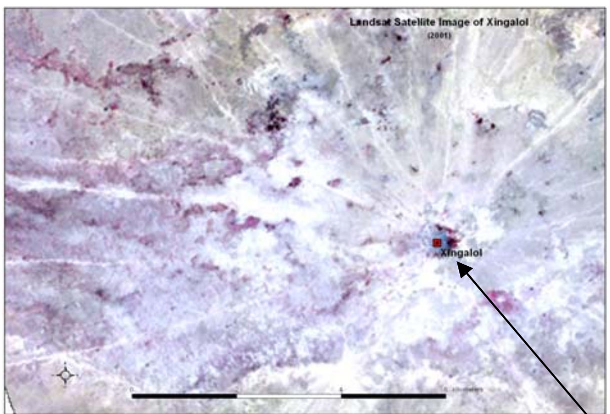
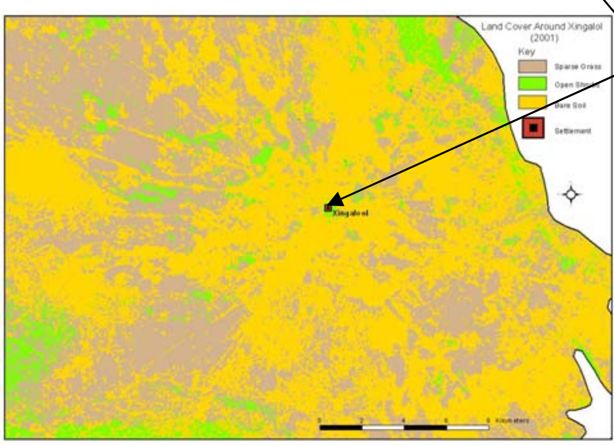
Application of Remote Sensing Techniques for the Assessment of Pastoral Resources in Puntland, Somalia





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LIST OF ACRONYMS

AOI	Area of Interest
AVHRR	Advanced Very High Resolution Radiometer
CC	Colour Composite
EC	European Commission
DEM	Digital Elevation Model
EROS	Earth Resources Observation System
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization of the United Nations
FCC	False Colour Composite
FEWSNET	Famine Early Warning System Network
FSAU	Food Security and Assessment Unit
GAC	Global Area Coverage
GIS	Geographic Information Systems
GLCN	Global Land Cover Network
GLCRSP	Global Livestock Collaborative Research Support Programme
GPS	Global Positioning System
ICPAC	IGAD Climate Prediction and Application Centre
LADA	Land Degradation Assessment in Drylands
LCCS	Land Cover Classification System
LINKS	Livestock Information Network and Knowledge System
LTM	Long Term Mean
MODIS	Moderate-Resolution Imaging Spectrometer
MOLAE	Ministry of Livestock, Agriculture and Environment in Puntland
MSS	Multi-Spectral Scanner System
NDVI	Normalised Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
PET	Potential Evapotranspiration
RCMRD	Regional Centre for Mapping of Resources for Development
RFE	Rainfall Estimates
SDRN	Sustainable Development Research Network
SRTM	Shuttle Radar Topographic Mission
SPOT	Satellite Probatoire d'Observation de la Terre (The French Remote Sensing Satellite)
SWALIM	Somalia Water and Land Information Management
TM	Thematic Mapper
TOA	Top-of-the-atmosphere
UNDP	United Nations Development Programme
USGS	United States Geological Survey
VCI	Vegetation Condition Index
VEDAS	Vegetation Dynamics Software

1 INTRODUCTION

1.1 Background

Somalia has experienced lack of policy development and policy enforcement in the management of natural resources following the collapse of the government in 1991. This has had negative impacts on the productivity of resources in the country (Besteman and Cassanelli, 2000, Mohamed and Viaconi, 2001). The rangelands have as such suffered and continue to suffer degradation, significantly diminishing the production potential of their resources. The country is today engulfed in structural food insecurity and internal displacement.

Several institutions and organizations among them Horn Relief (2006) and Food Security Assessment Unit (FSAU) (2005) have reported cases of deteriorating production potentials of rangeland resources in Somalia. Similarly, various researchers have also expressed their concern regarding decline in the production potential of resources in the pastoral lands of Somalia. Although several causes have been given for this decline, no quantitative and qualitative analyses of the pastoral resources have been carried out, specially with regard to pasture production and utilisation.

Livestock or pastoral production is a very important economic activity in Somalia. In most pastoral systems such as in Somalia, livestock production at farm level contributes as much as 70% or higher of economic production or income (RCMRD *et al*, 2006). In the Somalia context, pastoral activities focus on camel, goat, sheep, and cattle production. These livestock species are a major source of food (through the provision of milk and meat) and other domestic needs (such as clothes, beddings, and in some cases a source of energy through the use of livestock wastes for firing). Livestock can also be used as a financial entity or seen as a “bank” of some sort by the pastoralist. As such the importance of pastoral resources (water, grazing as well as browsing pastures, etc) to the Somali community cannot be overemphasized.

It is in view of the above that in March 2007 FAO-SWALIM embarked on the implementation of a pastoral resources study in Puntland. The conceptual aim of the study was to test and evaluate the applicability of remote sensing tools and products in the assessing pastoral resources. In the study remote sensing in combination with fieldwork were used to assess pastoral resources in two study areas falling within Sanag, Sool, Nugal and Mudug Regions of Puntland in northern Somalia. The key purpose of the study was to test remote sensing techniques as tools for assessing and monitoring pastoral resources.

Remote sensing, as defined by Lillesand and Kiefer (1994), is the “*science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in (physical) contact with the object, area or phenomenon under investigation*”. Although the use of our eyes constitutes remote sensing, conventional concept of remote sensing goes beyond the visual part to include what cannot be seen, i.e. the invisible part of the electromagnetic spectrum.

Historically remote sensing dates as far back as the end of the 19^{th} century when cameras were first made airborne using balloons and kites. The advent of aircraft further enhanced the opportunities to take photographs from the air. The First World War is seen as the first major use of remote sensing as a method of data and information acquisition.

Today, remote sensing is carried out using airborne methods (that employ the use of aircrafts and to some extent balloons) and space borne methods using space shuttles and satellite technology. The airborne techniques use film photography, cameras, and videos while space technologies use scanners as well as radar and thermal sensors.

Because of advancements in technology the use of non-visual part of the electromagnetic spectrum has enhanced details of information that can be collected about the environment. The technology is heavily utilized in environmental management which frequently has a requirement for rapid, accurate and up-to-date or near real-time collection. However, despite the numerous advantages that remote sensing has, it has not quite replaced ground-based survey methods. Some of the limitations include potential limitations with spatial, spectral and temporal resolutions of the various sensors, and also limitations with weather capabilities, as well as problems with data analysis and interpretation.

1.2 Objectives

The main objective of this study was to test the application of remote sensing techniques and products for assessing resources in pastoral areas and in particular with respect to rangeland and environmental degradation in the two study areas in Puntland, in northern Somalia. Specific objectives were:

- To assess changes and trends in land cover in the study area using satellite image interpretation and field surveys.
- Assess applicability of the average phenological behaviour of the major vegetation physiognomic groups as an input for the analysis of drought conditions in 2006
- To assess human and animal impacts on the pastoral resources using remote sensing techniques with focus on settlements, water points and vegetation removal.
- Outline potentialities and limitations of remote sensing techniques and products in assessing non palatable invasive species.

1.3 Structure of this report

This report has been divided into five main parts. Part 1 is the introduction which describes the background of the study and the study objectives. Part 2 describes the study area; Part 3 discusses the methodological approach of the study; Part 4 gives and briefly discusses the findings of the study; while Part 5 is the conclusions and recommendations of the study. Bibliography is given in Part 6 and Part 7 lists the annexes to this report.

2 THE STUDY AREA

2.1 Location and delineation

The two study areas are located to the north and south of Garowe. The northern one covers parts of Sanag, Sool and Nugal Regions while the southern one covers parts of Nugal and Mudug Regions (see Figure 1 below). The two areas are approximately 7 000 km^2 each. The northern study area lies between longitude 48^o and 48^{o}48' East and latitude 8^{o}36' and 9^{o}55' North. The southern one is located between longitude 48^{o}22' and 49^{o}25' East and latitude 7^{o}4' and 8^o North. The areas were selected based on their ecological variability comprising different eco-regions hence suitable for such a study. The selection of the study areas was also based on the advice by officials and technical staff from the Ministry of Livestock, Agriculture and Environment (MOLAE) in Puntland. The key ecological parameters of consideration during the delineation were landform, soils, climate and vegetation, but considerations were also made of socio-economic features using the livelihood zones of Somalia produced by the Food Security Analysis Unit (FSAU). The two study sites cover the following geomorphological features: the Sool and Sanag Plateaus, the Nugal Valley and the Mudug Plains. For purposes of convenience the two areas are described with Garowe as the reference point, as North Garowe and South Garowe.

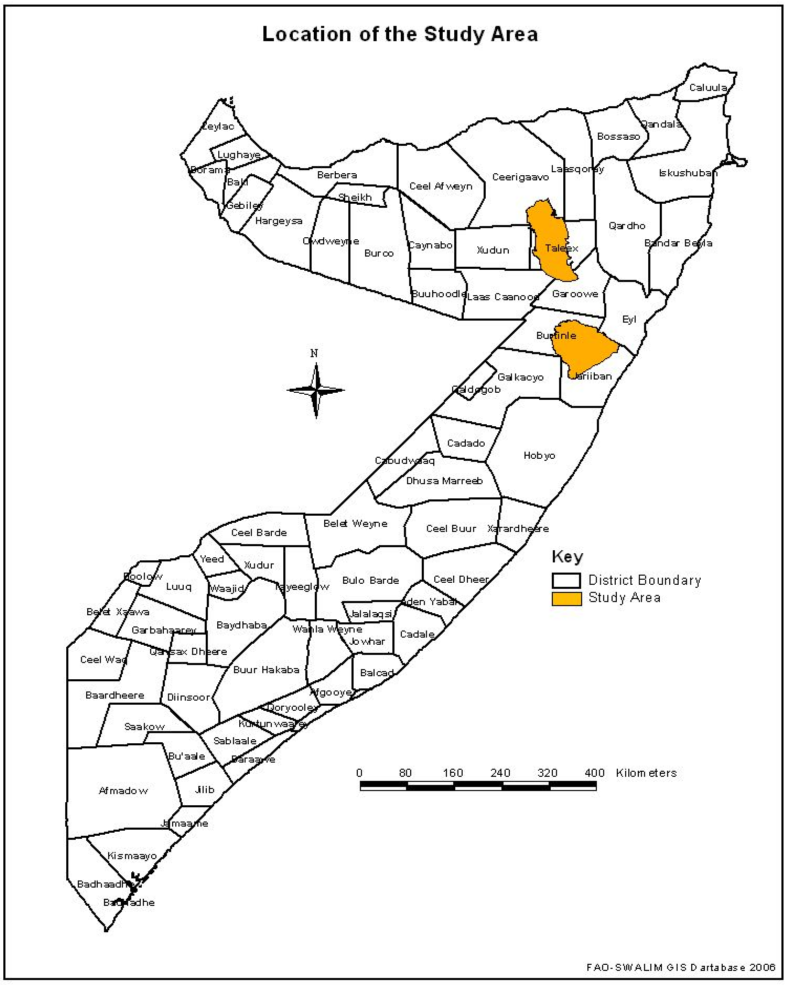


Figure 1: Location of study area seen in the context of Somalia

2.2 Climate and other environmental conditions

The climate of the study areas is classified as arid although some parts of the study areas are semi-arid. Rainfall in the two areas ranges between 100 to 200 mm per year while mean annual relative humidity is between 60% and 70%. The study area falls within the inter-tropical zone and generally has four seasons with bimodal rainfall distribution as can be seen in Figure 2 below. The first rainy season is called ***Gu*** and occurs between April and June. The dry season that follows the first rains is called ***Xagaa*** and lasts between July and September followed by the second rains called ***Dayr*** (October – November and sometimes December). The period between December and March is dry and is known as ***Jilaal***. Rainfall is highly variable temporally and spatially and can be described as erratic (typical of all rangelands). Figure 2 shows a typical rainfall distribution and the potential evapotranspiration curves for the study areas derived from rainfall and PET data from four meteorological stations as shown in the diagram.

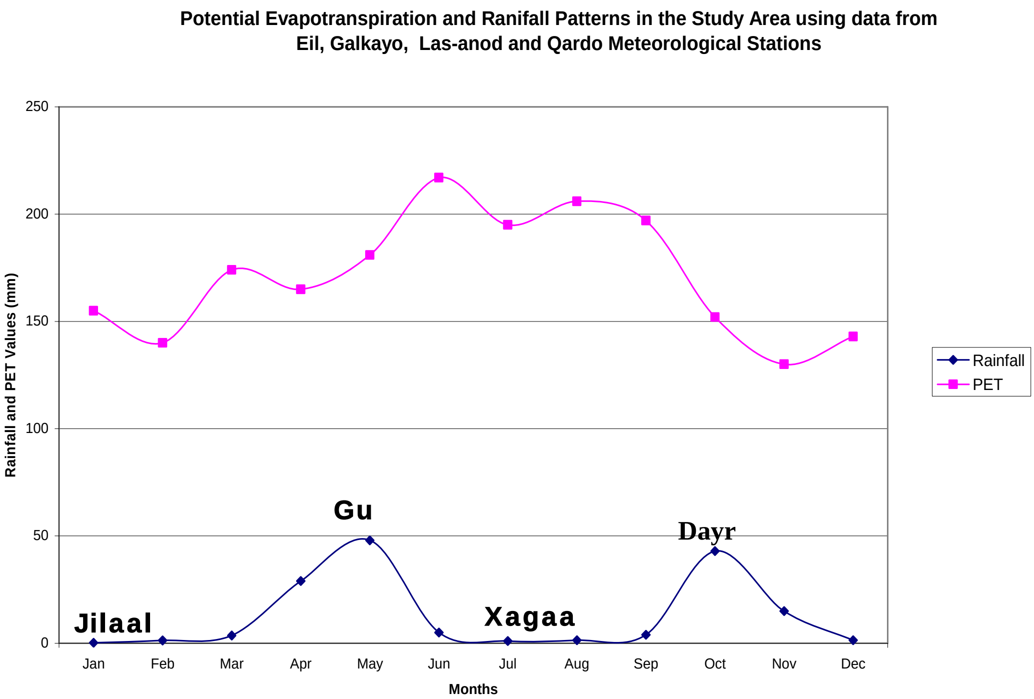


Figure 2: Rainfall distribution and Potential Evapotranspiration in northern Somalia

Mean annual potential evapotranspiration values from the same meteorological stations is 2054mm with mean monthly potential evapotranspiration of 174 mm. PET values derived from NOAA Satellite are given in the results section of this study.

The mean annual temperatures vary between 24^{o}C and 28^{o}C. Figure 3 below shows the mean monthly temperatures from 4 meteorological stations (Eil, Galkayo, Las-anod and Qardo) found near the study areas.

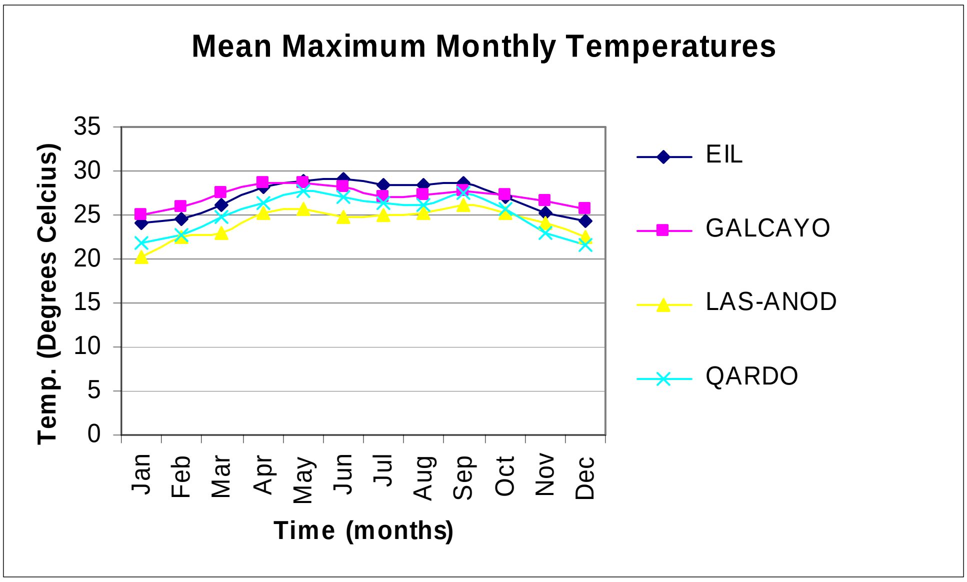


Figure 3: Mean maximum monthly temperatures from 4 meteorological stations

2.3 Land cover and land use

The land cover of the two study areas is made up, principally, of a terrestrial ecosystem of natural vegetation. The northern study area is made up mainly of sparse to generally open shrubland mixed with herbaceous vegetation (grasses and forbs). Some areas have low trees while others are completely denuded mainly due to over-use by man. The southern study area is made up of three main shrubland cover types – dwarf, open medium and high shrubs with herbaceous vegetation, and bare, non-vegetated areas that comprise built-up areas (settlements and towns) solid rock, bare soil and/or hardpans.

In terms of land use, the two study areas are mainly pastoral, principally nomadic pastoral system. The main livestock species are camels, goats, sheep and to a lesser extent cattle in the northern study area. Charcoal burning is carried out in the northern area of study as an economic activity. It greatly affects land cover. Several urban settlements have developed and commercial activities are thriving.

3 METHODS

The activities carried out in this study can be divided into pre-fieldwork, fieldwork and post-fieldwork. The pre-fieldwork activities included a bibliographic research, acquisition and preparation of remote sensing products and preliminary land cover mapping. Preliminary determination of drought conditions and drought events through generation of NDVI data was also performed. Other activities included statistical generation of sample points, preparation of field data collection forms and development of field questionnaire.

The fieldwork, on the other hand, was conducted for two weeks between 31st March and 14th April 2007. The aims of the fieldwork were the following:

- Ground verification of the preliminary land cover map
- Vegetation data collection
- Questionnaire administration aimed at validating remote sensing information and assessing land cover and vegetation change, impacts of human settlements and water points on environmental resources, and droughts and drought events, from the local people's perspective.

As part of the fieldwork a practical oriented three day training workshop was conducted in Garowe. The theoretical part of the training was conducted at the Care-Somalia Offices in Garowe and practical part of the training conducted in the surrounding areas. The training was aimed at helping the Somalia field consultants understand the methodologies used in land cover mapping and field verification procedures, vegetation mapping, and questionnaire administration using a semi-structured questionnaire. The training started on 1st April 2007 and covered:

- An overview of the field survey, its objectives and logistical procedures.
- Land cover mapping and the procedures followed.
- Land cover mapping field verification
- Ecological terminologies
- Vegetation surveys and vegetation survey procedures
- Questionnaire administration – techniques and experiences

The post-fieldwork activities comprised legend updating, finalisation of the land cover maps, data automation and analyses, and further bibliographic reviews. Appropriate Microsoft Access templates were designed to automate and store each data set in digital format. Every field form has its corresponding tables linked together in a relational database. More results were produced and analysed, and finally the preparation of this report.

3.1 Bibliographic review

The initial aspects of this work involved a bibliographic review and research to study what has been done elsewhere regarding similar work. Work on land cover and land cover change was reviewed. Work on how remote sensing has been applied in areas of invasive species, drought assessment and impacts of settlements and watering points on environmental conditions and pastoral resources were looked into. There was also need to understand the land cover and land use of the study area by studying previous work done by other scientist and programmes such as the FAO-Africover Project. The literature research focused on internet browsing and grey literature - principally peer-reviewed articles and books, and reports from projects implemented in the area. Many libraries were visited and many reports were collected. From the review of various reports and publication regarding this study, gaps were identified and field data collection forms were prepared. The field data collection forms included a land cover field verification form, vegetation data collection form and a questionnaire for interviews with the local people.

3.2 Acquisition and preparation of remote sensing products

Annex 1 lists the satellite images in terms of the satellite sensor type, scene number and date of acquisition, level of acquisition and purpose in the study. Figures 5 and 6 show the index of the Landsat and Aster satellite images covering the study areas. All the Landsat images were acquired from the FAO-Africover Project while the Aster satellite images were acquired as part of the collaboration between FAO-SWALIM and USGS-EROS.

Landsat data were received in single band GEOTIFF format. The Aster datasets were also delivered in single band but EOS format. All these images were received pre-processed for radiometric correction, atmospheric correction, geometric correction and noise-removal. However, these images were re-geo-referenced to the SWALIM base maps before they were integrated into the GIS. The single band images were then colour-composited and enhancement to improve their interpretability.

Colour compositing – This involved combining individual image bands to generate Colour Composites (CCs). False Colour Composites (FCCs) are created when the constituting bands are assigned the three primary (additive or true) colours (red, green and blue). The colour composites were produced in ArcView software using the Image Analysis extension. The Stack Images function of Arcview was used to process the images. Bands 4, 3 and 2 at 28.5 metre resolutions were used for spectral signatures in land cover/vegetation mapping.

Enhancement – The following enhancement procedures were applied:
<u>Stretching</u> – This was applied to the single bands to expand (proportionally reallocates) tonal distribution from lower to higher values present in the original image, to the full available grey scale display (usually subdivided into 255 grey tones). The contrast enhancement was characterized by improved appearance of different bodies with similar tones, emphasizing patterns and, to a lesser extent, roughness.

3.3 Land cover and vegetation mapping

Land cover mapping and assessment and, monitoring of its dynamics are essential requirements for the sustainable management of natural resources and for environmental protection (LCCS/FAO, 2005). However, many current monitoring programmes have no access to reliable or comparable baseline land cover data. In this exercise the FAO Land Cover Classification System (LCCS) was used to produce the land cover maps of the study areas.

The LCCS is a comprehensive, standardised and *a priori* classification system that is software driven. The classes in LCCS are predetermined, designed to meet specific user requirements, created for mapping exercises that are independent of the scale or means used to map (LCCS/FAO, 2005). It uses independent diagnostic criteria or classifiers, which allow correlation with existing classifications and legends. The classifiers are hierarchically arranged for high degree of geographical accuracy. The classification has two main phases; a Dichotomous Phase – with 8 major land cover types and a Modular–Hierarchical Phase that has a set of classifiers with their hierarchical arrangement tailored to the major land cover type.

The classification system has software, which assists in the interpretation process. The software-assisted interpretation reduces heterogeneity between interpreters, and between interpretations over time. The software allows the selection of appropriate classes using a step-by-step process: i.e. classifier by classifier

3.3.1 Preliminary land cover mapping

A preliminary land cover map based on Landsat ETM image of 2001 was generated by visual interpretation. According to Lillesand and Kiefer (Lillesand and Kiefer, 1994) interpretation refers to “the identification of the objects seen in the image and the ability to communicate the information so generated to others”. In this exercise, homogeneous land cover types were identified and delineated into polygons. These polygons were classified using the FAO-Africover developed land cover classification system (LCCS) by assigning labels from a legend code given in Annex 4.

On-screen digital satellite image interpretation procedure was used to produce the preliminary maps. However, the process for producing the preliminary maps was done without prior knowledge about the area under investigation other than application of expert knowledge of the interpreters. The preliminary maps were then verified using ground information collected as described in section 3.3.2.

Figure 4 shows a schematic presentation of the procedures that were carried out to generate both visually interpreted and automatically classified maps.

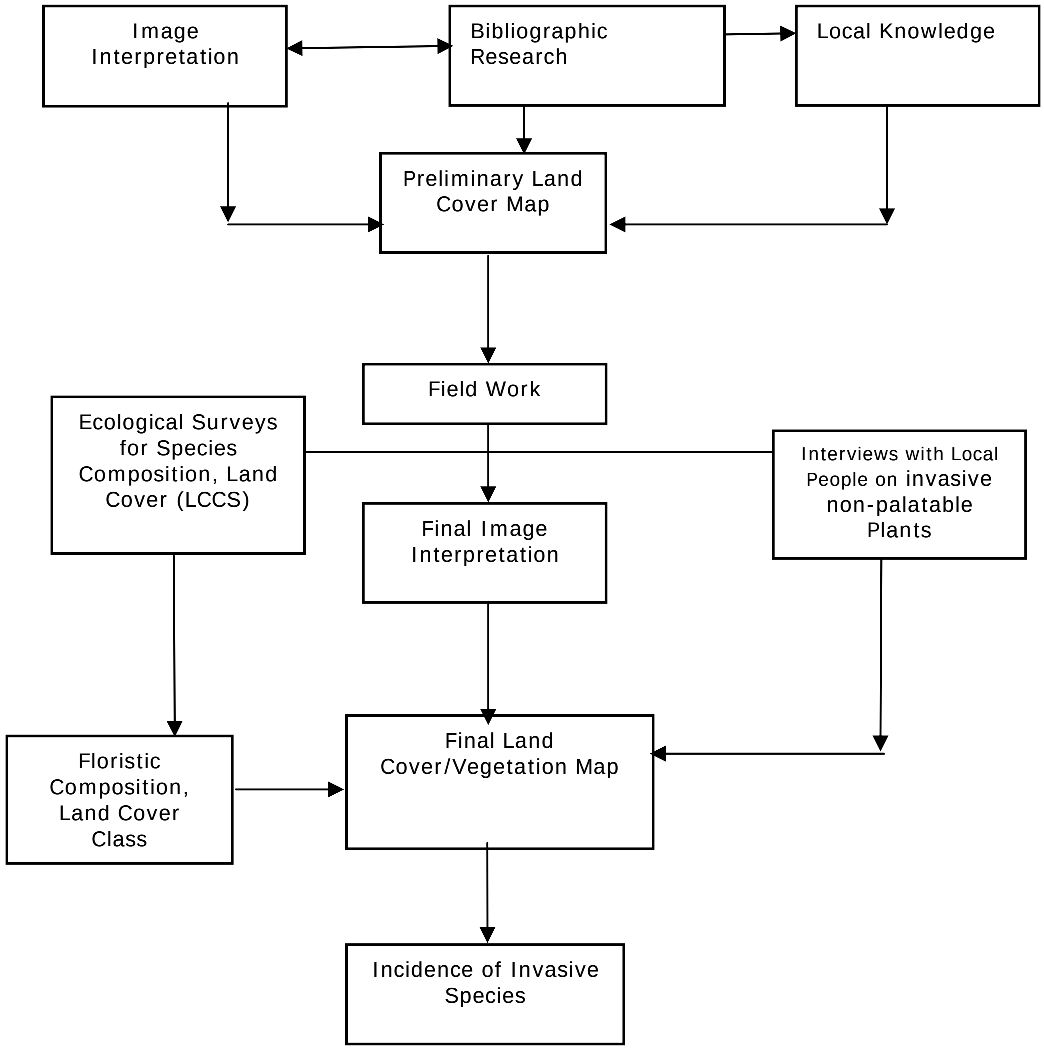


Figure 4: Land cover and vegetation mapping procedures

3.3.2 Field survey for land cover and vegetation mapping

Field sample points for ground verification were generated statistically by applying a stratified random sampling algorithm following the creation of buffers based on the following criteria:

- The sample point should be 500 - 1000m from the road
- The points to be placed to enable at least 3 points to be sampled in a day
- The sample points should cover all the land cover strata
- Settlements to be excluded from sampling sites for natural vegetation
- All the eco-regions should be covered (Mudug, Nugaal and Sanaag)

Land cover data, on the field sample points, was collected using the LCCS land cover field data collection form given in Annex 6. The data collected included the location of the cover type, general land form, the land cover type, the vegetation type, life form of the most dominant vegetation, height of the most dominant vegetation cover type, estimates of the percentage of cover, and leaf type and its phenology.

Additional land cover information was collected using the Rapid Rural Appraisal approach through interviews conducted with the local people by administering a questionnaire given in annex 7 of this report. The results of these interviews were used to verify and characterize vegetation in terms of phenological dynamics and physiognomic variability in the study sites. Within each sample site, data was also collected on plant species composition, species invasion and palatability.

Land cover and vegetation information was also recorded using digital cameras as shown in the Figure 5.

Figure 5: Taking pictures in the field for land cover verification

3.3.3 Vegetation sampling

Vegetation sampling and data collection was carried out using the line transects method as described by McIntyre (1953), Johnston (1957), Crocket (1963), Heady (1983), Westman (1984) and. A line transect measuring 100m in length was laid within the sample points. Sampling of vegetation was done by dropping vertical points at every 1 m interval along the line transect. The species hit by the vertical point was recorded and in the absence of a species at the vertical point, the nearest plant to the hit was recorded. The records also indicated if the hit was mineral soil, litter or base of a plant. Plant base was used to denote the presence of woody vegetation species within the sample point. In the northern study area, basal clipping of the herbaceous plants was done at every 20m interval using metallic quadrats that measured 0.5 X 0.5 meters. The clipped material was placed in paper bags and transported to Nairobi for further post field work analysis. The paper bags containing the clipped material were given the correct labels that corresponded to the field sample code. Annex 8 shows vegetation sampling data collection form.

The woody layer was sampled along the same transect lines and the woody crown interceptions were recorded. The following woody vegetation attributes were determined: species name, frequency, crown cover and height class. Figure 6 and Figure 7 show procedures followed during the vegetation sampling exercise.

Figure 6: Photo showing vegetation sampling procedure

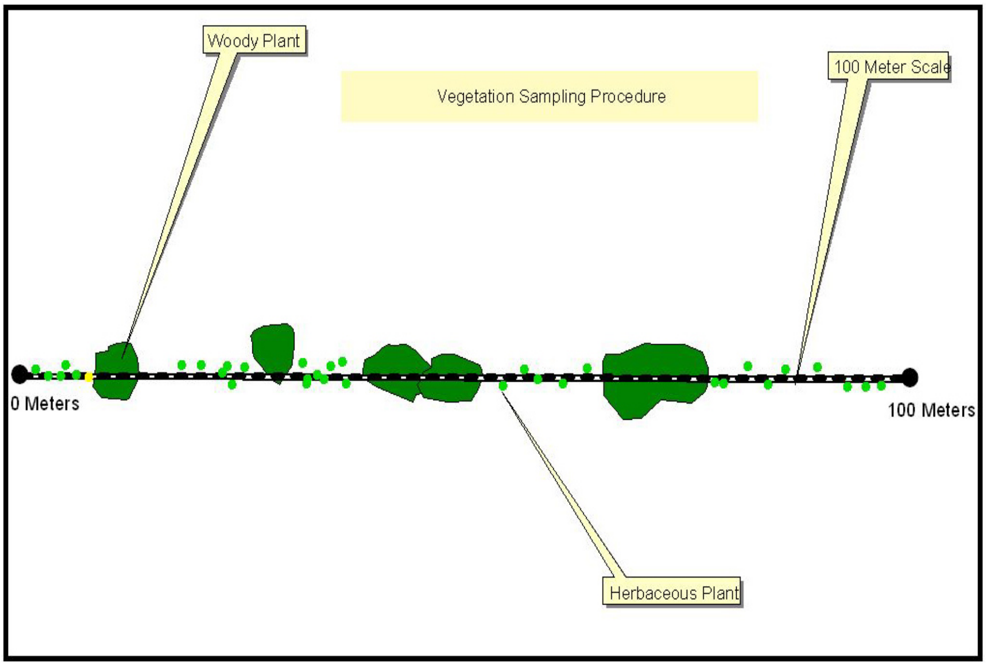


Figure 7: Vegetation sampling technique along a transect line

3.3.4 Biomass assessment and estimation

The clipped herbaceous material originating from the northern study area, and well labeled, was taken to the Kenya government Department of Resource Surveys and Remote Sensing (DRSRS) for further analysis on biomass. In DRSRS the clipped material was oven dried at 80^{o}C for 24 hours and then weighed to determine the dry herbaceous biomass as described by Muchoki (Muchoki 1988). The resulting biomass figures by land cover type were extrapolated for the whole northern study area. These results are shown in Map 3.

3.3.5 Final map preparation

Parameters and descriptions collected in the field in both study areas were compared with the preliminary land cover map, and the results used for revising the legend and interpretation. The updating of natural vegetation classes was based on descriptions of life forms (cover and heights of various vegetation species - trees, shrubs and herbaceous layers), and evaluation of photographs taken from the field.

Aster satellite images of the dates given in Table 1 were used to prepare the final land cover map. This was done again by on-screen digitizing of land cover, based on image characteristics, from the Aster satellite images. Before starting final revision of the interpretation, a conversion table was created to automatically transform, where possible, old codes into new ones. However, the majority of classes were updated through visual revision of the interpretation. The final land cover legend adopted for both study areas is shown in Annex 4. It is important to note that the final land cover by visual interpretation was based on Aster images mostly acquired in 2006.

The resultant land cover classes were then taken through a process known as aggregation that involves creation of spatial features and tabular data that are mappable based on conventional cartographic principles. Aggregation is used to generate the final land cover codes used in producing the final maps.

3.4 Assessing and detecting land cover change

Land cover change refers to changes in the attributes of a part of the earth's land surface and the immediate sub-surface. In semi-arid and arid regions, land cover modifications i.e. the subtle changes that affect the character of the land cover without changing its overall classification are common (Diouf and Lambin, 2001). Change implies a shift in land cover type usually associated with land use. The ability to distinguish land cover change from variability within land cover is one of the biggest challenges facing land and natural resources scientists today (Bradley and Mustard, 2004).

Land cover change was assessed using two techniques; first by comparing land cover maps generated by visual satellite image interpretation and second by comparing the land cover maps generated by supervised digital image classification.

The land cover maps produced by interpreting the 2001 satellite images in section 3.3.1 were superimposed on the images of the 1988 to identify changes in land cover between 1988 and 2001 (Landsat TM images of 1988 and Landsat ETM+ of 2001). This was done by either modifying the shapes of the polygons to incorporate changes, re-drawing the polygons around areas that had experienced changes in land cover or assigning a new land cover class in case of total change.

Land cover maps by visual interpretation showed very little change (less than 1%) in land cover between 1988 and 2001 (see Table 4). However, due to qualitative reports about considerable changes in land cover in the area under investigation, a second technique was applied. In this second technique, land cover maps were generated using supervised automatic digital image classification to establish the claims about changes in land cover in the two study areas. Local reference knowledge, besides expert knowledge, was used in this activity.

The supervised automatic digital image classification involved the generation of two land cover maps, one from the 1988 Landsat images and two from the 2001 Landsat images. The preliminary semi supervised digitally classified map from the 2001 Landsat images was subjected to field verification. The field samples data was then used as training data in the subsequent supervised automatic digital image classification of the 2001 Landsat satellite images. The ERDAS IMAGINE 8.6 software was used in this supervised automatic digital image classification. The maximum likelihood algorithm was used to classify the image into 5 major land cover classes (see Map 4 and Map 5). The resulting 2001 image based map was subjected to an accuracy test to establish the accuracy of interpretation for each land cover class. The maps were further improved using field information collected as described in section 3.3.2.

Changes in land cover were then calculated from the two resultant maps.

3.5 Assessing drought

One of the factors affecting plant forage production as a pastoral resource is drought. Drought also affects water supply in the pastoral production areas. Forage production and water supply are very important resources in the pastoral production systems.

Drought is generally defined as a period of months or sometimes years when an area or a region experiences a deficiency in its water supply due to consistently below average precipitation. Although a natural phenomenon, its effects can be worsened by anthropogenic activities. Usually droughts can persist for several years although even a short, intense drought can cause significant damage (see [1] in the reference).

Drought is divided into three types (Ropelewski and Folland, 2000, see also [2] in the reference). These are meteorological drought, agricultural drought, and hydrological drought. A meteorological drought is one that results from a prolonged period with less than average precipitation. It usually precedes the other kinds of droughts. Agricultural droughts are those that affect crop production or the ecological production of the range. They can arise out of a prolonged period of below average precipitation or when soil conditions and erosion triggered by poorly planned agricultural endeavors cause a shortfall in water available to the crop. On the other hand a hydrological drought occurs when the water reserves available in sources such as aquifers, lakes and reservoirs fall below the statistical average. Although a hydrological drought can occur due to prolonged periods of below average precipitation, it can also be caused by incidences such as water diversion or simply by interfering with the aquifer system.

Drought is a normal and recurring feature of virtually all climate regimes and affects most countries to some degree (Bussay, 2003). It differs from other natural hazards because of its slow onset nature without well defined boundaries of the affected areas (Narasimhan, 2003, Ropelewski, and Folland, 2000). Like many other natural disasters, droughts have been on the increase with the economic, social and environmental costs increasing dramatically (Wilhite, 2000). Hare and Ogallo (1992) have reported an increase in prolonged periods of dry spells in the recent years over sub-Saharan Africa while Downing and Washington (2002) have reported a lack of methodologies and seasonal forecasts for monitoring changes in environmental conditions.

In this study, drought was assessed by studying phenological dynamics and physiognomic variability of vegetation using remote sensing data. The resulting information was used to determine meteorological drought and drought events in the two study areas between 1973 and 2005. Two vegetation indices were applied, these are Normalised Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI) used to normalize deviations in NDVI.

Landsat images of 1973, 1988 and 2001 (see Annex 1) were used to assess temporal-spatial behaviour of vegetation across the study areas. IDRISI Software was used to generate Normalised Difference Vegetation Index (NDVI) data from Landsat images. A composite of the three images was created to generate a maplist using the Collection Editor function as a time series file. Using the digitize function, a transect line was drawn across notable change points (principally settlements) across the imagelist. NDVI values were then extracted from the maplist using the GIS Analysis function through the Database Query and Create Profile functions. The extracted NDVI database was then exported into a spreadsheet for analysis. Figure 11 is a schematic representation of steps taken to derive NDVI from Landsat images to assess environmental conditions.

However, these images were first co-registered to a common base map using ground control points and the SRTM DEM projection. The digital numbers of the images were then converted to the top-of-the-atmosphere (TOA) radiances using the calibration models in the Landsat handbook (http://ltpwww.gsfc.nasa.gov/IAS/handbook_toc.html, accessed on the 25th April, 2007). These TOA radiances were resampled to 90 m resolution and designated as L_{sat}. Since there were no reliable atmospheric profile data for correcting the images, the Chavez (1996) method was utilized. According to this method, ground reflectance, r_g, was obtained according to the following expression;

$$r_g = \frac{\pi(L_{sat} - L_p)d^2}{E_o \cos\phi_z \tau} \qquad (1)$$

where L_p is the atmospheric path radiance, d is the Earth-Sun distance at the time of satellite overpass, τ is the atmospheric transmissivity of the solar bands, ϕ_z is the solar zenith angle, and E_o is the extraterrestrial solar irradiance corresponding to the Landsat image. Atmospheric radiance is the upwelling radiance coming from the zero-reflectance of the ground and which can be approximated from the following expression (Liang, 2004);

$$L_p = L_{\min} - 0.01\tau E_o \cos\phi_z (\pi d)^{-1} \quad \text{.........(2)}$$

where L_{min} is the radiance corresponding to digital number of a pixel for which the sum of all pixels with digital numbers lower or equal to L_{min} is one percent of the total sum of pixels in the scene under consideration (Sobrino *et al.*, 2004). Chavez (1996) has suggested conservative values of τ as 0.85 for band 3 and 0.91 for band 4 of the Landsat images. The ground reflectance for bands 3 and 4 were then used in deriving vegetation index, NDVI as follows;

$$NDVI = \frac{r_{g,band4} - r_{g,band3}}{r_{g,band4} + r_{g,band3}} \quad \text{.........(3)}$$

NDVI is a measure of the presence of vegetation and can be used to index different kinds of land cover (De Jong, 1994).

Figure 8 represents the steps followed in generating NDVI data from Landsat Satellite images

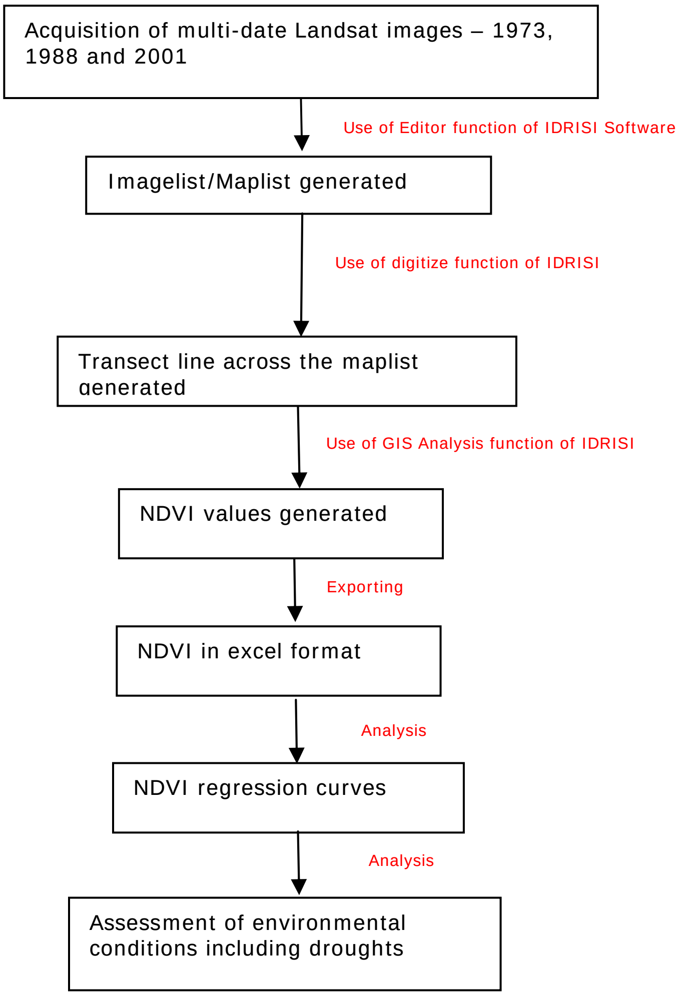


Figure 8: Schematic presentation of the steps to generated NDVI and drought maps from Landsat images

WINDISP Software (WINDISP 5.1) was used to generate NDVI databases from NOAA GAC images downloaded from the African Data Dissemination Service at http://igskmncnwb015.cr.usgs.gov/adds/datatheme.php site. The NOAA images used were for the years 1981 to 2003. The NOAA GAC data have a spatial resolution of 8km. Using Process, Stat and Avg functions of WINDISP 5.1 maplists were generated. Data for the study areas of interest were generated by clipping using .bna maps of the two study areas. The generated NDVI databases were for the years 1981 to 2003 and also the Long Term Mean for those years. The output files were in excel format and were analysed to study phenological dynamics and physiognomic variability in the two study sites in the assessment of drought events. A schematic presentation of the procedures used to generate NDVI statistics from NOAA-GAC data is given in Figure 9.

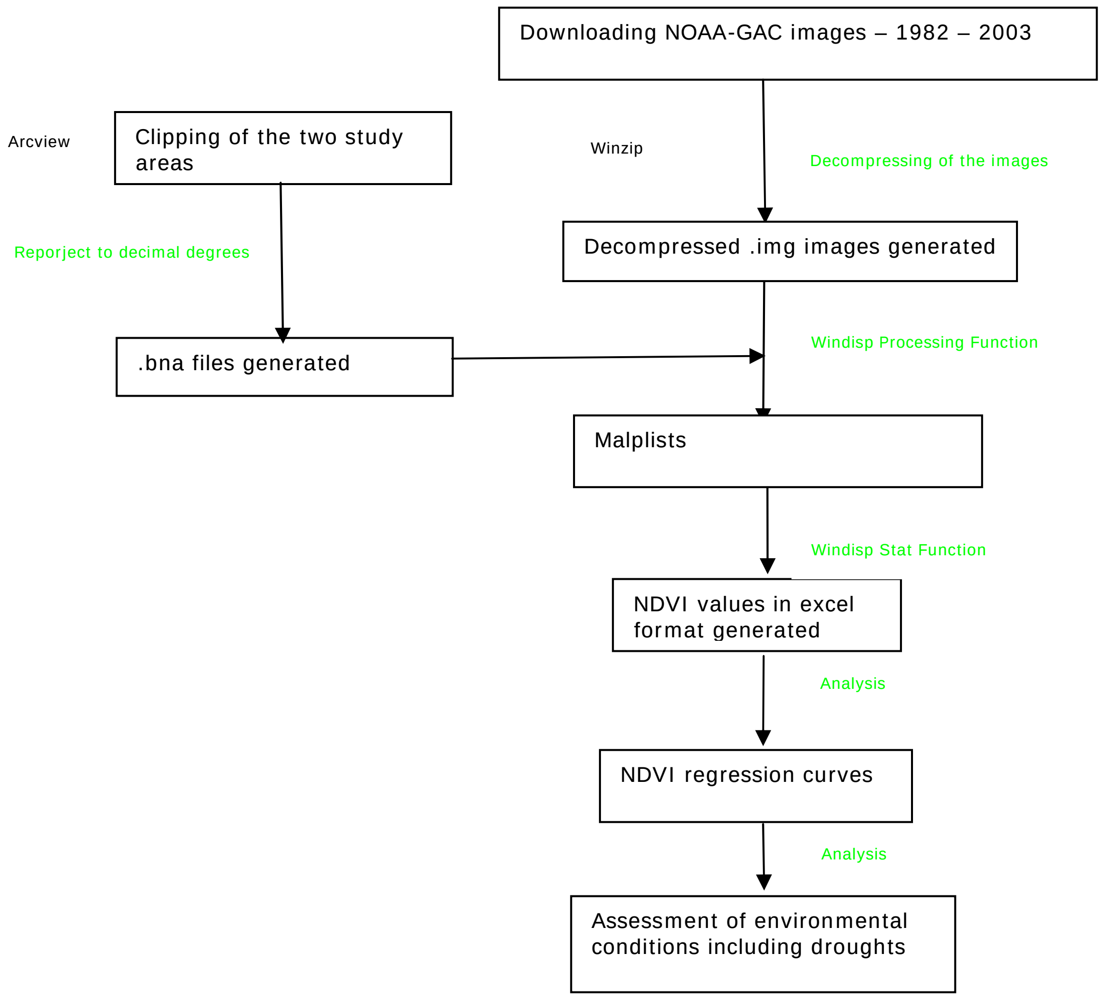


Figure 9: Diagram representing the schematic presentation of NOAA NDVI generation

SPOT-Vegetation and MODIS NDVI data were acquired and processed by the Global Land Cover Network (GLCN) in Italy. A software package known as VEDAS (Vegetation Dynamics Software) was developed for this study and it extracts NDVI data from SPOT and MODIS images for 1999 – 2005 and 2002 – 2005 respectively. The software is written in a low-level language (flow control procedures written in Perl engine procedures written in Fortran 90) (Di Gregorio and Capecchi, 2007). VEDAS is in three packages – VEDAS-A, VEDAS-B and VEDAS-C. According to Di Gregorio and Capecchi VEDAS performs an automatic procedure to extract NDVI. It is able to:

- Read and collect NDVI image series over the area of interest
- Perform temporal filtering of the images to reduce noise and cloud effects.
- Performs visual evaluation of the cleaned images to assess the effects of filterings

- Superimpose vectors describing the selected polygons
- Extract NDVI data for the selected polygons
- Clean the polygons to remove pixels belonging to different land cover classes
- Compute NDVI averages and standard deviations of the polygon pixels for the entire time series
- Define annual NDVI averages and standard deviation profiles of the polygons

From NOAA NDVI data, drought conditions and drought events were assessed by computing monthly and annual NDVI values for the two study areas. These values were compared with the long term means. The periods with NDVI values lower than the long term mean were considered drought periods.

Drought conditions were also assessed using the vegetation condition index (VCI) derived from the NDVI data generated above. VCI was derived using the methodology by Thenkabail, *et al* (2004):

$$VCI = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad \text{..........} (4)$$

Where:

$NDVI_i$ is the NDVI values at a given point in time (dekad, month or year)
$NDVI_{min}$ is the lowest NDVI values recorded for a given place usually derived from the long term mean
$NDVI_{max}$ is the highest NDVI values for the place also derived from the long term mean

Historical memory of years of drought and drought events gathered from using a semi-structured questionnaire administered through interview in the field during the fieldwork carried out in April 2007. The results of these interviews were then compared with the remote sensing information.

3.6 Identification of non-palatable and invasive vegetation species

Efforts have been made to apply remote sensing techniques in studying invasive vegetation species. These techniques, however, still have limitations in their applications in environmental assessment and monitoring. According to Joshi (2006) remote sensing has limitations in mapping invasive vegetation species. It has been used more direct only if the invasive species dominates the canopy or else more indirect methods are employed. The ability of high spectral and spatial resolution sensors to discriminate between invasive species can only be made possible by the use of intra-specific variability in spectral reflectance. Detecting understorey vegetation using direct remote sensing techniques is almost impossible.

Other remote sensing systems for instance Landsat TM/ETM and SPOT data with ground resolution of 30m and 20m respectively have been found not suitable for mapping at species level, unless the stand of the specific species being examined is large enough (Carson, 1995, Mast, 1997, Hessburg, 2000).

The approach adopted in this study was first to map land cover and then related the invader non-palatable plant species to the areas with negative and positive land cover change, respectively.

The land cover/vegetation maps produced in section 3.3 above formed the basis for identification of the invasive and non-palatable plant species. The ecological surveys and the semi-structured interviews with the local people were used to generate data on the incidences of non-palatable and invasive plant species.

3.7 Detecting impacts of water points and settlements

The impacts of water points and settlements on the environment and natural resources were assessed using remote sensing. A settlement map from the UNDP database was superimposed on the satellite image to indicate the location of the settlements. Recent settlements that are not included in the database were picked by GPS in the field and used to update the records. Then around these settlements, the NDVI values were generated using IDRISI software as described in section 3.5 above using the red and infrared bands. The NDVI values were used to evaluate vegetation conditions as a measure of environmental stress. Multi-year satellite images of 1973, 1988 and 2001 were used in this activity.

The change in vegetative vigour around these settlements and, the water points by extension, was also confirmed in the field by the semi-structured interviews during the field surveys. The assumption here was that settlements and watering points reduce vegetation cover, an indicator of environmental deterioration.

4 RESULTS AND DISCUSSION

4.1 Land cover and vegetation mapping

4.1.1 Land cover and vegetation maps

Table 1 and Table 2 are the results of the land cover mapping by visual interpretation of satellite images. The northern study area has 14 land cover classes while the southern one has 7 classes. This shows that the southern study area is less heterogeneous compared to the northern one, with Open Shrubs being the dominant land cover in both the study areas. Map 1 and Map 2 represent the land cover maps for the two study areas. The types of the various vegetation or plant species in each map are given in the description of the various land cover types below the tables.

Table 1: Land Cover Classes from the northern study area

No.	Land Cover Code	Land Cover Class	Cover in Hectares	% Cover
1	2HL	Closed to Open Herbaceous	2827	4
2	2HR	Sparse Herbaceous	4422	7
3	2HR/6S	Sparse Herbaceous mixed with Bare Soil	67	0.1
4	2SP	Open Shrubs	4585	7
5	2SP6	Open Shrubs with Open Herbaceous	5992	9
6	2SP6/6S	Open Shrubs with Open Herbaceous mixed with Bare Soil	3512	5
7	2SP7	Open Shrubs with Sparse Trees	2962	5
8	2SP7/6S	Open Shrubs with Sparse Trees mixed with Bare Soil	18538	29
9	2SR	Sparse Shrubs	11188	17
10	2SR6	Sparse Shrubs with Herbaceous	8063	12
11	2TP8	Open Trees with Open Shrubs	183	0.3
12	5U	Built Up Areas	12	0.01
13	6S	Bare Soil	2377	4
14	6SV	Bare Soil with Scattered Vegetation	223	0.3
		TOTAL	**64951**	

Table 2: Land Cover Classes from the southern study area

No.	Land Cover Code	Land Cover Class	Cover in Hectares	% Cover
1	2SP	Open Shrubs	2861	4.4
2	2SP6	Open Shrubs with Open Herbaceous	48910	75
3	2SP6/6S	Open Shrubs with Open Herbaceous mixed with Bare Soil	3033	4.7
4	2SP7	Open Shrubs with Sparse Trees	3039	4.7
5	2SR	Sparse Shrubs	5312	8.2
6	2SR6	Sparse Shrubs with Herbaceous	1607	2.5
7	6S	Bare Soil	75	0.1
		TOTAL	**64837**	

Open Shrubs with Open Herbaceous (2SP6) 54902 ha
This land cover comprises shrub and herbaceous vegetation cover of 15 – 65%.

The woody plants in this cover type included *Acacia reficiens*, *Balanites schilin*, *Acacia senegal*, *Acacia nubica*, *Boscia minimifolia* and *Dichrostachys kirkii.* The herbaceous species included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Open Shrubs with Sparse Trees mixed with Bare Soil (2SP7/6S) 18538 ha
This class is made of open shrubs covering 15 – 65% with sparse trees (1 – 15%).

The woody plants in this cover type included *Acacia bussei*, *Acacia tortilisl*, *Acacia nubica*, *Boscia minimifolia* and *Acacia melifera* while the herbaceous species included *Andropogon kelleri*, and *Sporobolus spicatus.*

Sparse Shrubs (2SR) 16500ha
The class refers to a land cover made up of shrubs with a cover of 1 – 15%.

The woody plants in this cover type included *Commiphora sp.*, *Euphorbia cuneata* and *Cadaba hetotricha* while the herbaceous species included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus*

Sparse Shrubs with Herbaceous (2SR6) 9670 ha
This is a predominantly shrubland that is sparsely covered (1 – 15%).

The woody plants in this cover type included *Zygophyllium hildebrandtii*, *Ipomea donaldsonii*, *Euphorbia cuneata, Crotolaria dumosa* while the herbaceous species included *Sporobolus ruspolianus*, *Sporobolus marginatus* and *Sporobolus spicatus.*

Open Shrubs (2SP) 7446 ha
This comprised Shrub vegetation with a cover of 15 – 65%.

The woody plants in this cover type included *Acacia reficiens*, *Balanites schilin*, *Acacia senegal*, *Acacia nubica*, *Boscia minimifolia*, *Acacia bussei*, *Indigofera arbica* and *Dichrostachys kirkii* while the herbaceous species included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Open Shrubs with Open Herbaceous mixed with Bare Soil (2SP6/6S) 6545 ha
The land cover here comprised open shrubs 15-60% mixed with bare soil.
The woody plants in this cover type included *Acacia reficiens*, *Balanites schilin*, *Acacia senegal*, *Acacia nubica*, *Boscia minimifolia* and *Dichrostachys kirkii* while the herbaceous species included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Open Shrubs with Sparse Trees (2SP7) 6001 ha
The class consists of Open Shrubs (15-65%) with emergent trees (1-15%).

The woody plants in this cover type included *Acacia reficiens*, *Balanites schilin*, *Acacia senegal*, *Acacia nubica*, *Acacia bussei*, *Acacia tortilis*, *Boscia minimifolia* and *Dichrostachys kirkii* while the herbaceous species included *Andropogon kelleri, Sporobolus ruspolianus*, *Sporobolus marginatus* and *Sporobolus spicatus.*

Sparse Herbaceous (2HR) 4422 ha
This is a basically non woody land cover class with the herbaceous vegetation covering 1-15 % of the surface.

The herbaceous plants included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Closed to Open Herbaceous (2HL) 2827 ha
This is also a basically non woody land cover class with the herbaceous vegetation covering 15->65% of the ground surface.
The herbaceous plants included *Chrysopogon aucheri, Arthrocarpum somalensis, Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Open Trees with Open Shrubs (2TP8) 183 ha
The Open Trees with Open Shrubs comprise Tree canopy of 15 -65 % with the shrubs covering 15-65 % of the ground. The woody plants in this cover type included Acacia bussei, Acacia tortilis and Acacia mellifera while the herbaceous plants included Andropogon kelleri and Chrysopogon aucheri.

Sparse Herbaceous mixed with Bare Soil (2HR/6S) 67 ha
This is a mixed unit class of 1-15% Herbaceous vegetation and Bare Soil. The herbaceous plants included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Bare Soil with Scattered Vegetation (6SV) 223 ha
This land cover is close to bare ground with vegetation which is scattered 1-5%.
The woody plants in this cover type included *Zygophyllium hildebrandtii, Ipomea donaldsonii, Euphorbia cuneata, Crotolaria dumosa* while the herbaceous plants included *Sporobolus ruspolianus, Sporobolus marginatus* and *Sporobolus spicatus.*

Annex 5 shows a list of the plants that were encountered in the study areas.

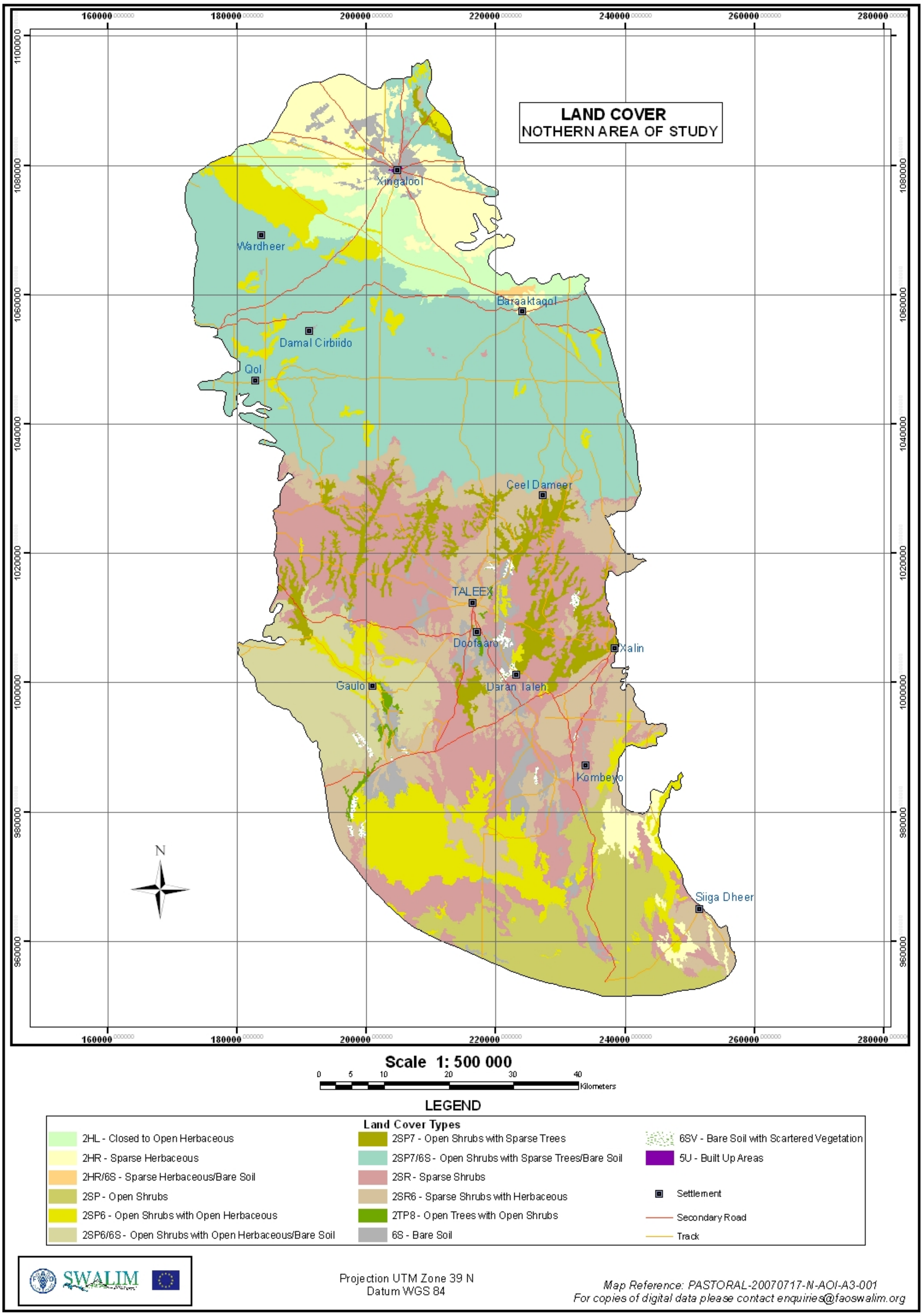
Results of land cover mapping by automatic digital image classification are given in Map 4 and Map 5.

4.1.2 Biomass assessment and estimation

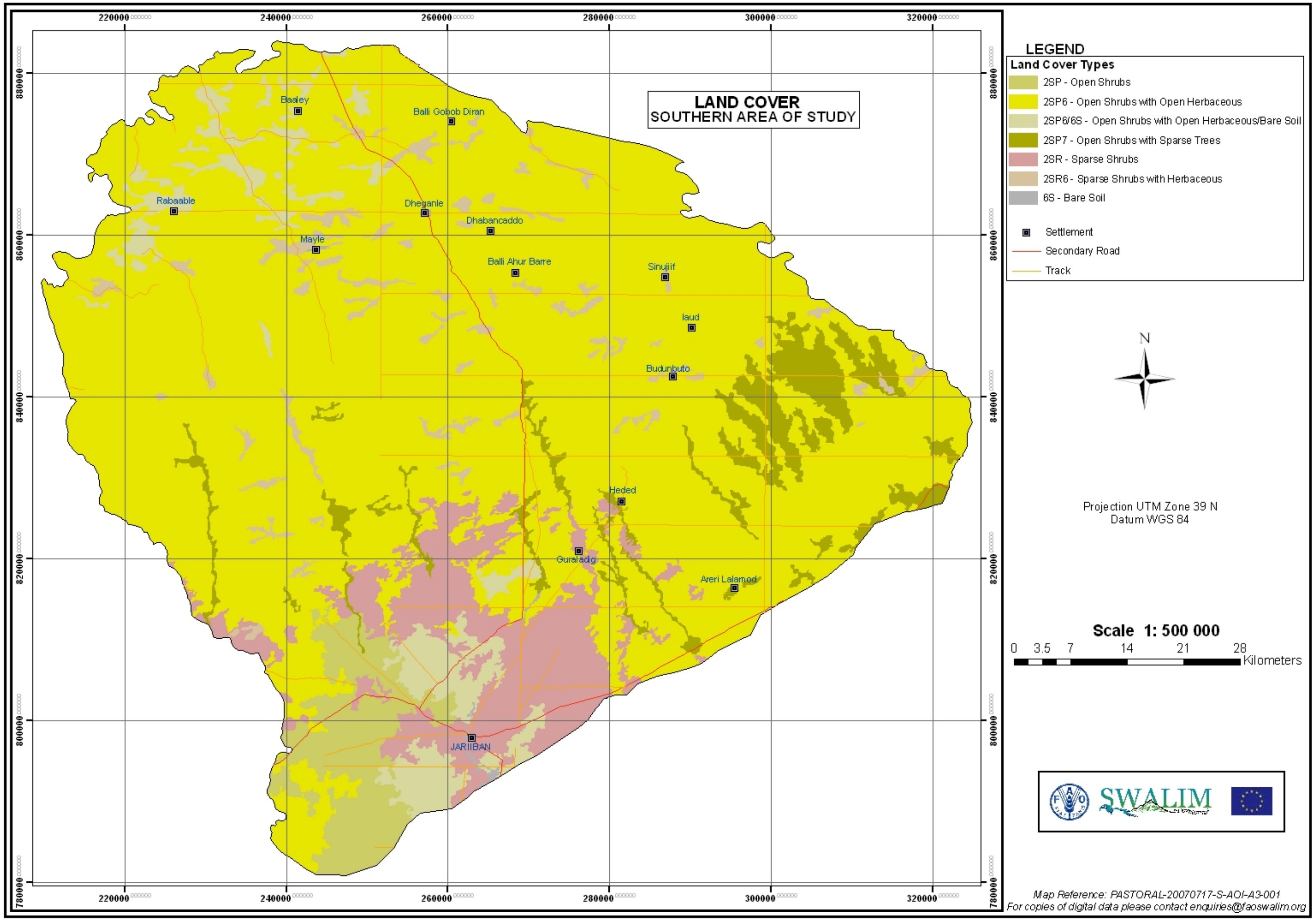
The results of the biomass assessment for the northern study area are shown in Table 3 as well as in Map 3.

Table 3: Herbaceous biomass results from the northern study area

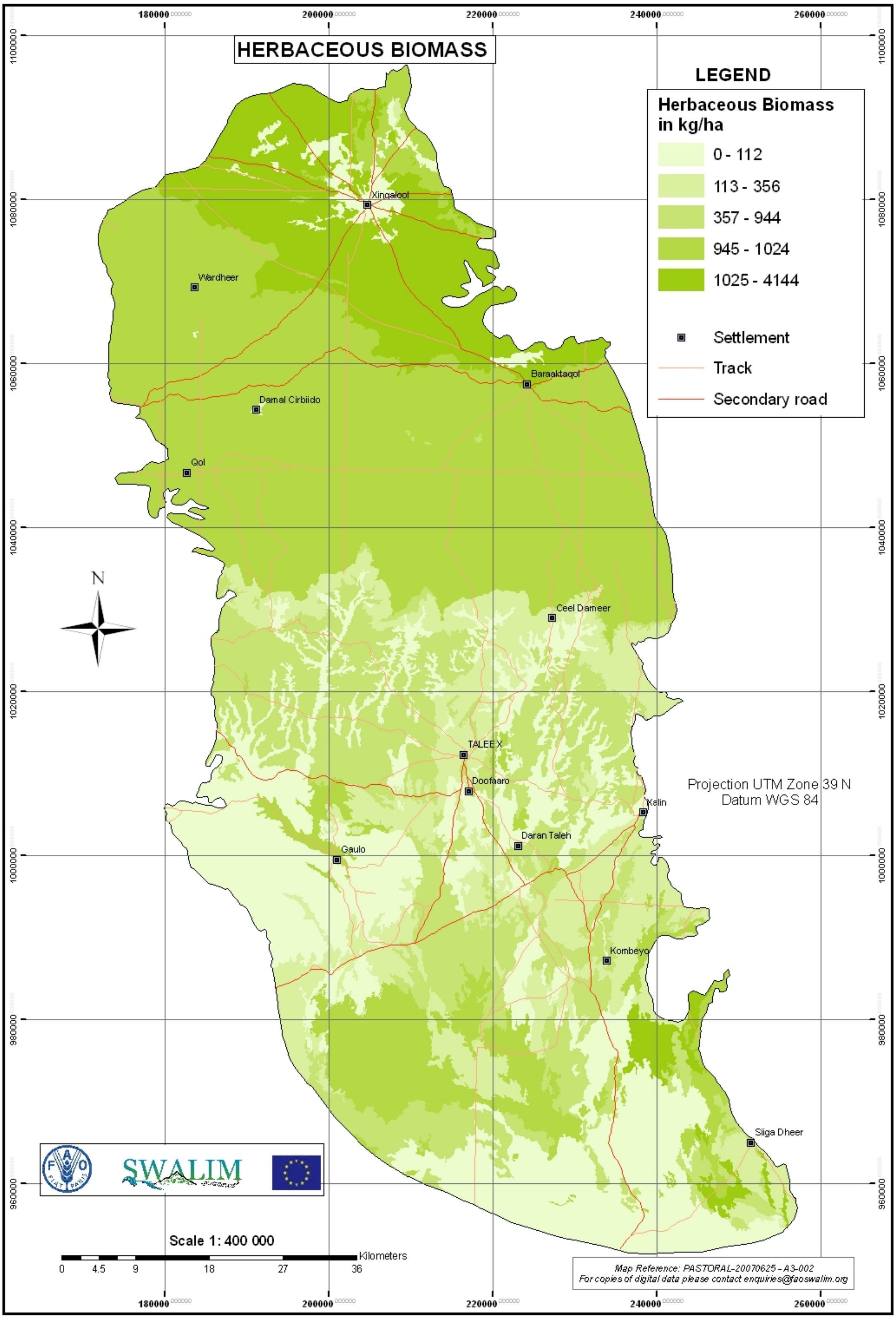
SNo.	Land Cover Code	Land Cover Class	Herbaceous Biomass (Kgs/Ha)
1	2SP6	Open Shrubs with Open Herbaceous	1024
2	2SP7/6S	Open Shrubs with Sparse Trees mixed with Bare Soil	1016
3	2SR	Sparse Shrubs	944
4	2SR6	Sparse Shrubs with Herbaceous	356
5	2SP	Open Shrubs	112
6	2SP6/6S	Open Shrubs with Open Herbaceous mixed with Bare Soil	0
7	2SP7	Open Shrubs with Sparse Trees	0
8	2HR	Sparse Herbaceous	1796
9	2HL	Closed to Open Herbaceous	4144
10	6S	Bare Soil	0
11	6SV	Bare Soil with Scattered Vegetation	0
12	2TP8	Open Trees with Open Shrubs	0
13	2HR/6S	Sparse Herbaceous mixed with Bare Soil	0
14	5U	Built Up Areas	0



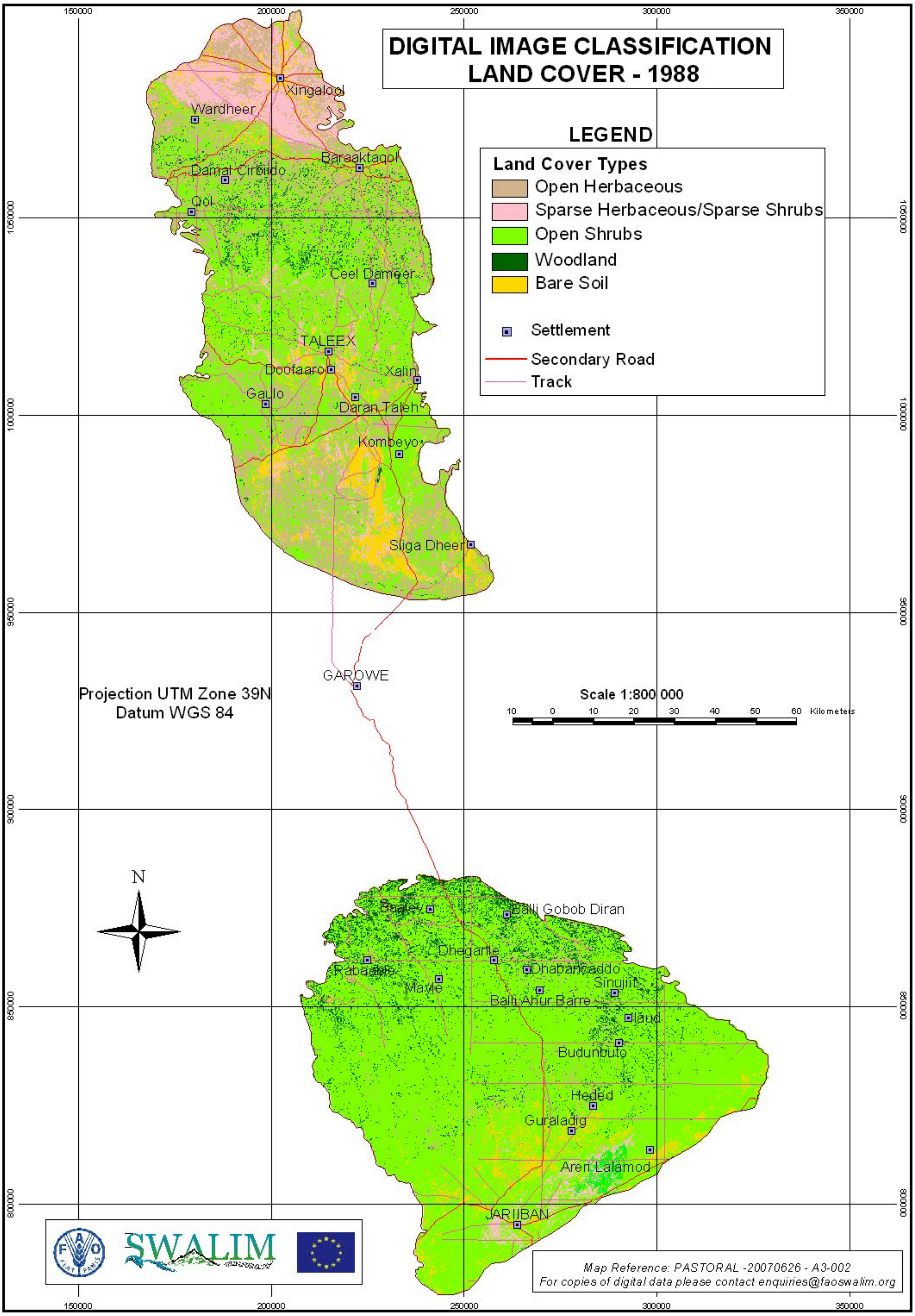
Map 1: Land cover and vegetation map of the northern area of study from visual satellite mage interpretation



Map 2: Land cover map and vegetation map of the southern area of study from visual image interpretation

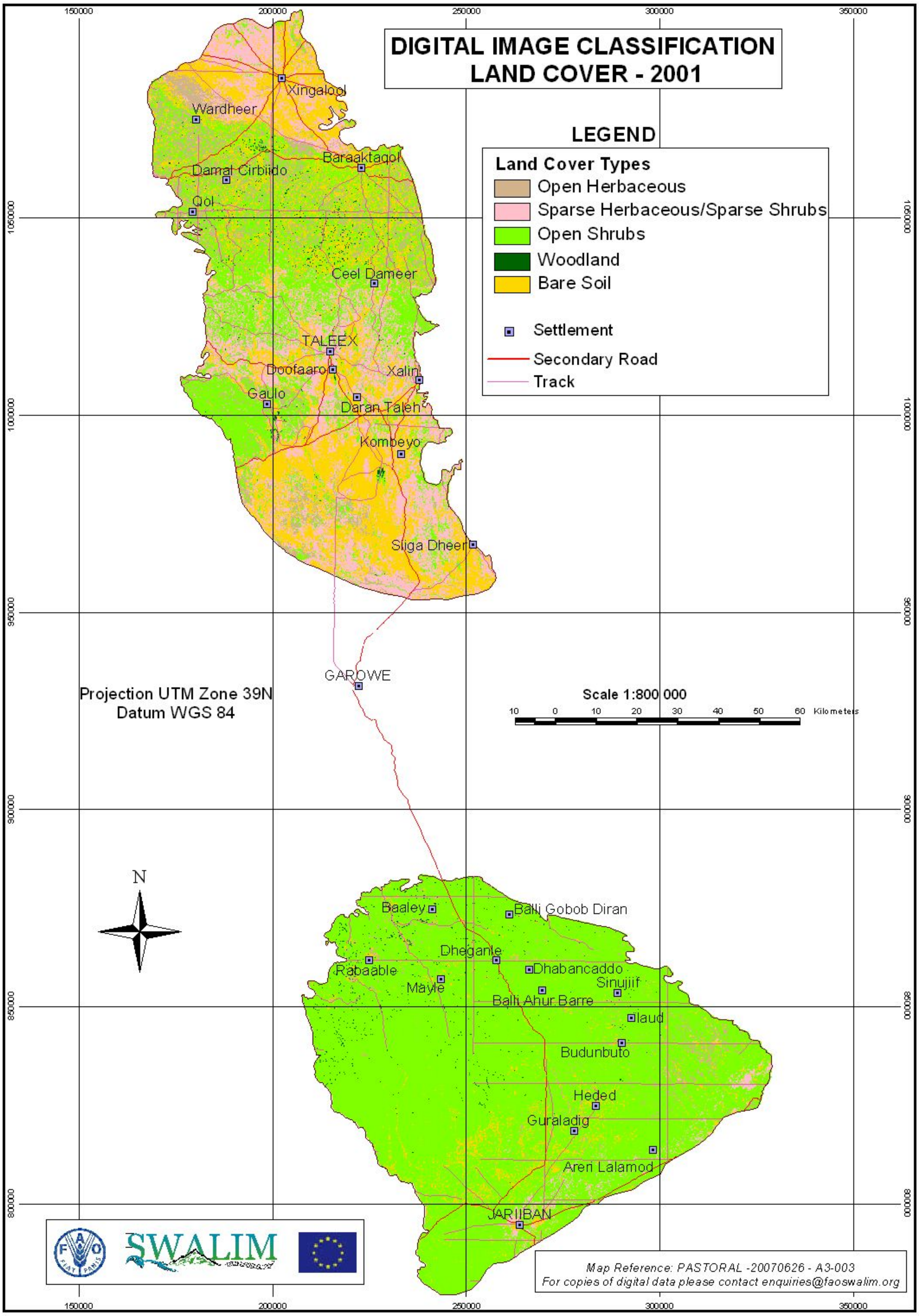


Map 3: Biomass Assessment map of the northern study area as in April 2007



Map 4: Land cover map of the study areas from automatic digital classification (Landsat images of

1988)



Map 5: Land cover map of the study areas from automatic digital classification (Landsat images of 2001)

4.2 Land cover change detection

Changes in land cover between 1988 and 2001 are shown in Table 4 and Table 5, for visual interpretation and automatic digital classification results, respectively. Map 6 shows the spatial changes in land cover from visual interpretation. The results in Table 4 and Map 6 show minimal changes (less than 1%) in land cover between 1988 and 2001. Table 5 shows the land cover types where changes occurred.

Table 4: Percentage land cover change by visual interpretation

Classes		Hectares	% change
2HL8	Closed to open Herbaceous vegetation with scattered shrubs	106.02	0.01
2HR	Sparse Herbaceous vegetation	140.26	0.01
2SR6	Sparse shrubs	527.25	0.04
2TP8	Open trees with open shrubs	225.96	0.02
5U	Urban built-up area	45.39	0.00
6S	Bare soil	-1044.89	-0.07

Table 5: Land Cover Change between 1988 and 2001

SNo.	Land Cover	Area in 1988 (Ha)	Area in 2001(Ha)	Land Cover Change (Ha)
1	Woodlands (Open Trees)	70 686	8 288	-62 398
2	Open Shrubs	91 0400	853 915	-56 485
3	Open Herbaceous	239 007	96 545	-142 462
4	Sparse Herbaceous/Sparse Shrubs	82 972	185 561	+102 589
5	Bare Soils	93 971	252 580	+158 609

The figures in Table 5 show the percentage variations from 1988 to 2001 (changes are greater than 50% in some cases,) from the automatic digital image classification. The changes in land cover are either positive or negative as shown in Table 5. Lots of vegetated land changed to bare lands over the years.

In the verification of land cover mapping during the change detection activity by automatic classification, a confusion matrix was developed. From the accuracy test the digitally classified map of 2001 satellite images had interpretation accuracy results of 76%. Expert knowledge coupled with local knowledge was used in this automatic classification. The 1988 image classification results, which were not field-checked, can therefore be assumed to have an interpretation accuracy of 76%. Table 6 the confusion matrix that was used to assess the accuracy of automatic image classification. The following are details of the interpretation accuracy test based on the contents of Table 6.

Map Accuracy for each land cover class:
1. Sparse Vegetation is 19/22*100 = 86%
2. Open Shrubs is 28/32*100 = 88%
3. Bare Lands is 7/21*100 = 33%
4. Shrubs with Emergent Trees is 5/6*100 = 83%
5. Tiger Bush is 11/12*100 = 92%
6. Open Trees is 1/1*100 = 100%.

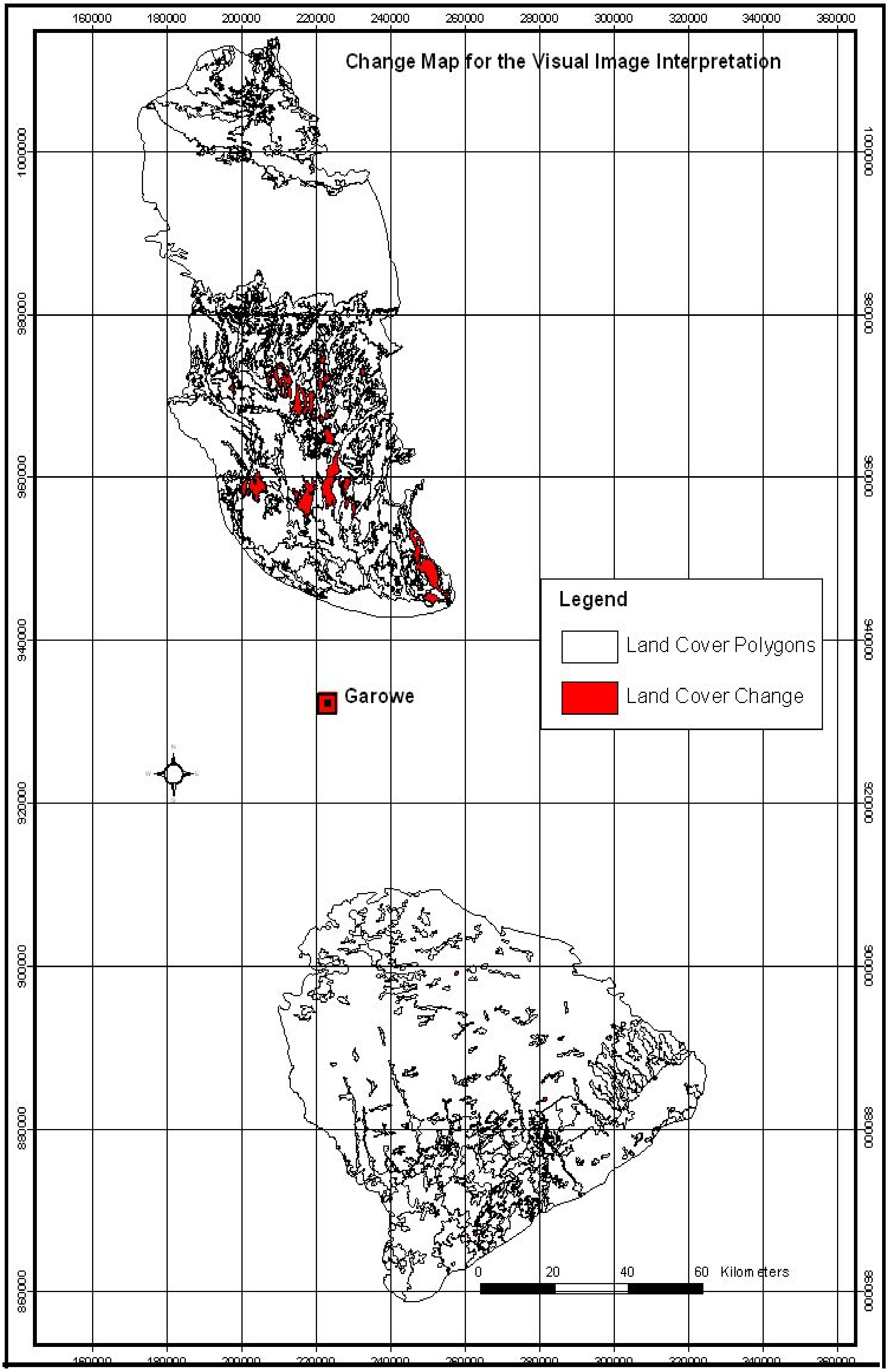
The accuracy with which each land cover has been interpreted is the following:

1. Sparse Vegetation is 19/25*100 = 76%
2. Open Shrubs is 28/38*100 = 74%
3. Bare Lands is 7/7*100 = 100%
4. Shrubs with Emergent Trees is 5/5*100 = 100%
5. Tiger Bush is 11/11*100 = 100%
6. Open Trees is 1/2*100 = 50%

The big difference in land cover changes from visual image interpretation and automatic digital image classification can be explained from two points of view. 1) Lack of prior local knowledge while carrying out the visual interpretation, 2) The application of the Minimum Mappable Unit rule that was applied while carrying out visual image interpretation hence changes below a certain area were ignored.

Interpretation Units Checked	**Land Cover Class**	**Units Found to Belong to**									
		Sparse Vegetation	**Bare Lands**	**Open Shrubs**	**Shrubs with Emergent Trees**	**Tiger Bush**	**Settlement**	**Open Herbaceous**	**Closed Herbaceous**	**Open Trees**	Accuracy (%)
22	**Sparse Vegetation**	**19**	0	**2**	0	0	0	**1**	0	0	
21	**Bare Lands**	**4**	**7**	**7**	0	0	0	**3**	0	0	
32	**Open Shrubs**	**2**	0	**28**	0	0	0	**2**	0	**1**	
6	**Shrubs with Emergent Trees**	0	0	**1**	**5**	0	0	0	0	0	
12	**Tiger Bush**	0	0	0	0	**11**	**1**	0	0	0	
0	**Settlement**	0	0	0	0	0	**0**	0	0	0	
0	**Open Herbaceous**	0	0	0	0	0	0	**0**	0	0	
0	**Closed Herbaceous**	0	0	0	0	0	0	0	**0**	0	
1	**Open Trees**	0	0	0	0	0	0	0	0	**1**	
94	**Total**	25	7	38	5	11	1	6	0	**2**	**76**

Table 6: Accuracy Test Matrix for the Digitally Classified Land Cover Map (FAO SWALIM)


Change Map for the Visual Image Interpretation
Legend
Land Cover Polygons
Land Cover Change
Garowe
0
20
40
60
Kilometers
160000
180000
200000
220000
240000
260000
280000
300000
320000
340000
360000
1000000
980000
960000
940000
920000
900000
880000
860000

Map 6: Land cover change map from visual interpretation

4.3 Drought assessment

4.3.1 Drought assessment using Landsat Satellite images

Figure 10 and Figure 11 show the vegetation condition index curves derived from Landsat images of 1973, 1988 and 2001 for the northern and southern study areas respectively.

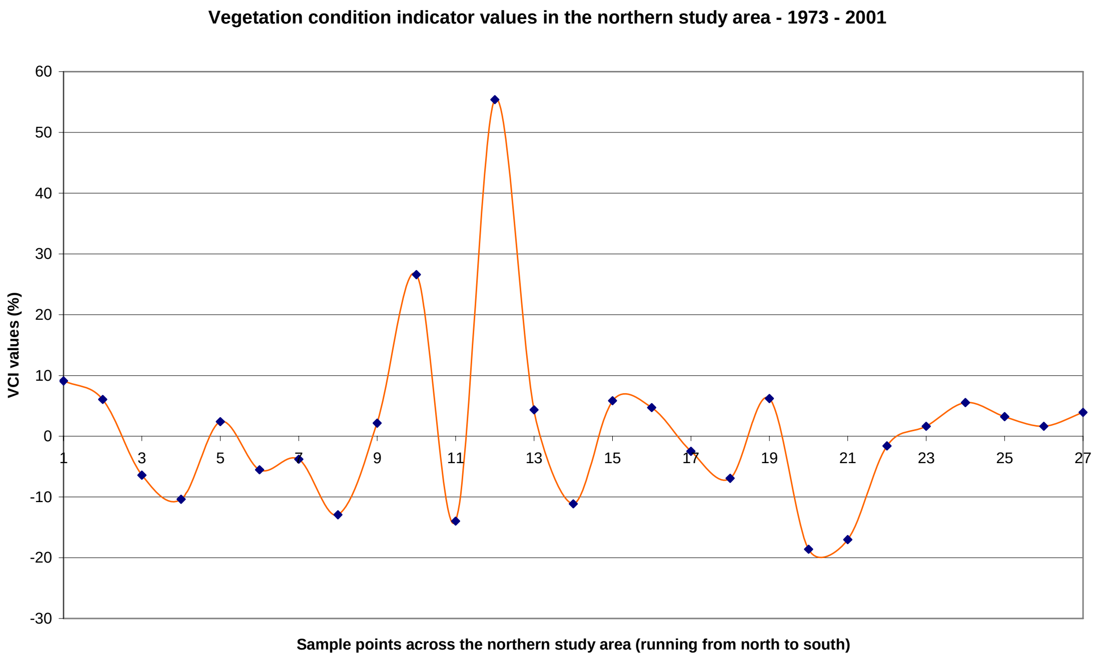


Figure 10: A vegetation condition index (VCI) curve showing drought onditions in the northern study area from Landsat images (1973 – 2001)

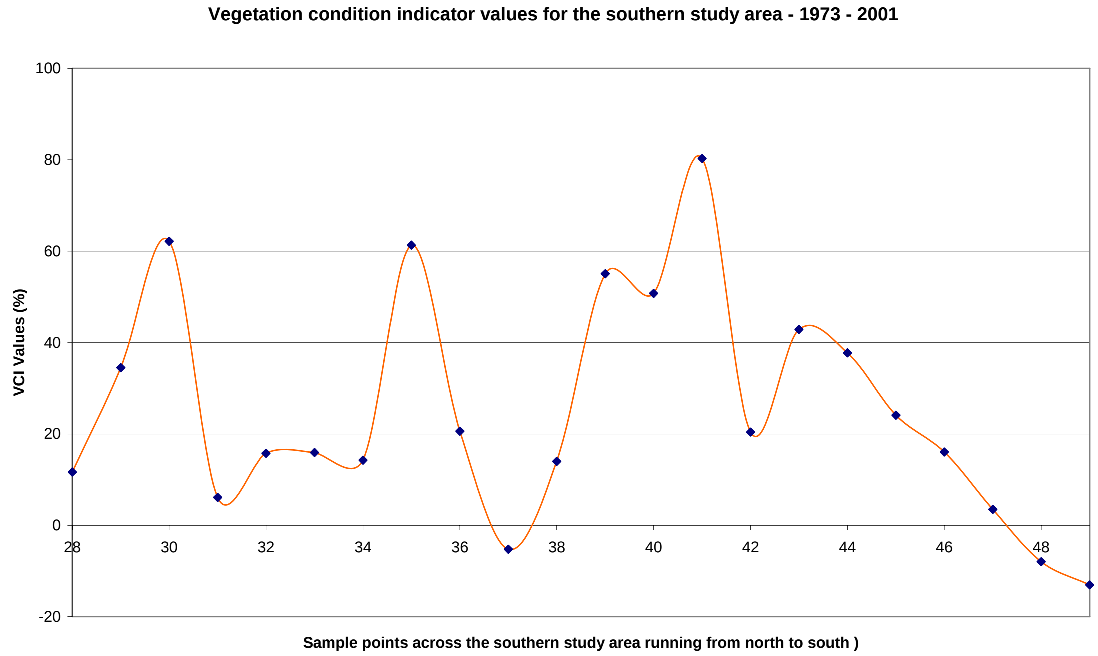


Figure 11: Vegetation condition index curve for drought assessment in the southern study area (Landsat images – 1973 – 2001)

Comparing Figure 10 and Figure 11, the northern study area persistently experienced drier conditions than the southern area. Vegetation Condition Index (VCI) values of less than 50 are an indication of drought conditions. The northern study area did, as such experience more drought conditions compared to the southern study area.

4.3.2 Drought assessment using NDVI and VCI values derived from NOAA NDVI and SPOT NDVI data

Figure 12 shows average monthly VCI values for the main growing seasons using NOAA NDVI data for the northern study area for the period between 1983 and 2003. The curves show that the environmental conditions improved between 1992 and 2002 particularly the second growing season.

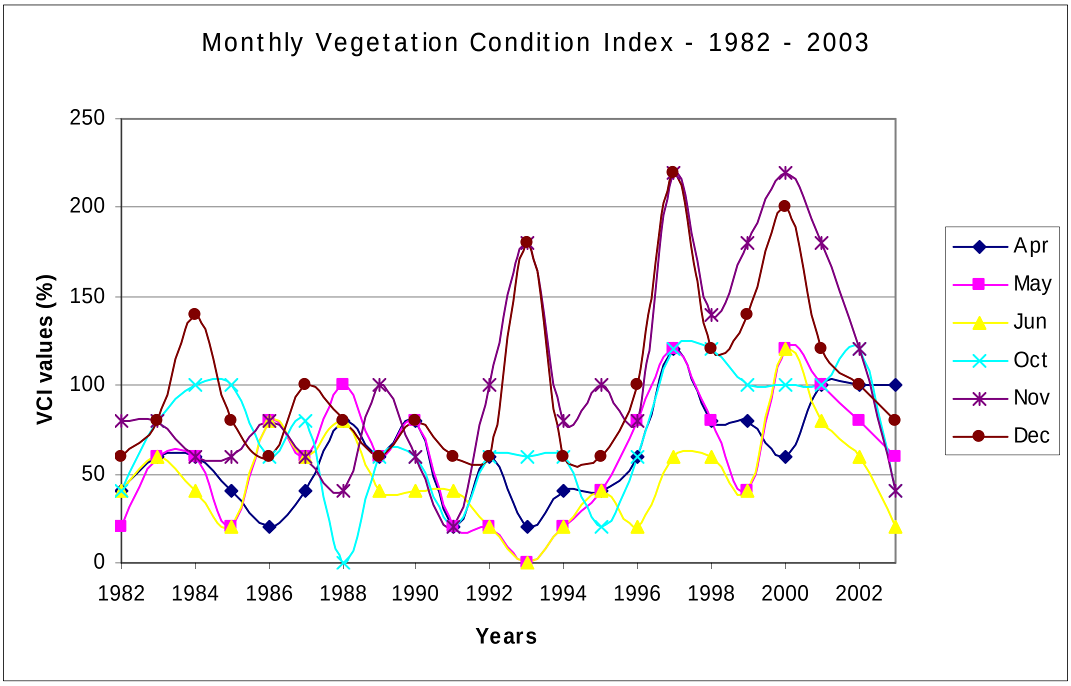


Figure 12: Average monthly vegetation condition index values for the main growing seasons in the northern study area from NOAA NDVI data

Figure 13 shows average monthly VCI values for the main growing seasons using NOAA NDVI data for the southern study area for the period 1983 - 2003.

The monthly average values show that the southern study area had on average good conditions, much better than the northern study area. In other words the drought conditions were less experienced in the south.

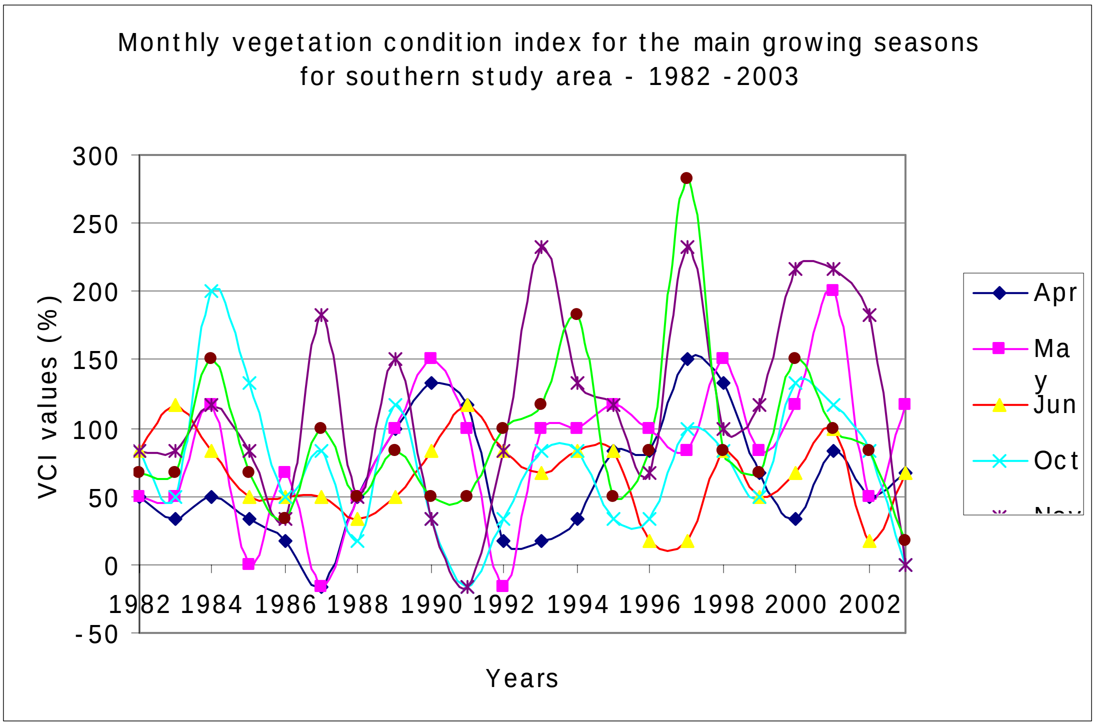


Figure 13: Average monthly Vegetation condition index values for the main growing season for the southern study area from NOAA NDVI data

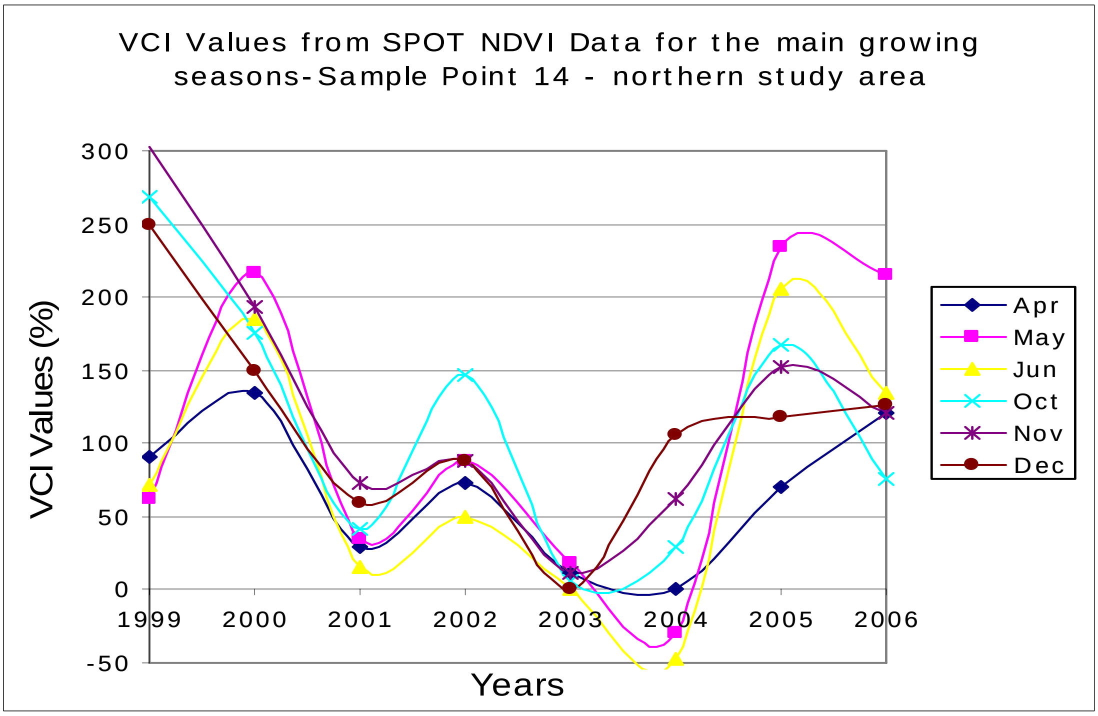


Figure 14: Average monthly vegetation condition index values for the main growing season for northern study area from SPOT NDVI data

Figure 14 represents average monthly VCI values for the period 1999-2006 derived from SPOT NDVI data for the northern study area. The monthly values show drought conditions between 2001 and 2004 although there was some slight improvement in 2002 but whose impacts can be considered minimal. Figure 15 is an average monthly VCI values for the southern study area derived from SPOT NDVI data. Drought periods are depicted between 2003 and 2004.

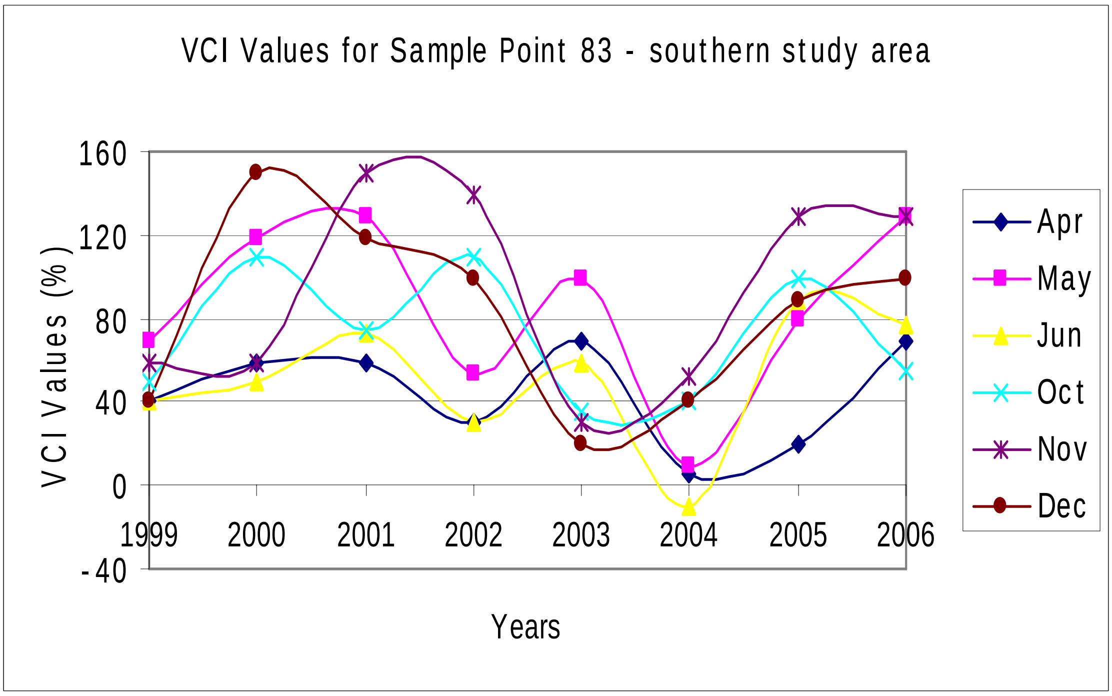


Figure 15: Monthly vegetation condition index for the main growing season for the southern study area from SPOT NDVI data

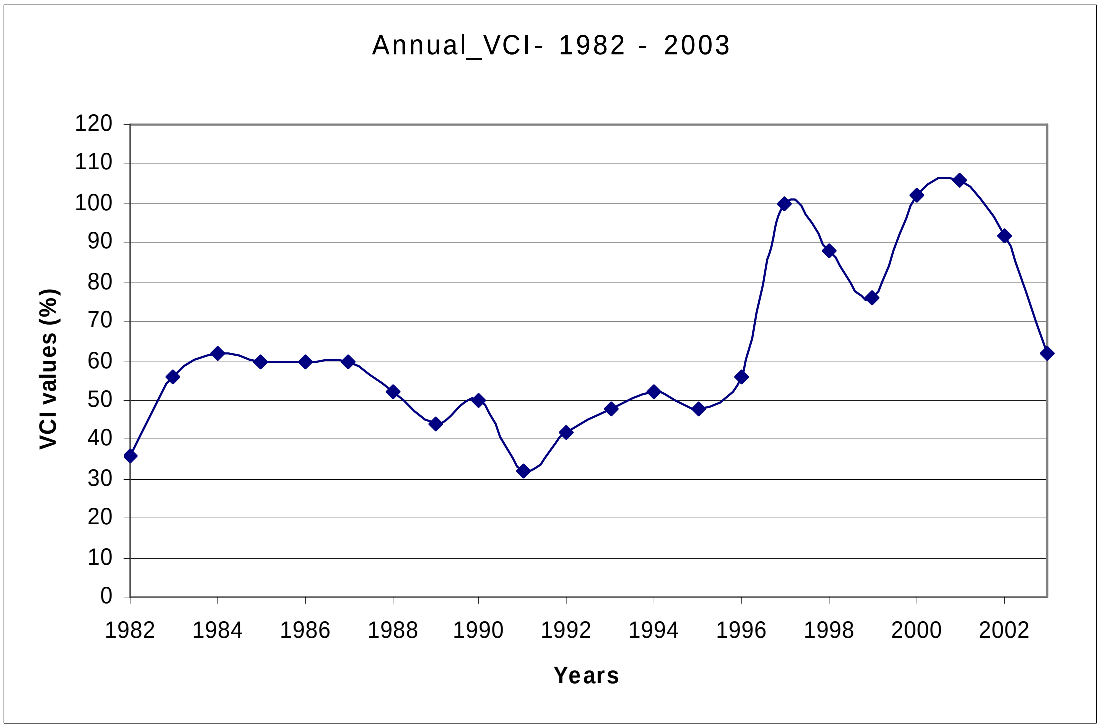


Figure 16: Annual vegetation condition index for the northern study area from NOAA NDVI data

Figure 16 and Figure 17 show average annual vegetation condition index values derived from NOAA NDVI data for the north and south respectively. Similarly the curves show a general improvement in environmental conditions between 1992 and 2002 for both study areas. However, the southern study areas still had better conditions compared to the northern one.

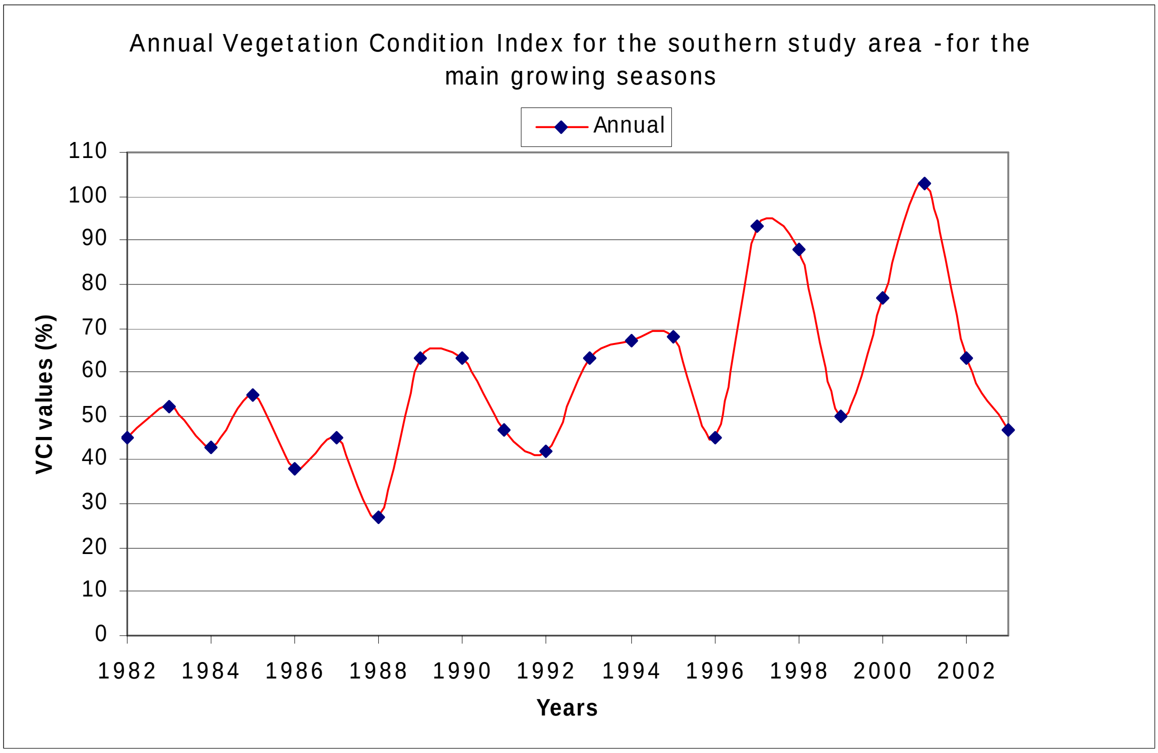


Figure 17: Annual vegetation condition index for the southern study area from NOAA NDVI data

In the assessment of droughts using VCI, any values below 50% represent drought condition while values between 50% and 100% show good conditions. Vegetation condition index has been used to assess droughts because it takes into account standard deviations from the mean which cannot be directly given by the normal NDVI values (see Thenkabail et al, 2004). As depicted in Figure 18 and Figure 19 using annual VCI values derived from NOAA, droughts were experienced in 1982 and the period 1990 – 1994 for the northern study area while from the same data droughts were experienced in the south in 1982, 1986 – 1988 and also 1991 – 1992 and in 1996.

Mean monthly values of NDVI were also used to assess environmental conditions. Figure 19 below shows mean monthly NDVI values derived from NOAA data downloaded from the African Data Dissemination Service at http://igskmncnwb015.cr.usgs.gov/adds/datatheme.php site (all NOAA NDVI data were downloaded from the same site). The NOAA NDVI values show that the northern study area has less vegetation cover compared with the southern study area.

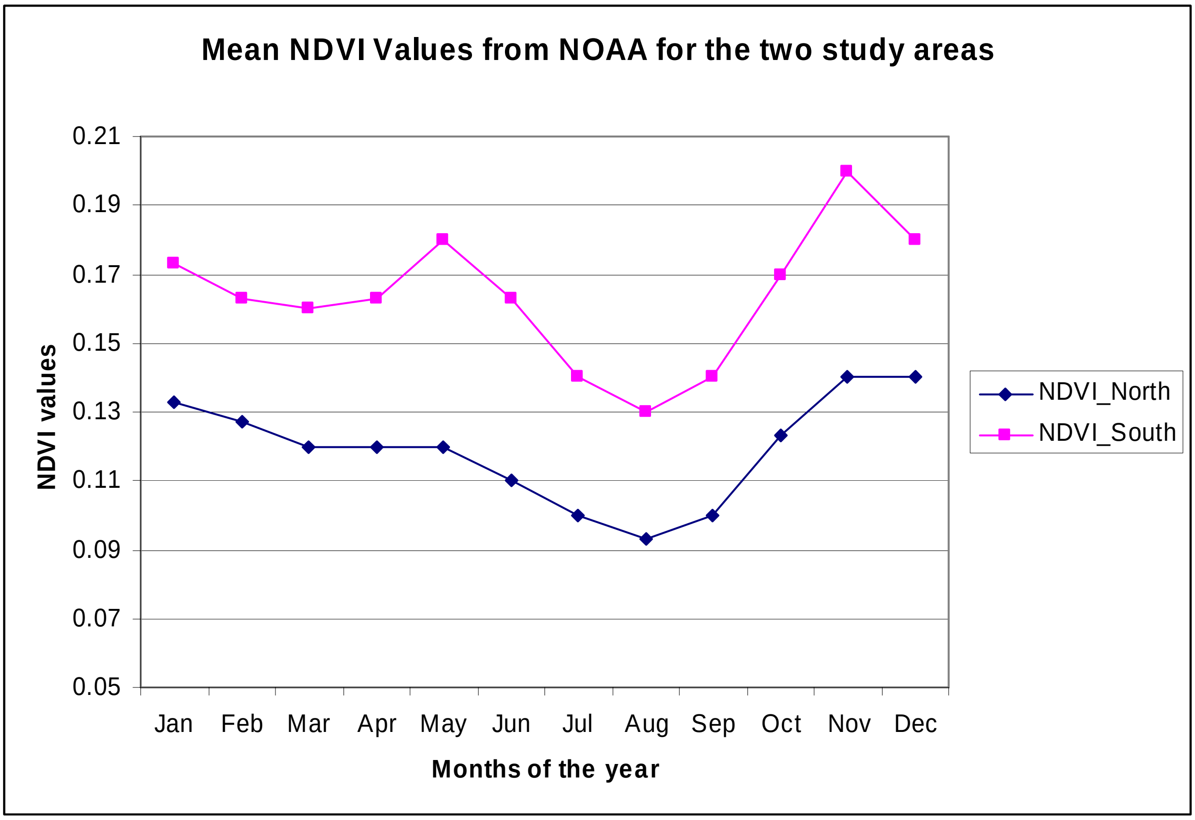


Figure 18: Long Term Mean NDVI values for the two study sites derived from NOAA

Figure 19 and Figure 20 are mean annual NDVI values derived from NOAA data (1982 to 2003) for the northern and the southern study areas respectively.

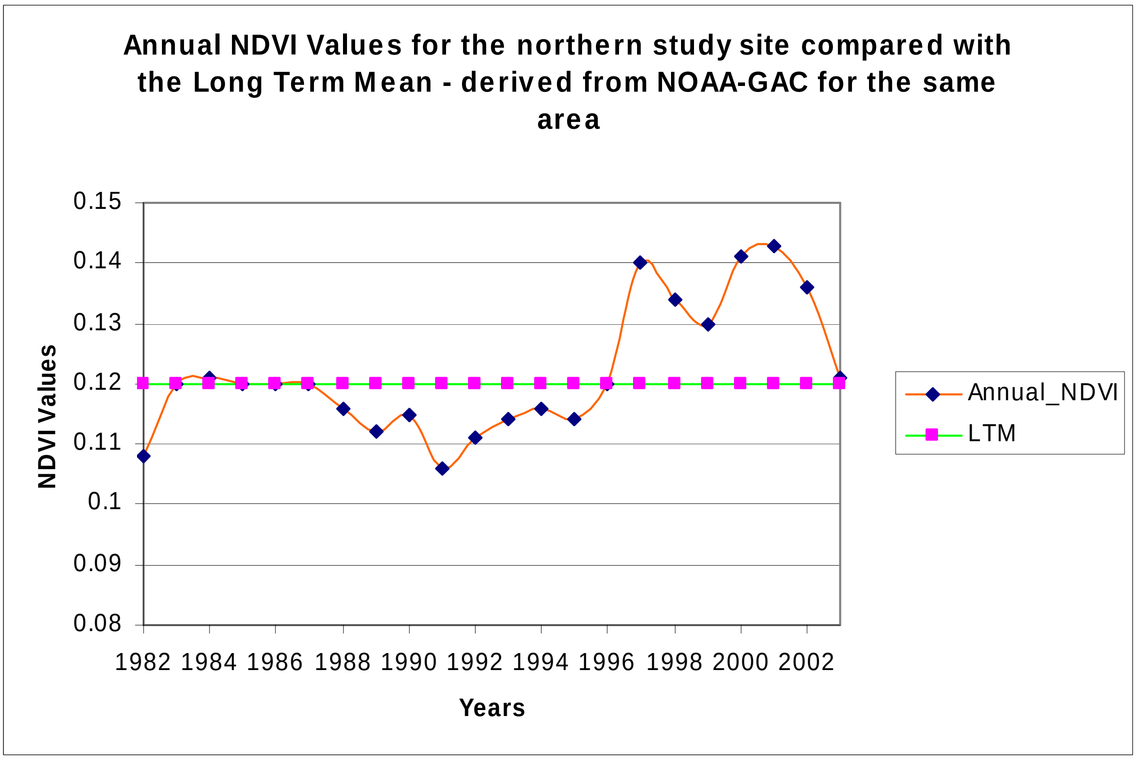


Figure 19: Annual NDVI values for the northern study site derived from NOAA GAC data

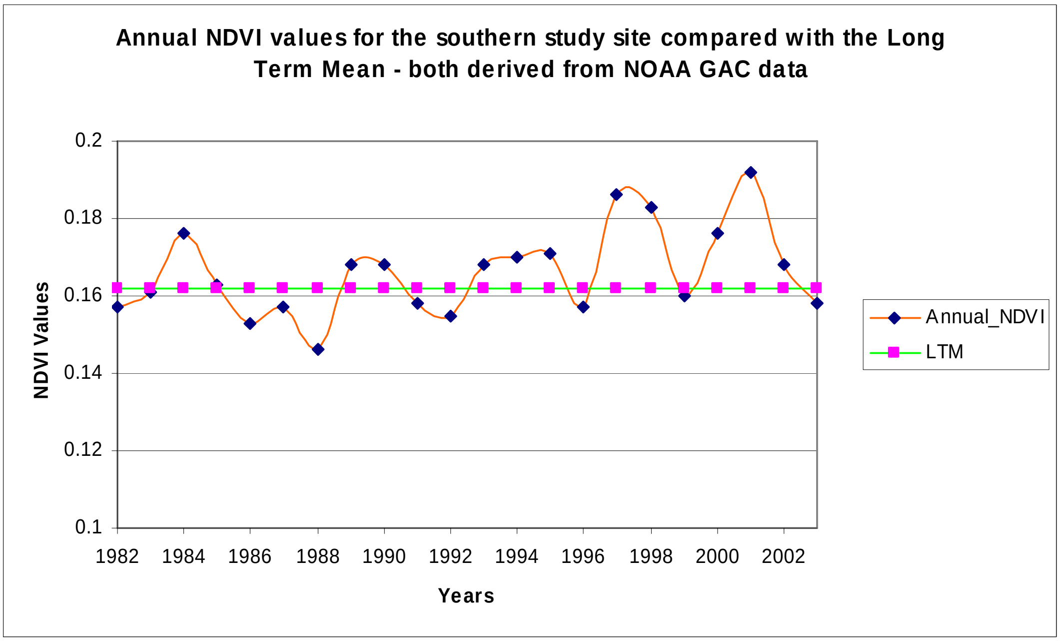


Figure 20: Annual NDVI values for the southern study site derived from NOAA-GAC data

As pointed out by Thenkabail (Thenkabail et al, 2004) NDVI may not be used on its own to assess drought but derivation of NDVI values are used to show drought or drought conditions. Figure 21 and Figure 22 show the deviations from the mean which were used to determine years of drought. Using NDVI values given above it is assumed that droughts occurred when NDVI values were below the Long Term Mean (LTM), which is a deviation from the mean. Using NDVI values the northern study area experienced droughts in 1982 and also in the period 1988 – 1996 and the southern study area experienced droughts in 1982 and the period 1986 – 1988 and also 1991 - 1992.

From the SPOT-NDVI data drought periods were shown as 2000 – 2004 with 2003 and 2004 being shown as the worst drought years of this period. SPOT NDVI data seem to have been more accurate in detecting drought than NOAA.

Given in Figures 21 - 26 are SPOT NDVI data from six sample points (three from the northern study area and three from the southern study area). The selected points have been spread to give a representation of the two study areas (the northern and the southern). The figures show values drawn against the long term mean given in purple colour. They show deviations from the mean. Any values below the mean are drought periods

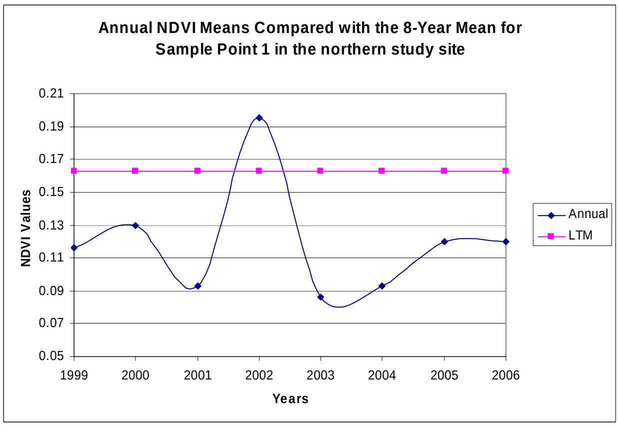


Fig. 21: SPOT NDVI sample point 1

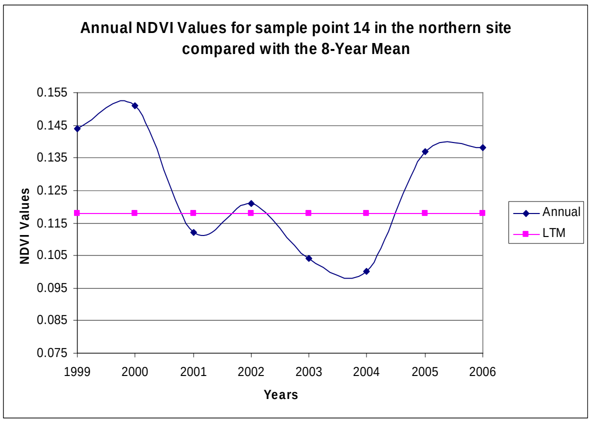


Fig.22: SPOT NDVI Sample Point 14

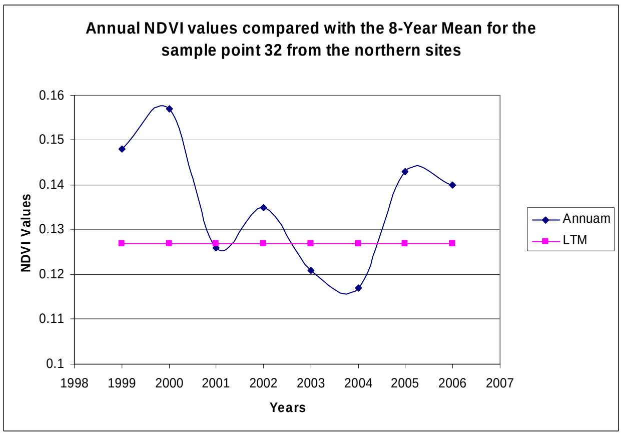


Fig.23: SPOT NDVI Sample Point 32

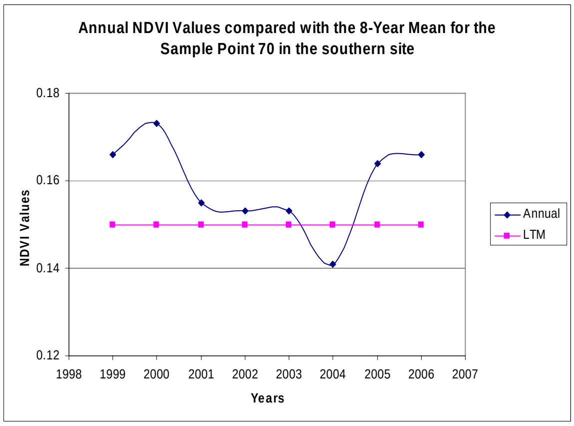


Fig.24: SPOT NDVI Sample Point 70

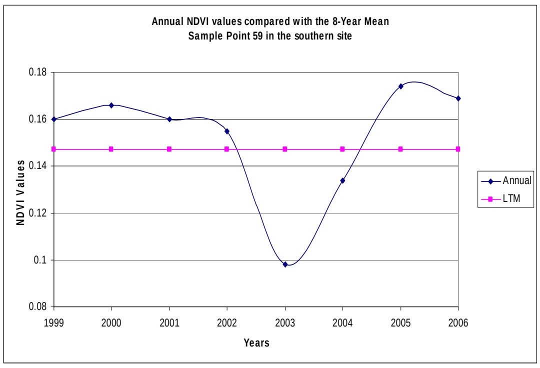


Figure 25: SPOT NDVI Sample Point 59

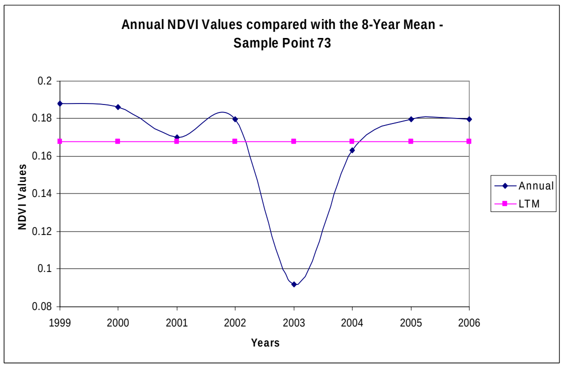


Figure 26: SPOT NDVI Sample Point 73

The remote sensing information was compared with field data. Figure 27 and Figure 28 show results of the interviews conducted in the field in April 2007. The figures show responses to the question on the years with drought.

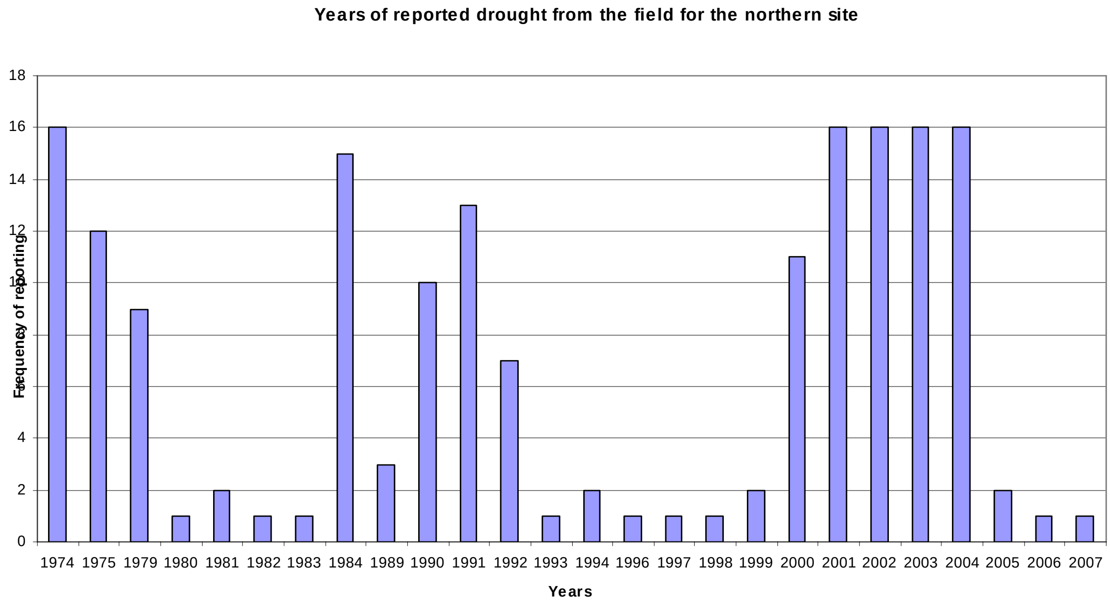


Figure 27: Years of drought as reported by the respondents from the field – northern study site

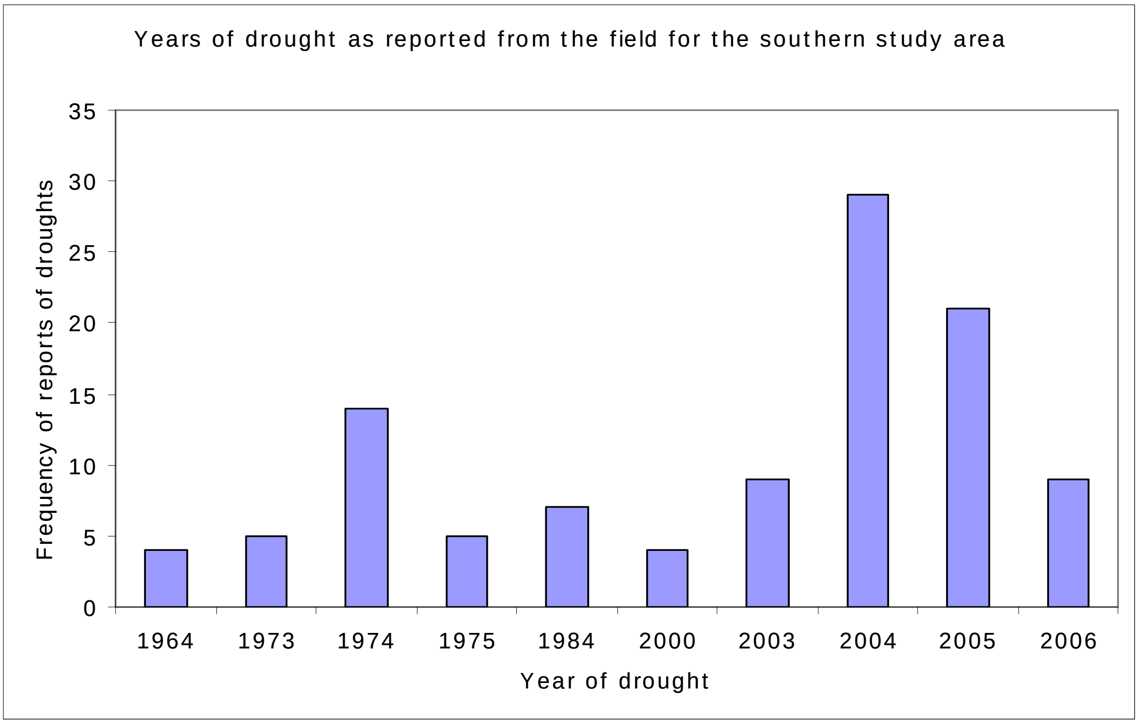
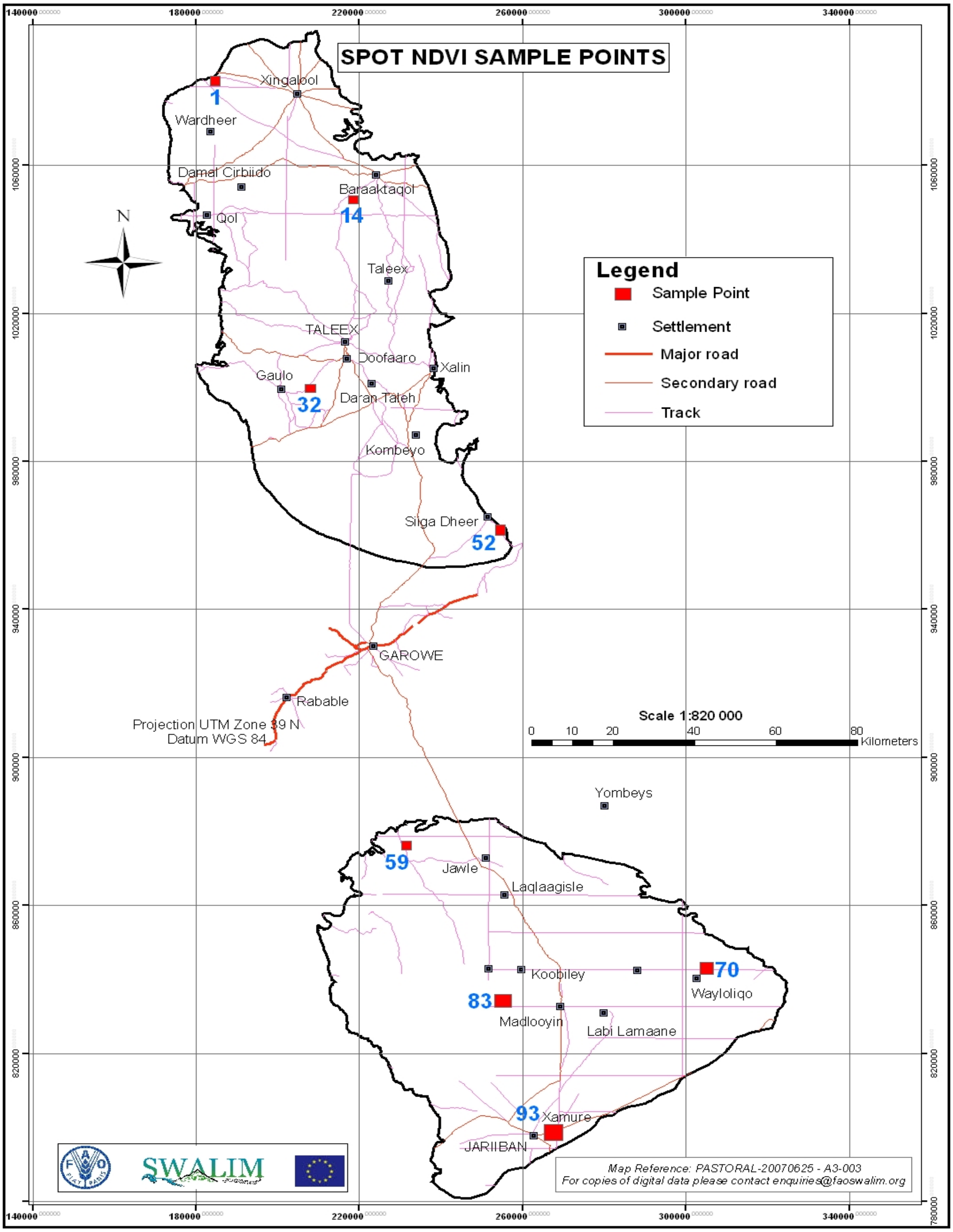


Figure 28: Years of drought as reported by the respondents from the field – southern study area

In the northern study area bad or drought years that were remembered by most respondents were years 1974 – 1975, 1979, 1984, 1990 – 1991, and then the period 2000 – 2004. From the field data drought years that could be remembered by most respondents in the southern study area were 1974, 1984, and the period 2003 – 2004.

Comparing the two sources of information (NDVI data from NOAA and the field information) the period 1990 – 1991 came out clearly as bad or drought periods. However, NOAA did not show 1984 as a drought year despite it being reported as a drought year from the field. This shows a limitation of NOAA in depicting droughts explicitly.

Map 7 shows some of the selected sample points from which SPOT NDVI data were generated.



Map 7: Selected sample points from which SPOT NDVI values were extracted.

4.4 Detection of impacts from water points and Settlements

Figure 31 shows the variation in NDVI values as derived from Landsat Satellite Images around some selected settlements and water points. Water points are usually located around settlements. These results are from satellite images of the study area taken in the years 1973, 1988 and 2001. The NDVI values decreased with time from 1973 to 2001 around these settlements. The inset photos show the situation on the ground in April 2007 from some of the settlements.

At Xingalol settlement, for example, in 1973 the NDVI values were around 0.2 but declined to below 0.12 in 1988. The figures declined even further in 2001. Field observations revealed that bare lands characterise the area around Xingalol settlement as can be seen from photos taken around the settlement in April 2007.

In the settlement of Gaulo, the environmental situation is so bad that the bare lands are now characterised by deep gullies as shown in the inset photograph taken during the field surveys in April 2007. Efforts to rehabilitate and or arrest continued gully encroachment have been too expensive, and in certain cases the gully controls are washed away by the fast running water as shown in the inset photograph (top left).

Figures 31, 32, 33, 34, 35, 36, 37 and 38 below show the impacts of settlements on land cover around some selected settlements within the study areas. The figures are clips from satellite images with pictures placed inside some of them to show the details of land cover on the ground.

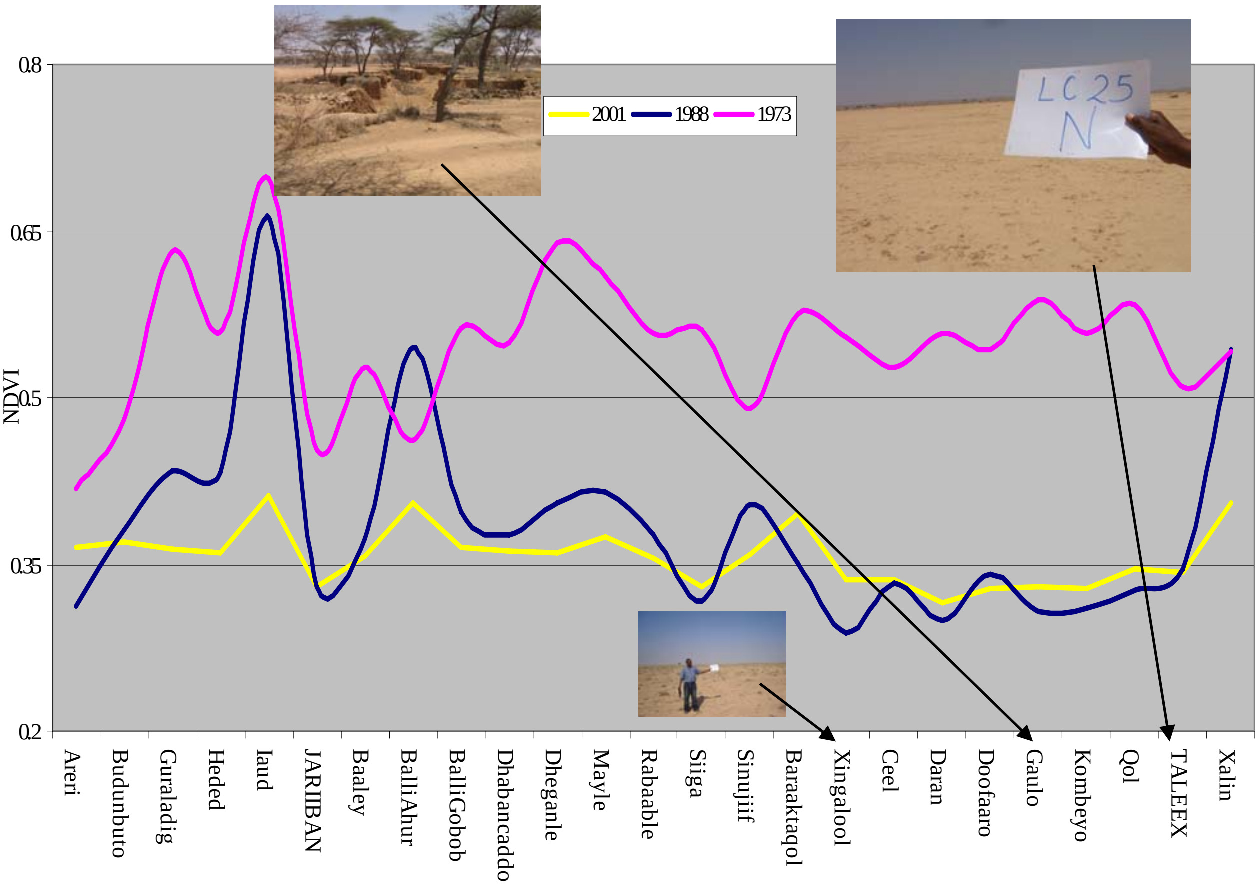


Figure 29: Changes in NDVI Values around Settlements and Water Points as derived from satellite images of 1973, 1988 and 2001

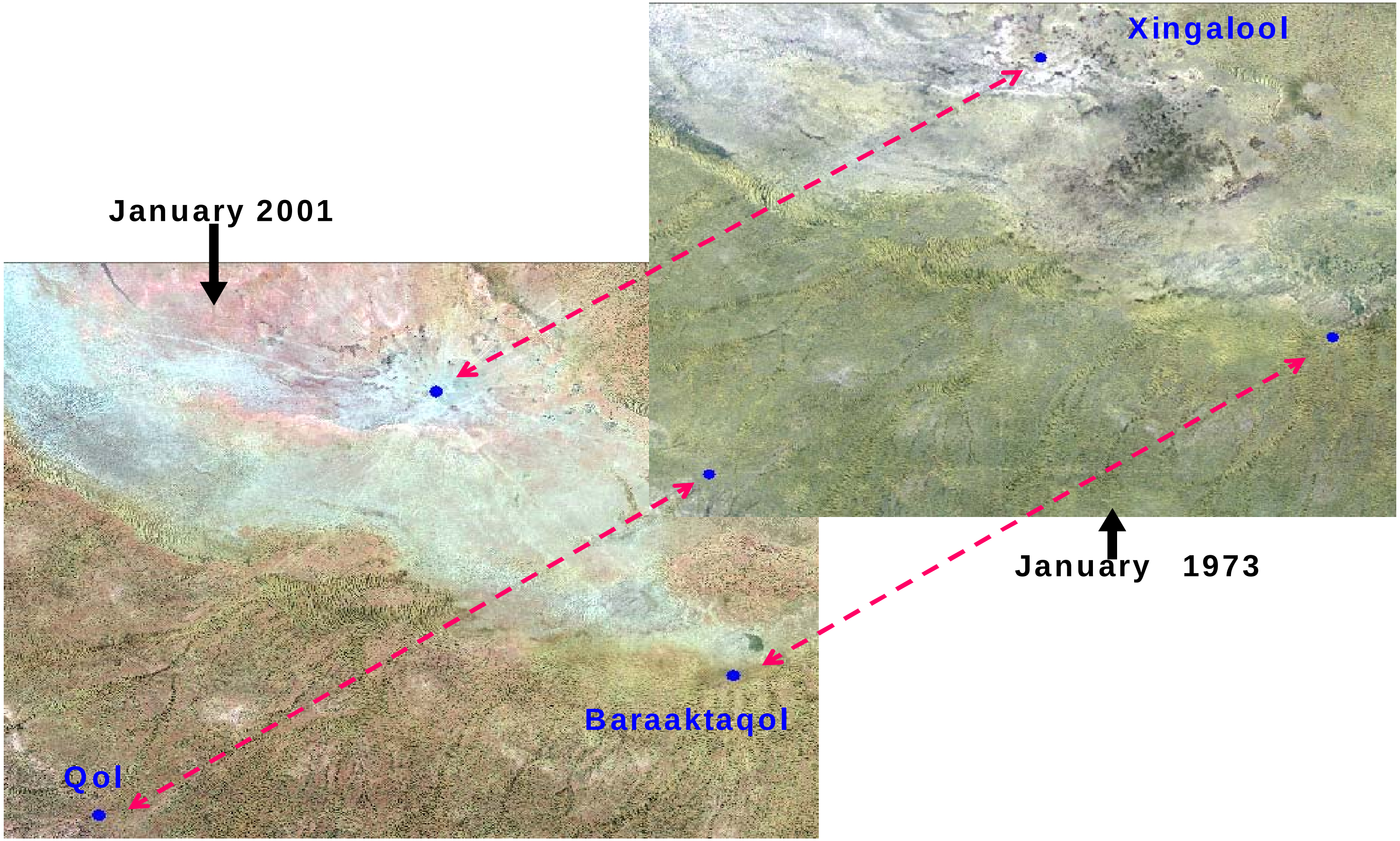


Figure 30: Land Cover Change around Settlements

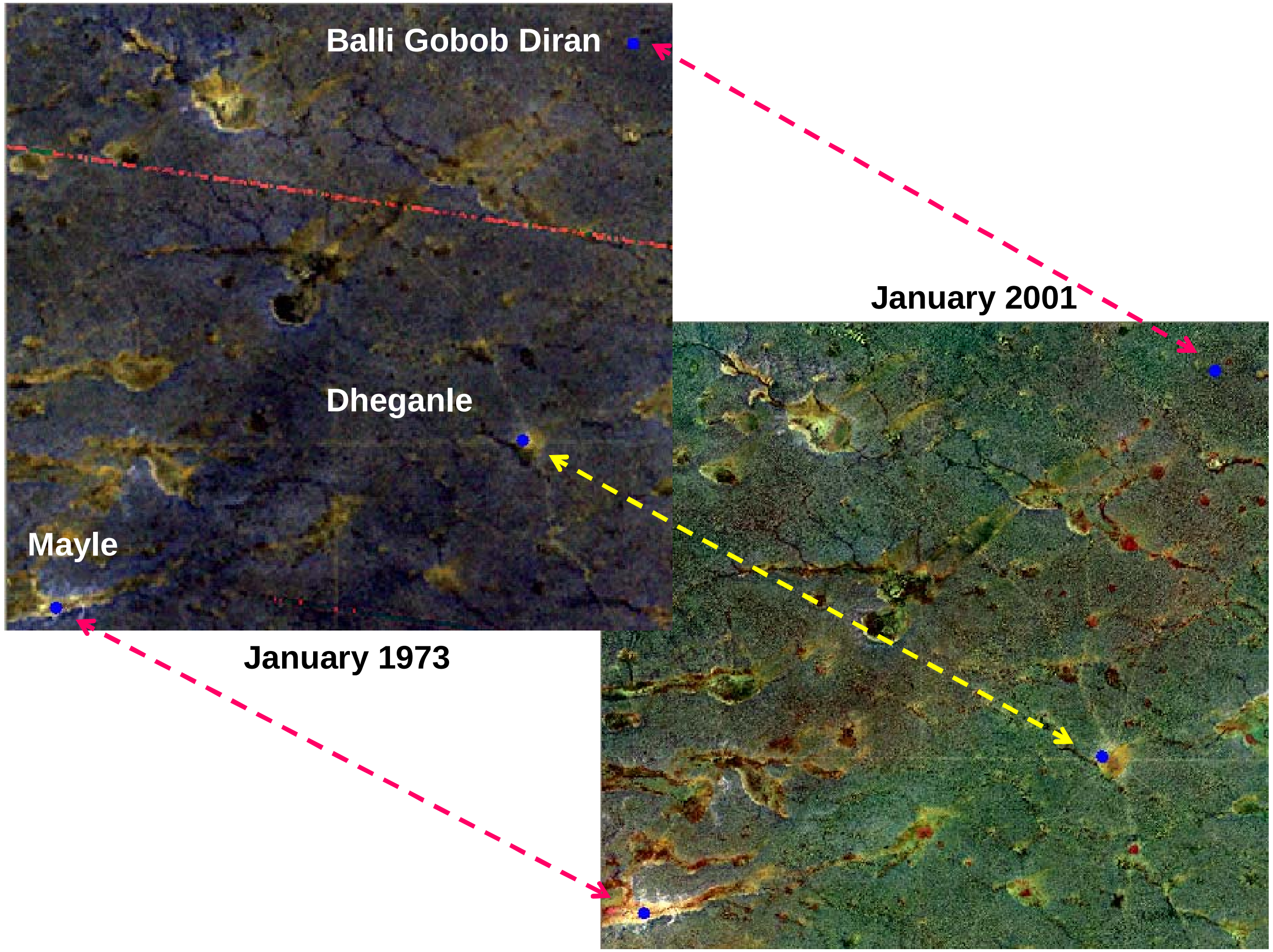


Figure 31: Land Cover Change around Settlements

Figure 32: Damal Cirbiido before being settled in this image of 1988

LANDSAT ETM SATELLITE IMAGE November 2001

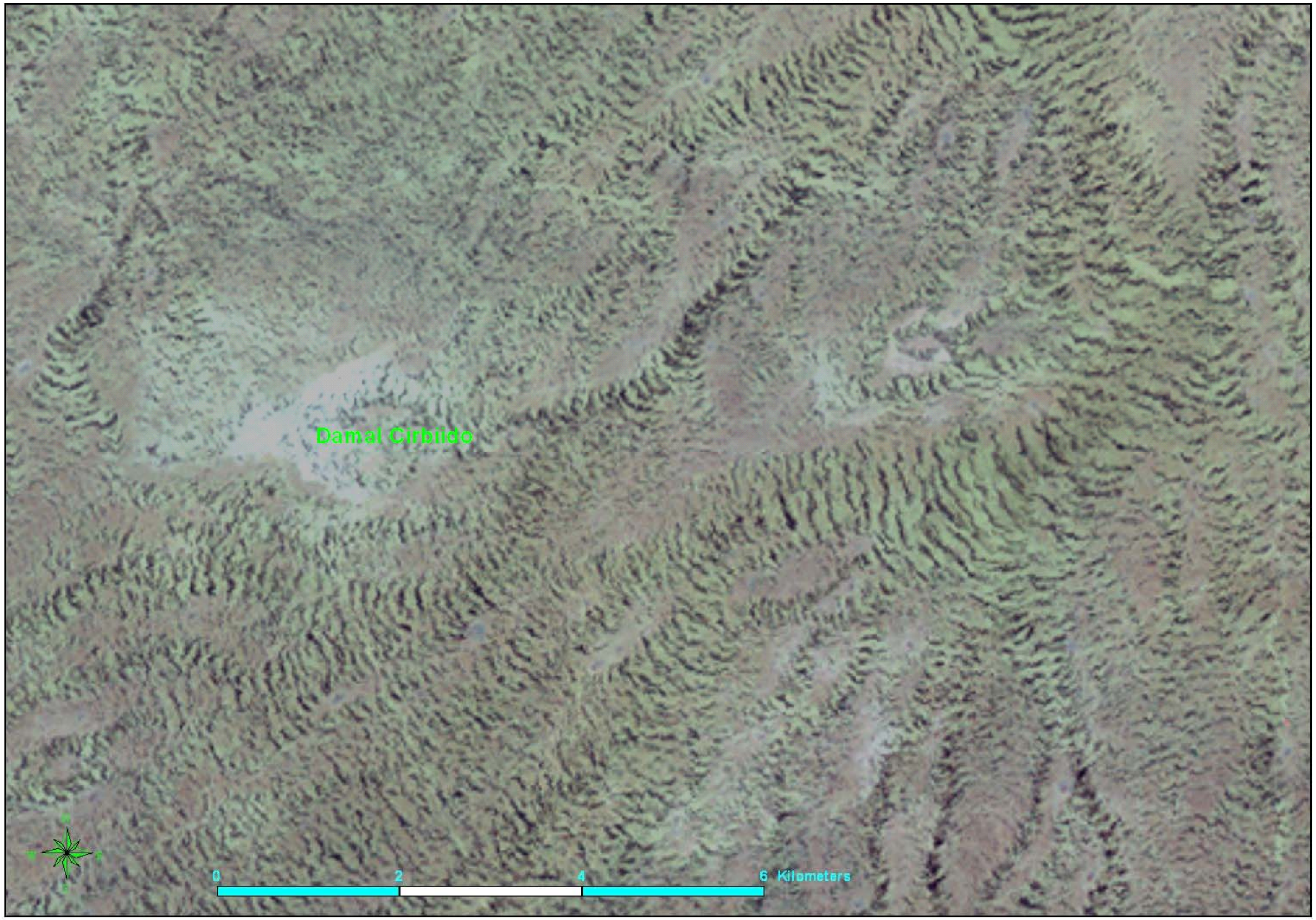


Figure 33: Damal Cirbiido: Land cover change and increase in vehicle tracks

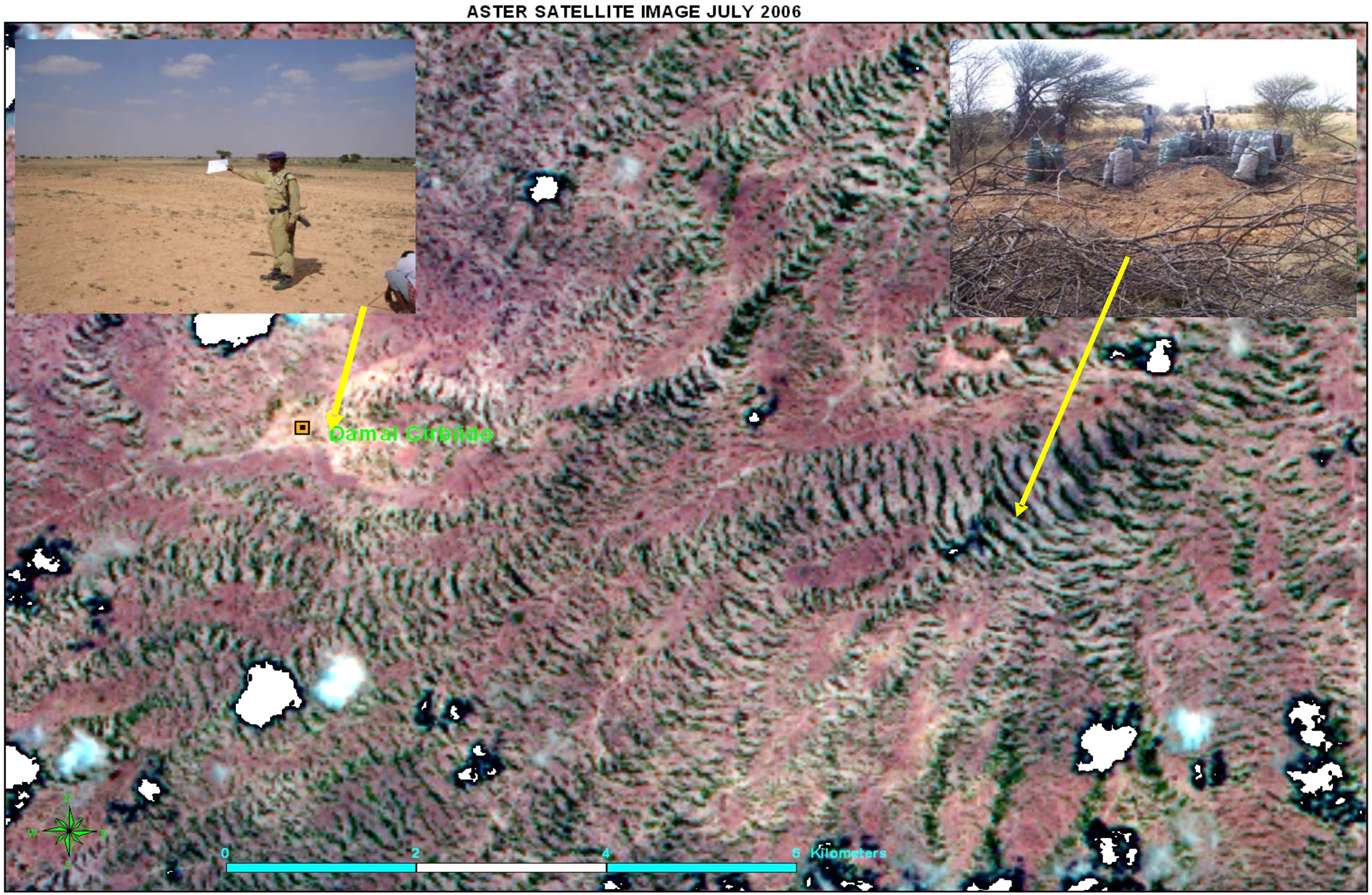


Figure 34: Aster Image of Damal Cirbiido showing changes in land cover and increased motor tracks

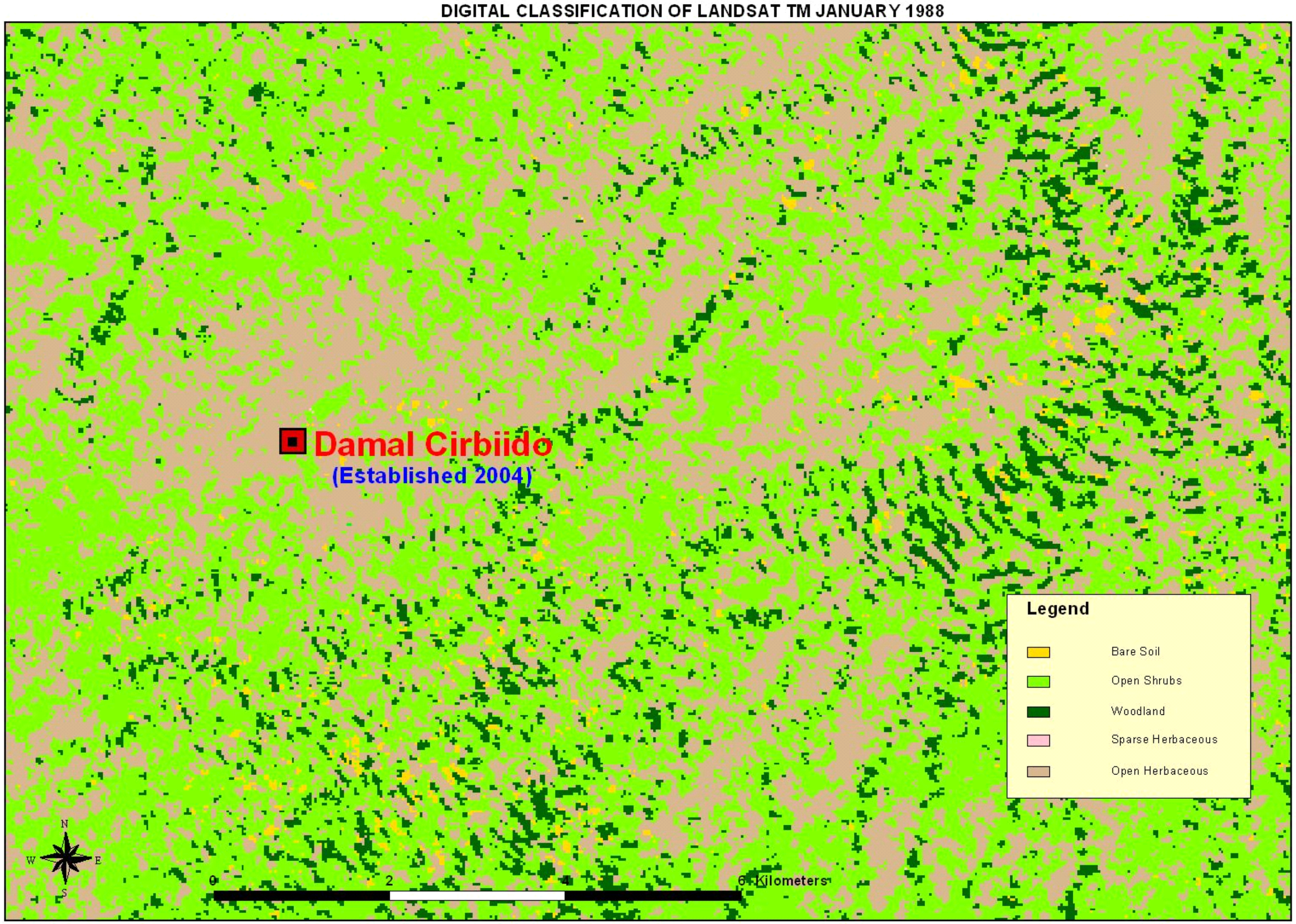


Figure 35: Impacts of settlements on land cover change between 1988 and 2001 – the example of Damal Cirbildo settlement

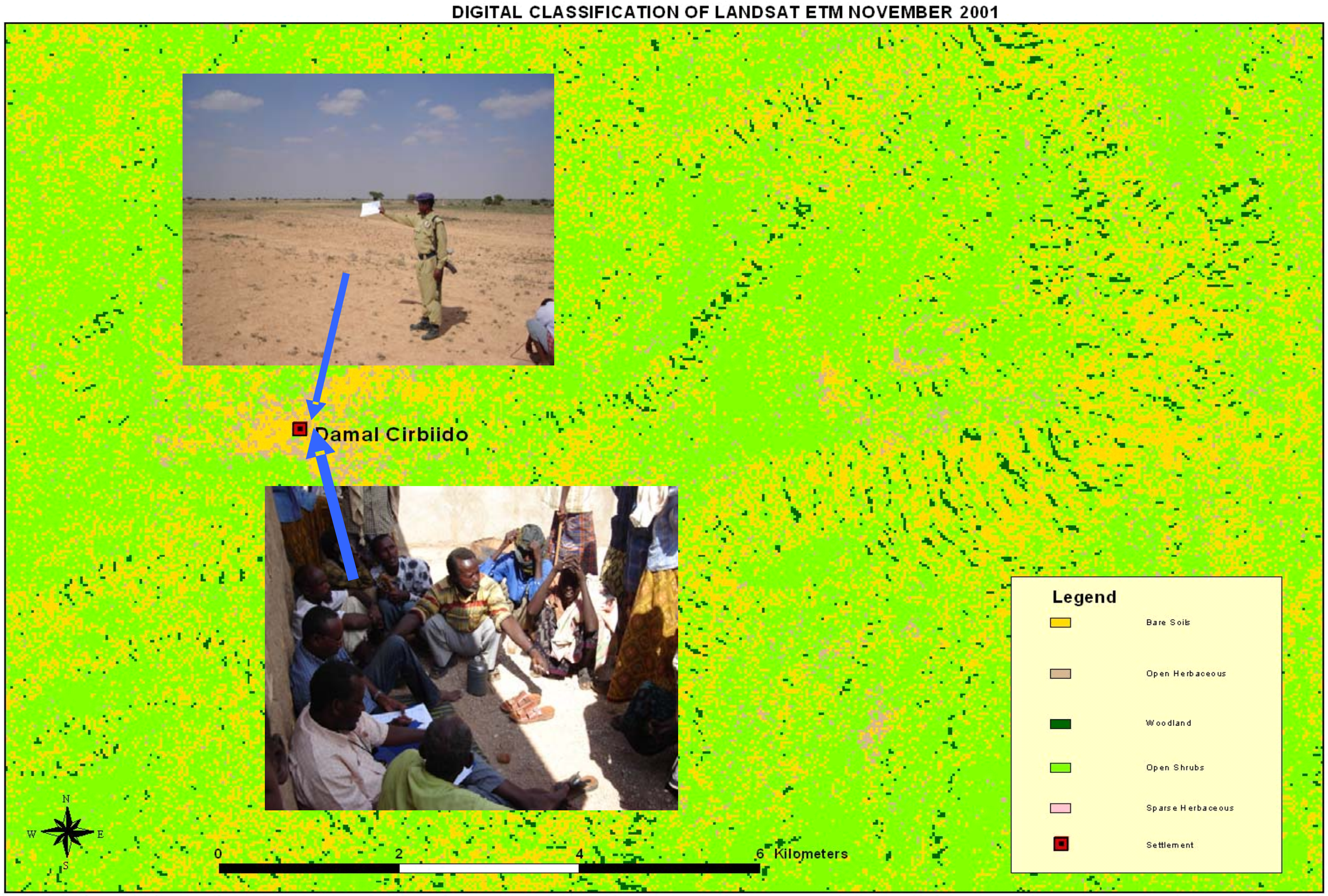


Figure 36: Impacts of settlements on land cover change between 1988 and 2001 – the example of Damal Cirbildo settlement

4.5 Assessment and detection of non-palatable and invasive vegetation species

Table 7 shows the invasive non palatable plant species found in the study area during the field work. These invasive non-palatable plant species were found in degraded land areas, hence their occurrence in sparse herbaceous and bare areas. Remote sensing was used to map land cover and species inventory results from field observations were associated with the land cover map. Degraded areas were identifiable from the land cover map generated using remote sensing. However, remote sensing could not directly be used to identify the invasive non-palatable plant species. This confirms the findings by Joshi (2006) that remote sensing cannot be used directly to map plant species unless dominate the ecosystem.

A semi structured questionnaire administered in the field established that these non palatable plant species had invaded the land cover gradually and were taking over as the palatable plant species disappeared, particularly being cleared by grazing animals.

Table 7: Incidence of invasive non palatable plant species

SNo.	Plant Species Name	Land Cover in 1988	Land Cover in 2001
1	*Fogonia brugueiri*	Open Herbaceous	Bare Land with Scattered Vegetation
2	*Fogonia brugueiri*	Open Herbaceous	Bare Land with Scattered Vegetation
3	*Fogonia brugueiri*	Open Herbaceous	Sparse Herbaceous
4	*Zygophyllium hildebrandtii*	Open Shrubs	Sparse Herbaceous
5	*Fogonia brugueiri*	Open Shrubs	Sparse Shrubs
6	*Zygophyllium hildebrandtii*	Open Herbaceous	Sparse Herbaceous
7	*Zygophyllium hildebrandtii*	Open Herbaceous	Sparse Herbaceous

In all the cases, land cover change was recorded as negative (from good to bad, for example Open Herbaceous land cover to sparsely vegetated herbaceous land cover).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Assessment of changes and trends in land cover using satellite image interpretation and field survey.

Assessing land cover is a very important input in assessing pastoral resources because cover determines biomass productivity.

Changes in land cover were mainly identified and mapped using automatic digital land cover classification. Visual image interpretation could not be used to map the changes because of the minimum mappable unit rule that characterises it. Consequently very small changes (less than 0.1%) were mapped using the visual image interpretation technique between 1988 and 2001 (the period of study). The visual image interpretation had also a low accuracy of interpretation, which could be attributed to the fact that prior field knowledge was not used in this exercise. There was no field visit carried out before the image interpretation. As such different land cover classes were confused with each other and hence misinterpreted.

The automatic digital land cover classification on the other hand produced significant land cover change results over the same period of study. This method was pixel based and was able to detect even the very small changes in land cover, which could not be detected by the visual image interpretation technique. The accuracy of interpretation was high and stood at 76% during the preliminary phase of interpretation. The high accuracy of interpretation was attributed to the fact that both local and expert knowledge were used in the interpretation.

Change in land cover within the period of study was confirmed by the semi structured interviews with the local people in the study area. According to the interview results, land cover had changed considerably during the period under review, and that these changes were negative in most cases.

5.1.2 Assessing applicability of remote sensing to study phenological behaviour and physiognomic variability of major vegetation groups as an input for the analysis of drought conditions

Remote sensing has potential in studying the phenelogical behaviour and physiognomic variability of vegetation in the arid and semi-arid environmental environments. Using two vegetation indices, NDVI and VCI, for example, it is very easy to assess and monitor droughts in the two study areas. Periods of drought (in terms of years) were easily detectable based on NDVI and VCI values. Field information based on indigenous knowledge did confirm the results obtained from remote sensing products on the years of drought. Phenological behaviour and physiognomic variability of vegetation can be assessed very well using remote sensing. Remote sensing can, therefore, be used effectively in assessing environmental conditions in areas where field data collection is not possible or is limited such as in Somalia. However, the accuracy of assessment can be influenced by the spatial resolution of sensors because, for example, NOAA NDVI missed out on some drought events reported in the field while SPOT Vegetation NDVI data more accurately pointed out the years of drought.

Drought assessment is very important because it is one of the leading factors affecting biomass productivity and water supply in pastoral production areas. Vegetation biomass and water supply determine livestock productions system in rangelands.

5.1.3 Remote sensing in assessing impacts of human activities the pastoral resources with focus on settlements, water points and vegetation removal

Denudation or vegetation removal was easily identifiable by remote sensing. In this sense, environmental degradation can easily be detected and mapped using remote sensing techniques. Settlements and water-points contributed to increased pressure on the fragile environment and consequently caused negative changes in land cover. Settlements and areas around water-point did experience high degradation through vegetation removal between 1973 and 2006. From the NDVI and temperature values derived from the red and infrared, and the thermal bands, respectively, of Landsat satellite images, the ability or potentiality of remote sensing in assessing land degradation through denudation was evident. Field information and indigenous knowledge collected through administering of a questionnaire did also confirm that areas around settlements and water points had experienced extensive land degradation through vegetation removal. By assessing the extent of land denudation, it seems possible to map extents of physical soil degradation, particularly erosion assuming that denudation results into or accelerates soil erosion. As such remote sensing is likely to help in mapping possible areas of physical soil degradation.

5.1.4 Potentialities and limitations of using remote sensing techniques and products in assessing invasive and non-palatable plant species

Remote sensing remained limiting in mapping the invasive and non-palatable plant species in this study. In the study area the invasive and non-palatable vegetation species did not dominate any land cover type thus remained difficult to detect by remote sensing in a direct and straight forward manner. Invasive and non-palatable plant species were, however, commonly found in degraded areas and, therefore, could only be detected through indirect means of associating them with degraded lands. Techniques for mapping such cryptic invader plants are yet to be developed. A combination of remote sensing techniques, GIS and expert knowledge can, however, be instrumental in detecting such vegetation through development of models and maps.

5.2 Recommendations

5.2.1 Assessing changes and trends in land cover using remote sensing and field survey

Although expert knowledge in remote sensing and the use of automatic image classification can yield good results in mapping land cover changes, field surveys still remain very important in the whole exercise. Familiarisation with the areas being interpreted or the use of indigenous knowledge is useful while using remote sensing for land cover mapping and cover change detection. Some of the changes detectable by automatic classification may be too small to be of any significance and as such automatic classification does not necessarily replace visual interpretation. Integration of multiple datasets into remote sensing is highly recommended. It is recommended that there should be need for further research in areas of data modelling techniques for purposes of assessing pastoral resources.

5.2.2 Assessing the phenological behaviour and physiognomic characteristics of major vegetation groups as an input in the analysis of drought conditions

Ecological knowledge and experience are highly recommended while applying remote sensing in studying the phenelogical behaviour and physiognomic variability of vegetation in a given area. Two vegetation indices, NDVI and VCI, are good in the assessment and monitoring of general environmental conditions especially in assessing droughts, particularly in the arid and semi-arid environments. Remote sensing techniques are fairly accurate and are, therefore, recommended for use where field data collection may be limited. However, regular calibration of remote sensing information using field information, whenever possible, is also recommended. Choice of remote sensing products is, however, important, for example, whereas NOAA NDVI data may be relevant in large and expansive areas with homogeneous land cover, it may not be very useful in detailed and heterogeneous land cover assessment because of its course spatial resolution.

5.2.3 Assessing impacts of human activities on the pastoral resources using remote sensing techniques

Field surveys and local knowledge are still recommended while using remote sensing in the assessment of impacts due to settlements and water points on pastoral resources in the arid and semi-arid areas. This is because some of the observable impacts may not necessarily be due to human activities but to some natural phenomena such as droughts. Remote sensing can, however, give a rapid assessment of the changes in land cover, and may also give possible areas of physical soil degradation by pointing out areas of denudation. Associating these changes in land cover to settlements and water points, coupled with interviews with the local people will confirm the causes of impacts on the environment.

5.2.4 Potentialities and limitations of using remote sensing techniques and products in assessing non-palatable and invasive plant species

Remote sensing cannot be solely relied upon in mapping the invasive and non-palatable plant species. This is more so in the conditions of the study areas where closed canopy cover of vegetation is rare. Vegetation in the study area is also heterogeneous, and this makes it even more difficult to map species by remote sensing techniques. Intensive research is, therefore, recommended in methodologies that may be combined with remote sensing in mapping plant species in general. There is need to develop models that may be applied in identifying plant species.

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L-04 Land use characterization of a selected study area in Somaliland *(Oduori, S.M., Vargas, R.R. and Alim, M.S., 2007)*

L-05 Soil survey of a selected study area in Somaliland *(Vargas, R.R. and Alim, M.S., 2007)*

L-06 Land suitability assessment of a selected study area in Somaliland *(Venema, J.H. and Vargas, R.R., 2007)*

L-07 Land use characterization of the Juba and Shabelle riverine areas in Southern Somalia *(Oduori, S.M., Vargas, R.R. and Alim, M.S., 2007)*

L-08 Soil survey of the Juba and Shabelle riverine areas in Southern Somalia
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L-09 Land suitability assessment of the Juba and Shabelle riverine areas in Southern Somalia *(Venema, J.H. and Vargas, R.R., 2007)*

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7 ANNEXES

Annex 1: List of satellite images used

SATELLITE SCENES USED IN THE STUDY				
Sensor Type	**Scene No.**	**Date**	**Level**	**Purpose**
LANDSAT				
MSS	P174r053	Oct. 8th 1972	L	Impact assessment
MSS	P174r054	Mar 1st 1973	N/A	Impact assessment
MSS	P174r055	Mar 1st 1973	N/A	Impact assessment
MSS	P173r055	Nov. 12th 1972	N/A	Impact assessment
TM	P162r053	Mar. 29th 1988	N/A	Land cover mapping /impact assessment
TM	P162r054	Jan. 25th 1988	N/A	Land cover mapping /impact assessment
TM	P162r055	Jan. 21st 1988	N/A	Land cover mapping /impact assessment
TM	P161r055	Jan. 17th 1985	N/A	Land cover mapping /impact assessment
ETM+	P162r053	Nov. 12th 2001	Level 1G	Land cover mapping /impact assessment
ETM+	P162r054	Nov. 12th 2001	Level 1G	Land cover mapping /impact assessment
ETM+	P162r055	Nov. 12th 2001	Level 1G	Land cover mapping /impact assessment
ETM+	P161r055	Jul. 29th 2000	Level 1G	Land cover mapping /impact assessment
ASTER				
Aster	Ast_l1b_0031104	Jul. 19th 2006 - 12	Level 1b	Land cover mapping
Aster	Ast_l1b_0030509	Jul. 25th 2006 - 55	Level 1b	Land cover mapping
Aster	Ast_l1b_0030715	Jul. 20th 2004 - 13	Level 1b	Land cover mapping
Aster	Ast_l1b_0030223	Jul. 14th 2007 - 37	Level 1b	Land cover mapping
Aster	Ast_l1b_0030509	Jul. 26th 2006 - 04	Level 1b	Land cover mapping
Aster	Ast_l1b_0030223	Jul. 14th 2007 - 46	Level 1b	Land cover mapping
Aster	Ast_l1b_0031104	Jul. 19th 2007 - 30	Level 1b	Land cover mapping
Aster	Ast_l1b_0030907	Jul. 20th 2006 - 15	Level 1b	Land cover mapping
Aster	Ast_l1b_0030509	Jul. 26th 2006 - 13	Level 1b	Land cover mapping
Aster	Ast_l1b_0030126	Jul. 19th 2006 - 10	Level 1b	Land cover mapping
Aster	Ast_l1b_0031104	Jul. 19th 2004 - 39	Level 1b	Land cover mapping
Aster	Ast_l1b_0030907	Jul 20th 2006 - 24	Level 1b	Land cover mapping
Aster	Ast_l1b_0030509	Jul. 26th 2006 - 22	Level 1b	Land cover mapping
Aster	Ast_l1b_0030331	20th Jul. 2006 - 10	Level 1b	Land cover mapping
Aster	Ast_l1b_0031104	Jul. 19th 2004 - 48	Level 1b	Land cover mapping
Aster	Ast_l1b_0030211	Jul. 19th 2006 - 45	Level 1b	Land cover mapping
Aster	Ast_l1b_0030331	Jul. 20th 2006 - 19	Level 1b	Land cover mapping
Aster	Ast_l1b_0030211	Jul. 19th 2006 - 54	Level 1b	Land cover mapping
Aster	Ast_l1b_0030331	Jul. 20th 2006 - 27	Level 1b	Land cover mapping
Aster	Ast_l1b_0030126	Jul. 19th 2006 - 36	Level 1b	Land cover mapping
Aster	Ast_l1b_0030211	Jul. 20th 2006 - 03	Level 1b	Land cover mapping
Aster	Ast_l1b_0030126	Jul. 19th 2006 - 45	Level 1b	Land cover mapping
Other Remote Sensing Products				
NOAA-GAC DATA				
AVHRR	Eastern Africa	1981 - 2003		Vegetation and drought assessment
SPOT				
SPOT-VEG	Grid 22/8	1999 - 2005		Vegetation and drought assessment

Annex 2: Landsat Satellite Index of the images covering the study area

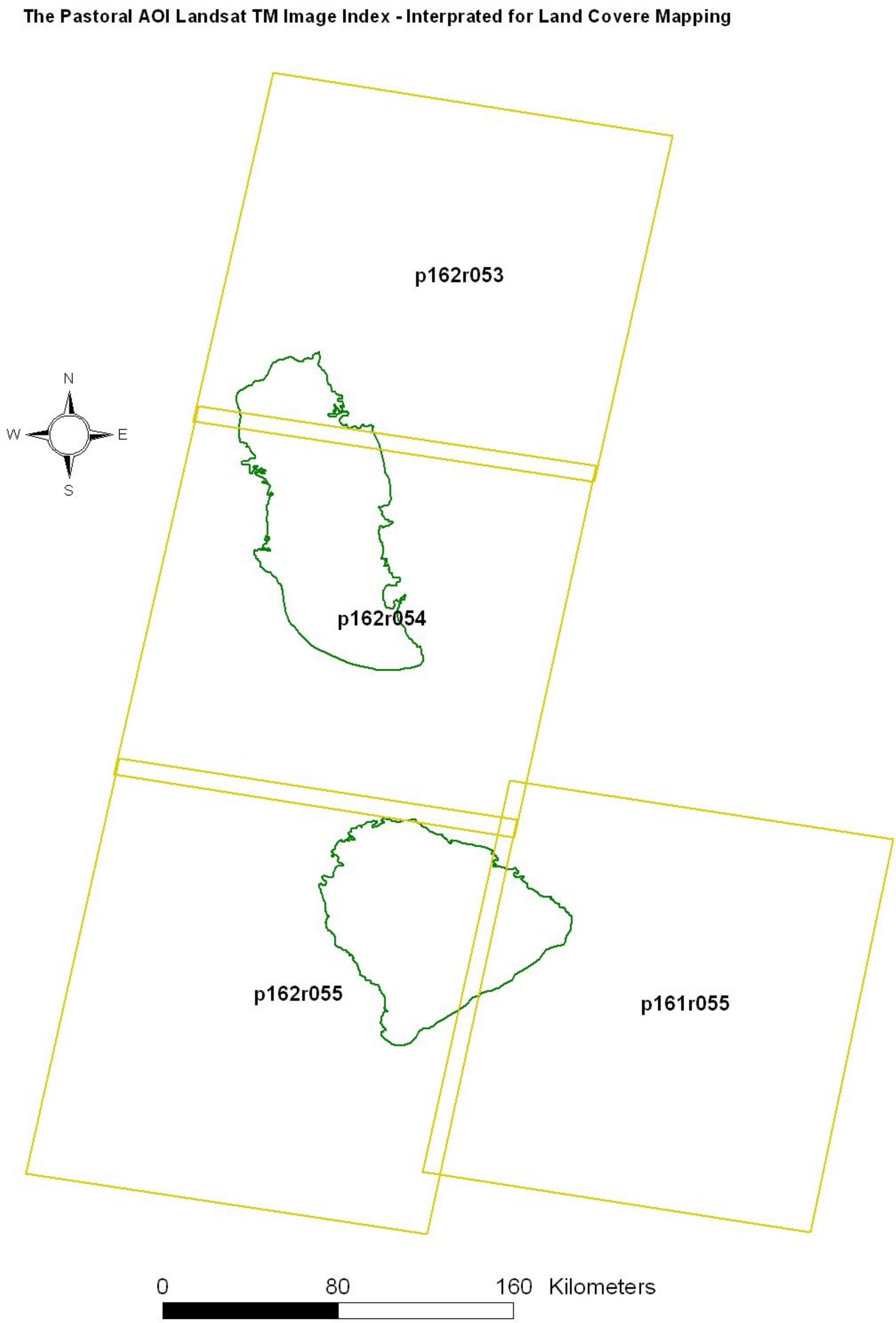


Figure 5: An index showing Landsat scenes used in the study

Annex 3: An index of the Aster images used in the study area

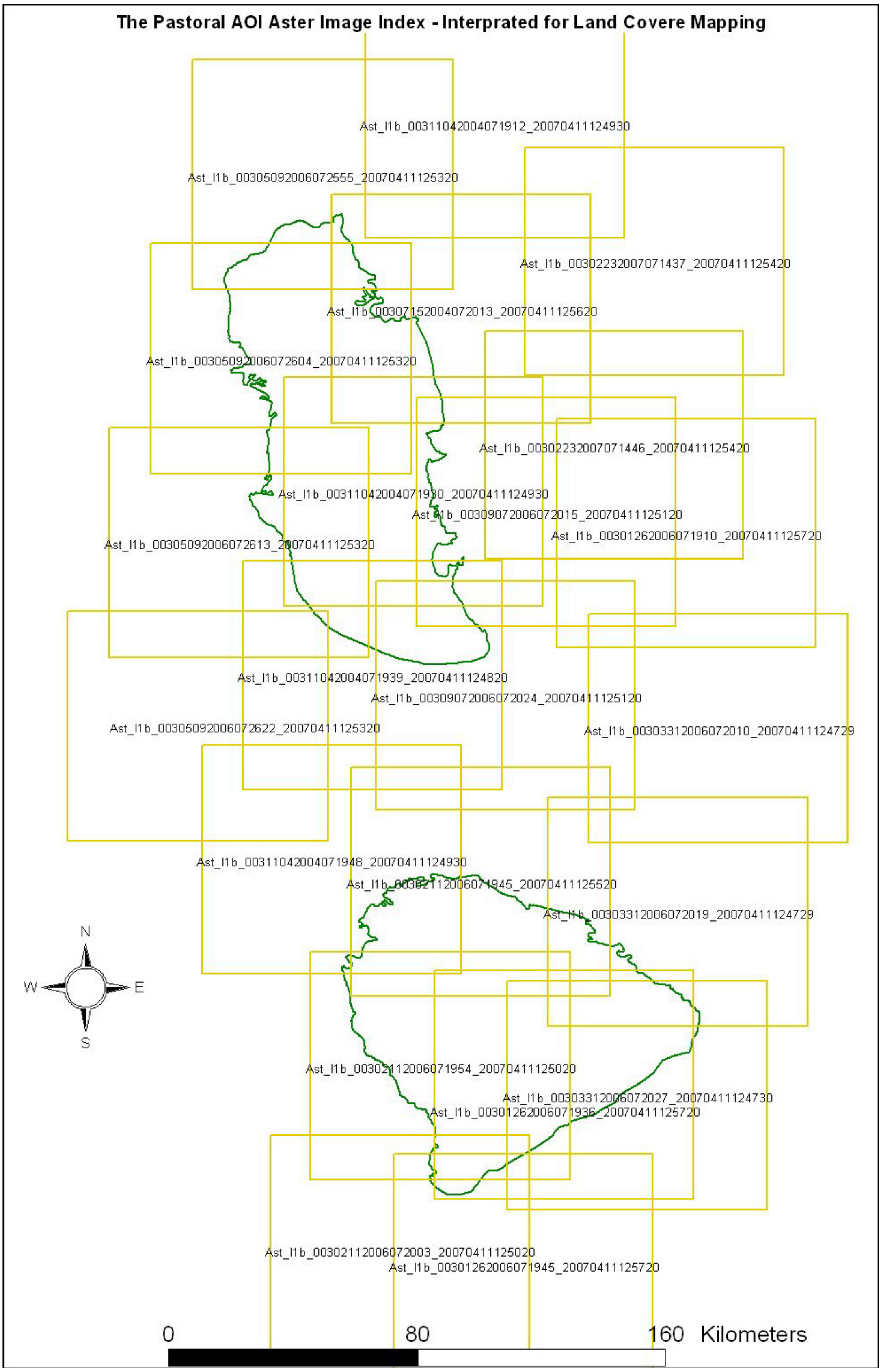


Figure 6: An index showing Aster image scenes covering the study area

ANNEX 4: Summary of the legend by main Land Cover type

FINAL LEGEND			
LCCOwnDescr	**MapCode**	**LCCLevel**	**LCCLabel**
A12-NATURAL AND SEMINATURAL TERRESTRIAL VEGETATION			
Herbaceous terrestrial			
Closed to Open Herbaceous (>15%)	**2HL**	A2 = Herbaceous	Continuous Closed to Open Herbaceous Vegetation
		A20 = Closed To Open 15% - 100%	
		B4 = 3 - 0.03 m	
		C1 = Continuous	
Closed to Open Herbaceous (>15%) with Sparse Trees and Shrubs	**2HL78**	A2 = Herbaceous	Closed to Open Herbaceous Vegetation with Trees and Shrubs
		A20 = Closed To Open 15% - 100%	
		B4 = 3 - 0.03 m	
		C1 = Continuous	
		F2 = 2nd layer	
		F5 = Trees	
		F10 = Sparse 15-5%	
		G2 = > 30 - 3 m	
		F2 = 3rd layer	
		F6 = Shrubs	
		F10 = Sparse 15-1%	
		G3 = 5 - 0.3 m	
Sparse Herbaceous	**2HR**	A2 = Herbaceous	Sparse Herbaceous Vegetation
		A14 = Sparse General 15-1%	
		B4 = 3 - 0.03 m	
Shrubs terrestrial			
Closed Shrubs	**2SC**	A4 = Shrubs	Continuous Closed Shrubland (Thicket)
		A10 = Closed >65%	
		B3 = 5 - 0.3 m	
		C1 = Continuous	

General Open Shrubs	**2SP**	A4 = Shrubs	Open Shrubs (Shrubland)
		A11 = Open General 65-15%	
		B3 = 5 - 0.3 m	
General Open Shrubs with Open Herbaceous	**2SP6**	A4 = Shrubs	Shrubland with Open Herbaceous
		A11 = Open General 65-15%	
		B3 = 5 - 0.3 m	
		C1 = Continuous	
		F2 = 2nd layer	
		F4 = Herbaceous	
		F9 = Open General 65-15%	
		G4 = 3 - 0.03 m	
General Open Shrubs with Trees 1-15%	**2SP7**	A4 = Shrubs	Shrubland with trees (Emergents)
		A11 = Open General 65-15%	
		B3 = 5 - 0.3 m	
		C1 = Continuous	
		F2 = 2nd layer	
		F5 = Trees	
		Z2 = Sparse 15-1%	
		G2 = > 30 - 3 m	
Sparse Shrubs	**2SR**	A4 = Shrubs	Sparse Shrubs
		A14 = Sparse General 15-1%	
		B3 = 5 - 0.3 m	
Sparse Shrubs with Herbaceous 1-15%	**2SR6**	A4 = Shrubs	Sparse Shrubs and Sparse Herbaceous
		A14 = Sparse General 15-1%	
		B3 = 5 - 0.3 m	
		F2 = 2nd layer	
		F4 = Herbaceous	
		Z3 = Sparse 15-1%	
		G4 = 3 - 0.03 m	

General Open Trees with Shrubs 1-65%	**2TP8**	A3 = Trees	Woodland with Shrubs
		A11 = Open General 65-15%	
		B2 = >30 - 3 m	
		F2 = 2nd layer	
		F6 = Shrubs	
		Z5 = Closed to Open 1-65%	
		G3 = 5 - 0.3 m	
B15-ARTIFICIAL SURFACES AND ASSOCIATED AREAS			
Airport	**5A**	A4 = Non linear	Industrial And/Or Other Area(s)Built-Up Object: Airport
		A12 = Industrial and other	
		A21 = Airport	
Urban Areas/Settlements	**5U**	A4 = Non linear	Urban Area(s)
		A13 = Urban area	
B16-BARE AREAS			
Bare Soil	**6S**	A5 = Bare soil a/o other unconsol. mat.	Bare Soil And/Or Other Unconsolid. Material(s)
Bare Soil with Scattered Vegetation	**6SV**	A5 = Bare soil a/o other unconsol. mat.	Bare Soil And/Or Other Unconsolidated Material(s) Scattered Vegetation Present
		U1 = Scattered vegetation (> 4%)	
B27-ARTIFICIAL WATERBODIES			
Artificial Waterbodies Standing	**7WP**	A1 = Artificial Waterbodies	Artificial Perennial Waterbodies (Standing)
		A5 = Standing	
		B1 = Perennial	

ANNEX 5: List of common Vegetation species

LIST OF COMMON PLANT SPECIES FOUND IN THE PASTORAL STUDY AREAS	
Northern Study Sites	
Botanical Name	**Local (Somali) Name**
Herbaceous (Grasses and Forbs)	
Oropetium mucronata	Afruug
Ochradenus somalensis	Awla-dhaye/Aura-diyeh
Paspalidium desertorum	Caqaqaro/Gargaro
Suaedamicromeris	Daran
Sporobolus marginatus	Dixi
Chrysopogon aucheri	Dureemo
Andropogon kelleri	Duur
Sericocomopsis	Food-cade
Paspalidium desertorum	Gargaro
Momordica sessifolia	Gasangas
Aerva persica	Geed-cad
Caesalpinia erianthera	Jirmo
Rhamnus staddo	Madooya
Sporobolus spicatus	Ramaas
Dactyloctenium aegyptium/Dactyloctenium aristanium/Dactyloctenium scindicum	Saddexo
Arthrocarpum somalense	Sarin
Sporobolus ruspolianus	Sifaar
Lycium europaeum	Surad
Jatropha spp	Taraxo
Cymbopogon schoenanthus	Wayrax or Werahr
Cystostemon heliocharis	Xabow
Tragus racemosu	Xarfo
Blepharis edulis	Yamarug
Shrubs and Trees	
Pulicaria somalensis	Adaar
Zygophyllium hildebrandtii	Aftaxole
Dyschoriste lycioides	Badanti
Astripomoea lachnosperma also Rinus communis	Balambal
Acacia mellifera	Bilcil
Ipomea donaldsonii	Bulumbul
Heldebrandtia sepalosa	Danyo
Pulicaria somalensis	Dawacure
Euphorbia cuneata	Dhirin-dir
Acacia bussei	Galool
Azadirachta indica	Geed-hindi
Turraea retusa	Geed-lab
Thephrosia obbiadensis	Geed-xajiin
Lantana somalensis	Geed-xamar
Fogonia brugueiri	Goroyo-kaxaris
Commiphora gawlalo	Gowlalo
Cadaba hetotricha	Higlo
Botanical Name	**Local (Somali) Name**

Vernonia uncinata	Hiil/Hihl
Indigofera arbica	Ilcas
Crotalaria dumosa	Ilgaal
Cadaba hetotricha	Qalanqaal
Acacia tortilis	Qurac
Neuracanthus robecchii subsp. Atratus	Rako
Indigofera intricata	Xajiin
Pistacia lentisucs	Xamur
Southern Study Site	
Botanical Name	**Local (Somali) Name**
Herbaceous (Grasses and Forbs)	
Ochradenus somalensis	Aurar-day
Eragrostis gloeophylla	Baldhoole
Chrysopogon aucheri	Dureemo
Sterculia africana	Garaho
Aerva persica	Geed-cad
General name for climbers	Geed-saar
Rhamnus staddo	Maddoyaa
Boscia minimifolia	Meygaag
Polygala irregularis	Nagaar
Euphorbia spp	Qabo-kabbood
Duossper maeromophilum	Sarin
Sporobolus ruspolianus	Sifaar
Lycium europaeum	Surad
Indigofera intricata	Xajiin
Blepharis eduli	Yamaarug
Shrubs and Trees	
Acacia mellifera	Bilcil
Pentanopsis fragrans	Bur-bur
Acacia senegal	Cadaad
Salvadora persica	Caday-biir
Jatropha dichtar	Deeg-taar
Acacia edgeworthii/Acacia gloveri	Dheer-dheere
Dichrostachys kirkii/Acacia puccioniana	Dhiigtar
Blepharispermum villosum	Gahaidh
Dobera glabra	Garas
Momordica sessifolia	Gasangas
Commiphora gowlalo	Gawlello
Rhynchosia minima var. nuda	Geed-saar
Acacia nubica	Gumar
Commiphora spp	Guurre
Terminalia spinosa	Hareeri
Grewia penicillata	Hohob
Astripomoea nogalensis	Jadeer
Indigofera ruspolii	Jilab
Justicia gesneriflora	Laqlaajis
Rhamnus staddo	Maddoya
Boscia minimifolia	Meygaag
Cadaba glandulosa/Calaba heterotricha	Qalaanqal
Acacia raficiens	Qansax
Commiphora enneaphylla	Qoron

Azima tetracantha	Qodax tool
Commiphora candidula	Raxanreeb
Albizia anthelmintica	Raydab
Loewia glutinosa	Ruumasan
Sesa-mothamnu rivea	Salaamaco
Acacia horrida	Sarmaan
Balanites scillin	Shillin
Jatropha spp	Taraxo
Lannea malifolia	Wacanri
Comiphora spp	Xagaar
Crotalaria dumosa	Xajiin
Tamarindus somalensis	Xammar
Pistacia lentisucs	Xamur
Erythrina malanacantha	Yoocoyo
Indigofera ruspolii	Jilab
Commiphora ogadensis also Commiphora serrulata	Xagar-madow
Trees	
Acacia mellifera	Bilcil
Dobera glabra	Garas
Azadirachta indica	Geed-Hindi
Cadaba heterotricha	Higlo
Acacia seyal	Jiic
Boscia minimifolia	Meygaag
Melia azedarach and also Azadirachta indica	Miri miri/Geed-hindi
Acacia tortilis	Qurac
Newtonia erlangeri or Albizia anthelmintica	Reydab

ANNEX 6: Land cover field verification form

FAO-SWALIM LAND COVER FIELD VERIFICATION FORM (LCCS)

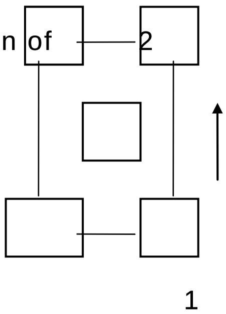
A. GENRAL INFORMATION

RELEVEE N^0		ACCESSIBILITY	☐	Very Good
AREA NAME			☐	Good
LOCATION			☐	Medium
OBSERVER			☐	Bad
DATE				
TIME				
RELEVEE SIZE		(in m^3 or ha)		

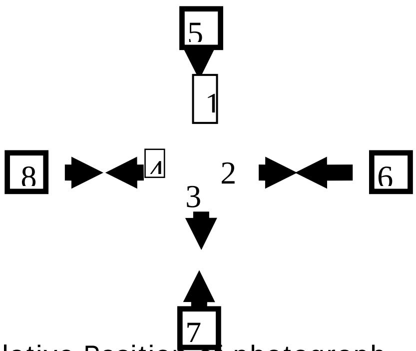
COORDINATES

N or S	East

On the spot	Observing the spot from a distance
Indicate relative position of 3 Coordinate	Distance from viewpoint to observed point (m) ☐
5 N 4	The bearing of the observed point (^{0}) ☐



FIELD PHOTOGRAPHS



Relative Position of photograph

GENERAL LANDFORM

Slope
- ☐ Flat to Gently Sloping Terrain (0-7%)
- ☐ Gently Sloping to Moderately Sloping (8-3%)
- ☐ Sloping to Moderately Steep, Undulating to Rolling terrain (14 - 20%)

☐ Steep to Very Steep, Rolling to Hilly terrain (21-55%)
☐ Extremely Steep Terrain, Steeply Dissected Hilly and Mountainous Terrain (56 - 140%)

B. GENERAL LAND COVER INFORMATION

LAND COVER

- General land cover Type Relevee Site

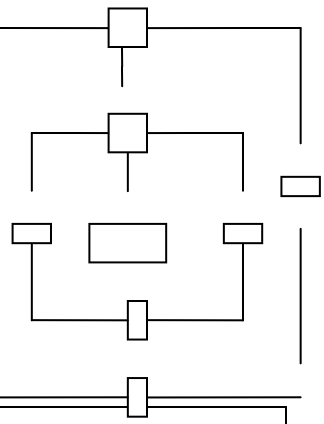
A.	☐ Vegetated	☐ Non - Vegetated
B.	☐ Terrestrial	☐ Aquatic or Regularly Flooded Land (including WADY Areas)

- Specific Land Cover Type	Single major Land Cover Aspect	Two Mixed major land Cover Aspects	
		Most Important	Second
Cultivated	☐	☐	☐
Natural/Semi-Natural	☐	☐	☐
Built Up	☐	☐	☐
Bare	☐	☐	☐
Artificial water Body	☐	☐	☐
Inland Water	☐	☐	☐

AREA LANDCOVER HOMOGENITY (Applicable if on spot) **150m**

Land cover Homogeneous for more than 150m ☐ 150 m Yes ☐

Around the sample area: ☐ No



LAND COVER SEASONAL ASPECTS

	Natural/Semi-Natural vegetation				Cultivated Fields			
	dry	green	flowering	fruits	ploughed	initial stage	full mat stage	harvested
TREES	☐	☐	☐	☐	☐	☐	☐	☐
SHRUBS	☐	☐	☐	☐	☐	☐	☐	☐
HERBS	☐	☐	☐	☐	☐	☐	☐	☐

C SPECIFIC LAND COVER INFORMATION

NATURAL & SEMI-NATURAL VEGETATION

				Leaf Type			Leaf Phenology	
	Level	Cover	Height	Broad	Needle	Aphyllous	Evergreen	Deciduous
WOODY				☐	☐	☐	☐	☐
Trees	1			☐	☐	☐	☐	☐
	2			☐	☐	☐	☐	☐
	3			☐	☐	☐	☐	☐
Shrubs	1			☐	☐	☐	☐	☐
	2			☐	☐	☐	☐	☐
HERBACEOUS								
Graminoids								
Forbs								

Cover Estimation of vegetation ☐ Visual ☐ Instrumental ☐ Other

CULTIVATED TERRESTRIAL AREA AND MANAGED LAND

-Life Form of **MAIN** CROP

	Leaf Type		Leaf Phenology			
	Broad	Needle	Evergreen	Deciduous	Fruit Trees	Plantation
☐ Trees	☐	☐	☐	☐	☐	☐
☐ Shrubs	☐	☐	☐	☐		
☐ Herbaceous						
☐ Graminoids			. Crop Name			
☐ Other						

-Life Form of SECOND CROP

	Leaf Type		Leaf Phenology			
	Broad	Needle	Evergreen	Deciduous	Fruit trees	Plantation
☐ Trees	☐	☐	☐	☐	☐	☐
☐ Shrubs	☐	☐	☐	☐		
☐ Herbaceous						
☐ Graminoids			Crop Name			
☐ Other						

-Average Field Size ______ (m^2 or ha)

-Field Distribution

☐ Bordering Fields

Distance between fields

☐ < average field size

☐ = 1 to 3 X average field size

☐ = 3 to 9 x average field size

☐ > 9 x average field size

- Cultivation period

☐ main crop, during two or more different periods within same year

☐ second crop in same period as main crop

☐ second crop in different period as main crop

☐ second crop starts during active period main crop

- Cultivation Time Factor

Time lap between two consecutive active ☐ =< 1 year

	periods	☐ 1 to 4 years ☐ > 4 years
-Water Supply/Irrigation	☐ Not Irrigated ☐ Supplementary Irrigation	☐ Post flooding ☐ Surface ☐ Sprinkler ☐ Drip ☐ Othe

-Life Form MANAGED LAND Urban Vegetated Area

Area covered by trees is
☐ > 40%
☐ between 20% and 40%
☐ < 20 %

_

BARE AREAS

☐ Consolidated	☐ Bare Rock ☐ Gravel, Stones and Boulders ☐ Hardpans	
☐ Unconsolidated	☐ Bare Soil ☐ Loose and shifting sands	☐ Stony (5 - 40%) ☐ Very Stony (40 - 80%)
☐ Dunes	☐ Barchans ☐ Parabolic ☐ Longitudinal	☐ Saturated ☐ Unsaturated

ANNEX 7: FAO-SWALIM PASTORAL RESOURCES STUDY FIELD QUESTIONNAIRE

Part 1: GENERAL INFORMATION

Questionnaire Number:__________

Administered by ……………………………………………………………

Location: x ………………………… y ……………………………………

Altitude ………………………………………………………

Date……………………………………………………………..

Village/site ……………………………District …………………… Region ……………………………………

What is the population of this village? ………………………………………………………………………

What is the approximate family size? ……………………………………………………………………….

PART 2: LAND COVER AND LAND USE CHANGE ASSESSMENT

1. State how land use has changed over time at the present settlement

	Historical use	Present use
Wet season Grazing Land		
Dry season Grazing land		
Wet and dry season Grazing land		
Charcoal production site		
Gully area		
Bare land		
Other		

2. List the various water sources

Water Source	Year Constructed	Seasonality (Number of month with water in a year)	No.	No. operational	Average depth	Average Capacity or yield	Source for WT	Distance from residence	Water Quality (good or bad)
Berked									
Shallow well									
Borehole									
Spring									
Water trucking (WT)									
Natural depression (Balli)									
Dam (war)									

SWALIM

PART 3: DROUGHT ASSESSMENT

A. Rainfall and Drought Conditions

1. Describe the rainfall patterns in this area? ………………………………………………………………..

………

8. Which are the severe droughts that you can remember? Please specify the years:

……..

…….

4. Do you have any prediction mechanisms for droughts? If yes, name them

………

5. If the droughts are predictable, what mitigation measures do you apply to prepare for them?
………

………

5. What are the drought coping strategies that you or the people here apply?

………

………

6. What are the general impacts of drought that you experience? ………………………………

………

7. How do you alleviate the impacts of droughts? ………………………………………………………

………

PART 4: IMPACTS

1. When did you settle here? ……………………………………………………………………

3. **a**. What is your major source of livelihood?

3. **b**. What do you think is the approximate average number of livestock per household in this village? **a**. Cattle ……… **b**. camels ……. **c**. goats ………. **d**. sheep ………… **e**. others ………. (specify) ……………………………………………..

5. List some of the environmental problems/hazards in this area

Degradation problems/env. hazards	
Overgrazing	
Vegetation removal (grass harvesting)	
Charcoal production	
Droughts	
Soil erosion	

6. Observed soil erosion types (rill, gully or wind erosion)

Soil erosion type	Water Erosion			Wind erosion
	Sheet	rill	gully	

7. General Land degradation assessment

Land Degradation Assessment	**Status**		
	Low	**Medium**	**Highly**
General land degradation			
Degradation around water points			
Degradation around settlements			

PART 5: VEGETATION ASSESSMENT

5.1. Palatable trees and shrub species (indicate trees good for charcoal production)

Botanical name	Local Name	Camels		Goats		Cattle		Sheep		Inva. or indig	Status	
		Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry		Inc.	Dec.
Acacia Bussei	Galool	high	high									
Acacia Tortillis	Qurac											
Acacia Mellifera	Bilil											
Acacia Etbaica	Sogsog											
Acacia Senegal	Adad											
Acacia Nilotica	Mara											
Acacia Seya (gum)	Jikh											
Moringa Oleifera	Damaal											
Delonix elata	Lebi											
Ziziphus Mauritania or spinacristi along the wadis or rivers	Gob											
Dobera Glabra	Garas											

5.2. Palatable herbaceous species (grasses and forbs)

					Palatability (High, Medium, Low)								**Status**
Botanical Name	**Local Name**	**A**	**P**	**Intruder**	**Camels**		**Cattle**		**Goat**		**Sheep**		
					Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	
Chrysopogon aucheri	Daremo?												
Melinis Grandiflora	Duremo												
Sporobolus spp													
Andropogon Kellery	Duur												
	Daran?												
Aspalidium desertorum	Gargoro												
chinochloa colona	Doomar												

5.3. Please name some of the known non-palatable trees, shrubs and herbaceous vegetation found in this area. What are their uses?

Botanical Name	Local Name	Uses							Trends	
		Timber	Char coal	Construction	Medicinal	Env. conservation	Land demarcation	Firewood / Energy	Declining	Increasing

ANNEX 8: Vegetation sampling data form

FAO-SWALIM VEGETATION SAMPLING DATA FORM

Herbceous and Woody Layer

Transect NO:___ Area Name:__________Location:____________Observer:________Date:_________Time:_______Transect Length:___

Coordinates (Start) N or S:________________ East:__________________UTM

(End) N or S:________________ East:__________________UTM

		1	2	3	4	5	6	7	8	9	10	#	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	Count
Major Category		**Presence**																																																				
Point <u>No.</u>																																																						
Mineral Soil																																																						
Litter																																																						
Plant Base																																																						
Animal Dung																																																						
Rocks and Pebbles																																																						
Vegetation Species																																																						

Point <u>No.</u> = every 1 meter along the 100 meter transect