification, and design forms and questionnaire. The field-work (section 4.4) was mainly for data collection i.e. biophysical and socioeconomic data. The last stage on the flow chart (post fieldwork) consists of data entry, analysis and image processing (supervised classifications) and writing thesis.

4.2. Land Evaluation Methods

System analysis in land evaluation implies the use of various types of knowledge, such as expert knowledge including stakeholder expertise and knowledge derived from scientific measurements, literature and model-simulation (Kropff et al., 2001). Kropff, Bouma and Jones (2001) explained that each problem requires its own research approach. Based on the output requirements and data availability, the proper systems approach can be selected. The Classic Land Evaluation can then be placed in the scheme at scale hierarchy based on the objectives of the evaluation. Considering the type of problem studied in land suitability evaluation a combination of a K2 & K4 (fig. 2-1) research approach was found to be more realistic for this study. It allows land suitability data to be obtained faster in which the classic land evaluation can be placed on another scale level.

4.2.1. K2 research approach

A K2 approach uses expert knowledge. After considering that these settled farmers are inexperienced and have not received any kind of training in agriculture production before. Hence local and international expert's knowledge and published tables were used for the undertaking of the land suitability evaluation. These are experts such as agricultural extension officers/ researchers within the surrounding area, Polytechnic of Namibia researchers/ agronomist, farm manager of the project and neighbouring commercial farmers.

Taking into account that the K2 application is facilitated by automated computer-driven decision support systems, Automated Land Evaluation System (ALES) (Rossiter, 1990) was used as one of the data analysis tool. The following data types was utilized in ALES to determine the suitability of different sites for the defined use: Current and potential land uses and their land use requirements, rainfall, temperature, and, soil types, soil depth, soil pH, input costs, sale prices and land (ha).

4.2.2. K4 research approach

A K4 approach was chosen because moisture requirement is such an important land use requirement for any rain-fed agriculture. A K4 approach requires quantitative models, hence CropWat 4 Windows 4.3 software (FAO. et al., 1998) was used for the simulations of effective rainfall, crop water requirements and crop reference evapotranspiration for different crops. This also allowed undertaking a field survey of rooting depths and measuring infiltration rates on each post within the project. CropWat was restricted to rain-fed schedule, based on annual practices of crops and planting dates. The methods for calculating effective rainfall, crop water requirements and evapotranspiration from meteorological data require various climatologically and physical parameters. Therefore, the following data types was utilized in CropWat software: Annual rainfall (mm), temperature (degree Celsius), air humidity (%), sunshine (hours), wind speed (km/day). Only the annual rainfall was inputted while the other climate parameters were assumed to be the default data in the CropWat model particularly for Tsumeb district, Oshikoto region.

The crop parameters required as input data in the model which include crop coefficient (Kc), and total available moisture, were also assumed to be the default data in the CropWat model. The only parameters inputted are rooting depths and infiltration rates measured per point (LEU) and planting dates for each crop, which were adjusted to the cropping calendar of the study area. Planting dates was dictated by the period of the onset of rains using the mean annual rainfall and dates followed at the project and as recommended per crop. On average rain-fed crops are planted between ends of November to December.

4.2.3. Relation of K2 & K4 approach

This research approach was based on level of complexity in Bouma (2000). The Classic Land Evaluation in the scheme (fig. 2.1) was placed at scale hierarchy of farm (i+2) while the knowledge level is K2 & K4. That also means the study approach was based on the Qualitative & Quantitative Land Evaluation Methods.

4.2.4. Land Evaluation Unit (LEU)

In this study, point based analysis to evaluate each measured site to determine the suitability for the current and potential land use types was used as Land Evaluation Unit (LEU). Therefore, it was not possible to classify based on the post or farm units due to the small size of the area. And also due to that soil information was not enough to stratify the area and post boundaries do not match the physical resource boundaries on the ground. Due to that the linkage of ALES to GIS for mapping results was not performed. The full range of the soil properties that were measured around the project including climatic situations were used for each LEU. This is only applicable to crops LUTs. The posts were used to evaluate rangeland LUTs. Because vegetation type is so important to livestock and can be extracted from images as land cover using Normalized Difference Vegetation Index (NDVI).

4.2.5. Identification of Land Use Types (LUTs)

There are certain factors that were considered during the identification of the land use types. In defining the land utilization types for the study area management, livestock production (cattle & goats), rain-fed maize & pearl millet, cultivation practices, crop calendar, sowing rate, land tenure, and market were considered. These were adapted to the local conditions of the study area upon the visit. Information for these factors was obtained through interviews from settlers, farm coordinators, and expert as well as written literatures. In this study both current and potential land use types were used for land evaluation. The current land use types (LUTs) are livestock production (cattle & goats) and rain-fed maize & pearl millet referred to as LUT1 & LUT2. Potential land use types are improved rangelands (Grazing); rain-fed maize (improved), pearl millet (improved), sorghum and cowpea referred to as LUT3, LUT4, LUT5, LUT6 and LUT7. They were chosen based on their relevance and use to the communities in the project.

4.2.6. Selection of Land Use Requirements (LURs)

The most important LURs were selected after taking into consideration the environmental conditions of the study area. The selection of LURs was based on the following four criteria (Rossiter, 2003):

- Importance (relevance) for the use
- Existence of differences in the corresponding land quality (LQ) in the study area
- Availability of data with which to evaluate the corresponding LQ
- Availability of knowledge with which to evaluate the corresponding LQ

The above criteria led to the selection of the following four LURs:

1. A moisture requirement – every crop require moisture for growth and is an important dominant factor in determining the suitability of growing a crop. And also taking into consideration that low and erratic rainfall and unfavourable rainfall distribution (variations) in the study area (figure3-3).
2. Temperature requirements – crops require temperature for growth both in the early and late stage of their life cycle. But too high or low temperature might not be favourable to certain crops.
3. Rooting conditions – very important, as it defines the soil volume available to roots to find moisture and nutrients. The deeper the soils, the more water and nutrients can be stored and absorbed by the crops. The area has been classified under very shallow as mapped on the soil map of 1:1 million scale Soil Map of Namibia (2000) (MAF, 2003a).
4. Absence of acidity and alkalinity (pH) – the effect of soil pH is great on the solubility of minerals or nutrients. Due to differences that were measured at different sites, pH has been considered as one of the LURs.

4.3. Land Use and Cover Change detection methods

The method of land use and cover change detection by comparing classification was applied to identify land-use/land cover changes using difference satellite imageries. The analysis was done using a GIS mainly Erdas 8.7 & ArcGIS 9.0 software. The sensors and images that were used are LandSat TM of the year 1990 & LandSat ETM+ of the year 2000 for the month of May at 30mx30m resolution and then ASTER (NASA, 2005) image of the year 2005 January at 15mx15m resolution. Satellite images were classified using supervised classification and compared with each other using the identical or same cover classes for both images. The difference map was then generated using matrix (intersection) which is a default in Erdas 8.7. Matrix dialog enables to create an output file that contains classes that indicate how the class values of the input files overlapped. Area for each class was calculated in Erdas 8.7 to determine the percentage change. Validation of the current classification imagery of the year 2005 was based on ground truth and extra information that were obtained during field-work. The 1990 and 2000 land use and land cover classifications could not be validated, due to the lack of GPS ground truth data for training site development and accuracy assessment. These years were validated subjectively. Normalized Difference Vegetation Index (NDVI) was also used for land use and cover change analysis of the project.

4.4. Field work

The components of the fieldwork (second stage fig 1-1) were soil survey, interviews, ground truth of the land-use/ land vegetation and collection of secondary data.

4.4.1. Soil survey

A reconnaissance survey was undertaken on the first day to get a general overview of the farm. The reason was to get to know the area better and try to figure on where to make the infiltration tests. After the tour, it was decided that three infiltration tests will be conducted in the dryland cropping and other two in potential site for dryland cropping as put forward by the settlers. This was decided because of evaluating rain-fed crops. Figure 4-1 shows the five points where infiltration rates, soil depth and pH were measured. These measurements were selected to match land quality with the land use requirements. Also to determine the amount and type of fertilizer that needs to be applied in relation to the amount of nutrients depleted by crops.

The infiltration rate – The infiltration rate and test were measured using the double ring infiltrometer (Appendix 6) at each farm unit. The double ring infiltrometer is a simple instrument that is used to determine the rate of infiltration of water into the soil (Eijkelkamp, 2005a; FAO, 2005). It is 30cm in diameter for the inside ring and 60cm diameter for the outer cylinder. The infiltrometer were inserted into the soil up to 15cm depth as vertical as possible to maintain the balance or bond between the infiltration ring and the soil.

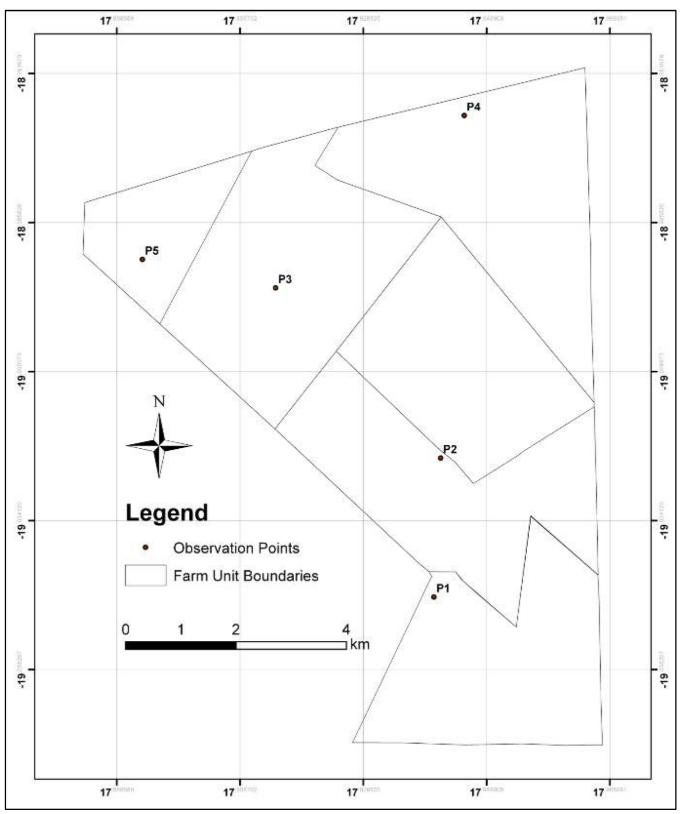


Figure 4-1: Location of observation points

The infiltration rate measurements were carried out on the dry soil and repeated twice per site. At each site 100L (litres) of water was used. The pressure of water was maintained at its original level in both buffer rings. The drop in water inside the small ring was recorded (Appendix 7) as described in the FAO guideline. For example the first reading was taken after 2 minutes then followed by 3, 5, 10, 10, 20, 20, 20 & 20 or sometimes with the interval of 30 minutes apart at the end. Every time the reading was taken, water was added to its original level.

Rooting depth –The rooting depth was measured using the soil probe to determine how deep the soil per farm unit at different sites. The soil probe was inserted into the soil until one feels that it is not penetrating anymore. The piece of the probe inserted in the soil was then measured by the 30cm ruler to determine the depth.

Soil pH – the field pH test was done using the Hellige pH-indicator (Eijkelkamp, 2005b). At each site where the infiltration test and rooting depth were conducted the pH were also recorded. Small quantities of soil were always put into the colour pH indictor, followed by the pH liquid added to it. The pH was determined based on the corresponding colour to the chart. This was repeated three times per site to make sure that the correct pH was recorded and no variability were found since the results were the same for each site.

4.4.2. Land evaluation

a) Interviews

One of the aims of the field-work was to conduct interviews with the experts and settled people for land evaluation. Arrangements were made in advance with the Ministry of Lands and Resettlement for permission to conduct interviews with the settlers at the project. Experts and farm coordinator together with the settlers were informed in advance on the days interviews was to take place. The aims and objectives of the land evaluation were outlined. These are experts such as neighbouring commercial farmers to Excelsior Resettlement Project, Agricultural Research and Extension officers in the surrounding area and the Polytechnic of Namibia researcher.

Individual settlers were interviewed using formal questionnaire (Appendix 8) that were prepared during pre-field activity. The farm coordinator was asked to give a brief history of the activities that is happening at the farm, and other information which could not be provided by the settlers. Settlers were disqualified to be in the category of experts as they are inexperienced and have few or no clues on land suitability.

Hence, experts were to be interviewed (Appendix 9) to provide information on land use types, land characteristics and other relevant information patterning to land evaluation. The neighbouring farmers and polytechnic experts were targeted to respond to questions focusing on crops and their requirements for the study area. The farm coordinator responded to management related questions pertaining to the activities of the project. Settlers and experts were informed earlier that information obtained through the interviews was going to be used for land evaluation.

b) Ground truth of the land-use/ land cover

Ground truth of the 2005 land cover map was undertaken after the map of transect was first classified using unsupervised classification. The aim was to identify the reality in the field. In return land use/

land cover was also known either through observation or information obtained from the land users. A cross transect (figure 4-2) from the South to the North (Appendix 10) was taken every one kilometre to determine the kind of land use/ land cover on the area. Certain land cover that was visible on the imageries, in which one was not sure what it was, was also visited for confirmation. For example areas that showed either dense or sparse vegetation on the image were visited. The overall classification accuracy was 50% (fig 4-2).

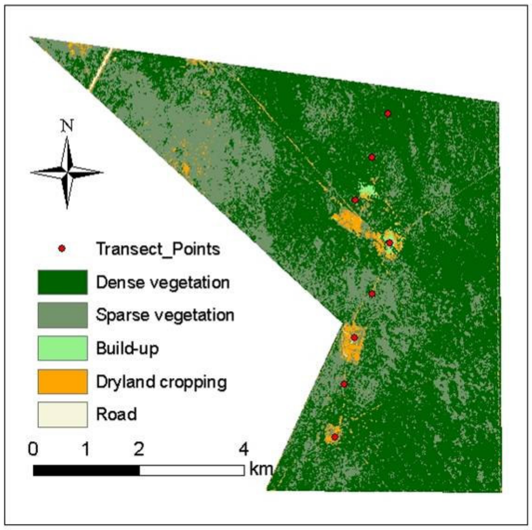


Figure 4-2: Excelsior map showing transect points

4.5. Data Capture and Processing (Post-field work: fig 1-1)

4.5.1. Data Requirements

The type of data needed depends on the approach and level at which the study was carried out. In this study, secondary data, field data and supported by existing literature were used. The data that was used in this study was collected from different sources in Namibia as shown in table 4.1 & 4.2.

Table 4-1: Biophysical data requirements and sources

Data	Description	Sources
AEZ map (at scale of 1:1000 000)	Soil/ climate suitability per crop Length of growing period	Ministry Agriculture & Forestry
Other Maps	Topography Administrative boundaries Farm Boundaries	Ministry of Lands & Resettlement Ministry of Agriculture & Forestry
Climate Data	Rainfall Temperature Sunshine Humidity Wind speed	Namibia Meteorological Services Ministry of Agriculture & Forestry and FAO (1998b)
Land Data	Land ownership information.	Farmers
Land cover and land use	Land cover imagery (1990 & 2000) Land use	ITC & Farm Manager & Farmers

Table 4-2: Socio-economic data requirements and sources

Data	Description	Source
Social information	Sizes and composition of households Distance to markets Land (ha)	Farm Manager & Farmers
Land Utilization Types	Present land use types Potential land use types	Farm Manager, Farmers & Neighbouring Commercial farmer
Economic data	Input costs Seeds Fuel & Lubrications Sale prices	Farm manager & AGRI-GRO NAMIBIA Mahangu Management Intelligence Unit (MMIU)
Government	Resettlement reports Land tenure Land reform policy	Ministry of Lands & Resettlement
Infrastructure	Roads Boreholes	Ministry Agriculture & Forestry

4.5.2. Image Processing

LandSat-TM & ETM+ imagery of dates 1990, 2000 & ASTER imagery of 2005, and a topographic and administrative boundary maps were used as input data for land use and cover change analysis (figure 4-3). To confirm the pixel grids and remove any geometric distortions in the TM & ETM+ imageries and ASTER imagery, a topographic map was first registered to the geographic (Lat/Lon) coordinate system, Spheroid name: Bessel (Namibia) and Datum name: Schwarzeck based on ground control points collected from Excelsior Resettlement Project. Then, the image of the year 1990 was registered to a topographic map followed by the image to image, from 1990 to 2000 and 2005 to ensure that all images have the same projection system.

During post classification comparison each single image was classified using 5 identical cover classes: dense vegetation, sparse vegetation, build-up, dryland cropping & roads. Matrix through intersection of the images was undertaken and the intersection attribute table was used for interpretation to determine the differences. The output is a map that presents, for example dense vegetation has changed to build up.

Three NDVI maps were generated using the same satellite imageries in Erdas 8.7 software. Before NDVI was calculated, the conversion of the DN values of the imageries to radiance was performed, followed by radiance to reflectance values and finally NDVI values. The aim of introducing NDVI was to double check the vegetation changes, since this was not possible in the first place because of not having the ground truth of the two difference imagery classifications for validating results.

4.5.3. Linkage of CropWat to ALES and GIS to ALES

CropWat is able to determine yield reductions (in percentages) when restricted to rain-fed conditions. The recommended kg/ha in the given conditions for LUTs based maize, pearl millet, sorghum and cowpea were regarded as optimum (S1) yield. Yield reductions (%) predicted by CropWat were used as input in ALES to set limiting yields for the land quality moisture requirement and rooting conditions. For other land qualities expert knowledge or knowledge specific for the study area were used (Fig 1-1 shows the link).

Then NDVI reflectance values were extracted for each post (Appendix11) using default, zonal statistics in ArcMap software (GIS). The average was used as input in ALES (Fig 1-1 link) to determine the vegetation density for each post in construction of the decision tree. For other land qualities expert knowledge or knowledge specific for the study area were used to set limiting factors in ALES for the construction of decision tree.

Data utilization (LandSat TM 1990, ETM+ 2000 & ASTER 2005)

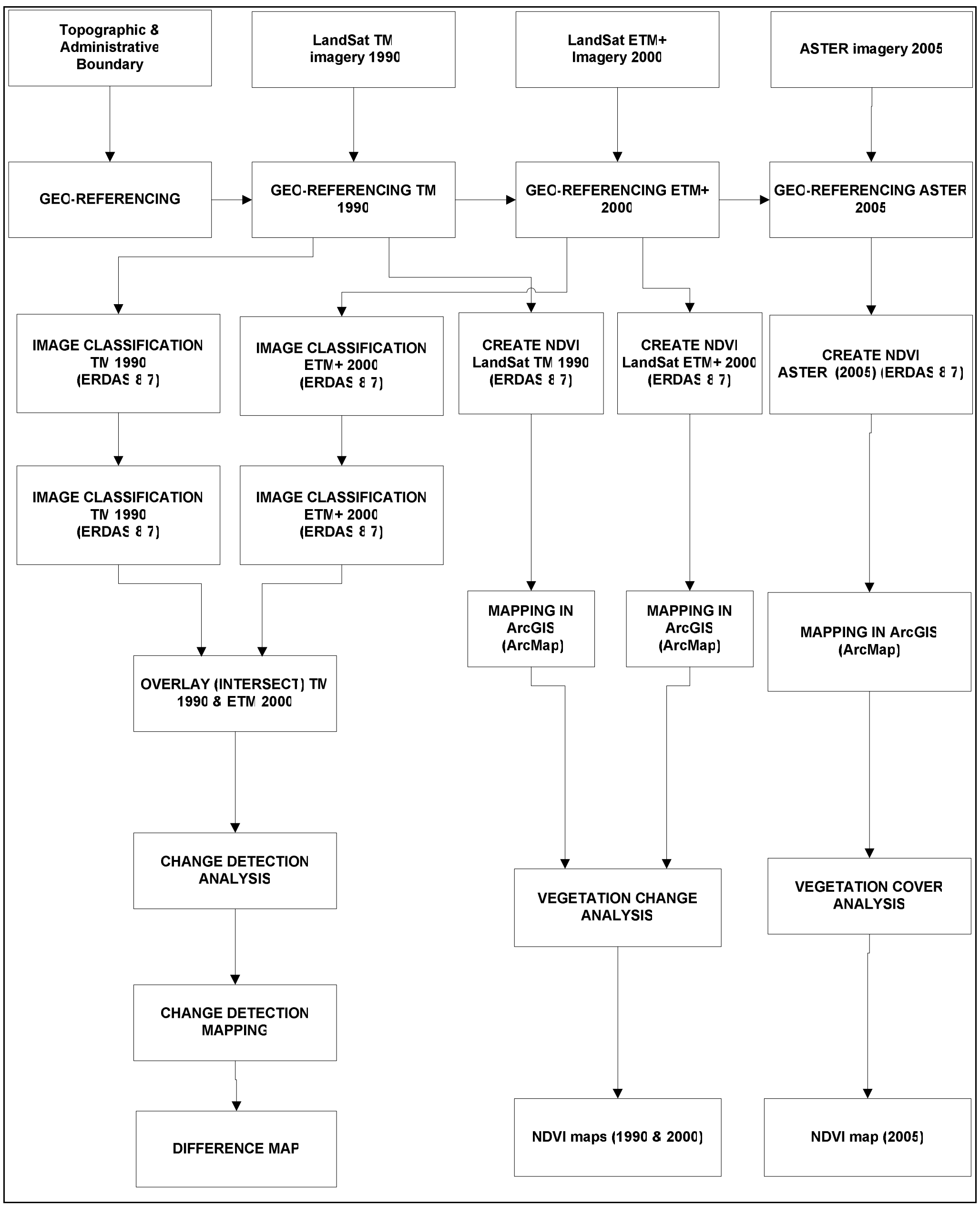


Figure 4-3: Flow chart showing major steps of image processing for land use and cover change detection analysis

5. RESULTS AND DISCUSSION

5.1. Interviews with settlers and local experts

All 14 settled families were interviewed. Most of the respondents were able to understand what was required of them. The difficulties experienced were that settlers could not provide records of the total land (hectares), produce and livestock numbers that belong to them. For that information they depended too much on the coordinator of the farm. Even the coordinator could not provide some of the information. Most of the socio-economic data used in this study was obtained through face to face interviews. Information obtained from both settlers & coordinator is incorporated in section 5.2.2 and table 5-1 below.

Table 5-1: Summary of the results of the settler's interviews

Settler's names	Post name	Area (ha)	No. of People/Family	Number of Livestock	
				Cattle	Goats
Erica !Nomases	ETYP	1055	11	6	18
Paul Hanab			6	6	3
Michael Joseph	EEP	1227	6	17	19
Olga !Nomases			13	14	28
Martha Awases			6	6	35
Hambeleleni-Tutaleni Shimbanda			12	17	51
Getrude !Aoses	EMP	1358	4	7	8
George Abaseb			9	3	18
Moses Shalongo			3	3	8
Albertina Petrus	ETP	1101	4	16	48
Hilma Jacob			4	8	48
Sikspens Namaseb	EJSP	478	17	7	6
Selma Simon			5	10	24
Tiekie Urikhob			8	4	1
Community Grazing area	EKE	1015			
Total		**6234**	**108**	**124**	**315**
Total area under cultivation: 60ha; **Crops grown**: Maize and Pearl millet; **Planting date**: November/ December					

One of the aims to conduct interviews was to extract expert's knowledge for the purpose of land evaluation. Several interviews were scheduled with the neighbouring commercial farmers, agricultural researchers and a researcher from the Polytechnic of Namibia. Only the letter actually materialized. The cause of the failure was assumed to be the sensitivity of the issue of land in the country. It has been assumed that commercial farmers had the idea that the interviews were linked to acquiring or expropriating of land by the government. This led farmers to feel insecure and unwilling to accommodate interviews. But it was not clear why the agricultural extension officers were not willing to take interviews. After they agreed in the first instance, they disappeared without explanations. However, the interview result (With expert from Polytechnic) indicates 35_ha (ETYP) as the preferred land for implementing rain-fed maize, pearl millet, sorghum and cowpea. Followed by

10_ha (EEP) and 15_ha (EJSP). This is due to calcrete depression overlain by enough soil and due to more moisture believed to be retained there. Different success is attributed to soil quality. These were separated into two groups namely; moisture and nutrients. Moisture regarded as the most important factor identified. Diagnostic land characteristics identified are soil depth, texture, carbon content and soil cover. These factors are believed to affect yield. Soil depth was identified as the most important in determining the severity level (See appendix 9 for details of interviews). These were incorporated in construction of decision tree section 5.3.1 and appendix 12.

Land suitability terminology remains a problem to different experts in general. People with different backgrounds communicate information on land suitability differently and land suitability terminologies need to be understood and interpreted correctly. The interview with the expert showed that he had a high level of knowledge in different land characteristics. But it was difficulty to interpret the land characteristics knowledge into terms of land suitability. Scientific experts, unlike land users, think in terms of observable LCs and may have difficulties with the concepts of LQs; particularly extensionists. Shepande (2002) in his study concluded that a simple and flexible questionnaire, supplemented with oral questions in simple language can help capture good land evaluation concepts from experts. Then, the rest can be left in the hands of the evaluator to transform collected data into expert system ALES.

5.2. Mapping and description of the land uses

5.2.1. Land Use Mapping

The main land uses at Excelsior Resettlement Project are livestock production (cattle & goats), rain-fed maize and pearl millet production. The dense and sparse vegetation (fig 5-1) is mostly used for grazing or browsing of livestock as indicated on the below mentioned map. The settlements represent homesteads that were established around the project. This map was produced as part of the LUCC analysis in section 5.5.

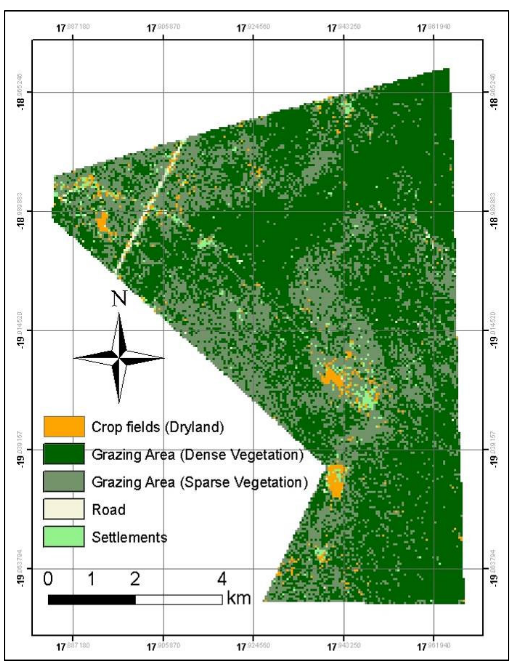


Figure 5-1: Land Use Map of Excelsior Resettlement Project (based on 2000 imagery)

5.2.2. Description of actual Land Utilization Types (LUT)

Livestock production (LUT1) is under extensive grazing, i.e., no supplementary feeds are given. Livestock has been the main emerging enterprise since people were settled. Livestock herds usually serve as a status symbol to the owners and as a saving account as animals are sold at any time. This is done especial during the time of poor harvest and when learners are returning from holiday to school. The farm units are commonly known as posts where different families are settled. There are paddocks around the project that limit the movement of livestock during grazing and are well fenced. There are approximately 439 animals, including both small and large stock, at the project. Out of the total livestock, 124 are cattle and 315 goats (table 5-1). Each household has a brand number of their livestock, to help them for identification when in the mixed herds. No animal disease was reported at the time of fieldwork. The project is outside the so called “red line” or veterinary line, which means the area, is not susceptible to diseases.

Rain-fed maize and pearl millet (LUT2) are the main crops grown at the project. These are sometimes grown under mixed cropping. These crops are used for making thick porridge, and to a lesser extent in the brewing of local alcohol and non-alcohol beverages. There are three areas for dryland cropping (10_ha, 15_ha, & 35_ha figure 5.1: land use map) utilized by all settlers on the project, which gives 60ha in total.

Ploughing is the most common approach for land and seedbed preparation. It is done late October and early November. Ploughing is done using a tractor provided by the government. Sometimes fields are left fallow, perhaps to rebuild soil fertility. The next season they are cropped while the previously cropped area will be left fallow. This practice should reduce the rate of degradation in the field, but still the large expansion of exposed soil results in high wind speeds and temperatures (Zimmermann et al., 2004). No fertilizer application was reported or observed.

The rainy season normally starts in October and ends in March (figure 3-2). Sowing is done from mid-December for both maize and pearl millet and then harvesting takes place late April and early May when the grains are completely dry (Table 5.2). Sowing is done using a planter, but no sowing rate and row spacing was reported. Weeding is undertaken in January and February respectively. Harvesting is done by hand, cutting the cobs or heads using knives. Both weeding and harvesting is undertaken by settlers themselves and their families. Crop calendar is based on the information provided by the farm coordinator during the discussion and others from literature.

Table 5-2: Crop calendar

Months **Activity**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Land preparation										↔	↔	
Sowing												↔
Weeding	↔	↔										
Harvesting				↔	↔							

Land Tenure pertains to the possession of rights to the use of land and such has a definite impact on farm management and farmers' incomes (Elsevier, 1989). In Namibia land acquired for resettlement purposes is provided to the beneficiaries on leasehold of 99 years (MLR, 2001b). So, the 99 years lease hold agreement applies also to the settlers at Excelsior Project who may use the lease as collateral to get a loan from lending institutions for agricultural production purposes.

The produce is consumed locally by settlers and surpluses are sold. The income is shared among the settlers. Table 5.3 indicates prices of maize and pearl millet grains when sold to different places. A total harvest of 3000_kg of maize and 1875_kg of pearl millet was recorded at the project for April/May 2005 harvest from both dryland cropping fields.

Table 5-3: Grain price ranges of different crops. Source: (MAF, 1998; MAF, 2003b; MMIU, 2005).

Product	Price type	Lata N$	Kg N$
Maize grain	Mill gate	20.85	1.39
Pearl millet grain	Mill gate	25.50	1.70
Maize grain	Retail	33.00	2.20
Pearl millet grain	Retail	30.00	2.00
Sorghum	Retail	-	1.50
Cowpea	Retail	-	5.00

- Lata is a measurement commonly used in trading grain assumed to be 15kg/bucket (N$ = Namibian Dollar)
- Mill gate (hammer mill) & Retail (Open market)

5.2.3. Potential land utilization types and relevant land use requirements

<u>LUT3 – Improved rangelands (Grazing)</u>: Approximately 70% of the entire project is used for extensive grazing. The existence of paddocks provides the opportunity for improved grazing systems. Such a grazing system is based on seasonal vegetation in a way that is in-line with the carrying capacity of the area. Carrying capacity refers to the number of livestock units which can be kept on the land without damaging the ecosystem and within limits of acceptable risk each year (Elsevier, 1989; FAO, 1991; FAO, 1998a). It is estimated to be at 10 ha/ LSU/year (Large Stock Unit) (MAF, 1997). The carrying capacity for the small stock unity (SSU) is estimated to be half of the LSU which is 5 ha/ SSU/year. Table 5-4 indicates carrying capacity for each post.

With 124 cattle and 315 goats on the farm at the time of the field-work, the grazing area seems to be large enough to support such a number of livestock if managed properly. By subtracting 2_ha of homestead/ households per post which gives 10_ha plus 60_ha dryland cropping this is 70_ha in total from 6234ha. The remaining 6164_ha of the areas is for grazing. Therefore, 6164ha*10ha^{-1} *LSU^{-1} per year = 616 LSU and 6164ha*5ha^{-1} *SSU^{-1} per year =1233 SSU (table 5-4). This means the project is able to keep 616 large stock units only or either 1233 if only small stock are to be kept without any harm to the vegetation in a year.

With a small number of livestock per household, a joint grazing system seems to be another option, to ensure a better utilization of the vegetation. The settlers within the posts would have to come together to decide how to apply a joint grazing management. Reaching an agreement may also avoid conflicts as a result of grazing space in the community grazing area. This will ensure a better utilization of vegetation if a large herd is restricted in one paddock for a given period. If correctly applied, it is an ideal grazing plan since it allows grazing strictly on a plant-physiological basis and effective resting of the veld in other paddocks.

Table 5-4: Carrying Capacity for each post

Post	Total ha	Available (ha)	ha/SSU/year	SSU/year	ha/LSU/year	LSU/year
ETYP	1055	1018	5	204	10	102
EEP	1227	1215	5	243	10	122
EMP	1358	1356	5	271	10	136
ETP	1101	1099	5	220	10	110
EJSP	478	461	5	92	10	46
EKP	1015	1015	5	203	10	102
Total	**6234**	**6164**		**1233**		**616**

One of the options will be to rent a few paddocks to neighbouring farmers who are overstocked. It should only be allowed during the dry season when the grasses are dormant. This should be a temporary measure until their herds have grown big enough to prevent most grasses from becoming moribund. Renting paddocks in the rainy season is not an option because re-growth of grasses will be damaged if grazed while still weak and will be forced to use all its reserved nutrients. Heavy stocking in the dry season is of little consequence, while wet-season grazing needs careful monitoring to prevent depletion of plant resources especially grasses (Ward et al., 2004).

To implement the grazing management, each paddock has to be assessed differently by estimating grazing capacity to determine how many cattle/ goats can be kept in the dry season. However in doing that, a representative area in each paddock that contains the average amount of grass for the whole land should be identified. This can be marked out a square, according to the settler's judgement which area they think it contains enough grass to feed one animal for one day and measure the area of the square. The measured area is then divided into the total hectare of each paddock/ rangeland to be grazed during the dry season to determine how many animal days can be supported. Final, divide this by the number of days remaining in the dry season and the answer will then be the number of animals that can be stocked on that paddock for that number of days.

Bush encroachment in the area is a serious problem. It is a symptom of range degradation. Methods used to combat the symptom include capital investments such as manual chopping, stem burning and mechanical clearing. Methods used to combat the causes of bush thickening include browsing pressure and prescribed burning (Zimmermann and Mwazi, 2002). These methods has been applied at the farm Hamburg (Otavi district, central Namibia) where an area of about 1000ha was burnt, followed-up by the application of goats pressure aimed at controlling bush thickening (Zimmermann et al., 2003).

LUT3-Requirements: Climate and vegetation cover determines the availability of biomass, type and number of livestock that can use the area sustainably. Climate is uniform in this area. The logical approach would be to look at the vegetation composition in the area and determine the quality (palatability) and number of livestock in terms of the carrying capacity of the land. The Agro-

Ecological Zones study indicates that the area is more suitable for grazing than for crop production (de Pauw and Coetzee, 2001). But currently the project area is bush encroached and this has reduced the grassland areas, as the open areas are invaded with woody plants often unpalatable to domestic livestock. The thickening of bushes limits the movement of animals in terms of accessibility. Most grasses in some parts of the areas that were observed have become moribund. This could be due to understocking (Zimmermann et al., 2004) when not grazed and results in poor grass quality. Grassland areas are utilized by cattle as they are grazers than browsers. Goats utilize grasses and bushes since they are both grazers and browsers which make them adapt well in the area.

The dry climate makes livestock farming in the area difficult and at risky. Due to the absence of perennial rivers and surface water sources, boreholes are the main source of water for animals at the project. Each post has a borehole, but no information was colleted on their capacity to hold water. Drying of these boreholes has become a major problem in the area. Unfortunately there is no information on the ground water hydrology in the area. Water availability in boreholes in most cases determines the distribution of livestock within the paddocks. This makes the implementation of the grazing system difficult as animals tend to be concentrated in one area. In this study, LURs grazing capacity, palatability of vegetation and accessibility of animals were used.

<u>LUT4 – Rain-fed Maize *(Zea mays)* (improved)</u>: Rain-fed maize is grown in the dryland fields of 10_ha, 15_ha and 35_ha. Plant population in the semi-arid and sub-tropical areas for rain-fed maize is recommended between 25 000 to 50 000 plants per hectare, 1 kg of maize seeds consists of 4500 to 5500 seeds (Elsevier, 1989; MAF, 1997). Therefore, 10 to 12.5 kg of maize seeds per hectare will be required. Average yield expected is between 320-1500kg/ha depending on the rainfall situation (MAF, 1997). Expenses are for fertilizers (N$6-75 per kg N, N$10-00/kg P & N$4-85/kg K), fuel and lubrications with 88litres/ha at a rate of N$5-09 per litre of diesel.

<u>LUT4 – Crop requirements</u>: Maize shows tolerance to a wide range of environmental conditions, but the growing season must be frost-free. Maize does best with 500-900mm of rain during the growing season. Temperature requirements are from 21 – 30^{o}C and optimum temperature for germination is 18 – 21^{o}C, while below 13^{o}C growth is greatly reduced and fails below 10^{o}C (MAF, 1997). Taking into consideration that moisture plays a huge role in determining plant spacing and that rainfall varies in the area, row width must be 200cm and 25cm plant spacing within the row (MAF, 1997). Maize grows on a wide variety of soils but it performs best on well-drained, well aerated deep (60 cm+), warm, loams and silt loams. Soil pH between 5.0 – 8.0, but 6.0 – 7.0 is optimum (MAF, 1997).

Fertilizers may be applied for manipulation of soil fertility by giving plant a balanced ratio of inorganic plant nutrients at adequate rates. Maize needs about 55kg of Nitrogen (Urea), 20kg of Phosphorus, and 12kg of Potassium per hectare per year for a yield of three tonnes per hectare (MAF, 1997).

<u>LUT5 – Rain-fed Pearl Millet *(Pennisetum glaucum)* (improved)</u>: Pearl millet is also a rain-fed managed land-use type at Excelsior Resettlement Project. Sowing is done on hills, with a spacing of between 0.5 x 0.5m to 0.75 x 0.75m and is done by hand (MAF, 1997). Average pearl millet grain yields are estimated by the Namibian Early Warning and Food Information System to be 200-400kg per hectare in the Northern Communal Areas. The main expenses are for fertilizers (table 5-5), fuels and lubrications with 88litres/ha at a rate of N$5-09 per litre of diesel (MAF, 1997).

LUT5– Crop requirements: Mean annual rainfall for the pearl millet growing in the Northern Communal Areas in Namibia is 300mm and more, with a growing season of one hundred days (MAF, 1997). As mentioned earlier on that sowing rate was not known at the time of field-work by the farmers and farm coordinator. Sowing rate is recommended in the literature that 15-25kg/ha for the drought tolerant varieties (Elsevier, 1989). Pearl millet performs best on well-drained, deep and light textured soils and has a good tolerance for salinity (MAF, 1997). According to MAF the ideal pH is "between" 5.5 – 6.5. Rooting conditions is 30-60cm. Ploughing depth is general shallow hardly exceeding 100mm as known when done traditionally or even when animal drawn plough is used. Use of 10 – 20kg Phosphorus (P) per hectare together with 10 – 20kg Nitrogen (N) per hectare have shown the potential of more than doubling pearl millet grain yield and this will boost the yield tones/ ha (MAF, 1997), table 5.5.

Literature information indicates that weeding should be undertaken within 2 to 3 weeks after sowing (Elsevier, 1989; MAF, 1997). Pearl millet normally benefits from the second weeding which is performed together with thinning. A third weeding does not have any additional yield benefits. However, it makes harvesting easier and fast (MAF, 1997).

Table 5-5: Potential grain yields for pearl millet due to N & P fertilizer use in the northern central part Namibia based on 1993/94 N-P on-farm trial results. Source: (MAF, 1997)

Northern Central Regions			
Fertilizer treatment	**Grain yield (t/ha)**	**Grain yield increase compared to no fertilizer treatment (t/ha)**	**Added value to cost ratio***
0	0,57	-	-
10P	0.93	0.36 (63%)	6.2
10P20N	1.00	0.43 (75%)	5.8 (4.0)
20P20N	1.11	0.54 (95%)	4.1 (3.3)
* An informal grain price of N$1/kg was used. Fertilizer price was based on 1993/94 ADC prices. For N and P prices were N$19 per 50kg Urea and N$30.15 per 50kg Single Super Phosphate. The figure in brackets in the last column indicates the ratio when current commercial prices of fertilizer are used.			

LUT6 – Rain-fed Sorghum *(Sorghum bicolor)*: Rain-fed sorghum can also be a potential land use type at the project. Sorghum is a crop of multiple uses and it is widely used for human food and traditional alcohol production. In the Northern Central Namibia sorghum is planted in the Mid-November or when the first 20 to 25mm of rain has been received. The literature information shows that sorghum can be used in a crop rotation with pearl millet, cowpeas and this avoids bacteriosis (MAF, 1997). Harvesting is done by hand at the time of complete ripening. Average yields in northern part of Namibia vary from 200 – 750kg/ha to 1500 kg/ha and even more if managed well (MAF, 1997). Expenses are mainly for seeds (N$8.70 per kg), fuel and lubrications for ploughing with 88litres/ha at a rate of N$5-09 per litre of diesel.

LUT6 – Crop requirements: The minimum annual rainfall requirement of a rain-fed sorghum is 250mm, but good yields are only obtained with a precipitation of 600mm or more (Elsevier, 1989). Sorghum is resistant to salt and grow better on medium textured soils of low water holding capacity and with a neutral pH (Table 5-6). Rooting conditions is 60-90cm. It is recommended to sow sorghum in wide rows, at a spacing of 35 – 40 cm to 100cm. The spacing between plants in the row can vary from 10 – 12 to 60 – 90 cm (MAF, 1997). Plant density is determined by the moisture availability in the soil, while closer spacing for soils with high moisture content and vice versa. Sowing rate of sorghum is recommended at 2-8kg/ha for rain-fed and its efficiency directly depends on soil water content (MAF, 1997). Weeding must be done in the first month of growth; otherwise sorghum gets suppressed by weeds.

LUT7 – Rain-fed Cowpeas (*Vigna unguiculata*): Cowpeas can also be a potential land use type at the project in a rain-fed situation. Cowpeas are legumes that fix nitrogen with the help of bacteria in their root nodules (Elsevier, 1989; MAF, 1997). Planting takes place from end December/January and harvesting happens when 80 to 90% of pods are dry (MAF, 1997). Sowing rate of 40-60kg/ha is recommended. Cowpea is traditionally grown in a mixed cropping system at wide spacings with plant populations of between 10 000 to 20 000 plants/ha (MAF, 1997). According MAF as a mono-crop plant populations of 100 000 to 150 000 per hectare is recommended and to produce such populations, a row spacing of 0.75m and plant spacing of 0.13m are required.

Cowpeas leaves can be harvested when young and pods can be picked as they ripen, when colour starts to change from green to purplish or cream (MAF, 1997). These may be consumed or sold immediately. It is recommended in the literature that if cowpeas are to be used at a later stage, pods with seeds should be dried in the sun, thereafter, threshed and stored. An average yield of 400-1900kg/ha can be expected in a rain-fed situation in most African countries (Elsevier, 1989). Expenses for cowpea are seeds (N$14-00/kg) and fuels and lubrications with 88litres/ha at a rate of N$5-09 per litre of diesel.

LUT7 – Crop requirements: Cowpeas are sensitive to cold and can be sensitive to high temperature (MAF, 1997). (Table 5-6 shows crop requirements summary) Therefore, it should not be planted too late in the season. According to MAF cowpeas tolerates heat and drought. Mean annual rainfall required is about 500mm/year. Best yield can be obtained on sandy loam but can grow successfully on wide range of well drained soils. Cowpea should not be planted in soils with a high pH (i.e. >pH 8) or a very low pH (e.g. <pH 4.5) but between 5.0 – 6.5 is ideal and at a depth of 80-120cm (MAF, 1997).

Table 5-6: Summary of LUT2, LUT4, LUT5, LUT6 and LUT7 requirements pertaining to the given climate and soil conditions

Crops	Temperature requirement (Degree Celsius)	Moisture requirement (mm)	Rooting Conditions (cm)	Absence of acidity and alkalinity (pH)
Maize	21 – 30	500 - 900	60-90	5.0 – 8.0, 6.0 – 7.0 is optimum
Pearl Millet	25 - 30	>300	30-60	5.5 – 6.5
Sorghum	25 - 30	250 - 600	60-90	6.5 - 7.0
Cowpeas	27 - 35	>500	80-120	5.0 – 6.5

Source: (Elsevier, 1989; MAF, 1997)

LUT8 – Rain-fed Maize, Pearl Millet, Sorghum and Cowpea (Intercropped): Rain-fed maize, pearl millet, sorghum and cowpea intercropped can be a potential land use at the project. This has not been evaluated in this study due to lack of information pertaining to intercropping in the given conditions, but are put as a suggestion only. Rain-fed maize, millet, sorghum has successfully been intercropped with cowpeas in the north central Namibia. When intercropped, cowpea provides increased yields, improved soil fertility and increased yield of the main crop (MAF, 1997).

This system offers settlers better alternatives to growing continuous maize, pearl millet, sorghum and cowpea intercrops. One of the other benefits of intercrop will be to reduce incidence of legume pod borer on the cowpeas and limits the movement, and therefore the damage that can be caused by insect pests. Intercropping has also been found to reduce crop losses compared to planting the same crop in one field like what most farmers are doing nowadays with maize and pearl millet (SCCROSA, 2005). However also an opportunity for the incorporation of cowpea or other good quality residues before planting maize, millet or sorghum with the aim of improving yields in adequate or good rainfall years as 20-25% of the residue N will become available to the planted crop (MAF, 1997; McDonagh et al., 2001). Intercropping gives an advantage to the settlers because they will manage more than one crop at a time in the same field. If settlers are not willing to risk the low planting density of the main crop (with reduced yield), then a very low cowpea density may be applicable. Expenses are as presented in table 5-3 for each crop.

5.2.4. Diagnostic Land Characteristics (LC)

Table 5-7 shows the relevant land characteristics associated to the study area. Cracked clay soil (picture 5-1) was observed at Twewaadha Post (ETP) (P4). These land characteristics were used as basis for the construction of decision trees together with LURs in Table 5-6.

Table 5-7: Relevant diagnostic LC's per observation point

LEUs	Location Post	Soil depth (cm)	Soil pH	Soil texture
P1	ETYP	70	8	Loam
P2	EEP	50	6	Sand loam
P3	EMP	30	5	Clay
P4	ETP	30	5	Clay
P5	EJSP	30	5	Clay

Picture 5-1: Cracked Clay soil, picture taken from Excelsior Twewaadha Post

Fig 5-2 shows the results of the infiltration experiment. (See map units/ posts section 3.6 for abbreviations used and also Appendix 7 for the results of the measurements).

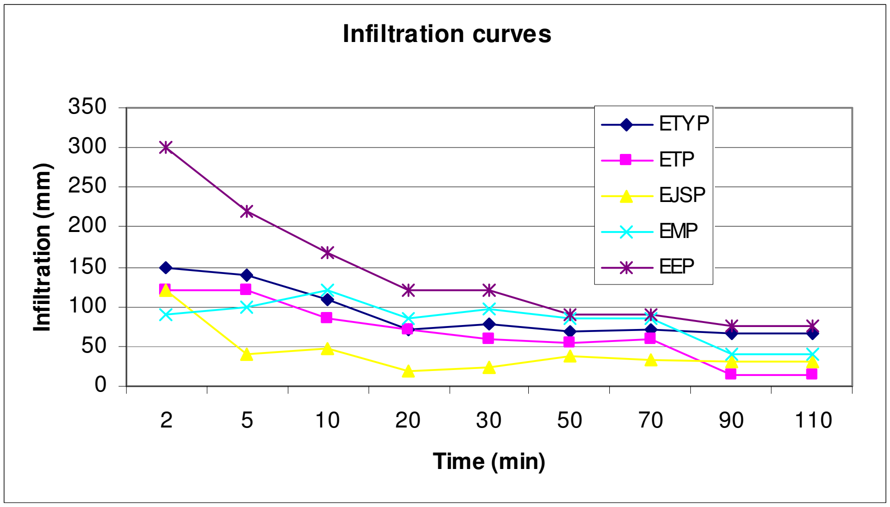


Figure 5-2: Basic infiltration rates at different sites

In most cases, the water intake was very high at the beginning (fig 5-2). As more water kept replacing the air space in the soil with time, the rate at which water was penetrating became slow until it reached a steady rate. The situation was different at site EMP where the initial infiltration rate was low. It kept increasing and then fluctuating but decreasing as time was increasing until the basic infiltration rate was reached. The high intake of water at EEP could be due to sandier area. One should keep in mind that the graphs are not smooth due to the fluctuating of water intake when it infiltrates into the soil as it was sometimes increasing or decreasing with time.

5.3. Qualitative Land Evaluation Method

This section shows results obtained using a qualitative method (Automated Land Evaluation System) which is a K2 approach. Biophysical data on each LEU and economic data on each LUT obtained either through interviews or as secondary data and literature information was entered into ALES for evaluation. A model was built for LUTs 2, 3, 4, 5, 6, and 7 based rangeland (grazing), maize, pearl millet, sorghum and cowpea.

5.3.1. Decision trees

Decision trees were constructed by which ALES can assess suitabilities of each LEU. The processing involved the construction of decision trees for each LUR based on expert knowledge and literature. Decision trees are land quality models in which diagnostic LCs are related to LURs. Each LUT (Rain-fed crops) was evaluated based on LURs in table 5-6. All LURs were considered as limiting factors for the LUTs. Severity level for moisture requirements for all crops were determined based on the crop water requirements obtained after simulations models made in CropWat. Results are shown in the evaluation matrix (table 5-8). This has not been validated, and is at this point only based on expert opinion. Decision trees are shown in Appendix 12.

5.3.2. Suitability of observed points for rain-fed crops

All observed points (LEUs) (fig 4-1) were evaluated for their suitability for LUT's based on maize, pearl millet, sorghum and cowpeas. Out of the five observed points four are marginally suitable and the remaining point is rated moderately suitable for all crops. Table 5-9 indicates the average yield expected (kg/ha) and table 5-10 shows the gross margin (N$/ha) of the LUTs 2, 4, 5, 6, & 7 based maize, cowpea, pearl millet and sorghum. Individual observed points are discussed below.

P1: (located in the Excelsior Thank You Post) is moderately suitable (S2) for all evaluated land use types. For example cowpea has physical suitability subclasses of **2m/rc/st** (table 5-8). It indicates that moisture, rooting conditions and absence of soil toxicity (pH) are the maximally limiting factors for cowpea. Moisture is classified as limiting for cowpea because precipitation for the area is classed from 250 to 400mm (section 3.2.1) while cowpea performs optimally for more than 500mm. The rooting condition required for cowpeas is 80cm and more, but due to soil depth of 70cm which is less than that, is the reason to be classed as moderately suitable. The pH for this point observed is 8, which does not meet the pH requirement for cowpea. Maize, pearl millet and sorghum are also moderately suitable (includes improved maize & Pearl millet) with a subclass of **2m/rc/st** for maize and sorghum & **2m/st** for pearl millet as maximally limiting factors.

P2: (located in the Excelsior Post) is marginally suitable (S3) for maize, cowpea and sorghum while moderately suitable (S2) for pearl millet. The physical suitability subclass for the first three is **3m/rc** and for the later **2m/rc/st.** It shows moisture and rooting conditions as maximally limiting factors for maize, cowpea and sorghum. Moisture is rated marginally suitable for these crops due to the influence of shallow soil depth at the point with 50cm i.e. compared to the first point where moisture falls under moderately suitable. The deeper the soils, the more water and nutrients can be tapped by the plant (MAF, 2003a). But for pearl millet, the maximally limiting factors at this point are moisture, rooting conditions and soil toxicity. These are rated moderately suitable because at this point, soil depth is

50cm; pH is 6 while pearl millet can do better under such conditions with rooting conditions as low as 30cm and ideal pH requirement is 5.5-6.5.

P3/P4/P5: (location of points: fig 4-1) are rated marginally suitable (S3) for all the land use types. At all these points the same soil depth (30cm), soil texture (Clay) and pH (5) were observed (table 5-7). The physical suitability subclasses for cowpea and pearl millet are **3m/rc** whereas, for maize and sorghum are **3m/rc/st**. This means the maximally limiting factors for cowpea and pearl millet are moisture and rooting conditions. In addition to that is the soil toxicity as maximally limiting factors for maize and sorghum. The moisture falls within the subclass at such points because of the influence of soil texture and depth. The soil depth does not meet the rooting conditions requirements of all the land use types. It is very shallow to have the capability to store enough moisture to be made available for plant roots. The pH for these points is 5, but optimum pH requirement for maize is 6-7 and for sorghum 6.5 - 7.0 respectively.

Table 5-8: Physical suitability subclasses calculated by ALES

LEUs	Actual LUT		Potential LUTs			
	Maize	Millet				
	LUT2		LUT4	LUT5	LUT6	LUT7
P1	2m/rc/st	2m/st	2m/rc/st	2m/st	2m/rc/st	2m/rc/st
P2	3m/rc	2m/rc/st	3m/rc	2m/rc/st	3m/rc	3m/rc
P3/P4/P5	3m/rc/st	3m/rc	3m/rc/st	3m/rc	3m/rc/st	3m/rc

Key for the table:
st-soil toxicity; m-moisture and rc-rooting conditions and also see appendix 13 codes used for decision trees.

Table 5-9: Yields calculated by ALES (kg/ha)

LEUs	Actual LUTs		Potential LUTs			
	Maize	Millet				
	LUT2		LUT4	LUT5	LUT6	LUT7
P1	600	560	1200	800	800	320
P2	300	560	600	800	300	120
P3/P4/P5	300	210	600	300	300	120

Table 5-10: Gross margins (N$/ha) calculated by ALES (K2 level)

LEUs	Actual LUT		Potential LUTs			
	Maize	Millet				
	LUT2		LUT4	LUT5	LUT6	LUT7
P1	409.58	447.08	1100.13	834.58	672.08	592.08
P2	-250.41	447.08	-219.86	834.58	-77.91	-407.91
P3/P4/P5	-250.41	-252.91	-219.86	-165.41	-77.91	-407.91

5.3.3. Vegetation analysis for each post

In this section posts was used as LEUs. Descriptive statistics for NDVI reflectance was used in the analysis of the vegetation density for each post including the community grazing area (EKEP, fig 3-9). High NDVI reflectance symbolizes much biomass. In this case average NDVI reflectance was used in determining density of vegetation. Descriptive statistics (table 5-11) indicate that average NDVI reflectance was high in post ETYP with the lowest in EJSP (Appendix 11). ETP have high standard deviation while EEP have the lowest.

Posts that were observed having vegetation dominated by grasses (Table 5-12) was considered having palatable vegetation. This is because the dominant grasses (*Stipagrostis uniplumis and Fingerhuthia Africana*) are palatable species to domestic animals (Muller, 1984). Posts dominated by thicket bush (*Dichrostachys cinerea*) were considered to have unpalatable vegetation. The assessment of the grazing capacity was based on the rainfall distribution. Because mostly determined by rainfall distribution and its reliability (Elsevier, 1989). Grazing capacity during time of low rainfall is poor. This has been rated the same for all posts due to uniformity of rainfall. Posts identified as having high vegetation density were regarded not accessible to animals. These are posts dominated by thickening bush or bush encroachment.

Table 5-11: Descriptive statistics for NDVI for each post calculated in ArcGIS-ArcMap software (based on 2000 imagery)

LEUs	Minimum	Maximum	Average	Standard Deviation
ETYP	-0.0440	0.3821	0.1614	0.0474
EEP	-0.1220	0.3153	0.1110	0.0457
EKEP	-0.0750	0.3333	0.1107	0.0482
EJSP	-0.0962	0.3247	0.0789	0.0514
EMP	-0.1111	0.2929	0.1177	0.0522
ETP	-0.0323	0.3805	0.1585	0.0553

Table 5-12: Diagnostic Land characteristics for each post

LEUs	Vegetation density	Observed vegetation
ETYP	High	Dominant Thicket bushes
EEP	Low	Dominant Grasses
EKEP	Moderate	Thicket bush/ Grasses
EJSP	Low	Dominant Grasses
EMP	Moderate	Thicket bush/ Grasses
ETP	High	Dominant Thicket bushes

5.3.4. Land suitability for rangelands for each post

For the rangelands analysis three relevant Land Use Requirements were selected: palatability of vegetation (pv), grazing capacity (gc) and accessibility to animals (aa). The diagnostic Land Characteristics are vegetation density, precipitation (mm) and observed vegetation. The overall physical suitability analyses for grazing shows that four posts out of six are moderately suitable (table 5-13). The other two are marginally suitable. Decision trees are shown in appendix 14. The posts are discussed below based on the physical suitability subclasses obtained from ALES.

Table 5-13: Physical suitability subclass calculated by ALES (K2 level)

LEUs	Rangelands
EEP/ EJSP	2gc
EMP/ EKEP	2aa/gc/pv
ETP/ ETYP	3aa

EEP/EJSP: These posts are dominated by grasses with very low thicket bush. The posts are rated moderately suitable (S2) for rangelands. The physical suitability subclasses is **2gc** as shown on table 5-13, which means the maximally limitation is grazing capacity of the land. Because the grazing capacity is influenced by precipitation whereas, an increase or decrease of precipitation (Appendix 14: Decision tree) results in a change of vegetation and land cover. Meaning if more rainfall is received high amount of grasses or plant biomass are expected and good grazing capacity.

EMP/EKEP: These two posts are also rated moderately suitable (S2). The physical suitability subclasses are **2aa/gc/pv**. This indicates that the major limitations are accessibility to animals, grazing capacity and palatability of vegetation. In terms of accessibility to animals, the movement is limited by the presence of high amount of thicket bushes in the posts. The influence of rainfall on grazing capacity of the land applies to these posts as well.

ETP/ETYP: These posts are dominated by thickets and rated marginally suitable (S3). The physical suitability subclasses are **3aa**. The major limitation is accessibility to animals, due to very high density of vegetation dominated by thicket bushes.

5.4. Quantitative Land Evaluation Method

This section presents results obtained from the analysis of climatic and soil data using a K4-approach (CropWat 4 Windows).

5.4.1. Effective rainfall

Effective rainfall means useful or utilizable rainfall by plants. Rainfall has its greatest value if it falls during the growing season of any crop. Table 5-14 left column shows the monthly total rainfall, while the right column indicates calculated effective rainfall for the rain received in the year 2003. Effective rainfall is calculated from the total rainfall using the FAO Penman-Monteith equation (FAO. et al., 1998).

Table 5-14: Total and effective rainfall for 2003

	Total	Effective	
January	118.7	96.2	(mm/month)
February	105.5	87.7	(mm/month)
March	0.0	0.0	(mm/month)
April	12.0	11.8	(mm/month)
May	0.0	0.0	(mm/month)
June	0.0	0.0	(mm/month)
July	0.0	0.0	(mm/month)
August	0.0	0.0	(mm/month)
September	0.0	0.0	(mm/month)
October	27.1	25.9	(mm/month)
November	73.4	64.8	(mm/month)
December	74.0	65.2	(mm/month)
Total	410.70	351.60	

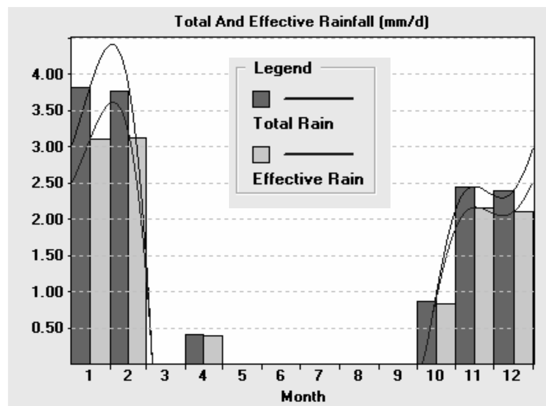


Figure 5-3: Distribution of daily total and effective rainfall amount for 2003

The difference between total rainfall and effective rainfall is the rainfall losses which is lost either through runoff or evaporation. Figure 5-3 shows the distribution of the average of total and effective rainfall amount in millimetres per day for each month. January and February (table 5-14 & fig 5-3) show the highest amount of effective rainfall, because also has the highest total rainfall that was received at that time.

5.4.2. Reference EvapoTranspiration (ETo)

The reference evapotranspiration has been estimated using CropWat 4 Windows 4.3 software which uses the FAO Penman-Monteith equation (FAO. et al., 1998). Figure 5-4 shows the reference evapotranspiration with a smooth curve fitted to monthly averages. It indicates that the highest evapotranspiration rates are in September-December when the temperatures are high and enough moisture is available. The lowest evapotranspiration is experienced in winter with a minimum of 3mm/day from May to July, when there is less moisture and the soil becomes drier. It means that crops will be stressed from September to March because more moisture is required, due to high evapotranspiration in the area during the growing period. Water stress can only be avoided by enough rainfall in rain-fed situations.

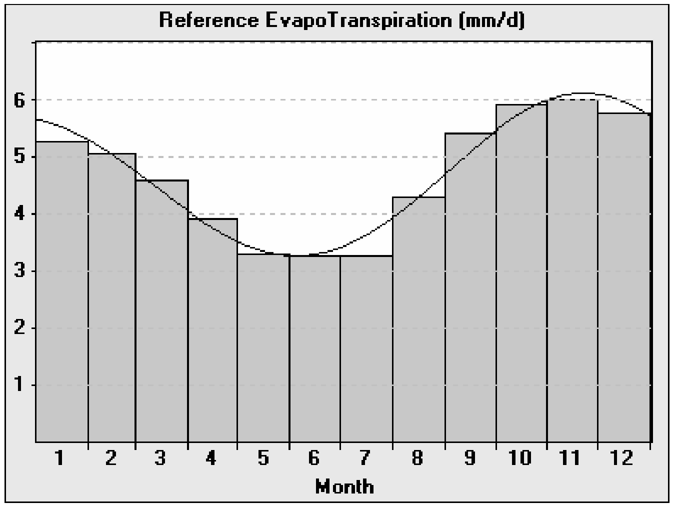
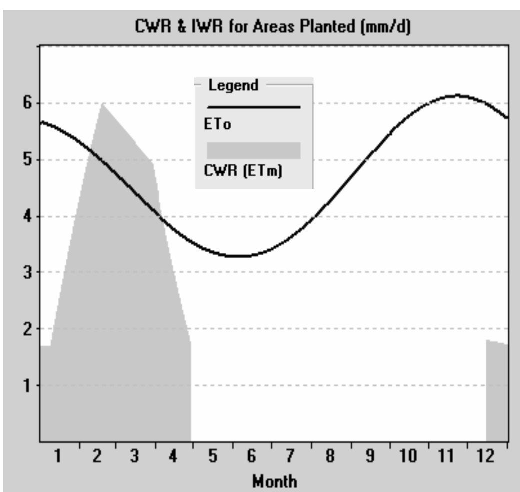


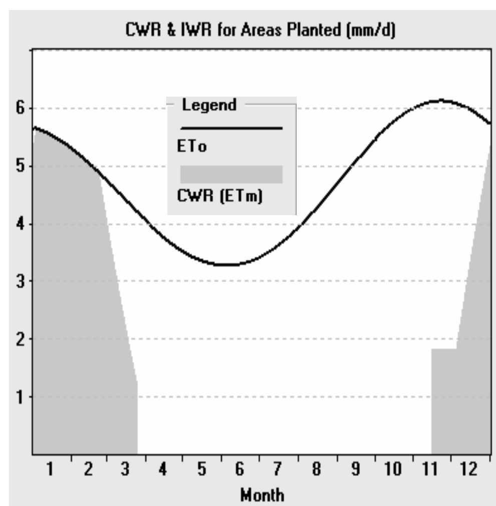
Figure 5-4: Monthly Reference EvapoTranspiration

5.4.3. Crop Water Requirements (CWR)

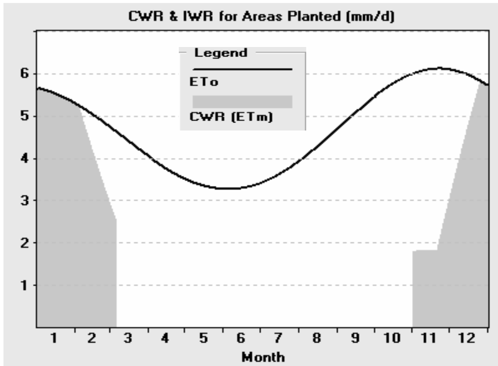
Different crops use different amounts of water over their life cycle stages. Figure 5-5 shows the estimation of the ETo and Crop Water Requirements for LUTs 2, 4, 5, 6 and 7 based maize, pearl millet, sorghum and cowpea. The curves in each graph from fig 5-5 A to D are the Reference Crop Evapotranspiration in mm/day, smoothed between the months with a polynomial curve. The total shaded area is the Crop Water Requirements in mm/day. The start of the shaded area is the planting date, for example fig 5-5B indicates that pearl millet is planted on the 15th November and harvesting is expected end-March.



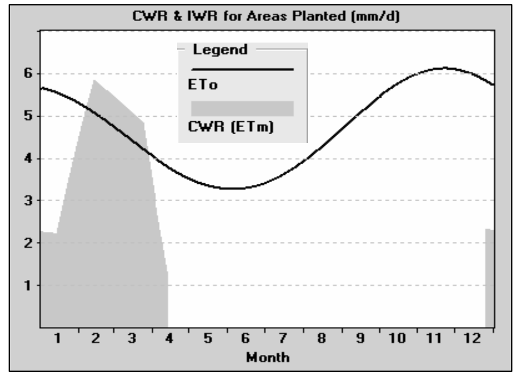
A) Maize



B) Pearl Millet



C) Sorghum



D) Cowpeas

Figure 5-5: Crop Water requirements: LUTs based Maize, Pearl millet, Sorghum and Cowpeas

The graphs show that all the modelled crops reach the maximum ET (Crop water use). As crops continue to grow through the reproductive stages and towards maturity, crop water use decreases. For example Graph 5-5 A: maize requires 1.8 mm/day of water at the beginning when sown in mid-December. The demand for water keeps increasing as it passes the life cycle stages. In February up to 6mm/day of water use is needed. The demand for water (mm/day) decreases as it approaches the final stage of its life by the end of April. Therefore water needs for crops during the late season is minimal compared to the early stages.

Maize (*Zea mays*): Table 5-15 indicates that maize requires 518mm (column CWR) for a growth period of 130 days. Total reference crop evapotranspiration of maize is 653mm i.e. higher than the CWR under the given environment. The irrigation requirement column indicates water deficit. The amount of water required to meet the demand of the crop is 62% of the CWR without reducing the yield (Calculation based on total deficit (323mm/period) over total CWR (518mm/period) in percentage). As a rain-fed crop, drought stress is likely to occur from the 24th January to the end of the growing season.

Table 5-15: Maize crop water requirements (CWR)

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effective Rain (mm/period)	Irrigation Req. (mm/period)
15/12	59.11	100	0.3	17.73	25.02	21.78	0
25/12	57.4	100	0.3	17.22	29.13	24.49	0
4/1	55.96	100	0.33	18.67	34.57	28.18	0
14/1	54.85	100	0.54	29.39	40.06	32.47	0
24/1	53.42	100	0.76	40.63	43.6	35.55	5.09
3/2	51.69	100	0.99	50.95	42.67	35.16	15.79
13/2	49.74	100	1.18	58.55	34.32	28.6	29.95
23/2	47.61	100	1.2	57.13	15.4	12.95	44.18
5/3	45.38	100	1.2	54.45	0	0	54.45
15/3	43.13	100	1.2	51.76	0	0	51.76
25/3	40.94	100	1.16	47.72	0	0	47.72
4/4	38.88	100	0.96	37.17	0	0	37.17
14/4	37.02	100	0.72	26.75	0	0	26.75
24/4	17.89	100	0.55	9.79	0	0	9.79
Total	**653.01**			**517.9**	**264.77**	**219.17**	**322.63**

Pearl millet (*Pennisetum glaucum)*: Table 5-16 shows that pearl millet requires 507mm (CWR) for a period of 120 days. Total reference crop evapotranspiration of pearl millet is 701mm/period, which is higher than CWR pertaining to the given climatic conditions. The amount of water required to meet the demand of the crop is 45% of the CWR (Calculation based on total deficit (230mm/period) over total CWR (507mm/period) in percentage). Drought stress can be expected from the 5th December onwards until the end of the growing season. This is due to not enough rainfall amount received within the given period.

Table 5-16: Pearl millet Crop Water Requirements

Date	ETo (mm/period)	Crop Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irrig. Req. (mm/period)
15/11	61.13	100.00	0.30	18.34	24.28	21.53	0.00
25/11	60.98	100.00	0.30	18.29	23.35	20.86	0.00
5/12	60.29	100.00	0.43	25.81	23.17	20.62	5.19
15/12	59.11	100.00	0.66	39.08	25.02	21.78	17.30
25/12	57.40	100.00	0.89	51.33	29.13	24.49	26.84
4/1	55.96	100.00	1.00	55.96	34.57	28.18	27.78
14/1	54.85	100.00	1.00	54.85	40.06	32.47	22.38
24/1	53.42	100.00	1.00	53.42	43.60	35.55	17.87
3/2	51.69	100.00	1.00	51.69	42.67	35.16	16.53
13/2	49.74	100.00	1.00	49.74	34.32	28.60	21.14
23/2	47.61	100.00	0.87	41.54	15.40	12.95	28.59
5/3	45.38	100.00	0.64	29.01	0.00	0.00	29.01
15/3	43.13	100.00	0.41	17.51	0.00	0.00	17.51
Total	700.69			506.57	335.58	282.18	230.15

Sorghum (*Sorghum bicolor)*: CWR for sorghum is 492mm for a period of 120 days, with ETo of 679mm. The effective rainfall is less than the required amount (Table 5-17). The amount of water required to meet the demand of sorghum is 44% of the CWR (Calculation based on total deficit (215mm/period) over total CWR (492mm/period) in percentage). The drought stress can be expected from 5th December until to the end of its growth cycle.

Table 5-17: Sorghum Crop Water Requirements

Date	ETo (mm/period)	Crop Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irrig. Req. (mm/period)
15/11	61.13	100.00	0.30	18.34	24.28	21.53	0.00
25/11	60.98	100.00	0.30	18.29	23.35	20.86	0.00
5/12	60.29	100.00	0.41	24.70	23.17	20.62	4.09
15/12	59.11	100.00	0.61	36.03	25.02	21.78	14.25
25/12	57.40	100.00	0.81	46.46	29.13	24.49	21.97
4/1	55.96	100.00	0.98	54.83	34.57	28.18	26.65
14/1	54.85	100.00	1.00	54.85	40.06	32.47	22.38
24/1	53.42	100.00	1.00	53.42	43.60	35.55	17.87
3/2	51.69	100.00	1.00	51.69	42.67	35.16	16.53
13/2	49.74	100.00	0.98	48.63	34.32	28.60	20.03
23/2	47.61	100.00	0.84	40.14	15.40	12.95	27.19
5/3	45.38	100.00	0.69	31.45	0.00	0.00	31.45
15/3	21.84	100.00	0.58	12.67	0.00	0.00	12.67
Total	679.40			491.52	335.58	282.18	215.10

Cowpeas (*Vigna unguiculata*): CWR for cowpeas is the lowest at 443mm/period (table 5-18), while ETo is 539mm/period compared to maize, pearl millet and sorghum. Cowpeas require 58% extra of under the given conditions to meet its demand (Calculation based on total deficit (256mm/period) over total CWR (443mm/period) in percentage). As a rain-fed crop, drought stress can be expected. This is due to shortage of water from 24th January to the end of its growing period. From the 5th March severe drought stress can be anticipated since no more rainfall is received after that time.

Table 5-18: Cowpea Crop Water Requirements

Date	ETo (mm/period)	Crop Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irrig. Req. (mm/period)
25/12	57.40	100.00	0.40	22.96	29.13	24.49	0.00
4/1	55.96	100.00	0.40	22.38	34.57	28.18	0.00
14/1	54.85	100.00	0.54	29.46	40.06	32.47	0.00
24/1	53.42	100.00	0.79	42.03	43.60	35.55	6.49
3/2	51.69	100.00	1.04	53.59	42.67	35.16	18.43
13/2	49.74	100.00	1.15	57.20	34.32	28.60	28.60
23/2	47.61	100.00	1.15	54.75	15.40	12.95	41.80
5/3	45.38	100.00	1.15	52.19	0.00	0.00	52.19
15/3	43.13	100.00	1.15	49.60	0.00	0.00	49.60
25/3	40.94	100.00	0.93	38.14	0.00	0.00	38.14
4/4	38.88	100.00	0.53	20.67	0.00	0.00	20.67
Total	538.99			442.97	239.75	197.39	255.92

Note that the demand for moisture also depends on the density of plants per hectares, in which the denser the plants per hectare the more moisture required.

Planting dates: Planting dates used in the above mentioned tables and figure (Table 5-15 - 5-18 & Fig 5-5) are as recommended in literature for the North Central Namibia for cowpeas and sorghum, but for maize and pearl millet (Mahangu) is planting date used for Excelsior project. These are dates within a year when planting or sowing is taking place. Planting dates is dictated by the period of the onset of rains. Sometimes planting date depends on preferences of the main crop i.e. cowpeas is always planted (if planted as monocrop) end of December each year in the northern communal areas of Namibia. Because of avoiding conflicts with the planting of staple food crops (maize & pearl millet) which is taking place early November/ December and requires high input of labour (MAF, 1997).

In some places not the study area, planting is sometimes delayed especially for people using oxen for ploughing. Animals might still be weak at the beginning of the growing season due to long drought season and then farmers have to wait until oxen are strong enough to be used for ploughing. However with the current crop production system (no external inputs in the area), the most important factor in determining yield success is timeliness of planting. This enables the crop to utilize the early nutrient flush and early rainfall both of which will be lost to the crop if planting is late (McDonagh et al., 2001).

5.4.4. Yields

The CropWat (K4 level) crop-growth simulation model was used to asses yield reductions in the given environment. Average yield reduction (table 5-19) was calculated for each LEU on the basis of rainfall and land characteristics such as soil depth, infiltration rate and soil texture. LUTs 2, 4, 5, 6 & 7 based maize, pearl millet, sorghum and cowpea shows different yield reductions at different LEUs. For example LUT2 & 4 based maize shows a yield reduction of 45% at P1, 54% at P2 and 63% at

P3/P4/P5 respectively. Different of soil depths and infiltration rates (table 5-7) for each LEUs seems to be the main influence in yield differences. This has been observed during the simulations for different crops. The last column shows the average yield kg/ha minus the yield reductions.

Table 5-19: Yield reductions in the given conditions (CropWat)

LEUs	LUTs	Average yield expected (kg/ha) (Literature)	Yield Reductions (%)	Average Yield (kg/ha) (after reduction)
P1	LUT4	1500	45	825
	LUT5	400	8	368
	LUT6	750	2	735
	LUT7	400	32	275
P2	LUT4	1500	54	690
	LUT5	400	16	336
	LUT6	750	8	690
	LUT7	400	41	236
P3/P4/P5	LUT4	1500	63	555
	LUT5	400	38	248
	LUT6	750	27	547
	LUT7	400	52	397

5.4.5. Comparison of results from ALES & CropWat

Table 5-20 shows yields obtained after applying both a K2-approach (ALES) and a K4 approach (CropWat). The differences show that average yields obtained from ALES are higher when it is a positive number, for example LUTs 4, 5, 6 and 7 are higher at LEU P1. Negative figures shows higher yields obtained from CropWat i.e. LUT6 at LEU P2 and P3, P4 and P5 respectively.

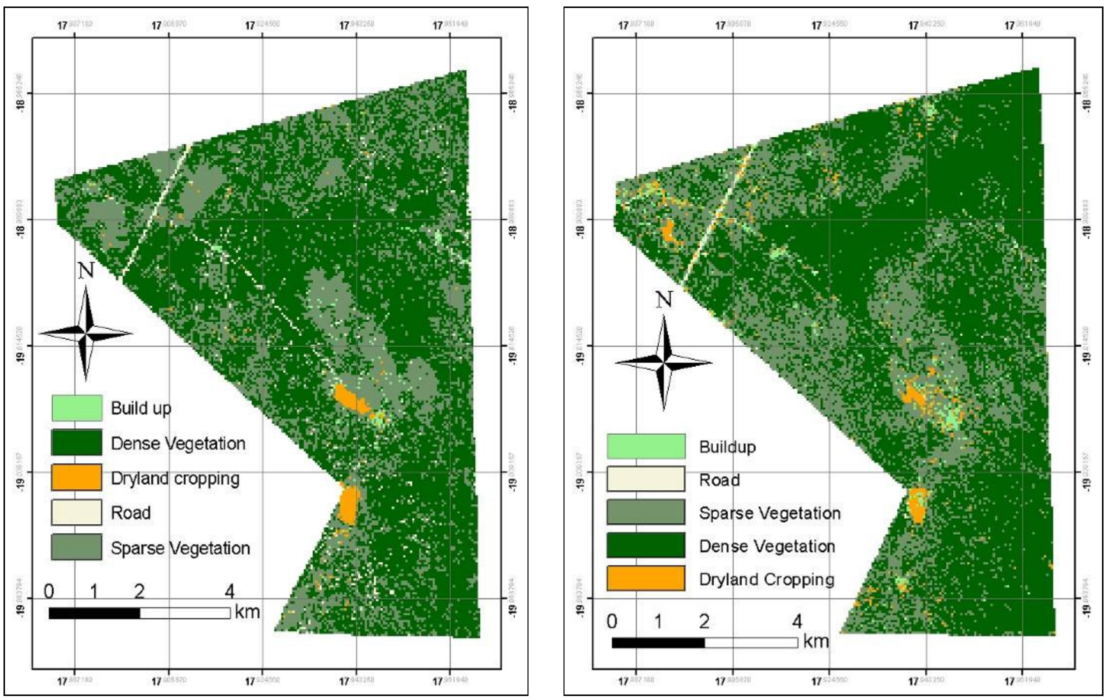
Table 5-20: Yield based on ALES & CropWat

LEUs	LUTs	Average yield (kg/ha) (ALES)	Average yield (kg/ha) (CropWat)	Difference (kg/ha)
P1	LUT4	1200	825	375
	LUT5	800	368	432
	LUT6	800	735	65
	LUT7	320	275	45
P2	LUT4	600	690	-90
	LUT5	800	336	464
	LUT6	300	690	-390
	LUT7	120	236	-116
P3/P4/P5	LUT4	600	555	45
	LUT5	300	248	52
	LUT6	300	547	-247
	LUT7	120	397	-277

5.5. Land Use and Cover Change Analysis

5.5.1. Change detection by comparing classifications

This section shows the results obtained after conducting change detection by comparing classifications of the LandSat images of 1990 and 2000 (fig 5-6 A & B). As explained in the methods, the validations were done subjectively. Figure 5-6 A shows one build-up (homesteads), two dryland for cropping and more sparsely vegetated areas to the northern parts of the image. Figure 5-6 B shows five build-up; three dryland for cropping and densely vegetated areas to the northern parts. Figure 5-7 shows the difference in land use and cover between 1990 and 2000. Table 5-21 provides an overview of the changes observed. These data shows that overall land use and cover change were 43 % while unchanged areas are 57%.



A) 14 May 1990 **B) 17 May 2000**

Figure 5-6: Land use and land cover of the Excelsior project at different years

The changed and unchanged areas are represented in the difference map fig 5-7. Changed areas are as shown on the legend and unchanged areas are given the same class on the map. Changes are mainly related to homestead construction after clearing of sparse and dense vegetation. Another change was due to the establishment of an extra dryland cropping field to the north western of the project. Other changes are attributed to bush thickening as a result of woody plants invading the open areas mostly to the north eastern parts of the project. Bush thickening changes are accounted for 25 % of the total change (table 5-21). Appendix 15 shows the attribute table with the calculated area per class and indicates how the class values of the input files overlapped.

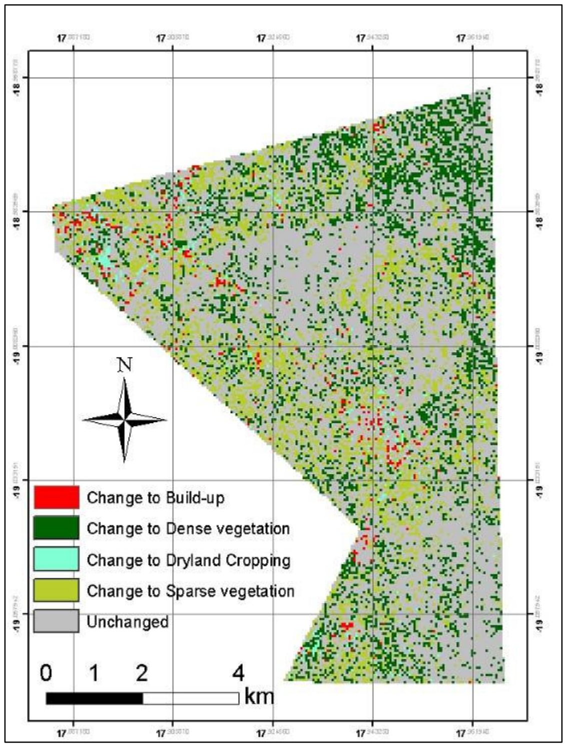


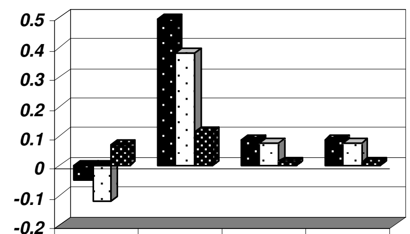
Figure 5-7: Difference map between 1990 and 2000

Table 5-21: Percentage change based on the comparison of image classification in May 1990 and May 2000

Class name	**Percentage (%) change**
Change to dense vegetation	25
Change to sparse vegetation	17
Change to build-up	0.5
Change to dryland cropping	0.3
Unchanged	57
Total change	43

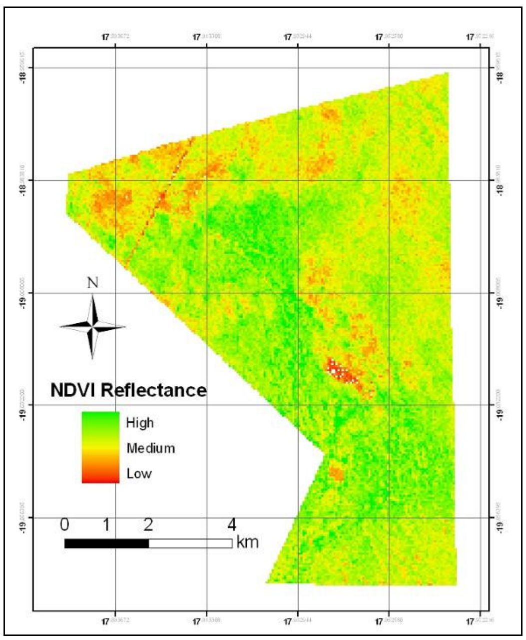
5.5.2. NDVI Change detection analysis

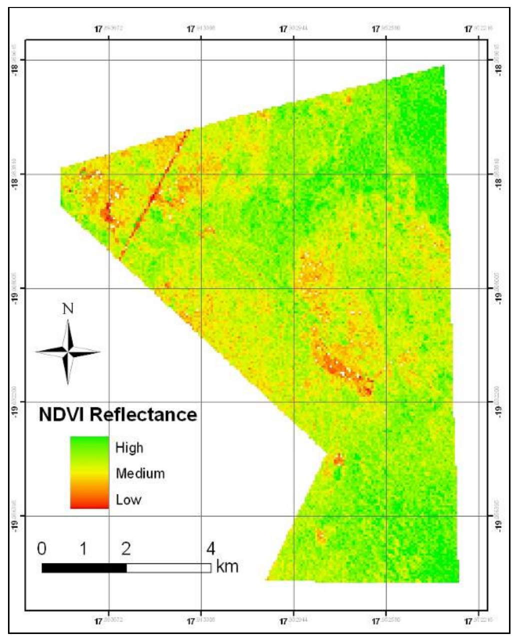
Figure 5-8 indicates descriptive statistics for NDVI for the difference images (1990 & 2000). The mean value for the NDVI image of 1990 was higher than for the year 2000. This implies that 1990 had more vegetation cover than 2000. The two images fig 5.9 represents the area with vegetation present at each time. In these images, high reflectance (green) represents areas with more vegetation, medium represents areas with less vegetation and low indicates areas with no vegetations. The 1990 image shows less vegetation both to the north western and north eastern parts of the project. The 2000 image indicates the increase in vegetation to both north and south eastern parts of the project. At the same time in the year 2000 there was a decrease in vegetation on west central parts of the project compared to the year 1990. This can still be observed on the NDVI map of January 2005 (figure 5-10); even though the image was not taken in May compared with the two difference maps figure 5-9. Hence figure 5-10 shows less vegetation to the west central parts. The 2005 NDVI image also shows vegetation increase to the north central parts of the project compared to the 2000 image.



	Min	Max	Mean	STDev
NDVI_1990	-0.0485	0.4957	0.0885	0.0875
NDVI_2000	-0.122	0.3821	0.0746	0.0767
Difference	0.0735	0.1136	0.0139	0.0108

Figure 5-8: Descriptive statistics for NDVI imageries





A) 14 May 1990 B) 17 May 2000

Figure 5-9: NDVI reflectance at difference time

The distribution of seasonal rain for 1989/1990 and 1999/2000 was also considered in the investigation of land use and cover changes. Because monitoring land cover changes (vegetation changes) alone is not sufficient, it needs to be linked to rainfall distribution in order to improve our understanding why certain changes occurred. In good rainfall years there is enough vegetation biomass and in poor rainfall years there is not. Hence, the condition of the rangeland is seen to be dependent upon rainfall.

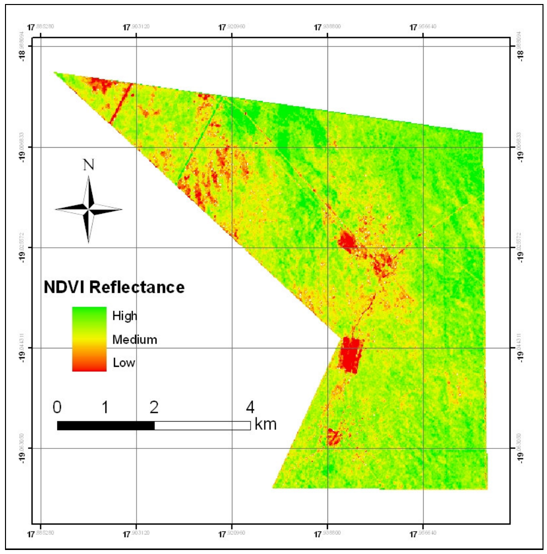


Figure 5-10: ASTER image showing NDVI reflectance for the year 2005 (half image of the project)

Figure 5-11 shows the distribution of seasonal rain in which 1999/2000 received a total rain of 599mm and 1989/1990 was 586mm respectively (Appendix 2). There was a normal distribution of seasonal rain for both years with a difference of 13mm. Rainfall is almost the same. Hence, Figure 5-11 shows that total rainfall in the two seasons compared in this section hardly differed. The totals were above long-term average for the area (Table 3-1). The distribution, however, did differ. When linking this information to the Figures showing land use and cover and NDVI, we can say that changes are attributed to human settlement than to drought.

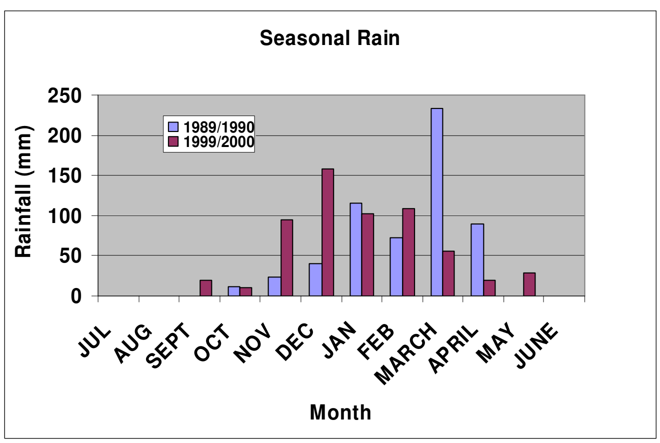


Figure 5-11: Seasonal rain at different time

6. CONCLUSIONS & RECOMMENDATIONS

- The actual LUTs in the area are Livestock (Cattle & Goats) and Rain-fed maize and pearl millet. Potential LUTs investigated were improved rangeland (Grazing), Rain-fed maize (improved), pearl millet (improved), sorghum and cowpeas. Results of the land evaluation have shown that it was relevant to evaluate these LUTs as they proved suitable to a marginal and moderate extent.

- The results obtained using the qualitative method (K2) shows that maize; pearl millet; sorghum and cowpea are moderately suitable (S2) at LEU P1. Pearl millet is moderately suitable for P2 while the maize, cowpea and sorghum are marginal suitable (S3). All the LUTs are marginal suitable (S3) for LEU P3/P4 & P5 respectively (section 5.5.2). The rangelands analysis indicates that four post are moderately suitable (S2) while the other two are marginal suitable (section 5.3.4) for grazing. The suitability status of the LEU is only based on the LURs, LCs & LQs considered in this study.

- The results from the quantitative method (K4) shows that reference crop evapotranspiration for LUTs 2, 4, 5, 6 and 7 based maize, pearl millet, cowpea and sorghum exceeds their crop water requirements in the given environment. The average yield is reduced due to water deficit and shallow rooting at different LEUs.

- Comparing a K2 and K4 approach results showed differences of average yields at different LEUs for LUTs 4, 5, 6 and 7 based maize, pearl millet, sorghum and cowpea.

- The research question concerning the eliciting of expert knowledge was not achieved, because not enough interviews took place to make a representative judgement.

- ❖ Therefore a hypothesis: Both a qualitative and quantitative land evaluation provides tools that allow useful comparison of current and potential land uses was accepted. Because ALES and CropWat were both successful used for evaluating the current and potential land uses.

- The result of the study on land-use and cover change showed that there are changes due to the development of homesteads around the project altering the vegetation cover; changes due to the developing of an extra dryland needed for cropping to the north western part; changes caused by bush thickenings, escalating to the north and south eastern parts of the project, from sparse vegetation (Dominant grasses) to dense vegetation (Thickening bushes); and changes from dense vegetation to sparse vegetation to the west central parts of the area. The research revealed that changes from sparse vegetation to dense vegetation have a negative impact on livestock production and continuation of such trends may reduce grazing area within the project. The overall changes were accounted for 43% while unchanged is 57%.

- ❖ Therefore a hypothesis: The study of land use and cover change reveals that resettlement of people has impact on the land use and cover pattern in space over time was accepted. Because resettlements of people have had impact on the land use and cover pattern in space over time.

- o The land use/ land cover was mapped successfully using geographical information system (GIS) & remote sensing (RS) techniques. Unavailability of historical land covers maps or photographs to validate the classification of images, led to the validation to be done subjectively.

- ❖ Therefore a hypothesis: Multi-temporal remote sensing data analysis is indispensable to understand land use and cover changes and should be used more often in land use monitoring in resettlement projects was accepted.

However the success of this study was constrained by the refusal of targeted experts to use their knowledge for land evaluation, which led to question D: How can expert's knowledge for ALES be elicited, not being achieved? The application of the research approach could have been better, if the study area was large enough to be divided into two different climatic situations. That could have allowed having different Land Mapping Units in order to produce maps in a GIS to show suitability pattern, which was not performed in this case. Also improvement would be if a soil map with more parameter values which could have given more LCs were generated. The limitation found for decision trees was due to validation. Because after construction of decision trees in ALES it is required to go to the field again to validate the model with experts in terms of ratings or limitation assigned to each LURs, LCs.

In conclusion, I believe the approach can play a vital role in the assessment of resettlement projects or for both communal and commercial areas targeted for resettlement especially for areas with different environmental conditions. Because more different Land Evaluation Units intended for such purpose could be evaluated quickly for the requirements to be met.

More research on Land Use Requirements for intercrops is required, to be investigated at field level in the given conditions. This will give a better understanding of aspects such as crop water requirements, row spacing and plant population when two or more different crops are intercropped. Intercroppings and rotations may also have additional benefits which are hard to disentangle in a single-crop-based land evaluation.

Research to find out soil nutrient deficiency is also required to be undertaken in order to determine the amount and type of fertilizer that needs to be applied in relation to the amount of nutrients depleted by crops.

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APPENDIX 1: Climatic data

Country: Namibia, Station: TSUMEB Source: (FAO, 1998b)

Month	Max Temperature (deg.C)	Mini Temperature (deg.C)	Humidity (%)	Wind Spd. (Km/d)	Sunshine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	31.1	18.6	56	95	8.3	23.7	5.27
February	30.1	18	58	95	8.5	23.5	5.06
March	29.3	17.1	61	86	8.8	22.5	4.58
April	28.5	15	54	86	8.8	20	3.9
May	26.5	11	43	95	9.3	18	3.29
June	24.1	8.5	38	130	10.2	17.6	3.27
July	24.5	8.1	35	112	10.8	18.9	3.27
August	27.3	10.7	29	130	10.7	21.2	4.3
September	31.5	15.5	23	130	10.5	23.8	5.41
October	33.1	18.8	30	130	9.2	23.9	5.92
November	32.3	18.6	42	130	9.3	25	6.01
December	31.7	18.7	51	112	9.3	25.3	5.77
Average	29.2	14.9	43.3	110.9	9.5	22	4.67

APPENDIX 2: Rainfall data

Station-ID: 10553743-Tsumeb Met Height: 1311M Latitude: 19.233 South Longitude: 17.717 East. Source: (NMS, 2005)

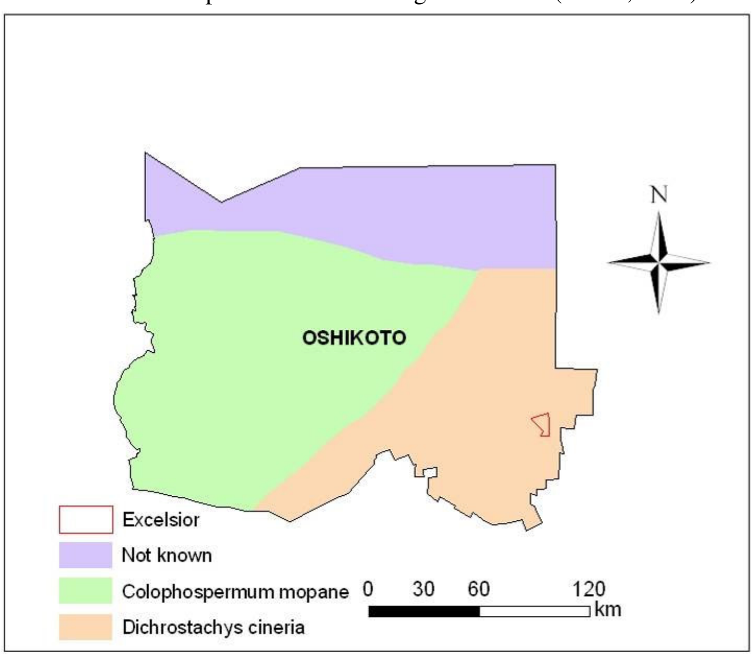
YEARS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total /Year	Seasonal rain
1989	115	138.5	35	54	0	0	0	0	0	12	23.2	40	417.7	
1990	115.8	73.0	233.0	89.0	0.0	0.0	0.0	0.0	0.0	22.0	36. 5	58.1	627.4	586
1991	161.7	126.5	18.0	0.0	0.0	0.0	0.0	0.0	0.0	38.1	29.0	111.5	484.8	422.8
1992	34.0	49.7	41.2	0.0	0.0	0.0	0.0	0.0	5.0	1.5	25.3	53.7	210.4	303.5
1993	59.0	122.9	17.0	38.3	0.0	0.0	0.0	0.0	0.0	40.0	27.0	83.0	387.2	322.7
1994	187.0	75.0	33.5	16.5	0.0	0.0	0.0	0.0	0.0	0.0	35.5	6.0	353.5	462.0
1995	21.5	185.0	119.9	0.0	4.0	0.0	0.0	0.0	0.0	95.5	76.5	60.0	562.4	371.9
1996	112.0	33.0	18.5	22.5	0.0	0.0	0.0	0.0	0.0	0.0	27.5	116.0	329.5	418.0
1997	215.5	102.0	74.0	0.0	0.0	0.0	0.0	0.0	0.0	42.0	10.0	66.5	510.0	535.0
1998	123.0	28.5	35.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	5.0	101.0	310.0	305.0
1999	140.0	74.0	76.5	0.0	0.0	0.0	0.0	0.0	20.0	11.0	95.0	158.0	574.5	414.0
2000	102.3	108.5	55.5	20.0	29.0	0.0	0.0	0.0	0.0	5.0	15.5	21.0	356.8	599.3
2001	27.0	131.5	168.5	68.8	0.0	0.0	0.0	0.0	0.0	0.0	61.9	11.0	468.7	437.3
2002	30.0	24.0	92.0	12.0	0.0	0.0	0.0	0.0	0.0	23.0	91.0	52.3	324.3	230.9
2003	118.7	105.5	0.0	12.0	0.0	0.0	0.0	0.0	0.0	27.1	73.4	74.0	410.7	402.5
MEAN	103.4	88.5	70.2	19.9	2.4	0.0	0.0	0.0	1.8	23.1	43.5	69.4	422.2	409.7
MEDIAN	113.9	88.5	48.4	12.0	0.0	0.0	0.0	0.0	0.0	19.8	32.3	63.3	378.0	642.1
std. Deviation	61.9	46.1	65.6	27.8	7.7	0.0	0.0	0.0	5.4	25.9	30.1	42.5	313.1	564.3
MIN	21.5	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	6.0	56.5	91.5
MAX	215.5	185.0	233.0	89.0	29.0	0.0	0.0	0.0	20.0	95.5	95.0	158.0	1120.0	2024.5
First Quartile	40..3	55..5	22..3	0.0	0.0	0.0	0.0	0.0	0.0	2.4	25.7	52.7	198.8	357.3
First Decile	4.0	5.6	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.6	5.3	19.9	35.7
Coefficiency	1.7	1.9	1.1	0.7	0.3	N/A	N/A	N/A	0.3	0.9	1.4	1.6	1.3	0.7

APPENDIX 3: Agro-Ecological Zones (Abbreviations)

AEZ_ID	AEZ_NAME
ETO	ETO Ekuma Plains and Etosha Pan
KAL3-2	KAL3-2 Kalahari Sands Plateau, stabilized sand drift with few pans, average growing period 91-120 days
KAL3-2	KAL3-2 Kalahari Sands Plateau, stabilized sand drift with few pans, average growing period 91-120 days
KAL3-3	KAL3-3 Kalahari Sands Plateau, stabilized sand drift with few pans, average growing period 61-90 days, dependable growing 60 % of average
KAL4	KAL4 Kalahari Sands Plateau, stabilized sand drift with common pans
KAL5	KAL5 Kalahari Sands Plateau, slightly incised river valleys
KAL8	KAL8 Kalahari Sands Plateau, 'omuramba'-dune association
KAL9-3	KAL9-3 Kalahari Sands Plateau, 'Oshana' flood system, growing period 61-90 days, dependable growing period 60 % of average
KALK-3	KALK-3 Kalkveld, average growing period 61-90 days, dependable growing period 60% of average
KALK-4	KALK-4 Kalkveld, median growing period 61-90 days, very short dependable growing period
R	R Undifferentiated rocky hills and inselberg mountains
R	R Undifferentiated rocky hills and inselberg mountains
R	R Undifferentiated rocky hills and inselberg mountains
CPL16-2	CPL16-2 Central Plateau, red Kalkveld, average growing period 91-120 days
KALK-2	KALK-2 Kalkveld, average growing period 91-120 days, dependable growing period 80% of average

Source: (de Pauw et al., 2001)

APPENDIX 4: Bush Encroachment map of the Oshikoto Region. Source: (Bester, 1996)



APPENDIX 5: Photographs showing vegetation within the project

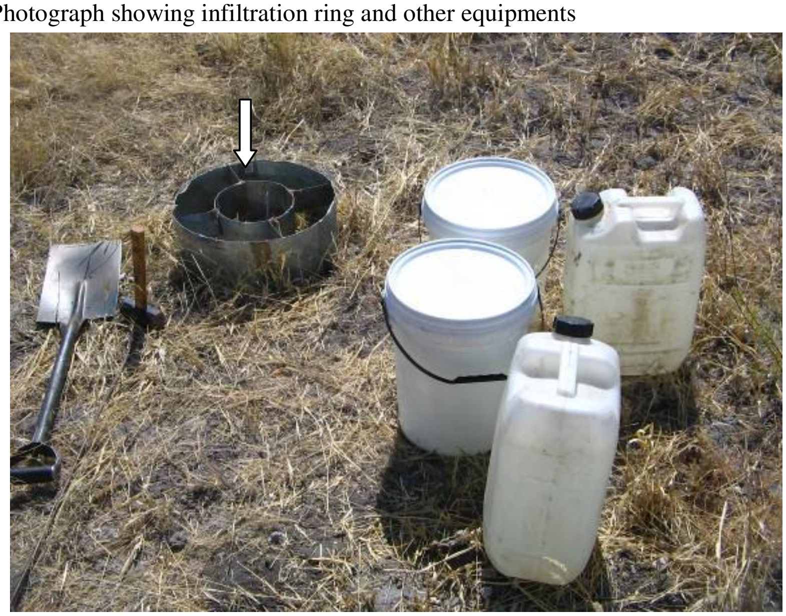
1. EMP

2. EJSP

3. EKEP

4. ETP

APPENDIX 6: Photograph showing infiltration ring and other equipments



APPENDIX 7: Infiltration Rate measurements

Execlsior Thank You Post (ETYP) S 19.04' 654" E 17.94' 036" Date: 15/09/2005
Soil depth = 70cm Soil pH = 8.0 Soil type = loam soil

Reading clock	Time Difference	Cumulative time	Water level readings		Infiltration	Infiltration rate	Infiltration rate	Cumulative Infiltration
			Before filling	After filling				
hr min sec	min	min	mm	mm	mm	mm/min	mm/hour	mm
	Start = 0	**0**	0	100	///////////////	///////////////	///////////////	0
10 06 00	2	2	95	100	5	2.5	150	5
10 08 00	3	5	93	101	7	2.3	140	12
10 11 00	5	10	92	100	9	1.8	108	21
10 16 00	10	20	88	102	12	1.2	72	33
10 26 00	10	30	89	97	13	1.3	78	46
10 36 00	20	50	74	100	23	1.15	69	69
10 56 00	20	70	76	101	24	1.2	72	93
11 16 00	20	90	79	101	22	1.1	**66**	115
11 36 00	20	110	79		22	1.1	**66**	137
11 56 00								

Excelsior Twewaadha Post (ETP) **E** 17. 56' 738 **S** 18. 58' 066" Date:13/09/2005
Soil depth = 30cm Soil pH = 5 Soil type = Clay soil

Reading clock	Time Difference	Cumulative time	Water level readings		Infiltration	Infiltration rate	Infiltration rate	Cumulative Infiltration
			Before filling	After filling				
hr min sec	min	min	mm	mm	mm	mm/min	mm/hour	mm
	Start = 0	**0**	0	100	///////////////	///////////////	///////////////	0
10 35 00	2	2	96	100	4	2	120	4
10 37 00	3	5	94	100	6	2	120	10
10 40 00	5	10	93	100	7	1.4	84	17
10 45 00	10	20	88	100	12	1.2	72	29
10 55 00	10	30	90	100	10	1	60	39
11 05 00	20	50	82	100	18	0.9	54	57
11 25 00	20	70	80	100	20	1	60	77
11 45 00	20	90	95	100	5	0.25	**15**	82
12 05 00	20	110	95		5	0.25	**15**	87
12 25 00								

Excelsior Excelsior Post (EEP) **E** 17.94' 145" **S** 19.02' 402" Date 16/09/05
Soil pH = 6 Soil type = Sandy Loam soil Soil depth = 50cm

Reading clock	Time Difference	Cumulative time	Water level readings		Infiltration	Infiltration rate	Infiltration rate	Cumulative Infiltration
			Before filling	After filling				
hr min sec	min	min	mm	mm	mm	mm/min	mm/hour	mm
	Start = 0	**start = 0**	**0**	100	///////////////	///////////////	///////////////	**start = 0**
08 35 00	2	2	90	100	10	5	300	10
08 37 00	3	5	89	100	11	3.666666667	220	21
08 40 00	5	10	86	100	14	2.8	168	35
08 45 00	10	20	80	100	20	2	120	55
08 55 00	10	30	80	100	20	2	120	75
09 05 00	20	50	70	100	30	1.5	90	105
09 25 00	20	70	70	100	30	1.5	90	135
09 45 00	20	90	75	100	25	1.25	**75**	160
10 05 00	20	110	75		25	1.25	**75**	185
10 25 00								

Excelsior John Steel Post (EJSP) E 17. 89' 290" S 18. 99' 185" Date: 14/09/2005
Soil depth = 30cm Soil type=Clay Soil pH = 5

Reading clock	Time Difference	Cumulative time	Water level readings		Infiltration	Infiltration rate	Infiltration rate	Cumulative Infiltration
			Before filling	After filling				
hr min sec	min	min	mm	mm	mm	mm/min	mm/hour	mm
	Start = 0	**0**	0	100	///////////////	///////////////	///////////////	0
08 10 00	2	2	96	100	4	2	120	4
08 12 00	3	5	98	100	2	0.666666667	40	6
08 15 00	5	10	96	100	4	0.8	48	10
08 20 00	10	20	97	100	3	0.3	18	13
08 30 00	10	30	96	100	4	0.4	24	17
08 40 00	20	50	87	100	13	0.65	39	30
09 00 00	20	70	89	100	11	0.55	33	41
09 20 00	20	90	90	100	10	0.5	**30**	51
09 40 00	20	110	90		10	0.5	**30**	61
10 00 00								

Excelsior Makalani Post (EMP) **S 18. 99' 646"** **E 17. 91' 458"** Date: 14/09/2005
Soil depth = 30cm Soil pH = 5 Soil type = Clay soil

Reading clock	Time Difference	Cumulative time	Water level readings		Infiltration	Infiltration rate	Infiltration rate	Cumulative Infiltration
			Before filling	After filling				
hr min sec	min	min	mm	mm	mm	mm/min	mm/hour	mm
	Start = 0	**0**	0	100	///////////////	///////////////	///////////////	0
14 56 00	2	2	97	100	3	1.5	90	3
14 58 00	3	5	95	100	5	1.67	100	8
15 01 00	5	10	90	102	10	2	120	18
15 06 00	10	20	88	100	14	1.4	84	32
15 16 00	10	30	84	100	16	1.6	96	48
15 26 00	20	50	72	100	28	1.4	84	76
15 46 00	20	70	72	100	28	1.4	84	104
16 06 00	30	100	80	100	20	0.67	**40**	124
16 36 00	30	130	80		20	0.67	**40**	144
17 06 00								

APPENDIX 8: Questionnaire for settler's interviews

(All information provided will be treated as strictly confidential)

A. General **Survey No.-------**

1. Name of Farmer
2. Name of farm/Plot name
3. Constituency
4. Traditional Authority
5. Family size
6. Family Composition: Age----Male-------Female
7. Dependants: Relatives----------Others---------
8. Off-Farm work
   - Do you have any work?
   - If yes, details

B. Farming Size and Activities

1. What is your Total land holding per ha?
2. What is the total area under cultivation per ha?
3. Does the land belong to you (yes/no)?
4. If no, how do you get land for cultivation?
5. What kind of crops do you grow?
6. How much land is taken up by each crop?
7. Do you have different kinds of land (soil) in your farm (yes/no)?

   If yes, justification
8. Do you have specific names for them (or soils) (yes/no)?

   If yes Names:
9. What are there differences between them?
10. Which land uses do you prefer on each land area under your control and Why?
11. Have you cultivated all your areas last seasons? (yes/no)
12. Have you managed these areas on your farm the same? (yes/no)
13. What did you do differently in different areas?

C. Cultural Practices

	Produce A	**Produce B**	**Produce C**	**Produce D**
Produce				
Variety				
Land Preparation:-Labour costs -Labour - Source of Power				
Seeds: -Seed rate (kg/ha) -Price (N$ /kg) -Others costs (specify)				
Sowing: -Date -Method -Labour costs -Other costs (specify)				
Fertilizer: - Do you apply fertilizer in your field - Type of fertilizer -Price / bag or kg - Transport costs - Method of application -Labour costs				

-Other costs (specify)				
	Produce A	**Produce B**	**Produce C**	**Produce D**
Pesticides: -Type -Price -Method of application -Labour -Other costs (specify)				
Weeding: -Source of power -Labour costs -Other costs (specify)				
Yields (kg/ha)				
Harvesting: -Labour -Method -Date -Other costs (specify)				

D. Source of Income

	Produce A	**Produce B**	**Produce C**	**Produce D**
Source of Income -Government loans scheme -Bank Loans -Money lenders -Support from children -Others (specify)				

E. What are the major Constraints facing your agricultural production activities?
F. What are the highest possible yields in this area for your major crops?
G. Other information

APPENDIX 9: Questionnaire for expert's interviews

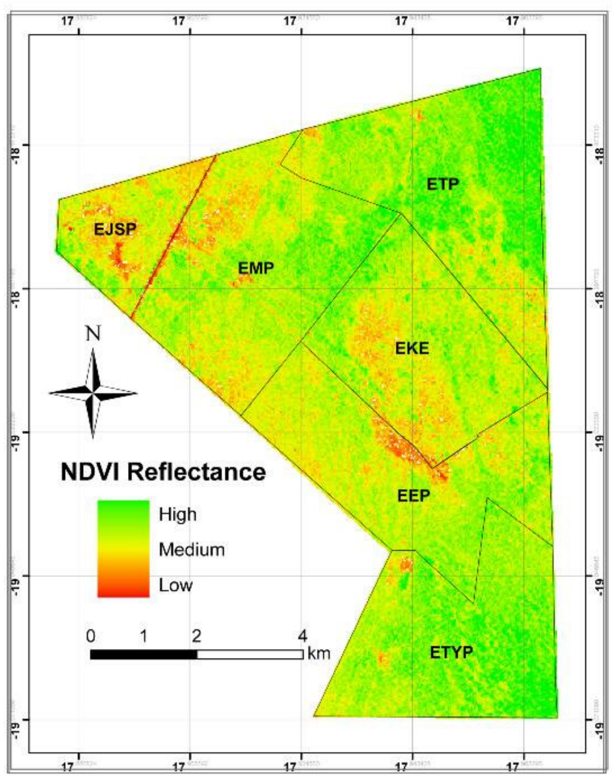
Respondent: Mr. Ibo Zimmermann	
Question	**Respond**
SECTION A: OPEN-ENDED WRITTEN QUESTIONS	
If you could choose to make use of any land at Excelsior Farm in order to implement Rain-fed agriculture (Particularly for Maize & Pearl millet (Mahangu) production), which area would you prefer? Why?	1st 35ha (ETYP), 2nd 10ha (EEP) and 3rd (EJSP) – due to calcrete depressions overlain by enough soil, due to more moisture being retained. Also due to soil depth and better pH.
Which area do you think will produce better crops this year? Why?	ETYP-because of better moisture being retained there.
Are there land areas that would have specific management problems if this LUT were implemented there?	Yes
What are these problems, and why do you think these areas will have them?	Sustainability of the methods used. Fast tillage pulverizes the soil. Due to management than susceptibility of the land type.
Which crops do you think can perform better under this condition apart from maize & Pearl millet? Why?	Sorghum & Cowpeas (Responded by one Commercial farmer as well). Due to drought resistance and root system.
Are there land areas on which you would have to undertake extensive preliminary preparations in order to implement these LUTs?	Yes
What are these preparations?	Bushes would need to be cleared for new land, try zero tillage, and keep mulch cover.
Do you observe (do you expect) this LUT to achieve different success on different land units? *If the answer to this question is no, there is no LE and if the answer is yes, the follow-up questions are:*	Yes
To what extent do you attribute the different success?	Soil quality
What makes one land unit more suitable than another?	Better water retention and greater availability of minerals.
Can you separate these into groups of factors?	Moisture & Nutrients
Are all the factors equally important when making an overall assessment of the success of the LUT?	No
If not, can you rank them and if possible give them weights?	Moisture (80%) & Mineral nutrients (20%)
How many suitability levels can be distinguished for this LUT at Excelsior Resettlement project?	Three
Are there areas where adaptations are needed if the LUT is to be successful?	Yes
If yes, please identify these?	Sustainable management practices, to protect soil from being exposed to the suns, wind and increase its carbon content.
Is the technological package the same everywhere for this LUT?	Yes
Are there differences in the fertilization, irrigation, tillage or if there is any?	Sandier soil needs more inputs
SECTION: B STRUCTURED QUESTIONS **Question Set 1: Selecting Land Use Requirements**	
What general conditions of land, with respect to *Agro-Ecology, Management, Spatial, Land modification, Environmental risks and Social, political and economic* , make this land use more or less successful within the project area?	Moisture retention, soil cover & carbon content, fertility, maintain cover & uncleared strips, Appropriate tillage, Distance to markets, reliability of rainfall amount and distribution over the season. Cooperation amongst settlers.
Do sub-optimal values of the corresponding LQ occur in the study zone? (For each possible LUR)?	Yes

Are there differences in the corresponding LQ in the study zone? (For each possible LUR)?	Yes
Question Set 2: Determining severity levels	
How fine a distinction can you make between degrees of Land Quality?	Only two qualities
For each of those classes, can you be more specific on what it implies for the results of the LUT?	Sandy soil needs more inputs and faces greater risk of drought.
Question Set 3: Selecting diagnostic Land Characteristics	
What information about a land area would you need to determine the severity level of this LQ in that area?	Soil depth, Texture, pH, Temperature, carbon content & cover and annual rainfall.
Question Set 4: Building a decision tree	
Which diagnostic LC is most important in determining the severity level of this LQ?	Soil depth
What values of this LC mark the break points in your decision process?	<30 too shallow >100cm holds insufficient moisture
Can you decide what will be the severity level, from just this information?	No
If yes (value)	
If not: "Given the LC values in the path so far, for this branch, what is the next most important diagnostic LC for determining the severity level?	Texture (<15% clay needs more inputs) (>30% clay excessive)
(Process continues until the tree is complete)	
Question Set 5: Economic Land Evaluation	
What are the optimum yields of each output of the LUT?	Pearl millet-1875kg Maize – 3000kg (Based on the Coordinator)
What are the *inputs* to this LUT on the best-suited and best-managed (in the context of the LUT) land?	Manure, Mulch, intercropping and integrated pest control.
Are there extra inputs on the less well-suited or less well-managed land?	High input levels needed e.g. fertilizers
What would be necessary to bring the land into production, for each severity level?	More moisture
Which Land Qualities affect yield?	Soil depth, texture, carbon content & cover.
Looking for differences in related LUTs	
Are any of the LURs which you identified for the base LUT now irrelevant?	No
Are there any new ones that should be added?	Nutrients requirements
Must any of the severity levels be adjusted?	Add temperature & nutrients, but these are linked to management inputs
Are the diagnostic procedures for severity levels still correct?	No
If not, how must they be modified?	soil depth, texture

APPENDIX 10: **Identified land-cover & Coordinates**

Unit_Code	Code_2005	Land_Cover	X_ Coord	Y_Coord
ETYP1	3	Buildup Thank You Community	17.94018	-19.06148
ETYP2	1	Dense vegetation and few grass cover	17.94240	-19.05257
ETYP3	4	Dryland cropping	17.94359	-19.04457
EEP1	2	Sparse vegetation with dominant grasses	17.94666	-19.03707
EEP2	3	Build up & Windmill (Houses) (Excelsior Community)	17.94675	-19.02784
EKEP1	2	Sparse vegetation with dominant grasses	17.94372	-19.02110
EKEP2	1	Dense vegetation and few grass cover	17.94666	-19.01386
EKEP3	1	Dense vegetation and few grass cover	17.94935	-19.00634
EKEP4	1	Dense vegetation and few grass cover	17.95210	-18.99867
ETP1	2	Sparse vegetation with dominant grasses	17.95185	-18.99072
ETP2	1	Dense vegetation and few grasses cover	17.95053	-18.98277
ETP3	1	Dense vegetation and few grass cover	17.94921	-18.97471
ETP4	3	Build up & Windmill (Houses) Twewandha community	17.94596	-18.96804

APPENDIX 11: NDVI_map with post boundaries



APPENDIX 12: Land Evaluation (LE) for Rain-fed crops (Decision Trees from ALES)

1. **Decision Tree – Maize (M) (LUT2a+b)**

a) Moisture requirement

> rof (Precipitation October-March)
  <250 [0-250 mm].........: 3 (Severe stress)
  250-400 [250-400 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100 cm] : 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 2 (Moderate stress)
      ?....................... : ?
    SL (Sand loam)..........: =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 3 (Severe stress)
      D (Deep) [100-1000 cm].. : 2 (Moderate stress)
      ?....................... : ?
      >400 [400-600 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 1 (Adequate)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam)..........: =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]...: 3 (Severe stress)
      M (Moderate deep) [50-100cm]: 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?

b) Rooting conditions

> tt (Topsoil texture)
  L (Loam) > sd (Soil Depth)
    S (Shallow) [0-50 cm]... : 3 (Poor)
    M (Moderate deep) [50-100cm] : 2 (Moderate)
    D (Deep) [100-1000 cm].. : 1 (Good)
    ?....................... : ?
  SL (Sand loam).......... : =1
  C (Clay)................ : 3 (Poor)
  ?....................... : ?

c) Absence of soil toxicities

> pH (Soil pH)
  va (very acid) [4.5-5 pH] : 3 (marginal)
  acid (acid) [5-6 pH].... : 2 (moderate)
  neut (neutral) [6-7 pH]. : 1 (no limitation)
  alk (alkaline) [7-9 pH]. : 2 (moderate)
  ?....................... : ?

d) Temperature requirement

> tof (Temperature October-February)
  <25 [0-25 Degree Celsius] : 2 (light risk)
  25-35 [25-35 Degree Celsius] : 1 (no risk)
  >35 [35-45 Degree Celsius] : 3 (risk)
  ?....................... : ?

2. **Decision Tree – Pearl millet (P) (LUT3a+b)**

a) Moisture requirement

> rof (Precipitation October-March)
  <250 [0-250 mm].........: 3 (Severe stress)
  250-400 [250-400 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]...: 2 (Moderate stress)
      M (Moderate deep) [50-100cm]: 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam).......... : =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 3 (Severe stress)
      D (Deep) [100-1000 cm].. : 2 (Moderate stress)
        ?....................... : ?
  >400 [400-600 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 1 (Adequate)
      M (Moderate deep) [50-100cm] : 1 (Adequate)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam).......... : =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?

b) Rooting conditions

> tt (Topsoil texture)
  L (Loam) > sd (Soil Depth)
    S (Shallow) [0-50 cm]... : 2 (Moderate)
    M (Moderate deep) [50-100cm] : 1 (Good)
    D (Deep) [100-1000 cm].. : 1 (Good)
    ?....................... : ?
  SL (Sand loam).......... : =1
  C (Clay) > sd (Soil Depth)
    S (Shallow) [0-50 cm]... : 3 (Poor)
    M (Moderate deep) [50-100cm] : 2 (Moderate)
    D (Deep) [100-1000 cm].. : 1 (Good)
    ?....................... : ?

c) Absence of soil toxicities

> pH (Soil pH)
  va (very acid) [4.5-5 pH] : 2 (moderate)
  acid (acid) [5-6 pH].... : 1 (no limitation)
  neut (neutral) [6-7 pH]. : 2 (moderate)
  alk (alkaline) [7-9 pH]. : 2 (moderate)
  ?....................... : ?

d) Temperature requirements

> tof (Temperature October-February)
  <25 [0-25 Degree Celsius] : 2 (light risk)
  25-35 [25-35 Degree Celsius] : 1 (no risk)
  >35 [35-45 Degree Celsius] : 3 (risk)
  ?....................... : ?

3. Decision Tree – Sorghum (S) (LUT4)

a) Moistur requirement

```
> rof (Precipitation October-March)
  <250 [0-250 mm]......... : 3 (Severe stress)
  250-400 [250-400 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam).......... : =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 3 (Severe stress)
      D (Deep) [100-1000 cm].. : 2 (Moderate stress)
      ?....................... : ?
    ?....................... : ?
  >400 [400-600 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 2 (Moderate stress)
      M (Moderate deep) [50-100cm] : 1 (Adequate)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam).......... : =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
```

b) Rooting conditions

```
> tt (Topsoil texture)
  L (Loam) > sd (Soil Depth)
    S (Shallow) [0-50 cm]... : 3 (Poor)
    M (Moderate deep) [50-100cm] : 2 (Moderate )
    D (Deep) [100-1000 cm].. : 1 (Good)
    ?....................... : ?
  SL (Sand loam).......... : =1
  C (Clay)................ : 3 (Poor)
  ?....................... : ?
```

c) Absence of soil toxicities

```
> pH (Soil pH)
  va (very acid) [4.5-5 pH] : 3 (marginal)
  acid (acid) [5-6 pH].... : 2 (moderate)
  neut (neutral) [6-7 pH]. : 1 (no limitation)
  alk (alkaline) [7-9 pH]. : 2 (moderate)
  ?....................... : ?
```

d) Temperature requirements

```
> tof (Temperature October-February)
  <25 [0-25 Degree Celsius] : 2 (light right)
  25-35 [25-35 Degree Celsius] : 1 (no risk)
  >35 [35-45 Degree Celsius] : 3 (risk)
  ?....................... : ?
```

4. Decision Tree – Cowpea (C) (LUT5)

a) Moisture requirement

```
> rof (Precipitation October-March)
  <250 [0-250 mm]......... : 3 (Severe stress)
  250-400 [250-400 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam).......... : =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 3 (Severe stress)
      D (Deep) [100-1000 cm].. : 2 (Moderate stress)
    ?....................... : ?
  >400 [400-600 mm] > tt (Topsoil texture)
    L (Loam) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 2 (Moderate stress)
      M (Moderate deep) [50-100cm] : 1 (Adequate)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
    SL (Sand loam).......... : =1
    C (Clay) > sd (Soil Depth)
      S (Shallow) [0-50 cm]... : 3 (Severe stress)
      M (Moderate deep) [50-100cm] : 2 (Moderate stress)
      D (Deep) [100-1000 cm].. : 1 (Adequate)
      ?....................... : ?
```

b) Rooting conditions

```
> tt (Topsoil texture)
  L (Loam) > sd (Soil Depth)
    S (Shallow) [0-50 cm]... : 3 (Poor)
    M (Moderate deep) [50-100cm] : 2 (Moderate )
    D (Deep) [100-1000 cm].. : 1 (Good)
    ?....................... : ?
  SL (Sand loam).......... : =1
  C (Clay) > sd (Soil Depth)
    S (Shallow) [0-50 cm]... : 3 (Poor)
    M (Moderate deep) [50-100cm] : 3 (Poor)
    D (Deep) [100-1000 cm].. : 2 (Moderate )
    ?....................... : ?
```

c) Absence of soil toxicities

```
> pH (Soil pH)
  va (very acid) [4.5-5 pH]: 2 (moderate)
  acid (acid) [5-6 pH].... : 1 (no limitation)
  neut (neutral) [6-7 pH]. : 1 (no limitation)
  alk (alkaline) [7-9 pH]. : 2 (moderate)
  ?....................... : ?
```

d) Temperature requirements

```
> tof (Temperature October-February)
  <25 [0-25 Degree Celsius] : 2 (light risk)
  25-35 [25-35 Degree Celsius] : 1 (no risks)
  >35 [35-45 Degree Celsius] : 3 (risk)
  ?....................... : ?
```

APPENDIX 13: Codes used in ALES

```
Land Characteristics codes
         Class Code       Class Name             Upper limit
pH┬Soil pH┬4┬pH
    1   va               very acid                 5
    2   acid             acid                      6
    3   neut             neutral                   7
    4   alk              alkaline                  9
rof┬Precipitation October-March┬3┬mm
    1   <250                                       250
    2   250-400                                    400
    3   >400                                       600
sd┬Soil Depth┬3┬cm
    1   S                Shallow                   50
    2   M                Moderate deep             100
    3   D                Deep                      1000
tof┬Temperature October-February┬3┬Degree Celsius
    1   <25                                        25
    2   25-35                                      35
    3   >35                                        45
tt┬Topsoil texture┬3┬classes
    1   L                Loam
    2   SL               Sand loam
    3   C                Clay
```

```
Land Use Requirement codes
LUR code     Name
m            Moisture requirement
rc           Rooting conditions
st           Absence of Soil toxicities
t            Temperature requirement
```

APPENDIX 14: Land evaluation for Rangeland (Decision Tree)

Grazing Capacity

> rof (Precipitation October-March)
  <250 [0-250 mm]......... : 3 (poor)
  250-400 [250-400 mm].... : 2 (moderate)
  >400 [400-600 mm]....... : 1 (good)
  ?....................... : ?

Palatability of Vegetation

> ov (observed vegetation)
  DG (Dominant Grasses)... : 1 (high)
  DT (Dominant Thicket)... : 2 (low)
  ?....................... : ?

Accessibility of Animals

> vd (vegetation density (NDVI Values))
  L (0.2922-0.3253)....... : 1 (accessible)
  H (0.3256-0.3321)....... : 2 (moderate)
  VH (0.3762-0.3782)...... : 3 (not accessible)
  ?....................... : ?

APPENDIX 15: Matrix table obtained from Erdas 8.7

Class name	Pixel values	1990_Class	2000_Class	Area_ha
Dense Vegetation (1)	28982	1	1	2608
Dense veg change to Sparse Veg	11878	1	2	1069
Dense veg change to Build-up	196	1	3	18
Dense veg change to Dryland Crop	89	1	4	8
Dense veg change to Road	3	1	5	0
Sparse veg change to Dense veg	16987	2	1	1529
Sparse Vegetation (2)	9897	2	2	891
Sparse veg change to Build-up	147	2	3	13
Sparse veg change to Dryland cro	51	2	4	5
Sparse veg change to Road	1	2	5	0
Build-up change to Dense veg	174	3	1	16
Build-up change to Sparse veg	31	3	2	3
Build-up (3)	39	3	3	4
Build-up change to Dryland crop	27	3	4	2
Build-up change to Road	2	3	5	0
Dryland change to Dense veg	81	4	1	7
Dryland change to Sparse veg	71	4	2	6
Dryland change to Build-up	7	4	3	1
Dryland cropping (4)	489	4	4	44
Dryland change to Road	5	4	5	0
Road change to Dense veg	78	5	1	7
Road change to Sparse	4	5	2	0
Road change to Build-up	5	5	3	0
Road change to Dryland	16	5	4	1
Road (5)	11	5	5	1
Total ha				6234
Unchanged				3548
Changed to dense vegetation				1559
Changed to sparse vegetation				1079
Changed to build-up				32
Changed to dryland				16
Changed to road				1
Total change				2687