ASSESSMENT AND MONITORING OF LAND DEGRADATION USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS): A CASE STUDY OF QOQODALA WITHIN THE WIT-KEI CATCHMENT IN THE EASTERN CAPE, SOUTH AFRICA

A thesis submitted in fulfilment of the
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by
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ABSTRACT

Land degradation is a global problem affecting many countries including South Africa. This study was conducted in order to assess and monitor the nature and extent of land degradation within Qoqodala in the Eastern Cape Province, of South Africa. The study used GIS and Remote Sensing techniques together with household interviews in determining extent, spatial characteristics and nature of land degradation within the study area. Vegetation cover and bare-ground change were the land degradation indicators assessed and monitored by this study.

Through RGB band combination, Tasselled Cap Analysis and Unsupervised ISODATA classification techniques, Landsat images over the past eighteen years (1984, 1993, 1996, 2000 and 2002) have been analysed. The results showed that there is vegetation cover and bare-ground increase in the study area. The vegetation increase has been seen as a sign of land degradation increase due to the encroachment of indigenous vegetation by *Euryops species* (also known as Lapesi by the local community). The bare-ground land degradation indicator has also increased. The analyses of slope showed the spatial characteristics of bare-ground occurring on moderate to flat slopes while vegetation cover occurs on steep to very steep slopes. Furthermore the photographs captured during field visits show rills and gullies or dongas occurring on bare-ground.

The interviewed respondents indicated that decline in food production, increase in dongas and vast increase in *Euryops* and a decline in grassland are the indicators of degradation that are observed in the study area. The occurrence of erosion features (rills and dongas) on bare-ground and the increase of vegetation shown by GIS and Remote Sensing techniques showed a positive correlation with field and household survey towards establishing the nature of land degradation.

In this study Landsat images together with interviews proved to be a very useful tool for land degradation research. However the suggestion of a higher spatial resolution satellite image on small catchment studies is recommended.

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DECLARATION

I, Luncedo Dalithemba Sanelisiwe Ngcofe declare that this dissertation is based on my own original work except where stated and that it has not been submitted for a degree at any university.

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L.D.S Ngcofe

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Date

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“How we perceive an environment depends on our own experience and knowledge. Perception not only differ between groups and between individuals but also over time” (Dahlberg and Blaike 1999, p155).

CHAPTER 1: INTRODUCTION

1.1 Introduction

Natural transformation processes that occur in landscapes include some form of land degradation, but "these processes are usually compensated for and counterbalanced by nature's inherent recovery ability" (Blaike and Brookfield, 1987, p5). Even though nature recovers naturally, in South Africa and the rest of the world land degradation is a huge problem (Meadows and Hoffman 2002).

Due to its negative impact on the environment and quality of life, land degradation is an important global issue (Eswaran *et al*., 2001). A global assessment of land degradation by Meadows and Hoffman (2002) concluded that more than one billion people, dependent on land for their livelihood, are affected by land degradation. Table 1 (UNCED 1992) gives a breakdown of the area of degraded land per continent. It reveals that 73 percent of drylands in Africa are affected. The major causes of this state of extensive global land degradation according to Singh (1998), cited by Horta (2002) is the repetitive cycle of human disturbance of the environment. This leads to the problem statement of this research.

Table 1: Estimates of all degraded lands by continent (bare land and vegetation) in million km² (Dregne and Chou, 1994, cited by Eswaran *et al.*, 2001).

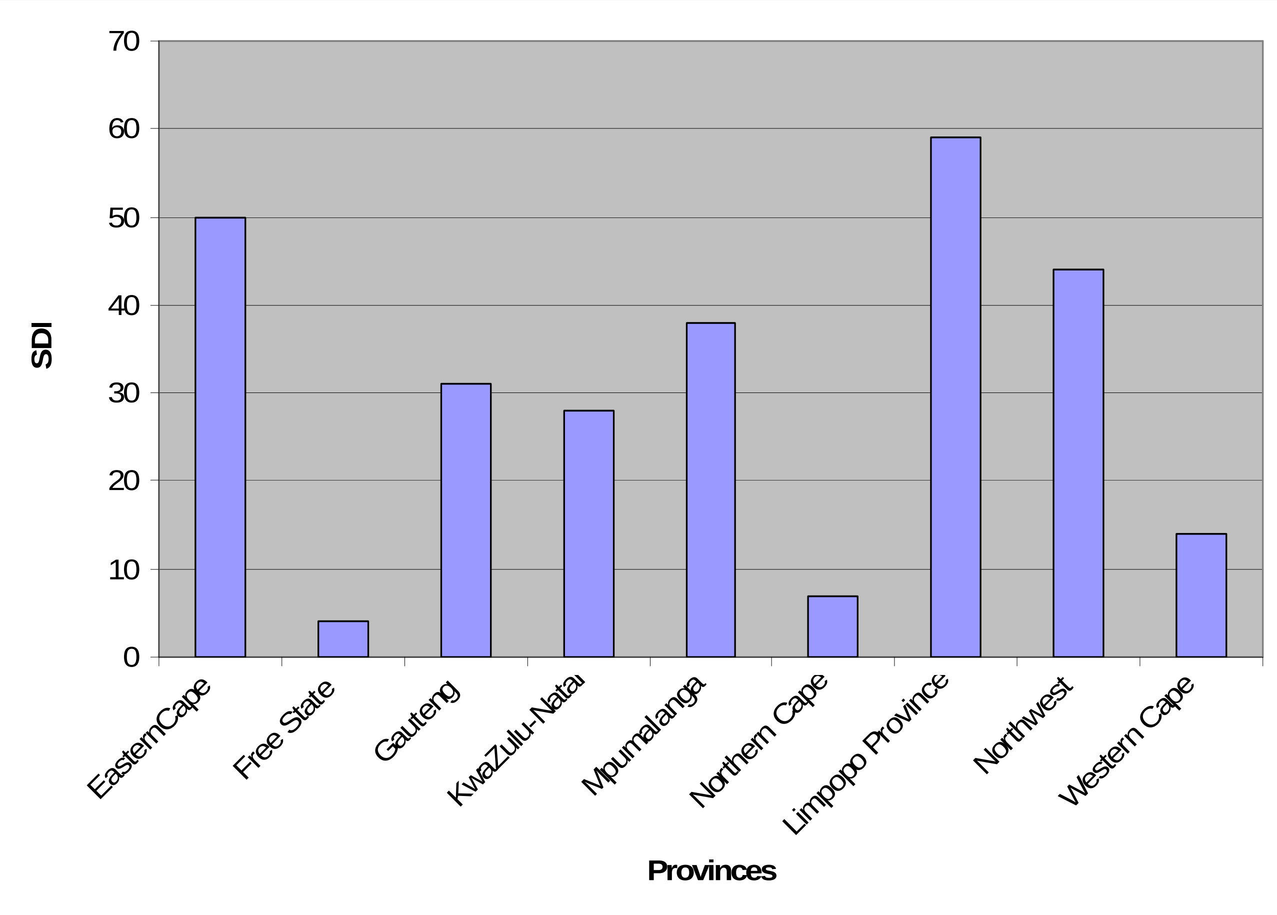
Continent	**Total Area**	**Degraded area**	**%degraded**
Africa	14.326	10.458	73
Asia	18.814	13.417	71
Australia and the Pacific	7.012	3.759	54
Europe	1.456	0.943	65
North America	5.784	4.286	74
South America	4.207	3.058	73
Total	51.597	35.922	70

1.2 Problem statement

According to the National Fact Sheet (2005), over-exploitation of natural resources and unjust land policies in South Africa have caused land degradation in the country. In addition lack of awareness of the causes of land degradation has resulted in communal land practices that lead to land degradation and can be blamed for negative effects on the environment. Hoffman *et al.*, (1999) cited by Meadows and Hoffman (2002) argue that 91% of the country is subject to degradation.

Hoffman and Ashwell, (2001) produced a soil degradation index (SDI) for the croplands of South Africa which shows the highest levels of degradation in the Limpopo Province and Eastern Cape respectively (refer to Figure 1). Acknowledging this, UNEP (1997) stated that communal land generally experiences high rates of land degradation through water erosion, which has been defined by Stocking and Murnaghan (2001) as removal of soil by water, usually observed through rill, gully and sheet erosion. However in many countries including South Africa, methods of assessing land degradation in order to promote awareness of the severity of the problem and promote sustainable land management still remain to be a challenging task. Hence the research problem for this study is to assess and monitor the extent of land degradation using Remote Sensing and Geographic Information Systems (GIS) methods in the Wit-Kei catchment.

Figure 1: SDI in the croplands of South Africa (Hoffman and Ashwell 2001)



1.3 Aim

Hoffman and Todd (2000) argue that not enough research to acquire knowledge about land degradation status in communal areas led to the inaccuracy of maps depicting the extent of land degradation. Bertram and Broman (1999), therefore suggest that an assessment of the past and present land degradation factors needs to be completed in order to redress the issue of land degradation and to achieve sustainable land use. This relates to the aim of this study which aims to establish the nature and the extent of land degradation in the Wit-Kei catchment in the Eastern Cape, using remote sensing (RS) and geographic information systems (GIS).

1.4 Objectives

The following are the objectives of this study.

1. To establish the extent of land degradation in Qoqodala in the Wit-Kei catchment at various time intervals, from 1984 to 2002 using image processing techniques.
2. To determine the spatial characteristics of degraded land using GIS and image processing techniques.
3. To establish local knowledge, history and nature of practices with regard to land degradation.
4. To relate results from image processing, interviews and ground-truthing in order to develop an informed perspective on land degradation in the area.

Table 2 explains tasks to be concentrated on when dealing with the above mentioned objectives.

Table 2: Key tasks

Sub-problems	**Key task**
What area of land has been degraded and how has it changed over time?	To analyse satellite images for different years (1984, 1993, 1996 2000 and 2002) to determine the land use change over time.
What are the physiographic characteristics of the degraded areas?	To analyse topography and slope of degraded areas.
Which land area is more sensitive to degradation?	To analyse from satellite images for different years the direction and expansion of land use changes.
What are the factors affecting land degradation and their impacts on the local community?	To conduct interviews seeking to establish the causes and impacts of land degradation and its possible solutions.

1.5 Structure of the research

The organisation of the research is shown in Figure 2. It demonstrates the various types of datasets used and how they were processed and integrated to derive information about land degradation in the area.

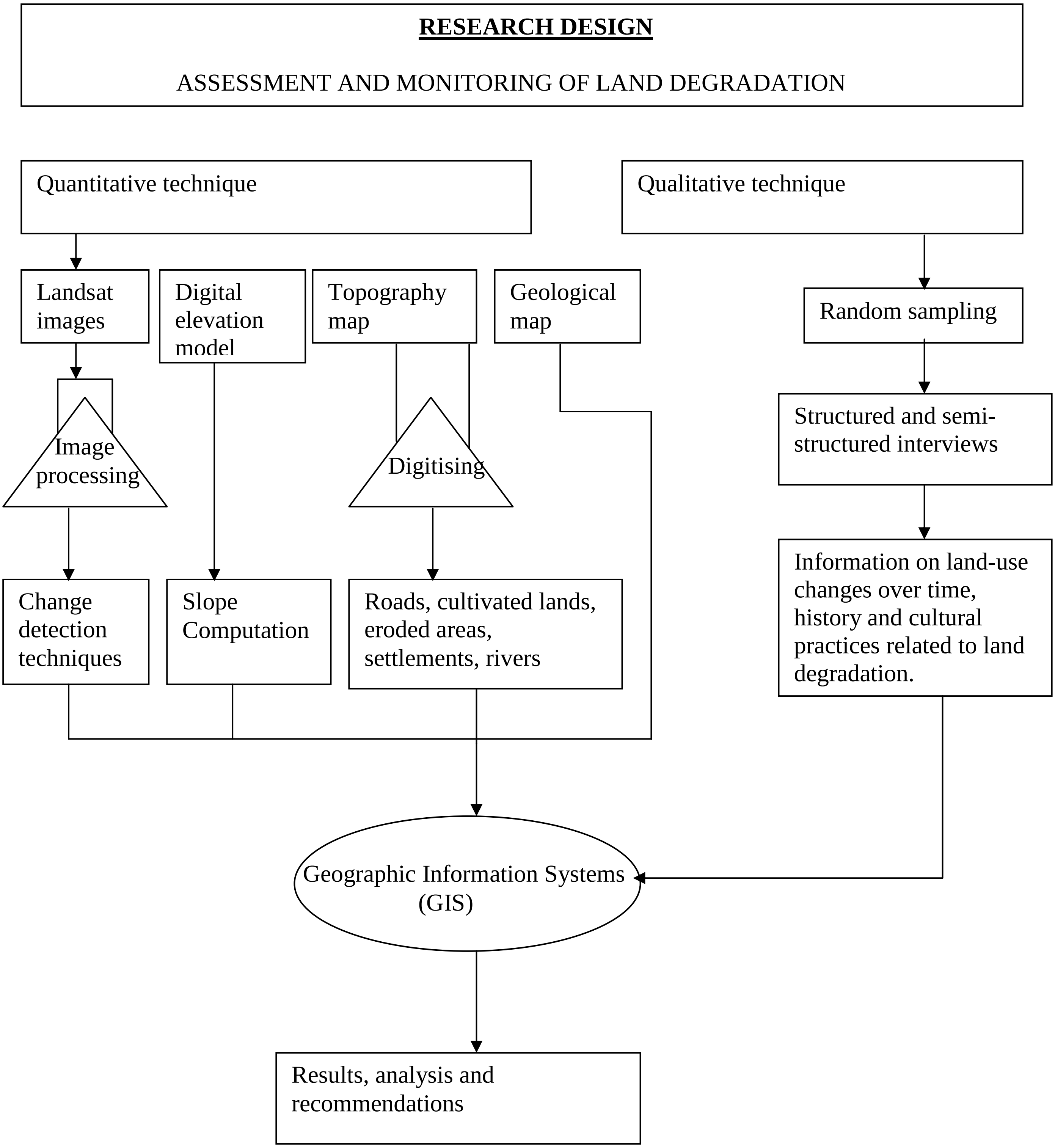


Figure 2: Structure of the research project

1.6 Significance of the study

In South Africa the policy of racial segregation during the apartheid era has led to the division of the rural landscape and economy into commercial and communal farming areas. Communal areas were reserved for Black Africans (in the case of Transkei and Ciskei the land was occupied by amaXhosa) and commercial areas were reserved for the white population. This has led to the allocation of large numbers of people in South Africa to be crowded on small spaces of land where soil erodibility was often high and the topography susceptible to land degradation (Hoffman *et al.*, 1999).

This has led to land degradation to be seen to occur at a faster rate in communal farm areas rather than in commercial farm areas due to a variety of factors which included financial support for white commercial farmers to reduce rate of land degradation. The apartheid government then regarded black commercial farmers as greedy and irresponsible exploiters of land for the short term benefits which resulted in land degradation (Hoffman *et al.,* 1999). Despite all this, land degradation also took place in commercial areas. Hoffman and Ashwell (2001) argue that in the post-apartheid era a need for more knowledge on the extent of land degradation is required in order to address the question of how severe land degradation is in this country.

Eswaran *et al.*, (2001) argues that one of the components of a national strategy to address land degradation is to make a research network of monitoring sites to detect changes in natural resource conditions. The assessment and monitoring of land degradation using Remote Sensing (RS) and Geographic Information Systems (GIS) in the Wit-Kei catchment forms part of a national strategy of the type suggested by Eswaran *et al.*, (2001) to address land degradation. Agenda 21 (UNCED, 1992) informs that one of the important challenges in land use planning and management is to develop land use models that incorporate both the natural and human factors that contribute to land degradation. This research considers both human and natural factors in a study of land degradation and with the intention of minimising the gap identified by Eswaran *et al.*, (2001) and UNCED, (1992). It incorporates an interview survey of the local community in order to record their knowledge of the Wit-Kei catchment condition and combines this with knowledge of the physical environment derived from image processing and GIS techniques.

This local scale study therefore intends to contribute to an increasing body of knowledge on land degradation in South Africa. This research will be part of the Integrated Water Resource Assessment of the Great Kei watershed (a study conducted by the Council for Geoscience). The results of this research may be helpful to the local government of the Eastern Cape when formulating policies to combat land degradation in the region.

1.7 Study Area

1.7.1 Background of the study area and demography

The study area falls within the Eastern Cape Province of South Africa. The Eastern Cape is the second largest province with an area of 169580km² (Eastern Cape State of Environment Report, 2004). Within the Eastern Cape the study area falls within ward 2 and ward 8 of Emalahleni Municipality in the Chris Hani District (refer to Figure 3). The population of the Eastern Cape was approximately 6.4 million in 2001, representing 14.4% of the total South African population, making the region the third most populous province in South Africa (Eastern Cape State of Environment Report, 2004). The dominant population group in the region (according to statistics South Africa, 2007) is African (88%), then Coloureds (7%), then Whites (5%) and Indians/Asians (0.3%).

The study area (ward 2 and ward 8) is characterised by high levels of illiteracy and poverty with 67% of population not having secondary education. 78% of the population are unemployed and not economically active and 97% of the population are still using paraffin and candles as their source of energy (Statistics South Africa 2007). The statistics of 2001 reveal that the 37% of the population does not have an income (refer to Figure 4).

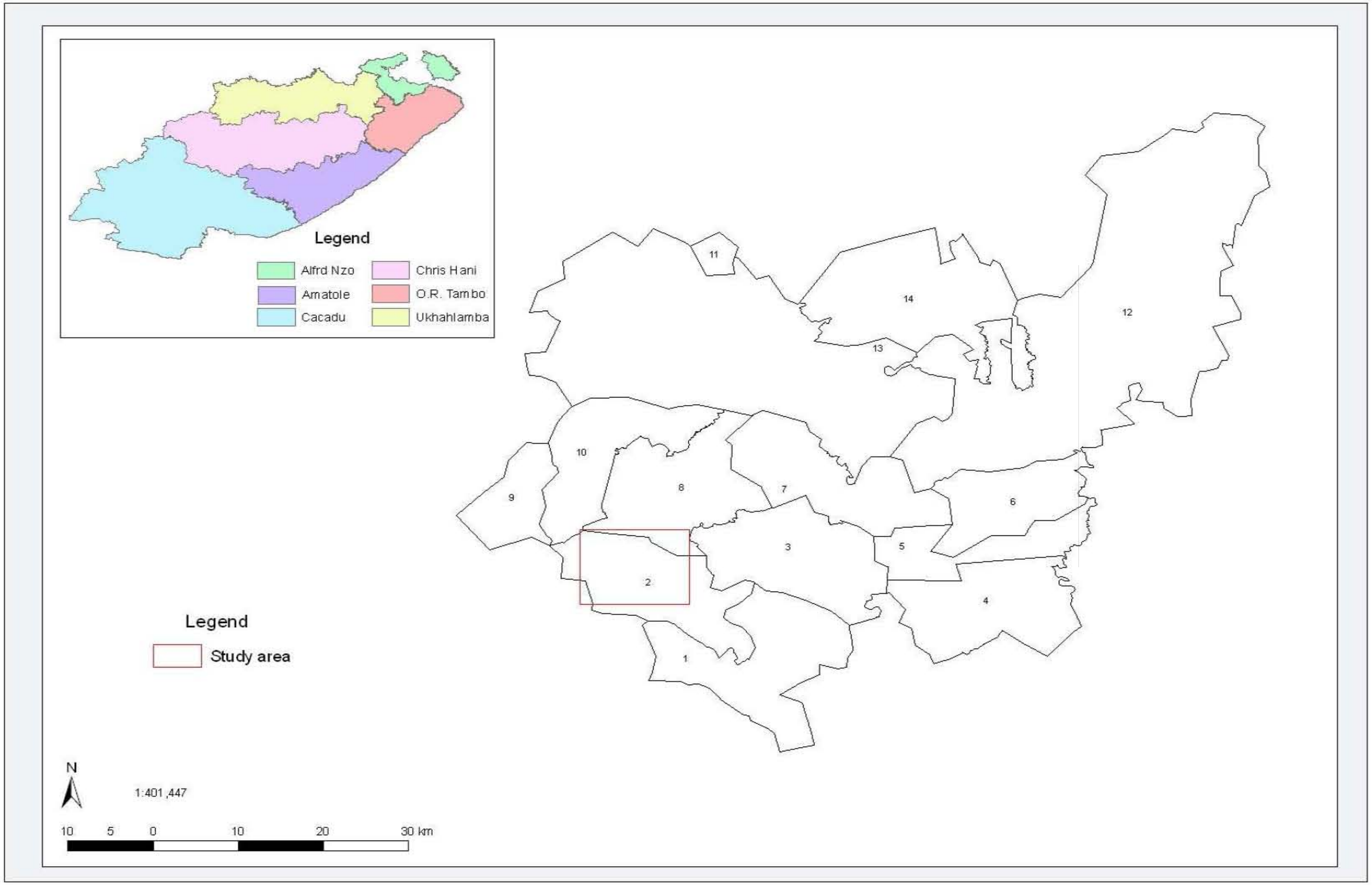


Figure 3: Study area ward number of emalahleni municipality

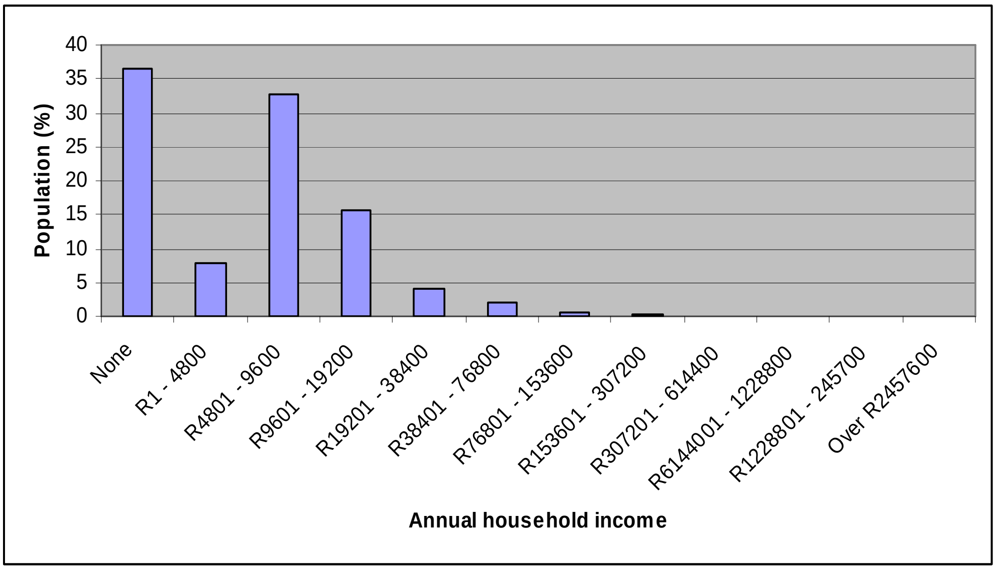


Figure 4: Annual household income of Ward 2 and Ward 8 (Statistics South Africa, 2007)

1.7.2 Physical characteristics of the study area

The study area lies within the Great Kei primary catchment in the Eastern Cape Province of South Africa (refer to Figure 5 and Figure 6). The major towns surrounding the Great Kei catchment are Queenstown, Stutterheim, Cathcart and Lady Frere. The Winterberg, Bamboesberg, Stormberg and the Amatola mountains define the boundaries of the catchment area. The Great Kei primary catchment consists of several sub-catchments of which one of them is the Wit-Kei. The study area falls in a tribal land area known as Qoqodala in the Wit-Kei catchment (Figure 7). The interviews were conducted in three villages known as Qoqodala, Thambekeni and Lalini (Figure 7).

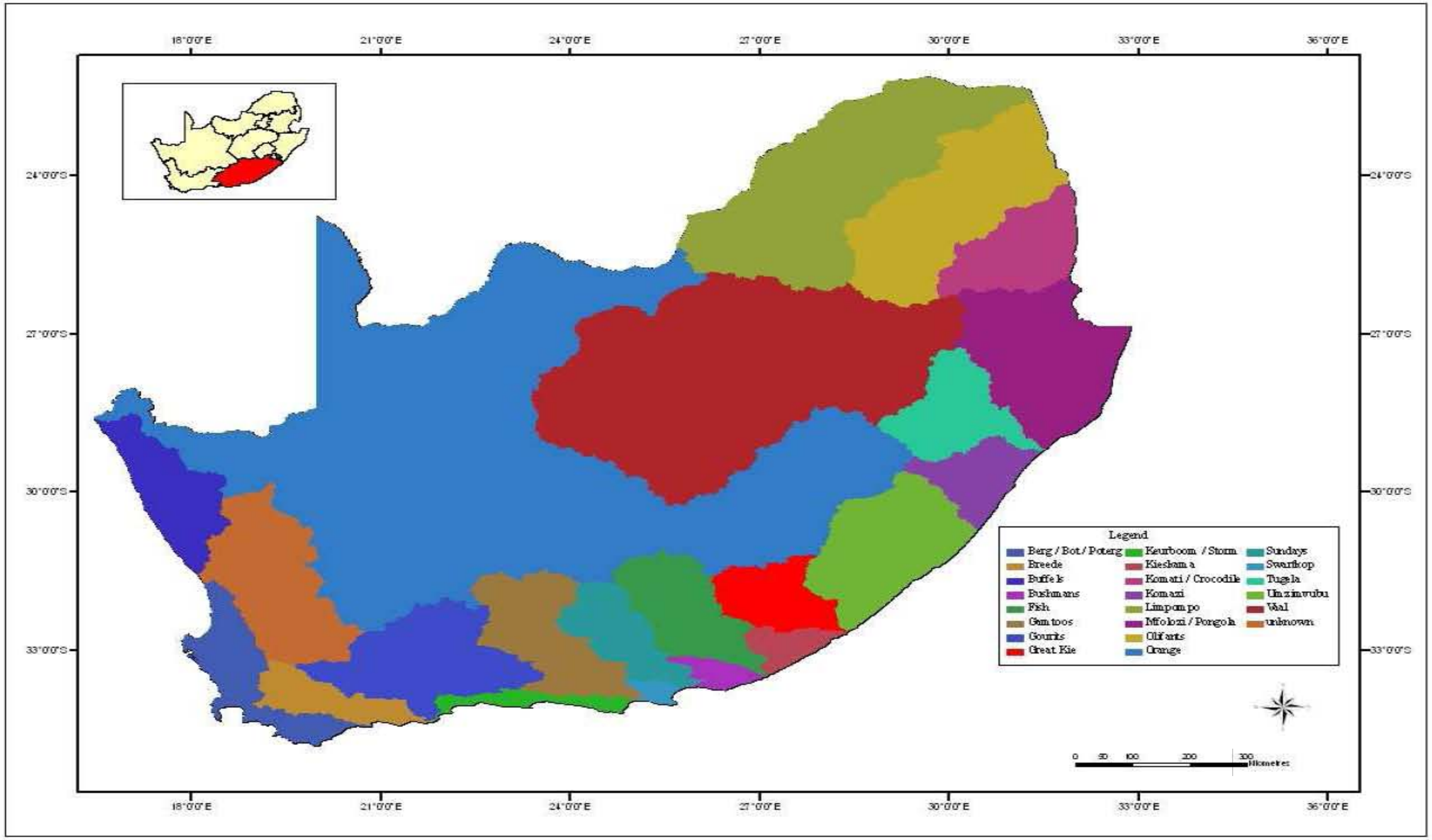


Figure 5**:** Primary catchments of South Africa

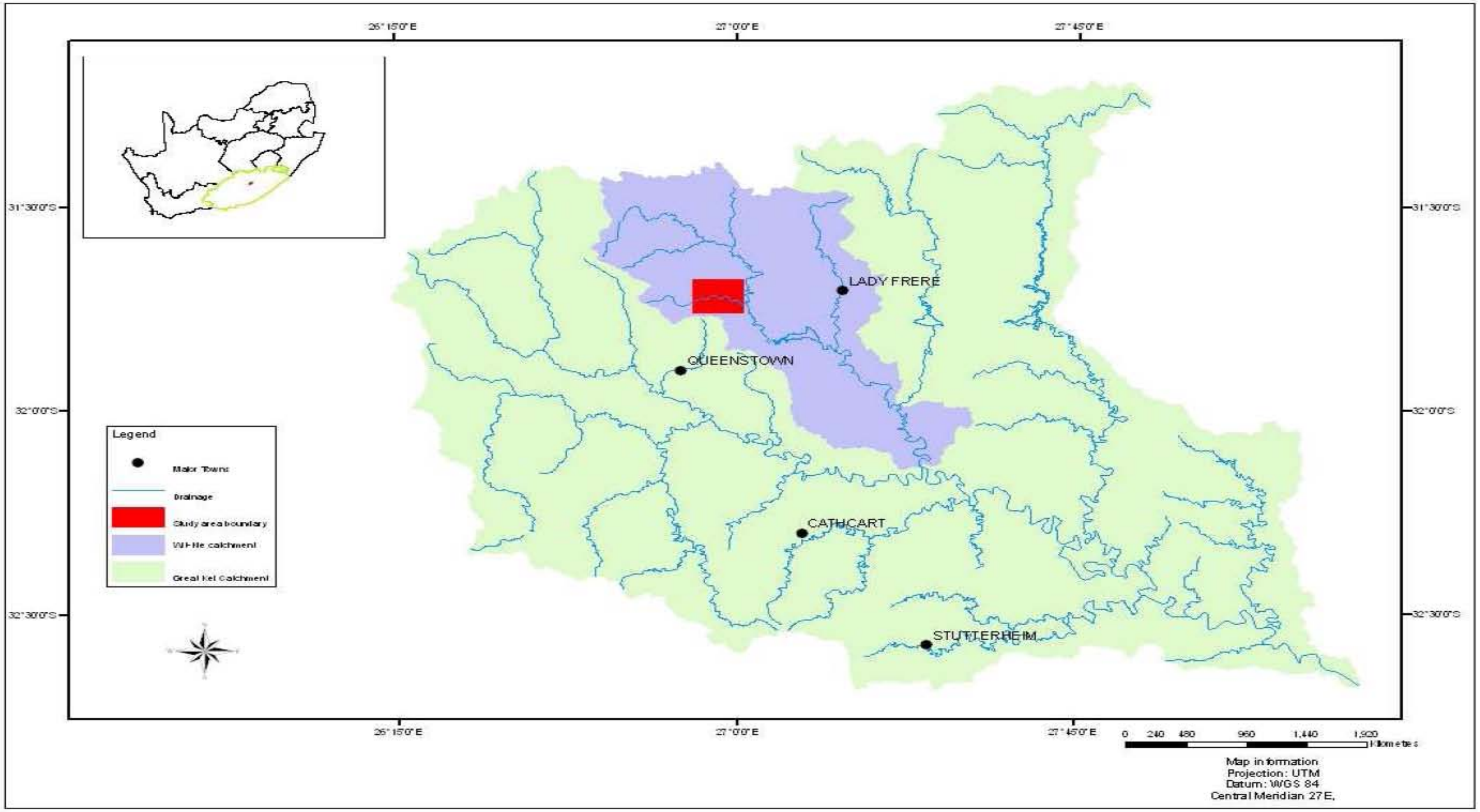


Figure 6**:** Study area within Great Kei Catchment in the Eastern Cape Province, South Africa

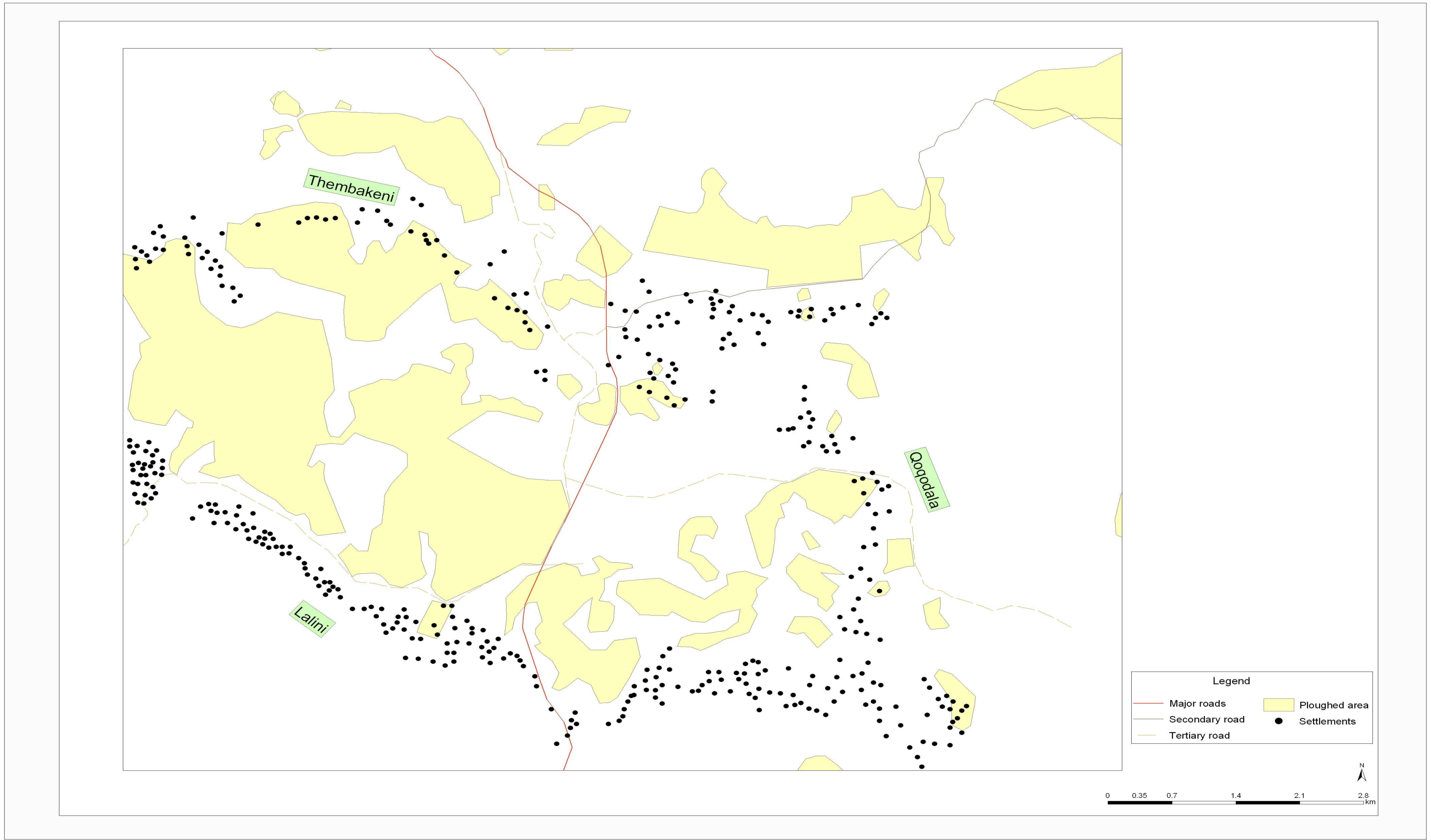


Figure 7: Qoqodala area within Wit-Kei catchment

1.7.3 Geology and vegetation

The geology of the study area is dominated by the mudstone and sandstone of the Burgersdorp Formation of the Beaufort Group in the Karoo Supergroup (Chevallier *et al.*, 2004). These rock types increase the potential for land degradation due to their high erodibility. The Karoo Supergroup sedimentary rocks are intruded by numerous dolerite dykes, sills and rings of Jurassic age, which are more resistant to soil erosion. The Qoqodala area is characterised by a coalescing saucer-shaped dolerite ring (Chevallier *et al.*, 2004) with most settlements within the area occurring at the base of these structures (Figure 8 and Figure 9).

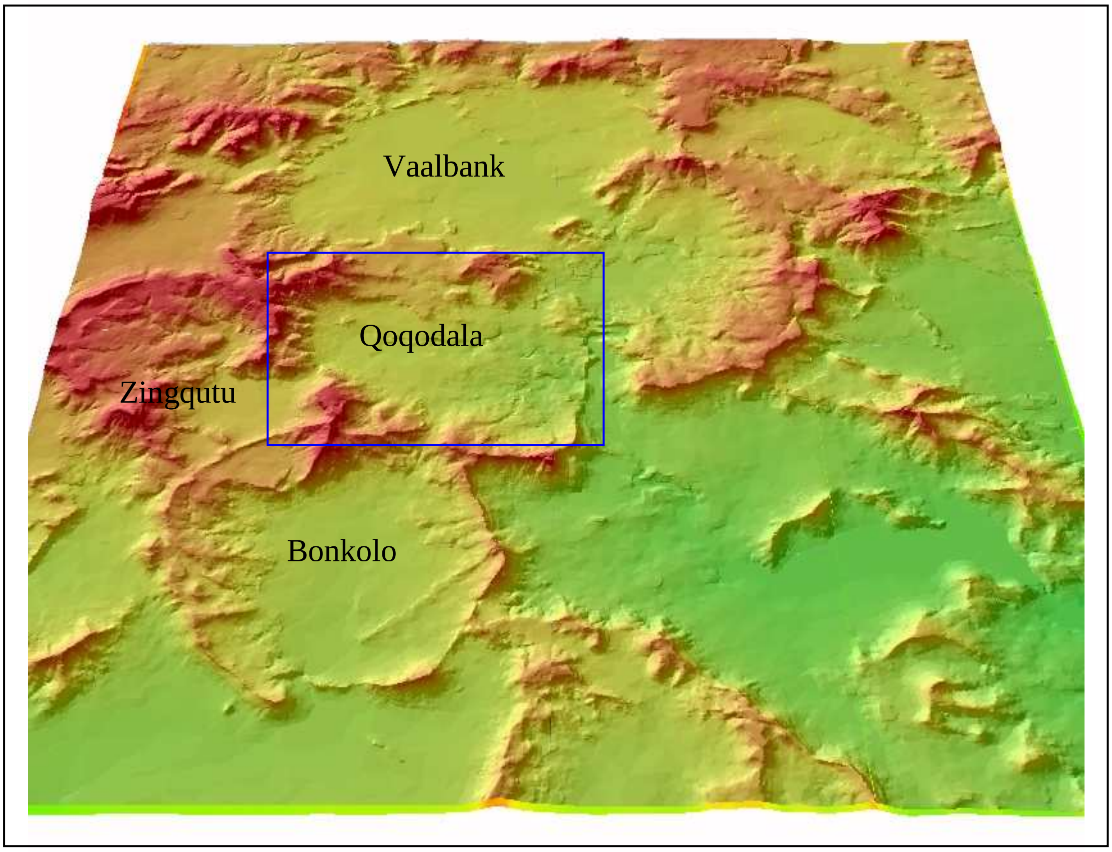


Figure 8: Dolerite rings of the Qoqodala area showing the coalescing nature and saucer-shape of the intrusive structures leading to a peculiar local drainage system (Chevallier *et al.*, 2004).

The flat area of the Qoqodala ring structure is characterised by soil of varied depth, texture and relief. Moderate to deep, sandy loam soils are found on the lower slopes of the dolerite ring structure whereas moderate to deep clay loam soils are found on flat terrain inside the ring structure (Chevallier *et al.,* 2004 and Gibson, 2003). The Environmental Potential Atlas for the Eastern Cape (DEAT, 2005) shows that the soil depth within the study area ranges from 450mm to 750mm. Soil assessment is important in land degradation studies because different soils erode at different rates according to their mineral content and structure.

An understanding of vegetation cover of the area as a contributor towards land degradation is equally important. The vegetation cover of the Wit-Kei catchment has been described differently by several authors, stating that it consist of several different vegetation types. Acocks (1988) cited by Chevallier *et al.,* (2004) describe this area as a mixture of grasslands, sourveld, bushveld, false thornveld and scrubs. Mucina and Rutherford (2006) classify the area as Grassland type and Southern Drakensberg Highland Grassland vegetation type. However field visits to the study area show that the area is covered by dense vegetation also called thicket (which is characterised by dense interlaced trees), Moderate vegetation also known as bush clumps (which are characterised by scattered islands of thicket vegetation with matrix grassland) and grassland (areas with grass and less than 10% tree cover) refer to Figure 9. There is also a shrub which is invading the natural indigenous vegetation. This shrub species have not been identified in laboratory, however the local residents call it Lapesi. Lapesi is known to come from Haarpuys which is an Afrikaans word for resin. It belongs to the *Euryops* type of species. The species are not palatable due to their strong smelling leaves. Although it has not been scientifically proven, this type of *Euryops* species is believed to be an allelopathic pioneer species, which contributes to degradation through its ability to suppress grassland recovery resulting in areas of bare-ground areas (Interview Tony Dold).

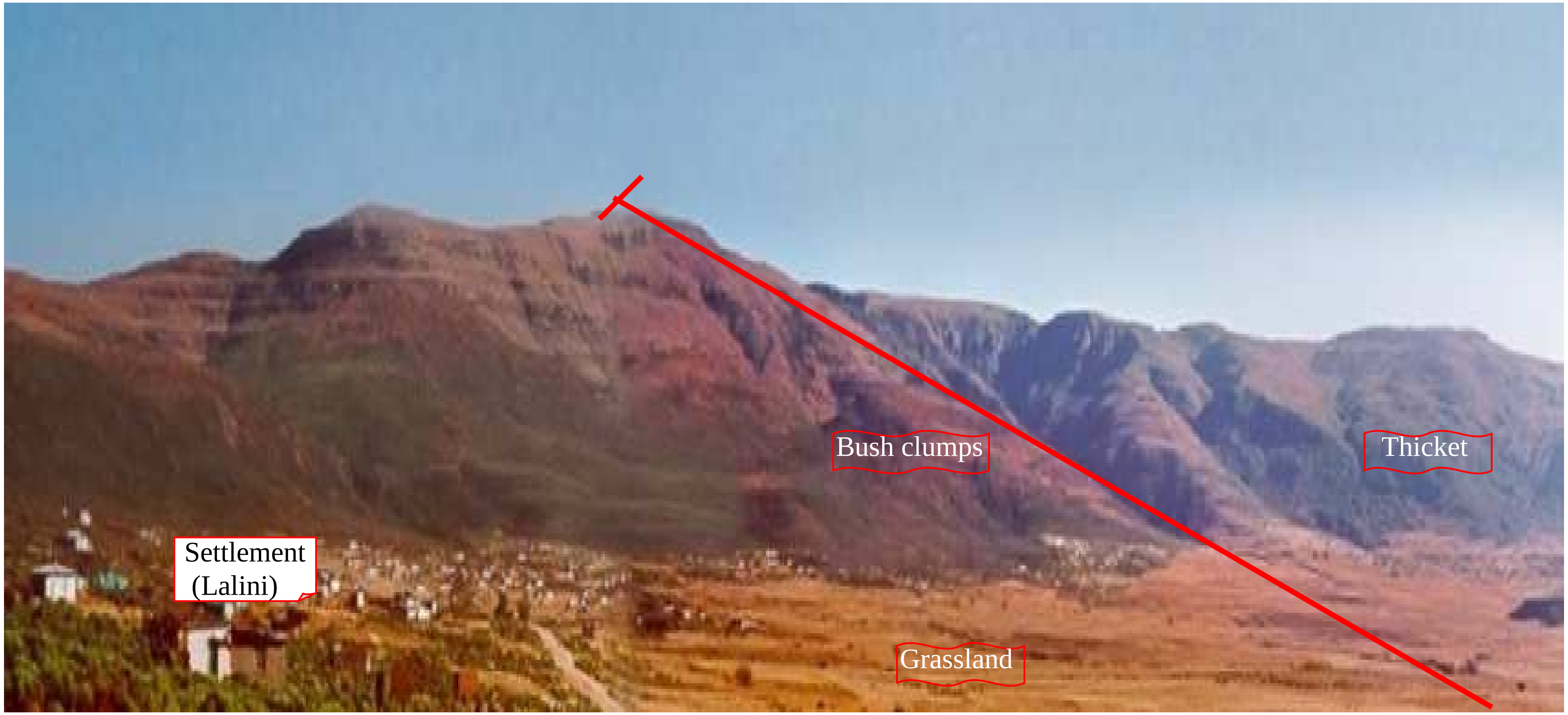


Figure 9: Vegetation cover of Qoqodala

Hoffman *et al.,* (1999) recognise the role that climate plays in land degradation, due to its effects on hydrological cycles and temperature regimes. Rainfall in the study area is in the form of orographic rain, resulting in mountain tops being wetter than inner sills (Chevallier *et al.,* 2004). Schultz (1997), cited by Chevallier *et al.,* (2004) states that the annual precipitation in Queenstown (which is the nearest town to the study area) is 600mm with a mean annual temperature of approximately 15°C. The temperature of the area ranges from below zero at night in winter months up to 40°C during the day in summer months. Most winter mornings are characterised by frost and the area experiences an occasional snowfall.

CHAPTER 2: LAND DEGRADATION

2.1 Definition of land degradation

There are various definitions of land degradation but most important is that they are all about the deterioration of land. Stocking and Murnaghan (2001) state that there is no single, readily identifiable definition of land degradation, but all of them describe how one or more of the land resources (soil, water, vegetation, rocks, air, climate, relief) has changed from better to worse. Barrow (2001) defines land degradation as loss of potential utility of land through reduction of the indigenous ecosystem and damage of physical, social, cultural and economic features. The Food and Agriculture Organisation of the United Nations cited by Stocking and Murnaghan (2001), states that land degradation is a temporal or permanent decline in the productive capacity of land. UNCCD, (1995) cited by Hoffman *et al.,* (2001, p3) and World Meteorological Organisation (2005), define land degradation as: "Reduction or loss in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland or range, pasture, forest and woodlands resulting from land uses or from process or combination of processes, including processes arising from human activities and habitation patterns such as:

i. Soil erosion caused by wind and / or water
ii. Deterioration of the physical, chemical and biological or economical properties of the soil and
iii. Long term loss of natural vegetation".

Horta (2002) and Bai *et al.,* (2006) argue that, vegetation degradation through long-term reduction in biomass is also a form of land degradation. However it is acknowledged that vegetation degradation is not easily recognisable. Its changes are revealed gradually, sometimes not in terms of biomass decrease in an area but through loss of species diversity, increase in invasive species and reduction of woody species (Horta 2002, Kakembo *et al.,* 2007 and Wessel *et al.*, 2004).

Lambin (1997) states that causes of land degradation are of major concern in terms of the environmental sustainability of catchments in many parts of the world and especially in developing countries. Some of the causes of land degradation are discussed in the following section.

2.2 Causes of land degradation

Land degradation is a natural process but it may be induced by human activities (Barrow, 2001). Blaikie and Brookfield (1987) argue that the relationship of humans with nature has in certain cases increased the rate of land degradation and therefore undermined nature's ability to recover. Stocking and Murnaghan (2001) have cited a number of studies, which identify poor land management, inappropriate technology, overpopulation, poverty and decisions of social and political structures as human factors associated with land degradation.

However it has been argued that land degradation can occur independently of human activities. Acknowledging this, Tooth (2004) and Gobena (2003) state that natural land degradation processes are slow and are often unnoticed. The rainfall is regarded by the World Meteorological Organisation (WMO, 2005) as the most crucial climatic factor in determining areas at risk of land degradation. This is due to the vital role the rainfall plays towards development and distribution of plant life. In areas where there is little or no vegetation, rainfall erodes soil by the force of raindrops, surface and sub-surface run-off and by river flooding (WMO, 2005). Climate change is clearly a factor which can increase the rate of land degradation through the alteration of spatial and temporal patterns in temperature, rainfall and wind. Soil erosion by water is recognised as one of the most land degradation problem world wide (Vrieling, 2005 Stocking and Murnaghan, 2001). The increase of invasive species as mentioned by Kakembo *et al.*, (2007) is also an increasing land degradation problem. He argues that in areas with a deep water-table invasive species gain better competitive advantage in obtaining water to grow (due to their long tap roots) than indigenous species (with short roots). However it is also acknowledged by Kakembo *et al.*, (2007) that factors influencing invasive environment are still a great challenge.

Land degradation is a complex issue and an understanding of the problem requires a multi-faceted approach. The understanding of science, policies governing a country and community practices at a local, regional and national level are considered important contributors towards the issue of land degradation management (Hoffman *et al.*, 1999). According to Stocking and Murnaghan (2001) the identification and analysis of social factors that contribute to land degradation deserve particular attention because they often set the stage for correcting actions and policies.

2.3 Indicators of land degradation

The definitions of land degradation mentioned above show that land degradation cannot be simply assessed by any single measure. Land degradation indicators which may be used to assess and monitor land degradation have been identified by Stocking and Murnaghan, (2001, p7) and are defined as "variables which may show that land degradation has taken or is taking place". There are many indicators of land degradation and these are usually related to one another (illustrated in Figure 10). This research uses vegetation cover and soil erosion as indicators of land degradation, highlighted by the yellow boxes in Figure 10. According to Meadows and Hoffman (2002) and UNEP (1997), loss of vegetation cover is probably the first visible form of land degradation. Florencia (2003) and Stocking and Murnaghan (2000), and Kakembo (1997) acknowledge that land degradation is shown by a serious depletion of vegetation cover, soil degradation and an increase in the proportion of bare land. Analysis of various land degradation studies reveal that reduction in vegetation cover due to for example wood cutting, fire, drought and overgrazing is the most serious problem in South Africa especially in Gauteng, KwaZulu-Natal and the Eastern Cape Province (Meadows and Hoffman, 2002).

De Baets *et al.*, (2006) highlight the importance of vegetation cover in the reduction of soil erosion. They explain that vegetation cover protects the soil from raindrop impact, slows down the movement of surface runoff and allows excess surface water infiltration. According De Baets *et al.*, (2006) roots also play an important role in protecting the soil from erosion by reinforcing and increasing the soil shear strength. Paesen (2003), also cited by De Baets *et al.*, (2006), demonstrated the importance of vegetation cover through his study which found that the cross section areas of gullies under grassed fields are smaller than those of bare-land and agricultural cropland for the same flow intensity.

Hoffman *et al.,* (1999) and Gobena (2003), claim that water erosion is the most common land degradation mechanism in South Africa. According to Stocking and Murnaghan (2001), water erosion is the removal of soil particles by water through sheet erosion (removal of thin layer of top soil), rill erosion (removal of soil resulting in small water channels) and gullies (removal of soil resulting in large water channels). They argued that the rate of soil loss by water erosion from bare soil is 250 times greater than that from areas covered by natural vegetation. Van de Berg and Keller (2005) state that the trend of degradation starts with the removal of vegetation cover over a small area which expands to a large area over time. Stocking and Murnaghan, (2001) state that the rate of soil erosion on bare-ground is faster than the rate of soil formation and might lead to irreversible degraded features on the surface.

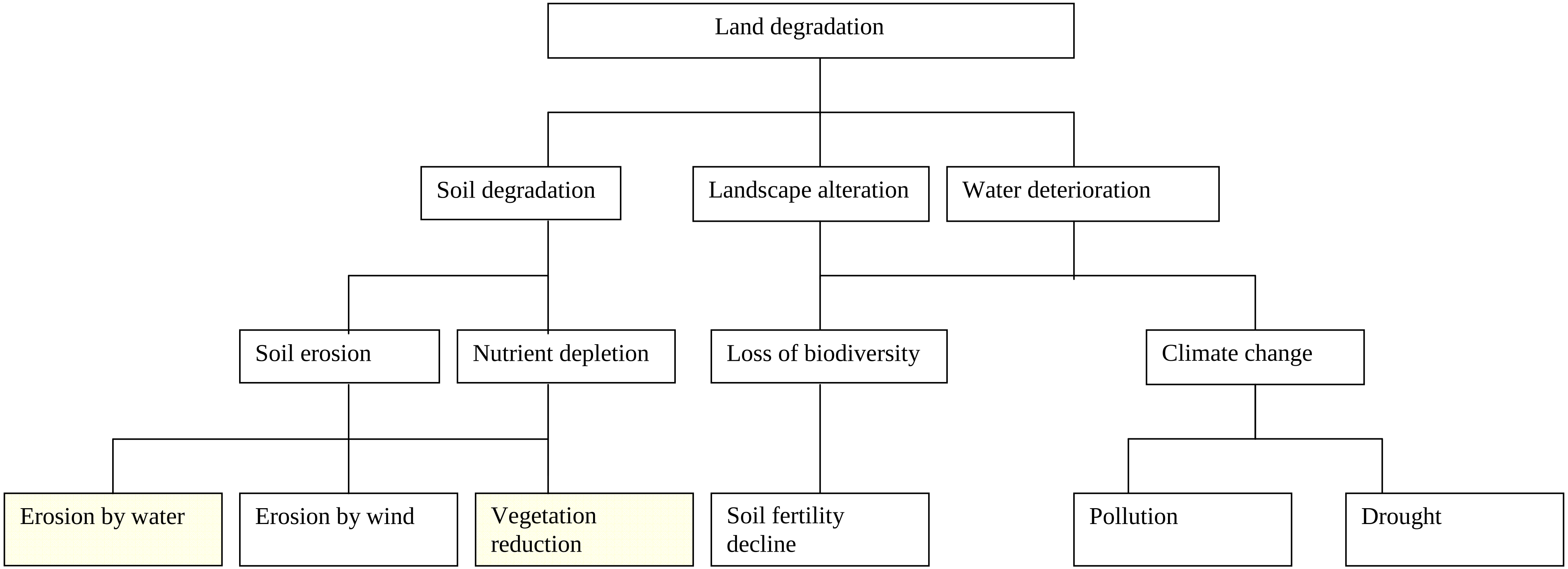


Figure 10: Indicators of land degradation (modified diagram from Stocking and Murnaghan, 2001)

2.4 Importance of the availability of land degradation information

Acknowledging the importance of land degradation information Beinart (1984) cited by Hoffman *et al* (1999, p69), gives a historical perspective on the problem of erosion in South Africa with the following quote by General Smuts in 1936 saying "… erosion is the biggest problem confronting the country, bigger than any politics." Improving the availability of land degradation information is likely to increase awareness of land degradation. The authors of Agenda 21 (UNCED 1992) agreed that land degradation is an important global issue due to its negative impacts on the environment, and they proposed that studies on land degradation are vital to increasing the knowledge base and possible solutions. Acknowledging this Evans and Geerken (2004), state that the willingness of countries to participate in land degradation reduction programmes requires better knowledge about causes of degradation. The emphasis of gaining information about land degradation through research programmes is also supported by Eswaran *et al.*, (2001) arguing that results from such research may find solutions to reduce, and if possible, reverse land degradation. Boardman *et al.*, (2003) further state that the assessment of the degree of land degradation is essential for decision makers, who are responsible for land management.

2.5 Land degradation assessment techniques

The use of Geographic Information Systems (GIS) combined with Remote Sensing techniques have been seen as one way of monitoring land degradation at a catchment level. Sah *et al.*, (1996) argue that these techniques can be utilised to organise catchment management methods with the effective design of data collection processes. GIS software is said to be a valuable technique for enhancing and organising the data required in catchment studies and it can provide sophisticated analysis of data necessary for assessment (Sah *et al.*, 1996 and Vckovski 1998).

Remote Sensing is the collection of information about an earth surface without being in physical contact with it. De Jong (1994) cited by Torrion (2002), states that remote sensing has high potential for land degradation assessment due to the regular time interval of data capture and high to low spatial and spectral resolution. Lambin *et al.*,

(1997) and Torrion (2002), suggest that when mapping features whether they are directly or indirectly visible on the ground, remote sensing should be considered.

Lambin *et al*., (1997) further argue that estimating temporal land use and land cover change is essential in assessing the rate at which these changes take place, the problems or impacts they cause and therefore assists in making predictions of future impacts and trends of degradation. Acknowledging this Vckovski, (1998) suggest that, physical data (e.g. landforms and slopes), land use data (e.g. vegetation, urban land-use) and socioeconomic data (e.g. employment conditions and income) are also essential for land degradation assessment and furthermore they can be integrated within a GIS. This research will use satellite images as its source of spatial information with incorporation of physical data, land use data and socioeconomic data for land degradation assessment.

2.6 Case studies on land degradation assessment and monitoring using GIS and Remote Sensing

The over-utilisation of catchments to provide food, fibre and shelter for the expanding population has resulted in degradation of catchments in most parts of the world (Sah *et al.,* 1996). Shalaby and Tateishi (2007) argue that 95 percent of the population in Egypt is concentrated around Nile River which covers approximately 5 percent of the land. They argue that out of 1 million square kilometres which is the total area of Egypt, 95 percent of the land is desert and uninhabited land.

The Government of Egypt therefore started a population redistribution plan through applying a horizontal urban expansion along desert areas and near the fringes of the Nile delta. The aim was to reduce pressure on high productive agricultural land. The objective of the study was therefore to accurately map land cover change information in order to understand consequences of population redistribution on the environment.

The study used a maximum likelihood supervised classification and post classification change detection techniques of 1987 Landsat 5 Thematic Mapper (TM) and 2001 Lansat 7 Enhanced Thematic Mapper (+ETM) images to map land cover changes in the Northwestern coast of Egypt. The results of the study showed that the area has undergone a sever land cover change. The areas of natural vegetation were replaced by urban settlements and agricultural land. This was therefore observed as land degradation in the area. Shalaby and Tateishi (2007) concluded that GIS and Remote Sensing provided valuable information on the nature of land cover change and spatial distribution of different land cover changes. This research by Shalaby and Tateishi (2007) relates to the current study as it aims to establish the extent and nature of land degradation in the Wit-Kei catchment. However this study will also incorporate house hold survey which was not conducted in the study by Shalaby and Tateishi (2007).

A study of catchment degradation and its socio-economic impacts using remote sensing and GIS was also conducted in Trijuga watershed in Nepal by Sah *et al.*, (1996). The aim of this study was to develop and test a methodology for assessing the degradation of the Trijuga watershed over time and its socio-economic impacts. The study used Remote Sensing, GIS, the Universal Soil Loss Equation (USLE) and household surveys. The remote sensed aerial photograph of 1978, Landsat MSS of 1984 and Landsat TM of 1991 were used to create and compare land use and land cover of the study area. The land use and land cover was obtained through visual interpretation from the 1978 aerial photograph while supervised classification was used for Landsat images. The land use and land cover for 1978, 1984 and 1991 were compared in order to determine areas of change and establish degraded areas. Sah *et al.*, (1996) argue that change has been too high for the sustainable use of natural resource in the study area and therefore highlighting land degradation. The USLE was used to calculate the exact amount of topsoil lost in the area. The study concluded that remote sensing and GIS in combination with the USLE are the appropriate tools for watershed resource monitoring whilst the household survey yielded results relating to the socio-economic status of people living within the watershed. The methods which will be used in this study are similar to the methods conducted by Sah *et al.*, (1996).The current study use remote sensed Landsat TM images, auxiliary GIS data and interviews but however will not use USLE due to limited scope of the research.

Dregne (1989) agrees with other authors that GIS and remote sensing have supported developments in information on land degradation which are valuable in combating land degradation. He further agues that for an informed decision to be made either by a local community, or a nation on financial and labour investments to control land degradation, information on land degradation trends are important. A case study on land use change detection and analysis using GIS to assess land degradation trends has been conducted in two Nepalese watersheds by Awasthi *et al.*, (2002). One of the objectives of the study was to assess land use and land cover change. This objective relates to one objective of the current research project which is the investigation of land use and land cover change using satellite images in the Wit-Kei catchment. To achieve the objectives of the study in the Nepalese watershed, image classification of land use and land cover types for both watersheds were prepared for different years (1978 and 1996). Field verification was carried out to improve the accuracy of the 1996 land use map. The results showed significant alteration and transformation from 1978 to 1996. Awasthi *et al.*, (2002) identified that land use and land cover change is not sufficient for explaining the land degradation. To bridge this gap, this research aims to include a socio- economic element based on land use history and the views of the people living within the Wit-Kei catchment.

In South Africa, a land degradation study was conducted by Hoffman *et al.*, (1999) for the whole country of which the results are summarised by Hoffman and Todd (2000). The research used a participatory approach which consisted of workshops and interviews. Information on land use practices and land cover changes over a ten year period was collected through interviews with agricultural extension officers and resource conservation technicians. Soil and vegetation were chosen as indicators for land degradation assessment and monitoring (Hoffman and Todd, 2000). The findings of this paper perceived soil degradation as being greatest in KwaZulu-Natal, Northern Province and Eastern Cape. Vegetation degradation was reported as high in KwaZulu-Natal and the Northern Cape. Soil and vegetation degradation were combined into a single land degradation value, and communal areas of the former Ciskei, Transkei and KwaZulu-Natal emerged as some of the most degraded areas in South Africa (Hoffman and Todd 2000). The gap, bridged by the current research, is through incorporation of other scientific methods (GIS and remote sensing) at a local scale in order to acquire more information on land degradation.

Another case study on land degradation in South Africa was done by Wessels *et al.*, (2004). They argue that soil degradation has an enormous effect on the regeneration and development of vegetation cover. Therefore they further state that there is an urgent need for repeatable, systematic and spatially explicit measure of land degradation. Wessels *et al.,* (2004) study focused on vegetation cover as land degradation indicator. Their study conducted a comparison of vegetation cover from the National Land Cover (NLC) map of 1996 with 1km Advanced Very High Resolution Radiometer (AVHRR) data. Using a definition of land degradation as loss or permanent irreversible decline in forage, this study suggested that the areas mapped as degraded by NLC were not necessary degraded. However they also argue that their results might have been influenced by limited spectral and spatial resolution of AVHRR data and therefore may lack the sensitivity required to accurately quantify degraded impacts. The recommendation identified by Wessels *et al.,* (2004) is that scientific methods may have limitations that can be addressed by field surveys and household interviews. This study therefore will also conduct field surveys and household interviews in support the remote sensing techniques to be used study.

CHAPTER 3: REMOTE SENSING FOR LAND DEGRADATION ASSESSMENT TECHNIQUES

3.1 Introduction

The ability to acquire and process remote sensed spatial information with ease has led to digital image processing playing a major role in land degradation studies (Lillesand and Kiefer, 2000; Cracknell and Hayes, 1991). This chapter explores change detection remote sensing techniques available for land degradation studies.

3.2 Change detection analysis

Lillesand and Kiefer (2000), Singh (1989), and Landstrom (2003), describe change detection as the use of multi-temporal data to identify differences in the state of an object or phenomenon.

A fundamental assumption of digital change detection is that a difference exists in the spectral response of a pixel at two dates if the biophysical materials within the initial field of view (IFOV) of the sensor have changed between the dates (Jensen, 1996). Ideally change detection procedures should involve data acquired by the same sensor or similar sensor, recorded using the same spatial resolution, spectral bands, radiometric resolution and at the same calendar date and time (Lillesand and Kiefer, 2000). Gibson and Power (2000) argue that it may not be possible to obtain images taken on the same calendar date in different years for two reasons:

- The repeat cycle for the satellite may be such that on the same calendar date, the satellite may not be imaging the same area.
- Even if the anniversary date and the satellite's overpass do coincide, there may be an extensive cloud cover for one of the dates.

Obtaining images that are cloud free for the same area taken on the same calendar date in two given years may prove very difficult. One is often forced to approach the change detection exercise by determining what cloud free images are available for a specific area and deciding whether any of the available data are suitable for the investigation being undertaken (Gibson and Power, 2000). The cloud free Landsat images for this study were taken on different calendar dates (refer to Table 3).

3.3 Change detection methods

According to Jensen (1996) there are a number of change detection approaches which may be categorised under the following:

- Manual, on screen digitising
- Write function memory insertion
- Image enhancement
- Multi data classification
- Comparison of two, independent, land-cover classifications
- Spectral change vector analysis

The selection of an appropriate change detection algorithm is very important as it indicates whether change in terms of land cover can be extracted from the imagery or not (Jensen, 1996). To improve the success of uncovering any changes that exist, change detection methods can be used jointly. This research will employ some of the change detection methods explained below.

3.3.1 Manual, on screen digitising

Manual change detection can be performed using on screen digitising to identify changes between images (Campbell, 1996). This relies mostly on visual interpretation to identify the areas of change to be digitised. After digitising, the areas of change are compared from two or more images and the results are overlaid to show change.

3.3.2 Write function memory insertion / RGB band combination/ colour composite

Write function memory insertion is also known as RGB band combination or colour composite. It entails the display of multispectral bands of imagery in red, green or blue write function memory banks (Lillesand and Kiefer 2000). The use of colour in display is an important aspect of image processing as it visually enhances information of interest (Schowengerdt, 2007). Lillesand and Kiefer (2000) argue that mind is an excellent tool in interpreting spatial attributes on an image and identifying obscure features. Therefore they argue that the process of visually interpreting digital imagery attempts to optimise the complementary abilities of the human mind and the computer

3.3.3 Post-classification change detection

Post-classification change detection is used to compare two or more independently produced spectrally classified (supervised or unsupervised) results (Coppin *et al.*, 2004 and Shue, 2003). The classified results are produced using the same information classes to facilitate their comparison. Shalaby and Tateishi (2007) emphasise that this procedure not only allows areas of no change to be identified, but also allows the nature of change to be determined. The principal advantage of post-classification as argued by Coppin *et al.,* (2004) is the fact that the different dates of imagery are separately classified, thereby minimising the problem of radiometric calibration between dates.

3.3.4 Change vector analysis (CVA)

When land undergoes changes or disturbances, its spectral appearance will change from one date to the next (Jensen, 1996). Change vector analysis (CVA) therefore is a multivariate change detection technique that processes the full dimensionality (spectral and temporal) of image data and produces two outputs: change magnitude and change direction (Coppin *et al.,* 2004). The direction of change can be positive or negative (showing areas changing from better to best or worse). While the magnitude of change show the total change per pixel. Lambin and Strahler (1994) cited by Coppin *et al.,* (2004) states that CVA technique proved to be effective in detecting and categorizing different land cover changes operating at different timescales in West Africa.

3.3.5 Image enhancement

Image enhancement is described as the process by which data displayed on an image can be made more obvious to the human visual system (Gibson and Power, 2000). It involves techniques for increasing visual distinction between features in a scene (Lillesand and Kiefer, 2000). The following image enhancement techniques were used in this research:

- Contrast stretching
- Ratio imaging
- Density slicing

There are several case studies which have used the above mentioned change detection techniques. A colour composite image of landsat 5 of 1996 and landsat 7 image of year 2000 was used to assess the land cover change in the tropical rainforest by Dahal *et al*., (2002). A visual false colour band combination 453 in RGB order was used and a comparative view of land cover classes between the two images was identified. The on-screen digitising technique was then applied to map the land use and land cover of the two images from the false colour composite. Then the change between the two land use and land cover was derived by comparing the area of change of each class. They concluded that use of remotely sensed data was a successful approach in change detection of land use and land cover.

In Minnesota metropolitan area post classification change detection technique using multi-temporal Landsat data of 1986, 1991 and 1998 was used to study change by Bauer *et al.,* (2003). The post classified images used a subtraction approach to derive the area of change. The 1986 image was subtracted from the 1991 image and the 1991 image was subtracted from the 1998 image. The total of each land cover class at each date were tabulated and the trend of each class between the different years were analysed. They concluded that the post classification technique provided an economical and accurate way to quantify, map and analyse changes over time in land cover.

Image enhancement techniques have also been used for analysing and mapping change. Image differencing using image ratios or vegetation indices is another commonly used change detection technique for identifying land use and land cover change (Coppin *et al.,* 2004). An example of such a study in South Africa has been conducted by Wessels *et al.,* (2004) and has been mentioned in the previous chapter.

Approaches to change detection in image processing are many and varied, and choosing one to use is a difficult task. It relies largely on the experience and confidence of the researcher on the technique and on the quality of the images. This research will use write function memory insertion, post-classification change detection and image enhancement techniques. The chosen techniques are further explained under data processing in the following methodology chapter.

3.4 Accuracy assessment of image classification

No map created from remote sensing data alone can be completely accurate (Steele *et al.* 1998) and consequently, no image classification is complete until the accuracy of the classification has been assessed (Lillesand *et al.* 2004). The term accuracy in thematic maps created from remotely sensed data is used to express the degree of correctness of the map or image classification when compared to reality (Foody 2002). Different authors undertake classification accuracy assessment for different reasons including 1) to provide an overall measure of the quality of the product, 2) to form the basis of an evaluation of different classification algorithms or 3) to help gain an understanding of errors in the classification process.

A variety of classification accuracy assessment techniques are described by Foody (2002), Congalton (1991), Steele *et al.* (1998) and Stehman *et al.* (1998). The most common technique for accuracy assessment is through the construction of an error matrix in which the relationship between reference data and the result of the image classification can be presented. The error matrix is constructed by listing the know land cover types used as reference versus the pixels actually classified into each land cover category (Lillesand *et al.* 2004). The error matrix method is widely considered to be the most accurate since the accuracy of inclusion and the accuracy of exclusion can be assessed for each category present in the classification. However this study conducted accuracy assessment proposed by Richards (1996). He argued that one of the ways to assess accuracy is by taking samples from the thematic map and checking their accuracy against ground data. The reliability of accuracy assessment is dependent on whether the map has been effectively sampled. Regardless of accuracy assessment technique used, Foody (2002), Steele *et al.* (1998), Stehman *et al.* (1998) and Richards (1996) state that, if information from available land cover maps are to be used as input for scientifically sound management and policy decisions, the maps should be accompanied by a statistically defensible accuracy assessment.

CHAPTER 4: METHODOLOGY

4.1 Introduction

To address land degradation, a conceptual framework proposed by Hoffman and Ashwell (2001) has been adopted (refer to Figure 11). This conceptual framework presents the view that climate and humans, either individually or jointly, can modify the environment of a region by changing its water, soil and vegetation resources. (Land degradation has been defined in chapter 2 as the deterioration or depletion of natural resources). This research considers change in vegetation cover and bare-ground as indicators of land degradation. Information was collected using Remote Sensing, GIS techniques and household surveys.

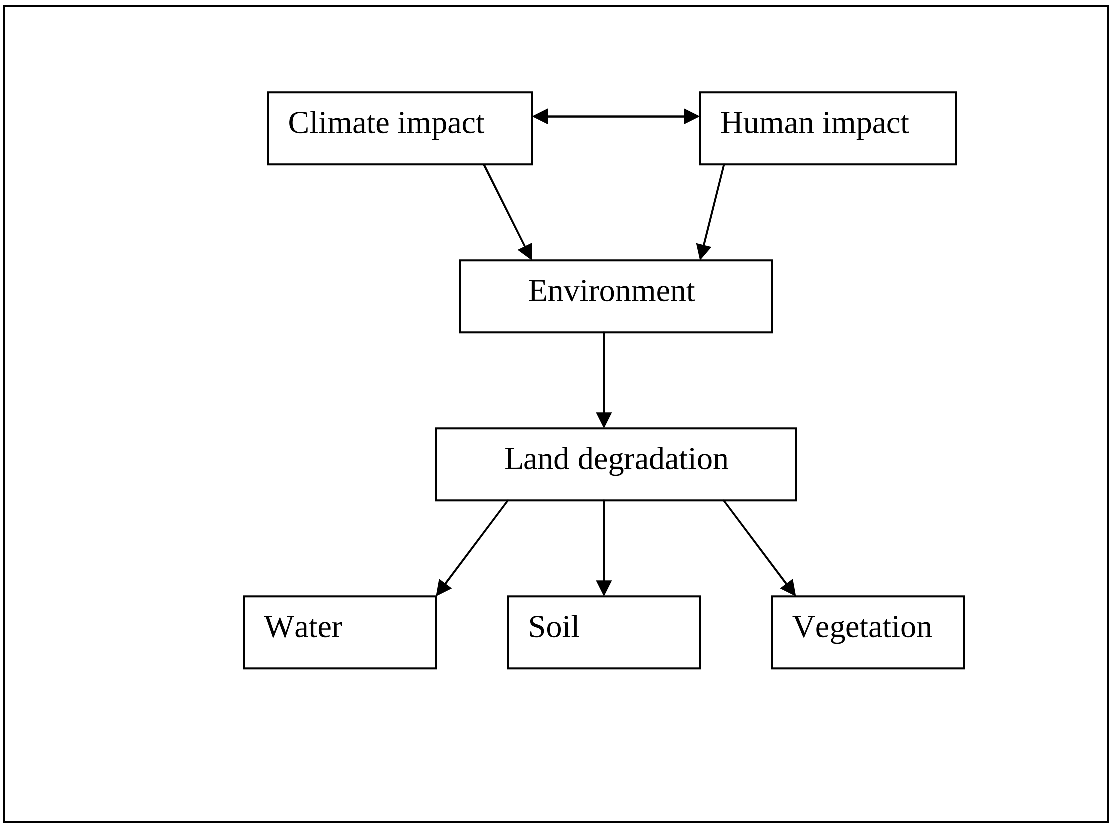


Figure 11: A conceptual framework for land degradation (Hoffman and Ashwell 2001)

4.2 Selected and pre-processing of Remote Sensed Satellite imagery

One of the ways of capturing remotely sensed images is by satellite. Images for this study were obtained from the Landsat satellite, a research satellite provided by the National Aeronautics and Space Administrator (NASA). Further information about it can be found in Jensen (1996), and Mather (2003). Satellite imagery is used for land degradation studies due to its capacity to provide imagery of low to high spatial and spectral resolution. Landsat data used was based on the availability of Landsat data by the Council for Geoscience.

The Council for Geoscience acquired Landsat images from the Satellite Application Centre in South Africa. The images for 1984, 1993 and 1996 came from the Landsat 5 TM and the images for 2000 and 2002 came from Landsat 7 ETM+. However Landsat of high quality was recommended. The quality of an image was accessed by the cloud cover percentage in an image and categorised as high, medium and low. High quality representing zero cloud cover, medium quality representing less than twenty percent cloud cover while low quality represent greater than twenty percent cloud cover. Table 3 shows the capture dates of the images and their quality level. The 1984 image was captured during winter season while other images were captured during summer season. Yang *et al.,* (1999) argues that the land use and land cover change of one class to another is a slow process when compared seasonally and therefore not easily quantified. Hence this study also used a winter image in 1984 rather than an unavailable summer image. The medium quality data for 1993 image was used as less than twenty percent cloud cover occurred at the edges of the image and therefore not hiding the land use and land cover of interest. Table 4 shows the differences and the similarities between Landsat 5 TM and Landsat 7 ETM+.

Table 3: Landsat image data acquisition information

Year of images	Day	Month	Sensor	Quality	Notes
1984	24	May	Landsat 5	High	Zero cloud cover
1993	15	December	Landsat 5	Medium	Less than twenty percent cloud cover
1996	16	December	Landsat 5	High	Zero cloud cover
2000	20	November	Landsat 7	High	Zero cloud cover
2002	25	November	Landsat 7	High	Zero cloud cover

Table 4: Landsat 5 TM and Landsat 7 Enhanced Thematic Mapper (ETM+) properties

Properties		**Landsat 5**	**Landsat 7**
Spatial resolution	Band 1	30m	30m
	Band 2	30m	30m
	Band 3	30m	30m
	Band 4	30m	30m
	Band 5	30m	30m
	Band 6	120m	60m
	Band 7	30m	30
	Band 8	Not available	15m
Swath width		185km	185km
Temporal resolution (Repeat-coverage interval)		16 days	16 days
Radiometric resolution		8 bits	8 bits
Inclination		98.2°	98.2°

The normalized difference vegetation index and other comparison techniques computed by Vogelmann *et al.*, (2001) as cited by Florencia (2003) concluded that Landsat 5 TM and Landsat 7 ETM+ are very similar and therefore can be used interchangeably to measure and monitor the same landscape and conduct change detection. However, pre-processing of remote sensed images need to be conducted.

Pre-processing of remote sensed images starts by rectifying the distortions on an image. Satellite images are affected by distortions due to the sensor angle towards an object. In order to reduce distortion, images are subject to the process of orthorectification. Jensen (1996) states that orthorectification is the process of correcting the distortion within an image. Figure 12 illustrates the process of orthorectification which was used in this study to compensate for the distortion problems within images.

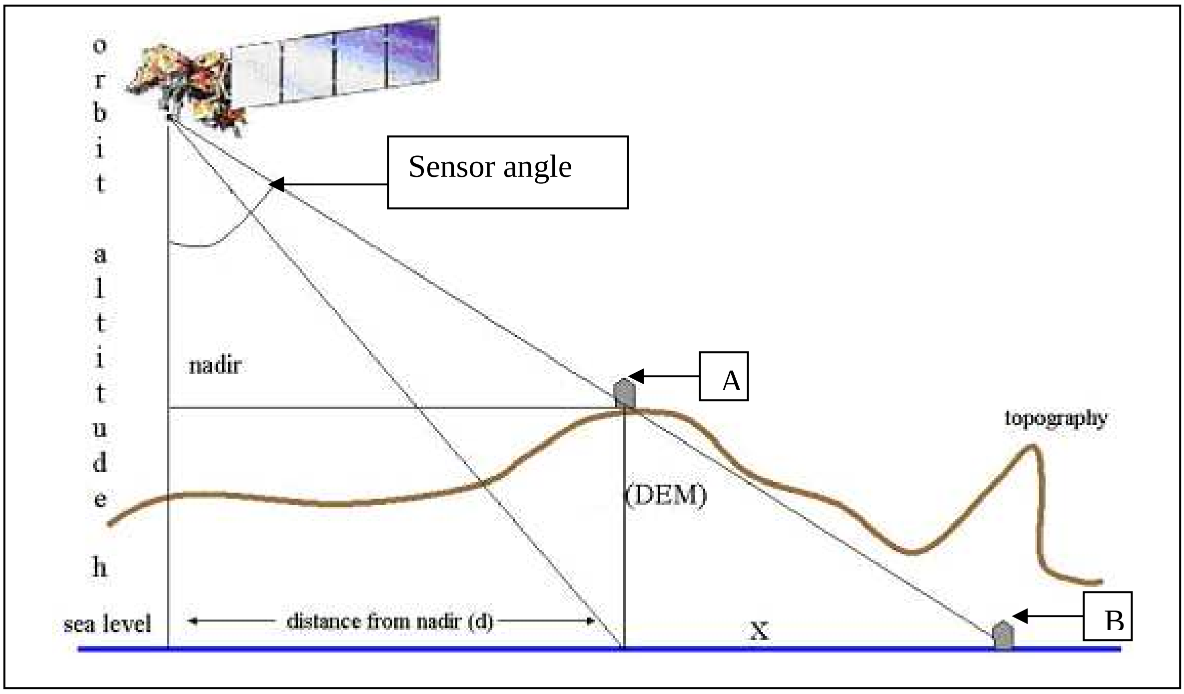


Figure 12: Illustration of process of orthorectification (modified diagram from Lück 2004)

The sensor records the object at an oblique angle (except for some satellite images like ASTER which can also record the object directly vertically). This results in the object being recorded as if is in position B rather than A, which is its true position. The purpose of orthorectification therefore is to compensate for the error created by the sensor angle. The remote sensing software used for this pre-processing was ENVI software.

Another typical pre-processing step involves atmospheric correction. Atmospheric correction has been stated by Song *et al.*, (2001) as the correction or removal of the atmospheric effects on an image. Song *et al.,* (2001) further argue that whether atmospheric correction is needed depends on the information desired and analytical methods used to extract information. Therefore they state that atmospheric correction is unnecessary for change detection for land use and land cover, when multidate images are rectified and analysed separately as a single dataset. Since this study analysed and compared the results of each image separately as single datasets, it was deemed unnecessary to apply this process.

4.3 Data processing

The change detection techniques identified as suitable for this study include: image enhancement, write function memory insertion and post-classification.

4.3.1 Write function memory insertion (RGB band combination)

For visual understanding and interpretation of changes in the images, colour composites were created. Colour composites also known as Red Green Blue (RGB) were generated using different band combinations. The different colour composites were used to highlight different information within the image. The useful colour composites used within the study are:

- RGB = 321 (used to give a true visual image of the area)
- RGB = 432 (used to visually observe changes in vegetation)
- RGB = 574 (used to visually observe changes in bare ground)

4.3.2 Image enhancement (Tasselled Cap Analysis (TCA))

Tasselled Cap Analysis is one of the methods for enhancing spectral information content of Landsat data. Mather (2003), Levien *et al.,* (1998), Urban (2000) and

Huang *et al.*, (2001) promotes the use of TCA as a method which clearly differentiates between vegetation and bare-ground which are the land degradation indicators being studied. TCA is based on a mathematical equation that converts an image acquired by Landsat multispectral sensor into an image which has three main output components that highlight bare-ground, vegetation and water feature. The TCA was run on ENVI software for this study through the processes explained by Figure 13. Soil brightness and vegetation greenness were the bands used for vegetation and bare ground monitoring for the study years 1984, 1993, 1996, 2000 and 2002. The result of TCA for each band is grey scale image (similar to a black and white aerial photography) where brightness in a particular image represents area of interest. The vegetation cover and bare-ground monitoring TCA bands were analysed in this study. Bare ground represented areas of exposed soil surface as influenced by human and / or natural causes while vegetation represented areas of dense interlaced trees and shrub species.

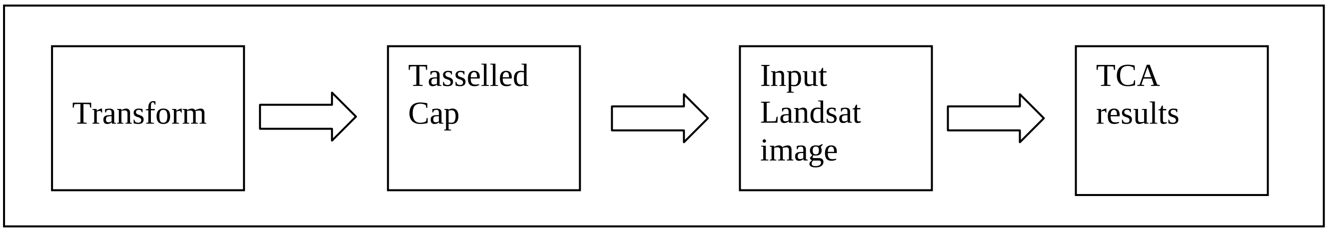


Figure 13: Steps involved in TCA processing using the ENVI software. The boxes represent the control icons which must be activated when computing the application.

In order to identify specific areas of interest from TCA bands for bare-ground and vegetation, a density slicing techniques was used. Density slice is a technique which highlights a range of values which are of interest to the researcher. The values of interest which density slice was applied to were chosen based on histogram analysis of each image separately. The histogram being defined as a graphical representation of the brightness values that comprise an image (Mather, 2003). It therefore allows a concise portrayal of information in a bar graph format. The histogram of all the TCA images for the years being studied were unimodal (refer to Figure 14). The histograms are automatically divided into 3 ranges, those with low range value (representing dark pixels in an image), medium range value (representing grey pixels in an image) and high range values (representing bright pixels in an image, refer to Figure 14). The density slice was computed to select only the high range values of the TCA of each image. The default high range values from density slice were analysed. The areas for the selected high range values in each year were calculated and compared with each other. The end result demonstrates the change in area of vegetation and bare ground.

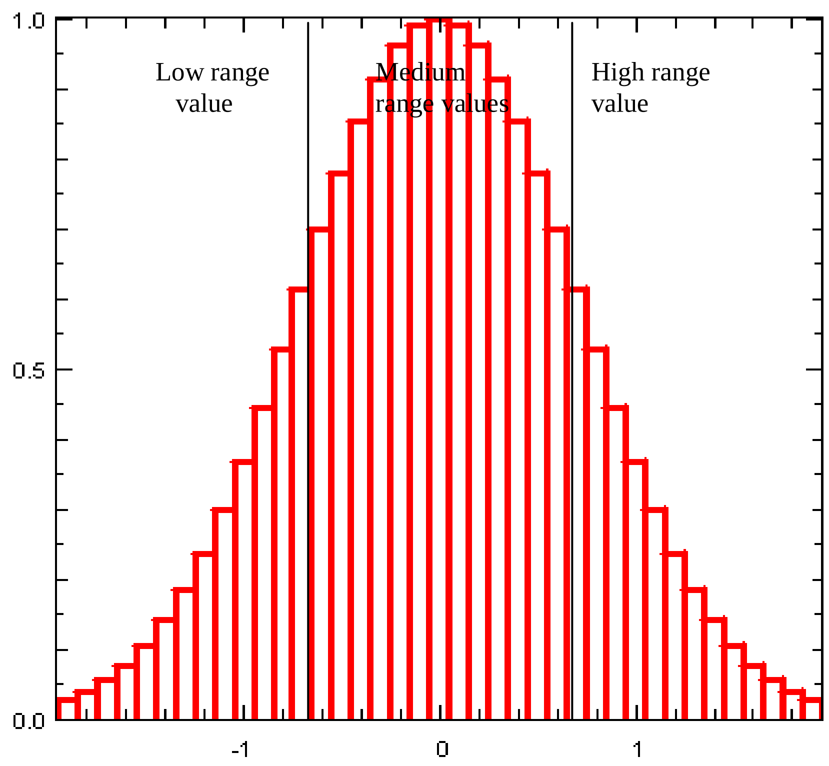


Figure 14: Histogram analysis of Tasselled Cap

<u>4.3.3</u> <u>Post-classification (Unsupervised classification)</u>

Post-classification is a process which allows a comparison of change between classified images (Jensen 1996, Shalaby and Tateishi 2007). The image classification procedure automatically categorises all pixels in an image into information classes (Campbell, 1996). Image classification is divided into two techniques; supervised and unsupervised classification.

The supervised classification technique requires the analyst to select sample sites which are known classes within an image. The supervise classification technique then determines the character of each sample site and compares every pixel in an image with those in different sample sites selected by the analyst. The pixels are then labelled according to the closest class they represent (Campbell, 1996 and Lillesand and Kiefer, 2000). The major risk presented by this method is that the analyst may not be able to select sample sites to represent all the different classes within an image.

Due to the shortage of enough information to set sample sites an alternative unsupervised classification technique was chosen for this study (refer to Figure 15).

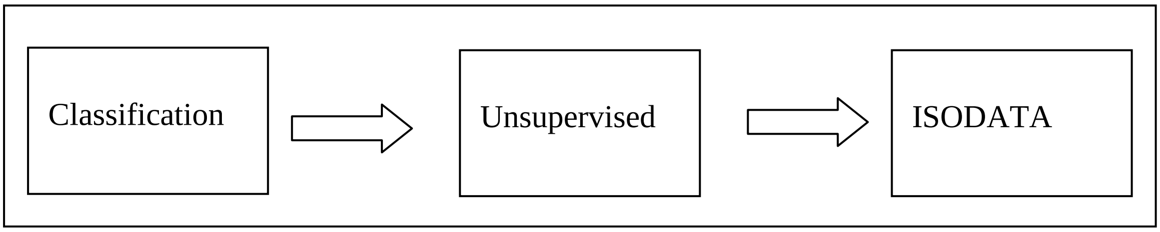


Figure 15: Steps involved in ISODATA unsupervised classification processing using the ENVI software. The box represents the control icons which must be activated when computing the application.

With the unsupervised classification technique, pixels in an image are examined by the computer and classified into spectral classes. The spectral classes are then matched by the analyst to information classes (Campbell, 1996 and Gibson *et al.*, 2000). Campbell (1996) argues that the advantage of the unsupervised classification method is that it reduces human objectivity. The algorithm used for unsupervised classification method for this study is Iterative Self-Organising Data Analysis (ISODATA). The ISODATA unsupervised classification finds an optimum set of groupings under chosen constraints. The user has to supply a range for a number of possible classes plus the maximum number of alteration to be performed. The minimum number of classes chosen for this study was 3 classes and maximum number of classes was 15. The minimum predictable number of classes was derived from visual analysis of the RGB images and captured photographs of the area. It is advised that the maximum number of classes chosen for unsupervised classification should be atleast 3 times more than the predicted minimum number of classes. For the alteration 100 percent was chosen for the ENVI software in order to get clear group of classes as possible. The other parameters were left as default. The final step was to analyse and assign class names to classes resulted by unsupervised classification. The assigning of information classes was conducted through the use of auxiliary data (1:50 000 toposheet of 1994, RGB colour combination of images and photographs by Gibson, 2003). The classification of grouped pixels into land cover and land use classes was based on land cover classes developed by the Council for Scientific and Industrial Research of South Africa. The classes were dense vegetation, moderate vegetation, grassland, stressed or degraded grassland and bare-ground. Dense vegetation and bare-ground classes were further related to the vegetation and bare-ground class from the TCA. The unsupervised classification has a dense vegetation cover and a bare-ground class which represents healthy vegetation type and exposed soil surface type. The greenness and brightness band of TCA promote the equivalent land cover type. This therefore brought a direct comparability of dense vegetation and bare-ground from these techniques. To enhance and comprehend results, the two classes (dense vegetation cover and bare-ground) from the unsupervised classification and TCA technique were compared.

4.4 Geographic Information Systems (GIS)

ArcMap 9.1 GIS software was used as a tool for integrating the various layers of spatial data and for carrying out analysis of land degradation assessment and monitoring. The main data layers overlaid and analysed within a GIS for this study were: Landsat images, a digital elevation model, Aspect map, topographical maps and a geological map (refer to Figure 2). The results derived from the GIS were used together with interview results in order to get a holistic view of land degradation in the study area.

4.5 Interviews

Interviews serve as a method of clarifying and verifying the meaning of desktop study findings. Although interviews are time consuming (in terms of transport to visit the area and making necessary arrangements with the interviewees) they have the potential to provide highly illuminating material (Robson, 2002). The purpose of interviews in this research was to assess the status and knowledge of land degradation from the perspective of the community who are affected by land degradation in the study area. A crucial part of the interviews was input from older community members who contributed to the historical perspective of the study.

A field trip to the study site was undertaken in August 2005 and May 2006. The main purpose of the visits was to capture images of degraded lands in the study area and conduct interviews with members of the community. The choice of participants was randomly selected covering three villages within the study area (Qoqodala, Lalini and

Thambekeni). De Vos *et al.,* (1998) argues that random selection minimises bias in choosing interviewees as it give equal chance of each member of the community to be selected. The people in the villages interviewed are Xhosa speakers with a varied level of education (from those who understand and speak English with a tertiary qualification up to those who cannot understand English with informal education). This therefore led interviews to be conducted in IsiXhosa in order to get a holistic view and understanding of community regarding land degradation. However for the purpose of this research the questioners and analysis of response from the interviewees were converted into English (refer to annexe 1).

A total number of 14 interviews were conducted by the researcher with 32 people using both focus group and personal interview techniques. This resulted in 5 focus group interviews and 9 personal interviews. Difference of opinion exists with regard to the minimum number of respondents that should be involved in an investigation. Nachmias and Nachmias (1987) states that there are arguments that suggest the sample size should be 5% of the population while other argument suggest that the samples size should be total of 2000 people. Grinnel and William (1990) cited by De Vos *et al.,* (1998) argue that a sample size of 30 people is enough. In this study 32 people were interviewed due to time constraints and also the homogeneity of the study area (all people were amaXhosa) which minimize the need of larger sample in order to accommodate different groups (Vos *et al.,* 1998). “The observation of the study of a phenomenon in its entirety is tedious and time consuming, leading to massive of data which would be difficult to processing and interpretation” (Vos *et al.,* 1998, p194).

The choice of a focus group interview technique was due to its ability to integrate people with different backgrounds, age, employment status and experience in one group. Robson (2002) argues that the focus group technique enriches the discussion as people with different backgrounds view the topic differently. The capacity of the focus group technique to focus on a specific topic in a group setting made it a suitable tool for gathering information on a particular aspect of land degradation. The focus group within the study was not organized in an appointment form but rather occurred when the people visited each other. Each focus group was having a minimum number of three people and a maximum of six people.

However it is also acknowledged by Johnston (1996), cited by Robson (2002), that the focus group approach has the potential of leading people not to freely discuss their opinions, so personal interviews were also conducted in order to enhance the limitations of the focus group technique. Personal interviews also served as a method of gathering information from interviewees who were at their homes by themselves at the time of the field visit. Personal interviews also targeted individual perceptions, opinions and facts about land degradation. The personal interviews were conducted in 9 households.

CHAPTER 5: RESULTS

5.1 Introduction

This chapter presents the results of the desktop analysis together with community interviews and field work.

5.2 RS and GIS perspective on land degradation

The current research monitors and assesses the nature of land degradation over a period of 18 years. The vegetation cover and bare-ground increase or decrease are the chosen land degradation indicators for this study. Florencia (2003) and Kakembo *et al.*, (2002), consider vegetation clearance and bare-ground increase as recognisable indicators of land degradation. Van de Berg and Keller (2005) have been mentioned arguing that trends of land degradation starts with the removal of vegetation cover over a small area which expands to a large bare-ground area over time. Land degradation in this study is analysed through Remote Sensing, GIS, field and household surveys.

5.2.1 RGB band combination (Colour Composite)

The goal of RGB band combination is to improve the visual interpretability of an image. It has been mentioned by Lillesand and Kiefer (2000) that mind is an excellent tool in interpreting spatial attributes on an image and identifying obscure features. Therefore RGB band combination have been analysed in this study.

RGB band combination in this study was computed in order to determine what land use and land cover information is captured by the images. Band combination 3, 2, 1 (RGB order) was computed for all the years (1984, 1993, 1996, 2000 and 2002, refer to Figure 16). This combination is also known as true colour combination as it represents the object under investigation in its true colour (e.g. green vegetation will appear green in the image). The results show that green areas throughout the images highlight vegetation (e.g. healthy grasslands) whereas the bright areas show bare-ground. Black areas indicate shadow while moist areas (water bodies, wetlands) are shown by a blue colour. At the edges of the 1993 image, clouds are observed with a very bright colour and with a distinct shape.

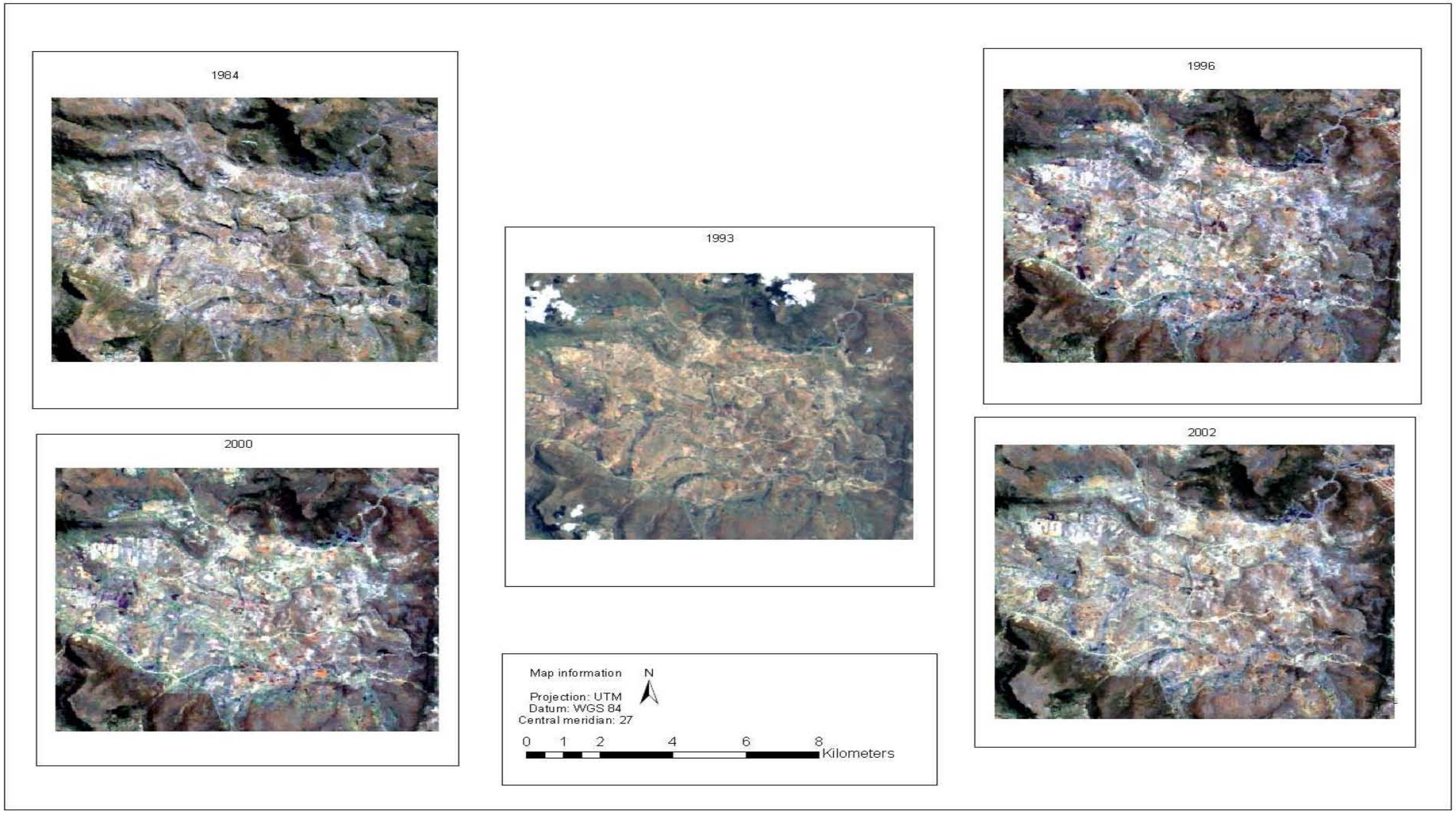


Figure 16: True Colour Band Combination

The false colour band combination was also used to further enhance visual analysis and interpretation of the land use and land cover information more especially for vegetation and for bare-ground land degradation indicators. The 432 false colour composite was computed specifically for healthy vegetated areas. This combination was chosen due to the capability of band 4 and 2 to detect vegetation while band 3 is useful for determining soil boundaries. Figure 17 shows the vegetated areas indicated by the red colour.

The 574 false colour was computed for the purpose of detecting bare ground areas (refer to Figure 18). The green colour within the image reflects the bare ground while blue highlights vegetation. The choice of these false colour combinations had been led by the sensitivity of band 5 to discriminate between clouds snow and ice when detecting bare ground. The ability of band 7 to distinguish between soil and vegetation led to the chosen band combination to assess bare ground.

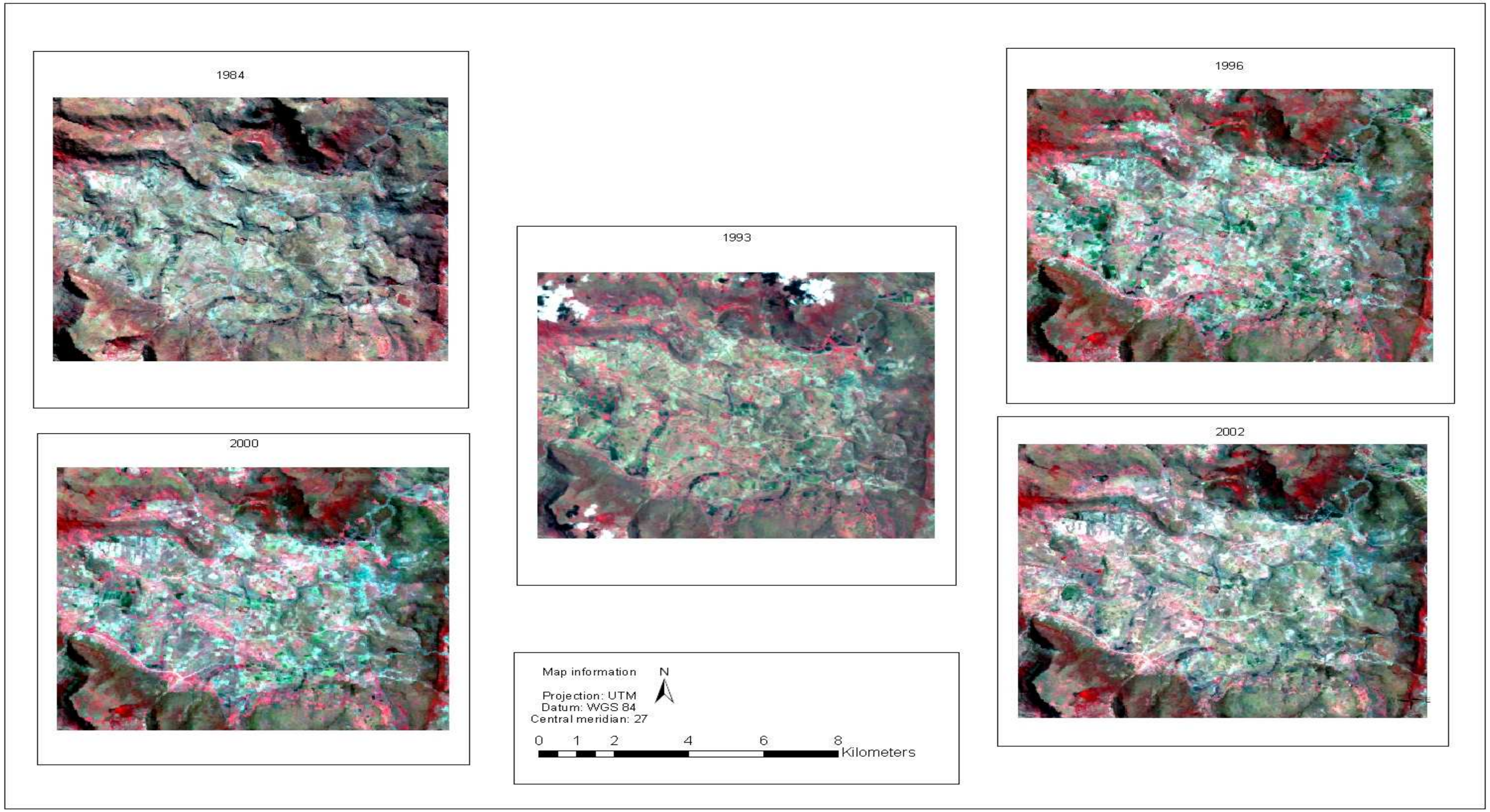


Figure 17: False Colour Band Combination R = 4, G = 3, B = 2

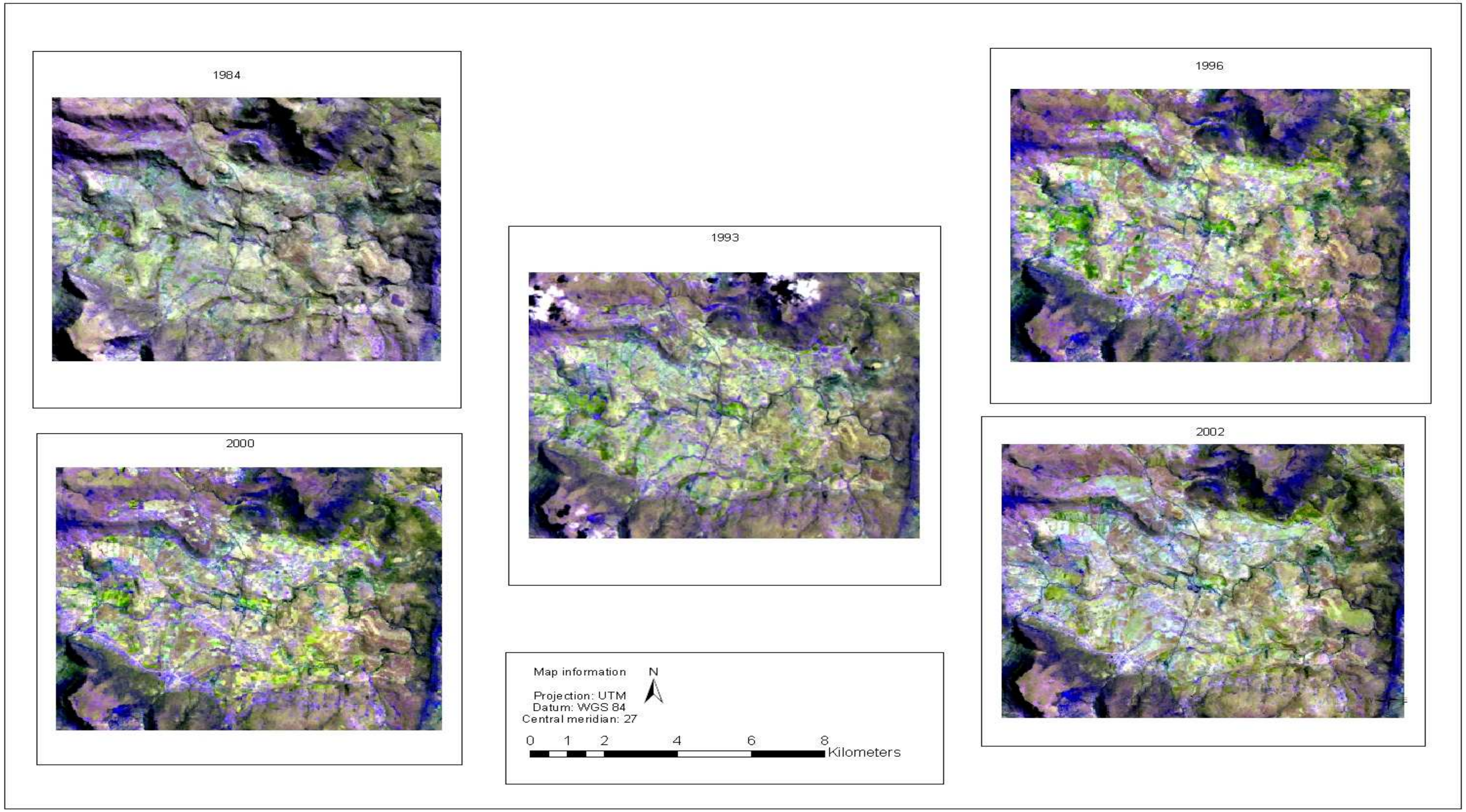


Figure 18: False Colour Band Combination R = 5, G = 7, B = 4

5.2.2 Tasselled Cap Analysis (TCA)

In this study, the tasselled cap components were used to differentiate between bare-ground and vegetation cover areas. The brightness and greenness bands were found to be especially useful to distinguish between these classes. The greenness band provided a measure of the amount of healthy green vegetation biomass while the brightness band provided an indication of bare-ground. The result of one of the tasselled cap bands is a grey scale image in which lighter shades indicate area of interest while darker shades indicate area of low interest. For instance, in the image representing the greenness component (refer to Figure 19), the lighter shades represent a large amount of healthy green vegetation while the darker shades represent non-vegetated regions. Conversely, in the brightness image (refer to Figure 20), the lighter shades represent reflection from bare-ground surfaces. The dark remaining area is unclassified information.

A density slicing technique was used to define threshold values for the greenness and brightness components with the aim of classifying vegetated areas and bare-ground surfaces (refer to Figure 21). The total vegetated surface area and total bare-ground surface area between different years was compared. A graph representing the changes observed is displayed in Figure 22.

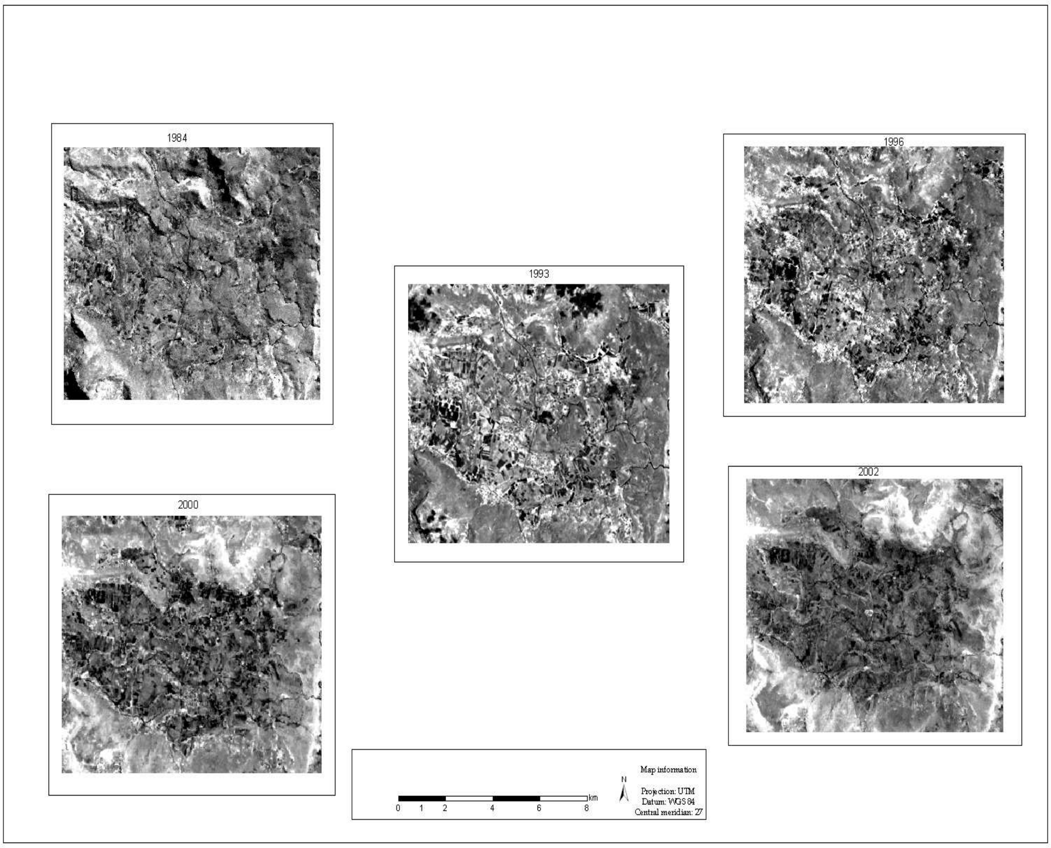


Figure 19: TCA of greenness

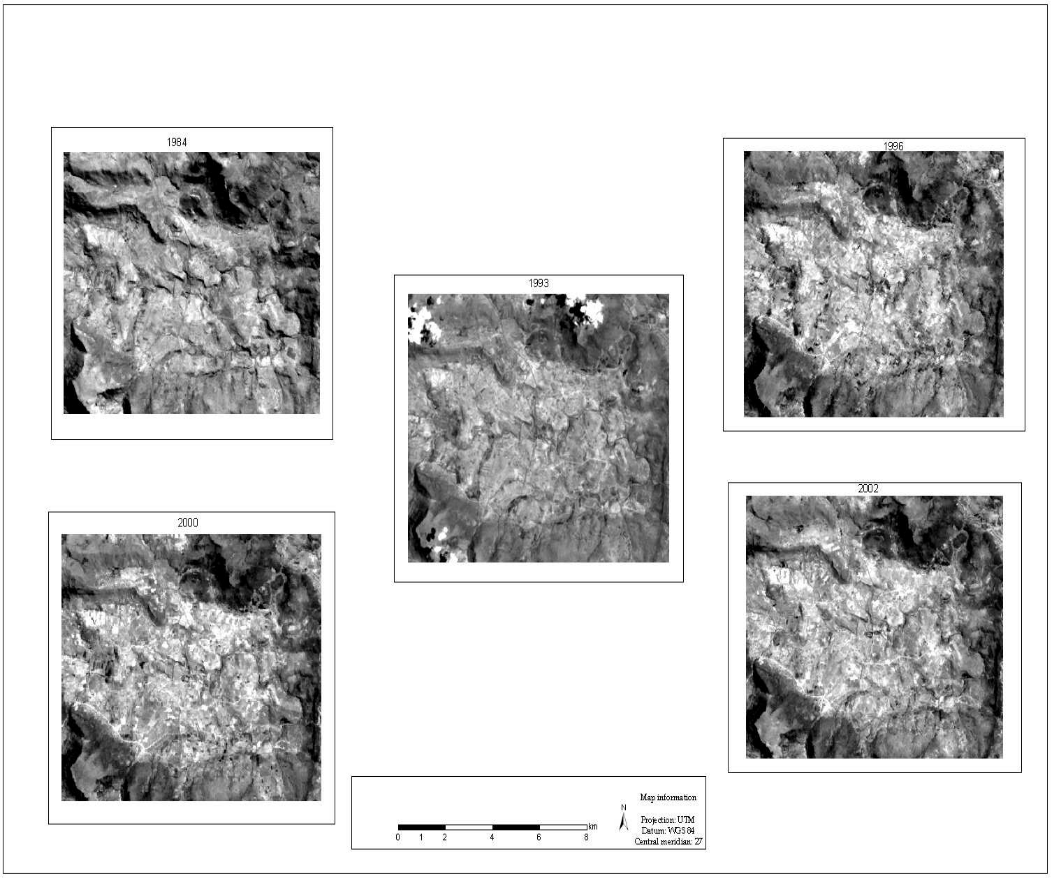


Figure 20: TCA of bare-ground

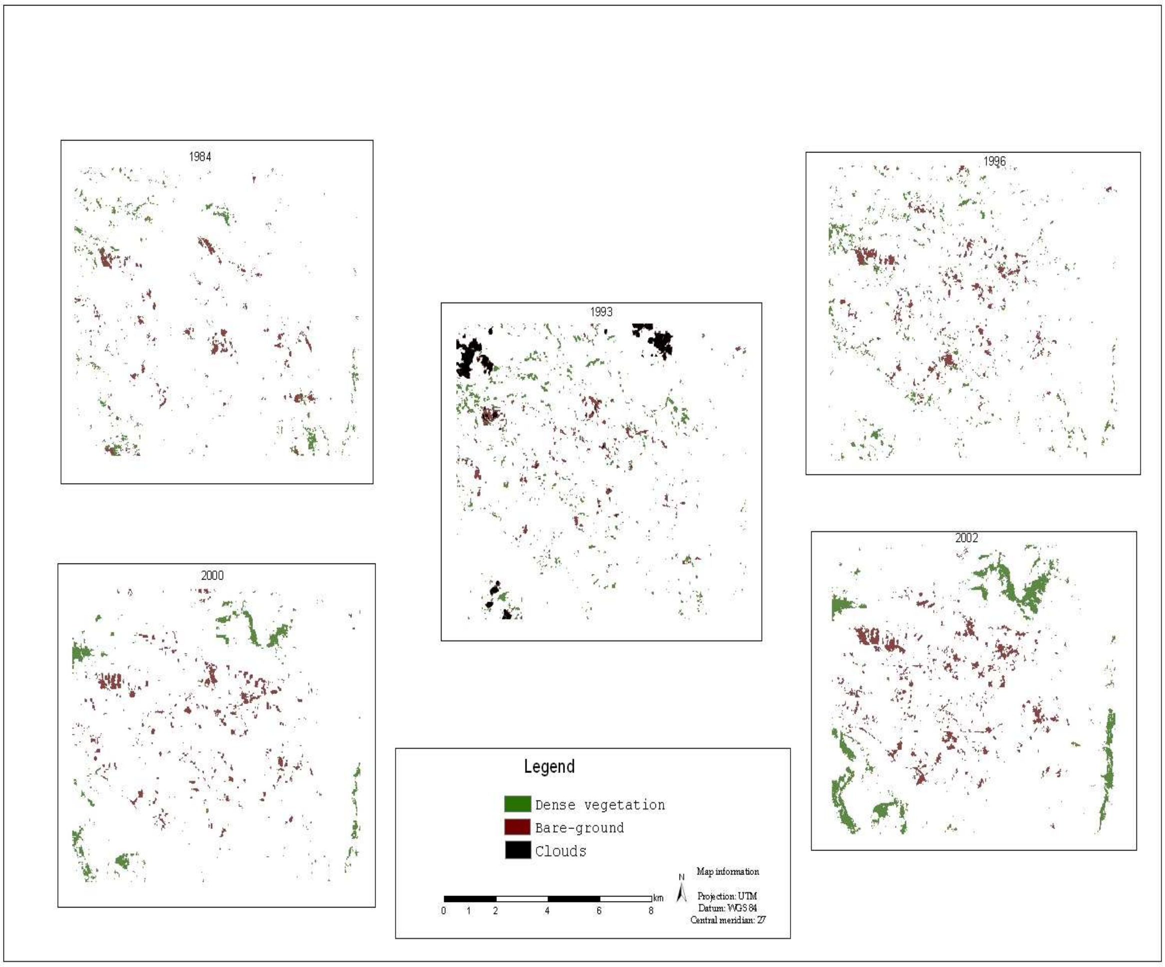


Figure 21: Density slicing of vegetation greenness and bare ground

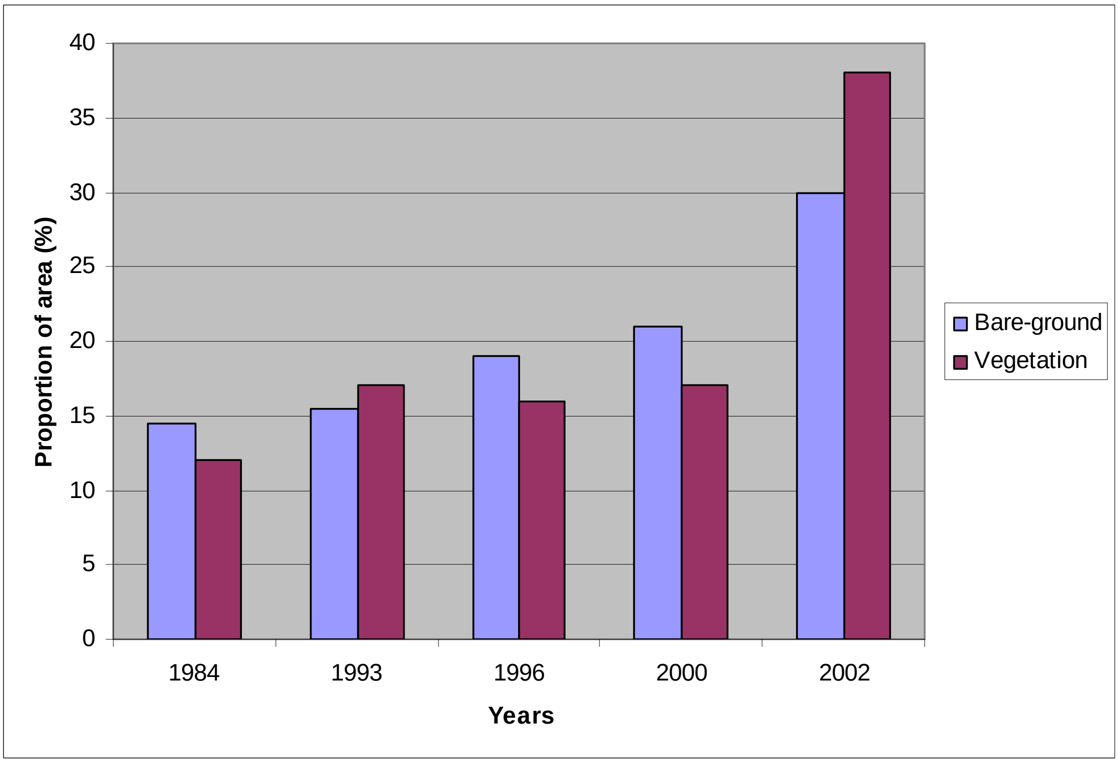


Figure 22: Differences in vegetation and bare-ground of the captured images

The results of the TCA are presented in Figure 22 in the form of a comparison of vegetated areas against areas of bare-ground, per image. The yearly rate of change from one image year to another has been calculated using the formula of annual rate of change, which is proportion of an area of one image subtracted by proportion of the next image and divided by number of years. The results therefore reveal the annual average change in bare-ground and vegetation per year (refer toTable 5).

Table 5: Yearly rate of change per time period from one date to the next

Year	Bare-ground in (%)	Vegetation in (%)
1984 – 1993	+0.2	+0.5
1993 – 1996	+0.6	-0.3
1996 – 2000	+0.75	+0.25
2000 - 2002	+4.5	+10.5

The results in Table 5 show a gradual increase in bare-ground over each time period, with a high figure for 2000-2002 period. Vegetation increases over each time period except for a decrease in 1993-1996 but increases substantially in the 2000 -2002 period.

5.2.3 Post-classification (unsupervised classification)

Unsupervised ISODATA classification was the chosen technique to be analysed for post-classification technique. An unsupervised (ISODATA) classification technique uses a computer programme that automatically groups pixels in an image into different cluster groups depending on their spectral features (Brogaard *et al.*, 1998). This method requires minimum user input to create the classified image however the output tends to require a great deal of user knowledge of the land use and land cover spectral signatures to make the results more meaningful. Unsupervised classification of each image date produced a result of 5 classes which were described as follows (based on the land cover classes developed by the Council for Scientific and Industrial Research of South Africa); dense vegetation, moderate vegetation, grassland, degraded or stressed grassland and bare ground (refer to Table 6 and Figure 23). The grassland is the dominating land cover type within the study area in each image (refer to Figure 24).

Table 6: Description of Land cover / land use based (Thompson, 1996).

Class name	Description
Dense vegetation or Thicket	Areas of dense interlaced trees and shrub species. They are composed of multi stemmed plants with no clearly definable structure with >70% cover.
Moderate vegetation or Bush clumps	They are scattered islands of thicket vegetation with a matrix of grassland.
Grassland	They are all the area of grassland with less than 10% tree and / or shrub canopy cover.
Stressed grassland / degraded grassland	They are grassland with patches of bare-ground.
Bare-ground	Land of exposed soil surface as influenced by human and / or natural causes.

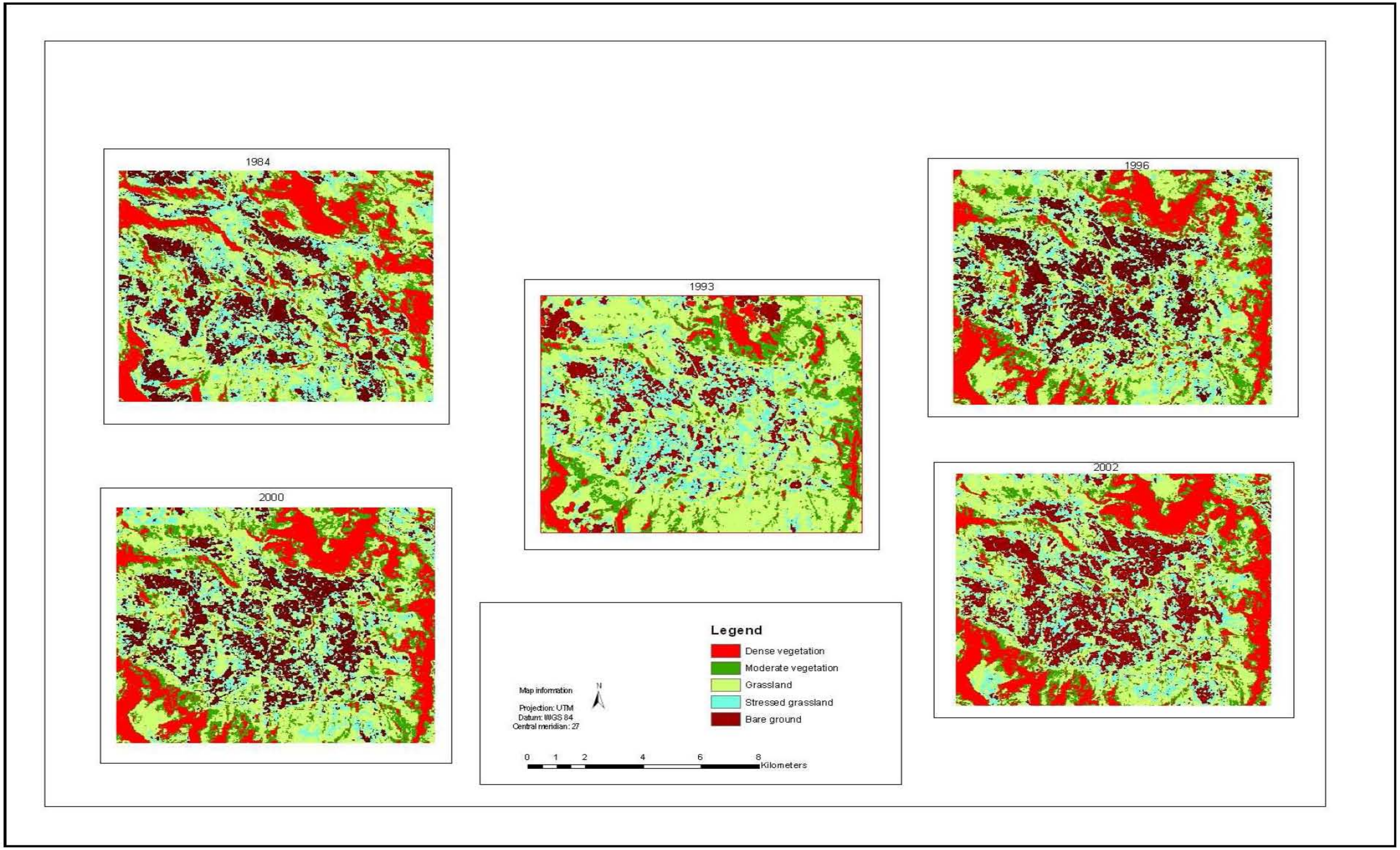


Figure 23: Land cover classes derived from the unsupervised classification technique

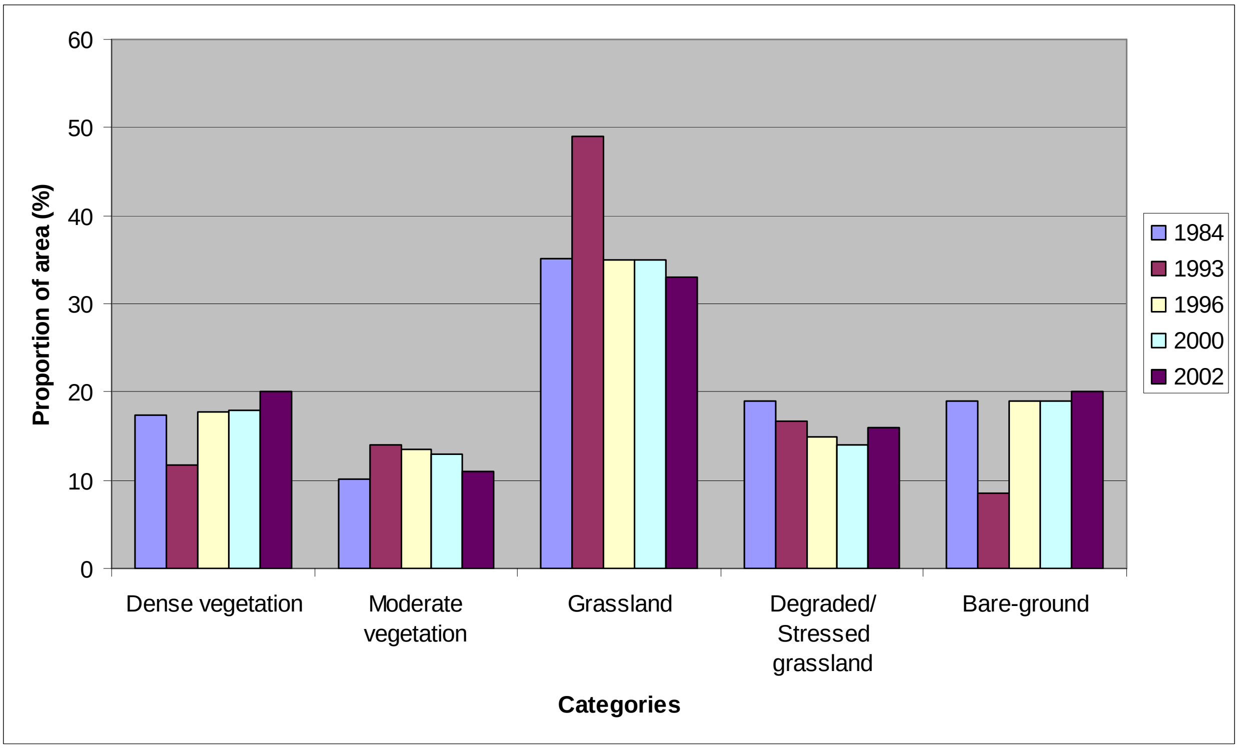


Figure 24: Results of unsupervised classification: area of land at each date in each category.

Dense vegetation experienced a decrease in 1993 and gained an increase in 1996 up to 2002. Moderate vegetation experienced a fluctuation from a low in 1984 and an increase in 1993 but further decrease in 1996 up to 2002. Grassland experienced a stable state characterised by an increase in 1993. Degraded / stressed grassland experienced a decrease from 1984 to 2000 and increased in 2002, while bare-ground showed a decrease in 1993 and was characterised by an increase from 1996 to 2002. The rate of change in each year is shown by Table 7.

Table 7: The area (km²) of change in each land cover class from one image date to the next

	1984-1993	1993-1996	1996-2000	2000-2002
Dense Vegetation	-5.6	+5.9	+0.3	+2
Moderate vegetation	+3.8	-0.5	-0.5	-2
Grassland	+13.9	-14	0	-2
Degraded / stresses grassland	-2.3	-1.8	-0.9	+2
Bare-ground	-10.5	+10.5	0	+1

5.2.4 Accuracy assessment of unsupervised image classification

In this study, accuracy assessment have been undertaken to provide an overall measure of the quality of the classified scenes. Due to issues related to inaccessibility of field areas as well as time and cost constraints, only 21 reference data points were collected representing the GPS coordinates of known land cover categories. Of the 21 points, 8 points coincided with bare-ground, 3 points were associated with dense vegetation and 4 points were associated with grassland, 2 points were associated with stressed grassland and 4 points were associated with moderate vegetation

Due to the small number of observation points and the distribution in the study area, the error matrix method could not be used for accuracy assessment purposes. The classification accuracy was achieved by employing a procedure proposed by Richards (1996) whereby accuracy is assessed by extracting samples from the classification results and comparing it to ground reference data. Accuracy assessment was achieved by determining the percentage of pixels in the classified image that were correctly classified compared to the reference points. The result of the classification accuracy assessment is summarized in Table 8.

Table 8: Classification accuracy assessment results

Category	Number of correctly classified pixels	Misclassified pixels	Classification Accuracy (%)
Dense vegetation	3	0	100%
Moderate vegetation	4	0	100%
Grassland	4	0	100%
Stressed grassland	2	2	0%
Bare-ground	8	0	100%
		Overall classification accuracy	80%

The results of the accuracy assessment reveals that the classification achieved 100% for dense vegetation, moderate vegetation, grassland and bare-ground while the accuracy for stressed grassland is 0%. This provided for an overall classification accuracy of 80%. However, these results may be somewhat misleading. It is important to note that the ground truth data was collected during a field season in August 2005 while the classification accuracy assessment was conducted for the classified result for an image captured in December 2002. Therefore one cannot assume that no land cover change occurred during 2002 (when the image was captured) and 2005 (when ground reference points were captured). If changes did indeed occur during the time period, the classification accuracy result would be negatively influenced and the availability of ground-truth data collected in 2005 may have increased the classification accuracy to a certain degree. Another limitation of the accuracy assessment performed in this study is the limited number of ground control points and the distribution of the points in the study area. The issues of inaccessibility meant that ground control points where only collected in areas directly accessible by road while cost and time constraints meant that only 21 samples where collected. It is recommended that future studies should focus on collecting ground truth data as close as possible to the time of satellite image capture; thereby a more reliable estimate of the accuracy of the methodology can be established.

5.3 Physical factors affecting land degradation assessed: slope, aspect, geology and climate

5.3.1 Slope and Aspect

The influence of slope and aspect cannot be examined in isolation if vegetation dynamics are to be clearly understood (Kakembo *et al.*, 2007). The slope map for this study was computed using a 50m pixel resolution Digital Elevation Model (refer to Figure 25) and slopes were categorised into 4 classes (refer to Table 9).

Table 9: Slope description of the study area

Slope category	**Percentage of slope (%)**
Flat	0 – 5
Moderate flat	> 5 – 15
Steep	> 15 – 30
Very Steep	> 30

The percentage of slope compilation for this study was achieved using ArcMap (ESRI software) slope classification. The formula for percentage of slope is: Tan = Rise/ Run (further reading for this formula is provided in ArcMap user manual guide). This produces a result in which lower slope values represent flatter terrain and higher slope values represent steeper terrain (refer to Figure 26). The slope map was then overlaid with TCA classes in order to establish the relationship between slope; bare-ground and vegetation cover (refer to Figure 27). The resulting image shows that bare-ground most commonly occurs on moderate to flat slopes while vegetated areas most commonly occurs on steep to very steep slopes (refer to Figure 28 and Figure 29).

Aspect measures the direction of slope in a clockwise direction from 0 to 360 degrees. The importance of aspect in land degradation studies has been mentioned by Kakembo *et al.*, (2007). They argue that an invasive species (*P.incana*) was strongly influenced by slope angle and aspect. However in this study aspect could not be related to bare-ground and vegetation cover increase or degrease and therefore was not further analysed.

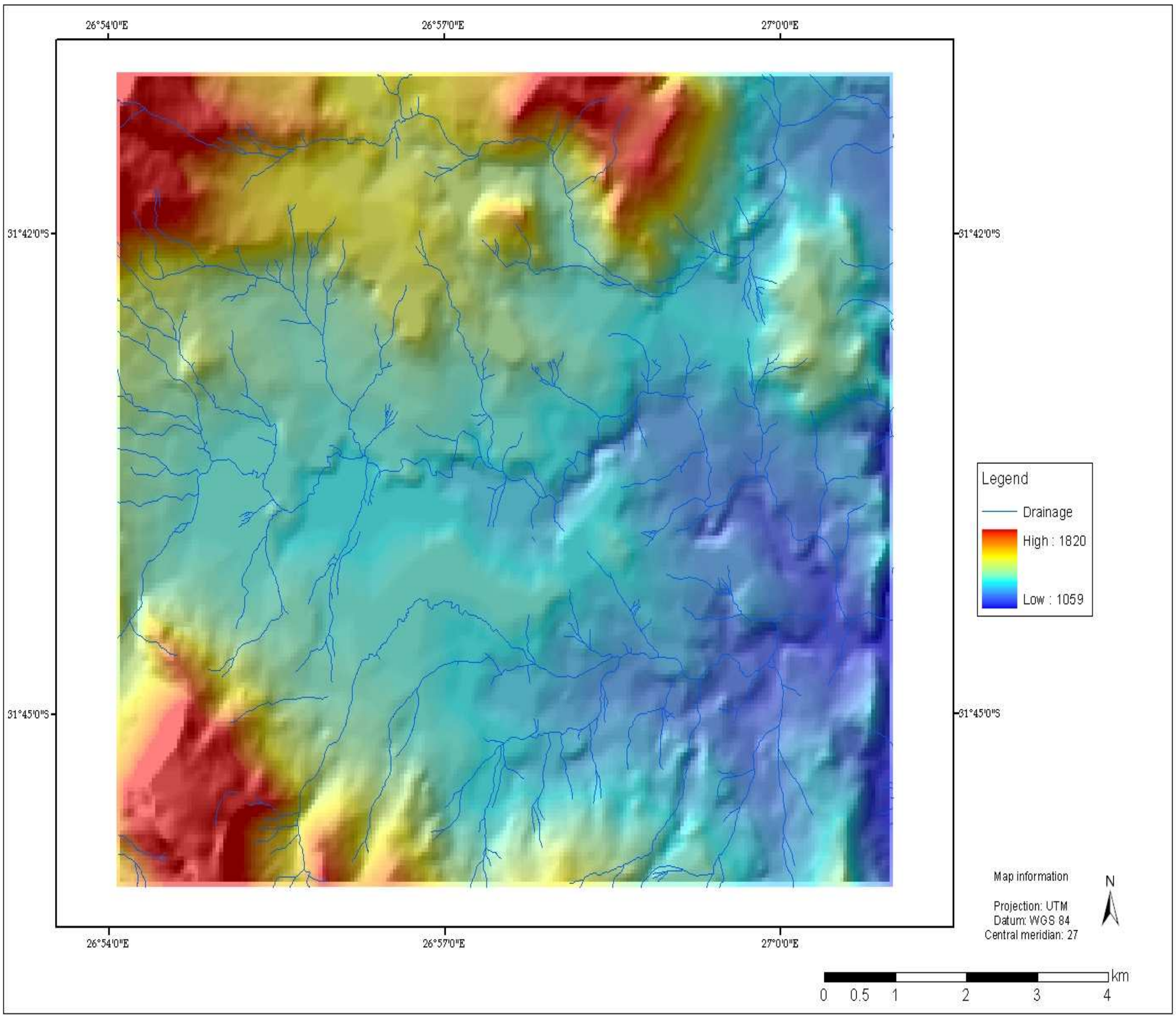


Figure 25: Drainage overlaid on 50 metre DEM of the study area

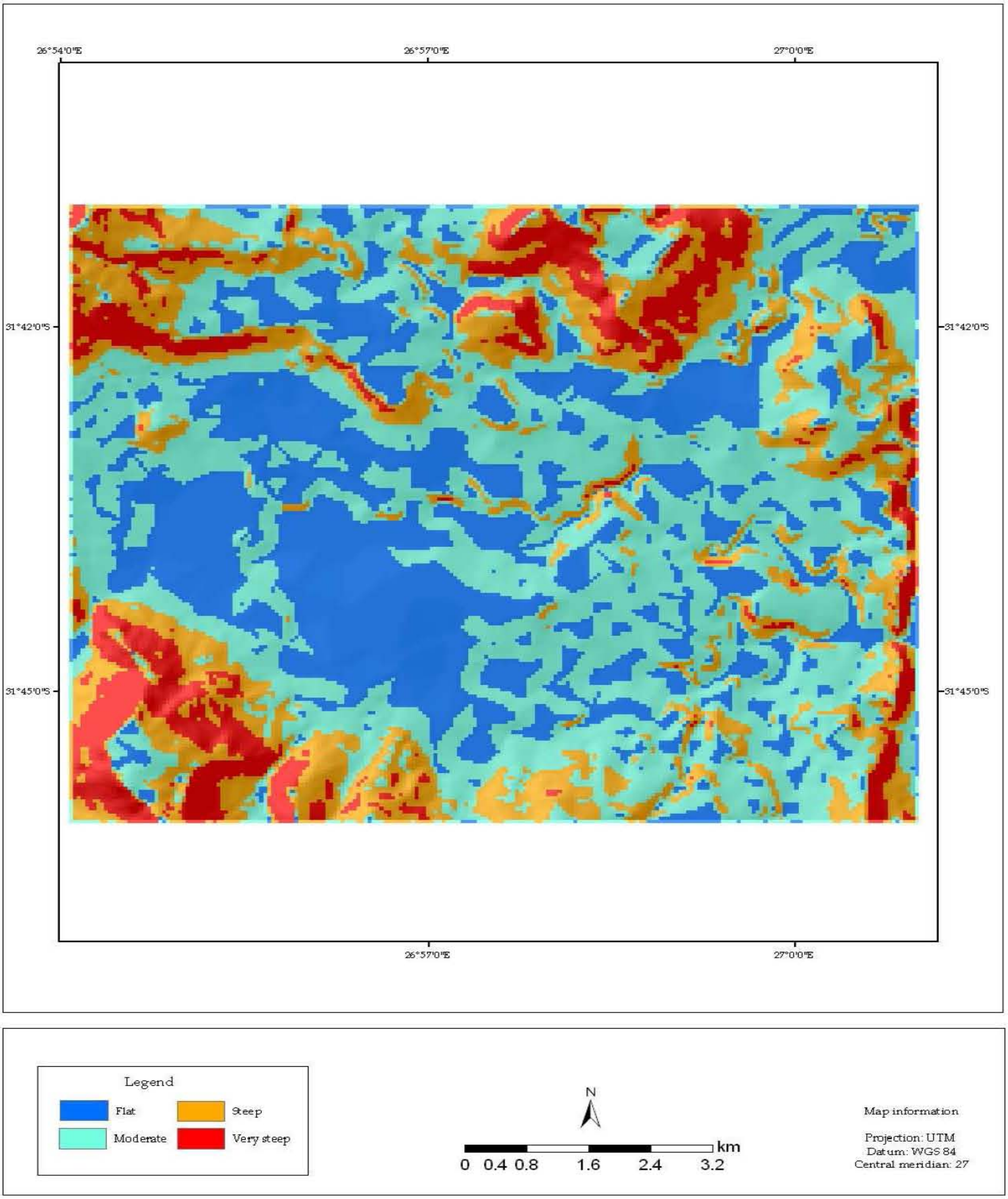


Figure 26: Slope map of the study area

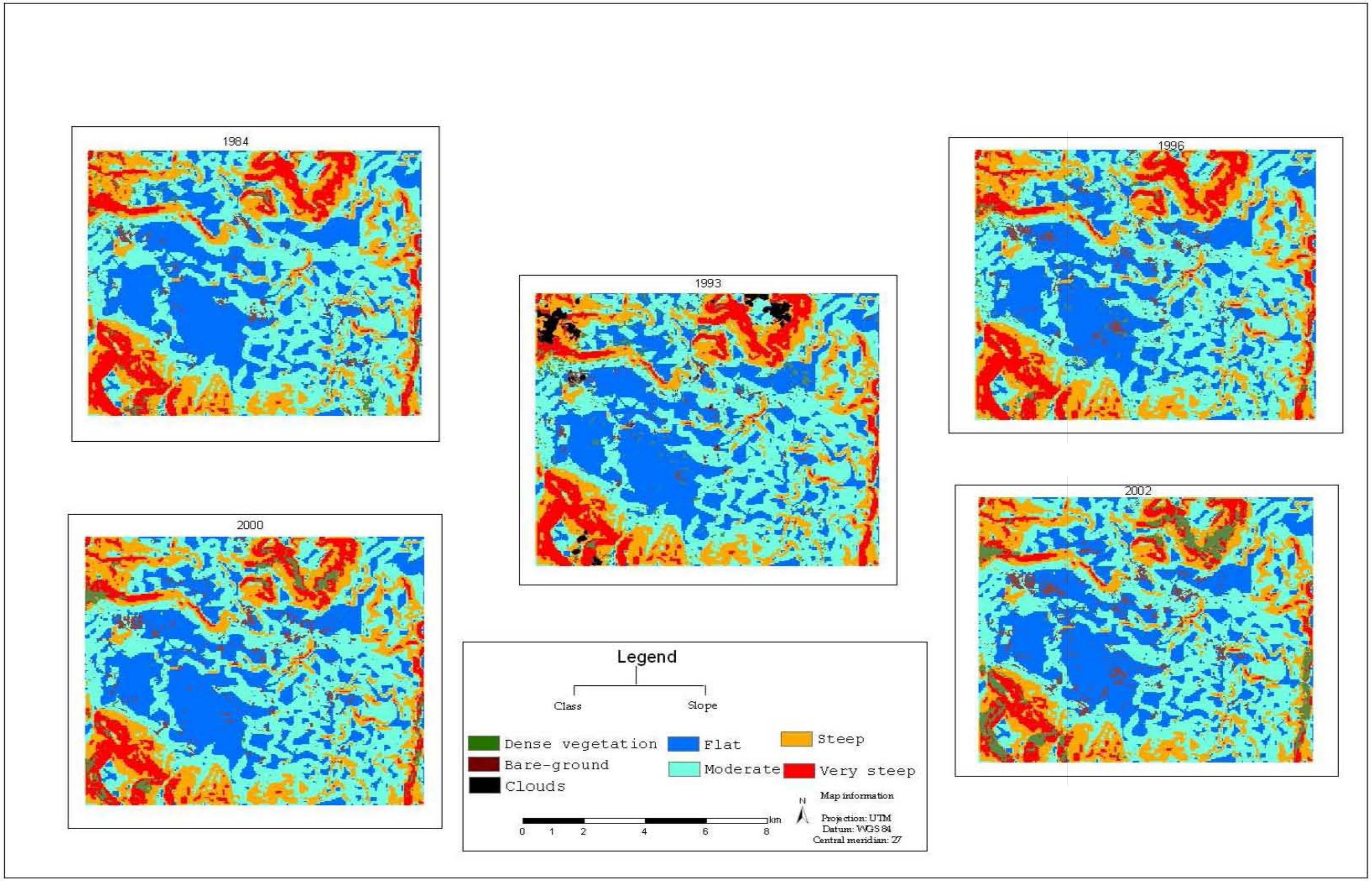


Figure 27: Slope map overlaid with vegetation and bare ground

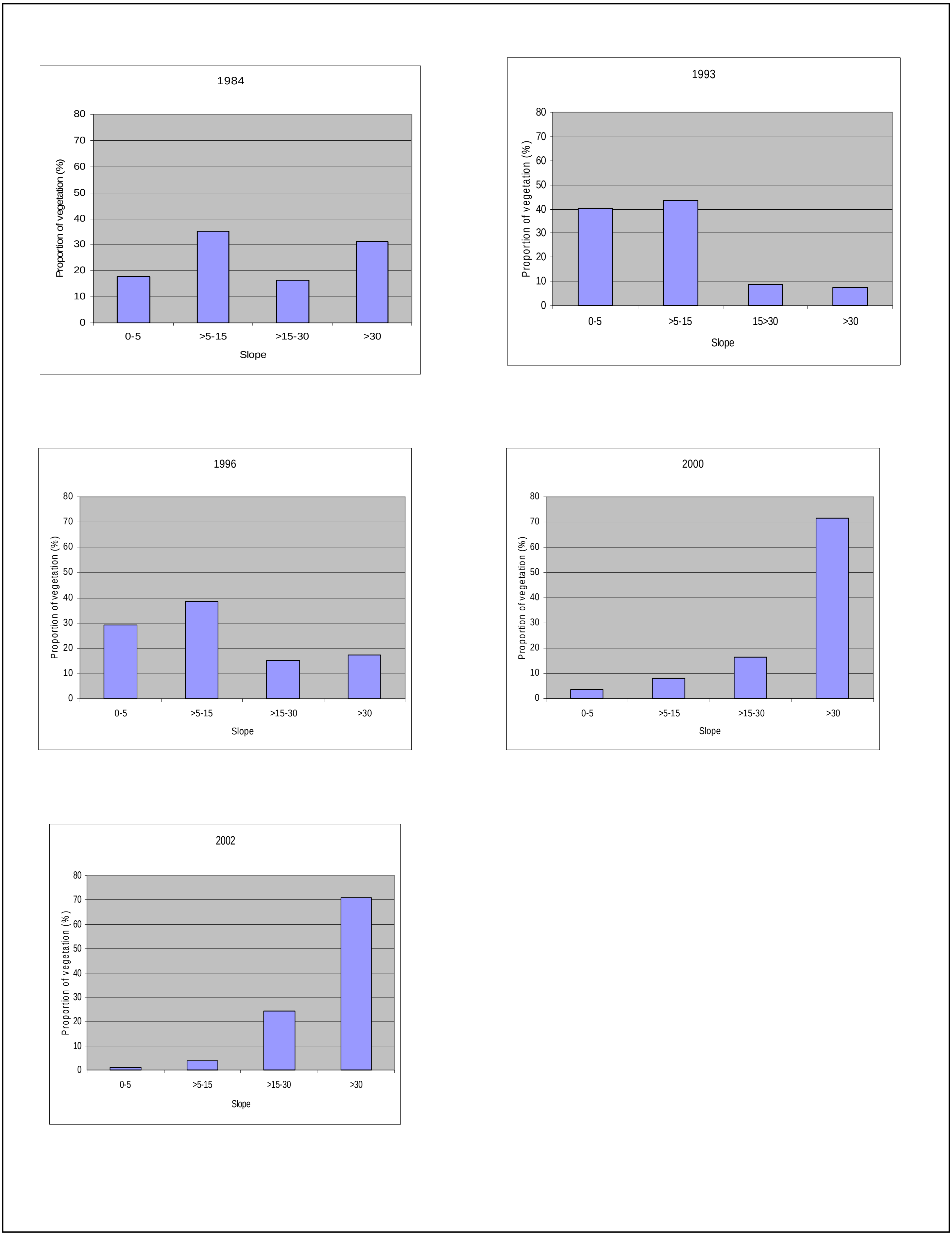


Figure 28: Proportion of vegetation on different slope categories at each date

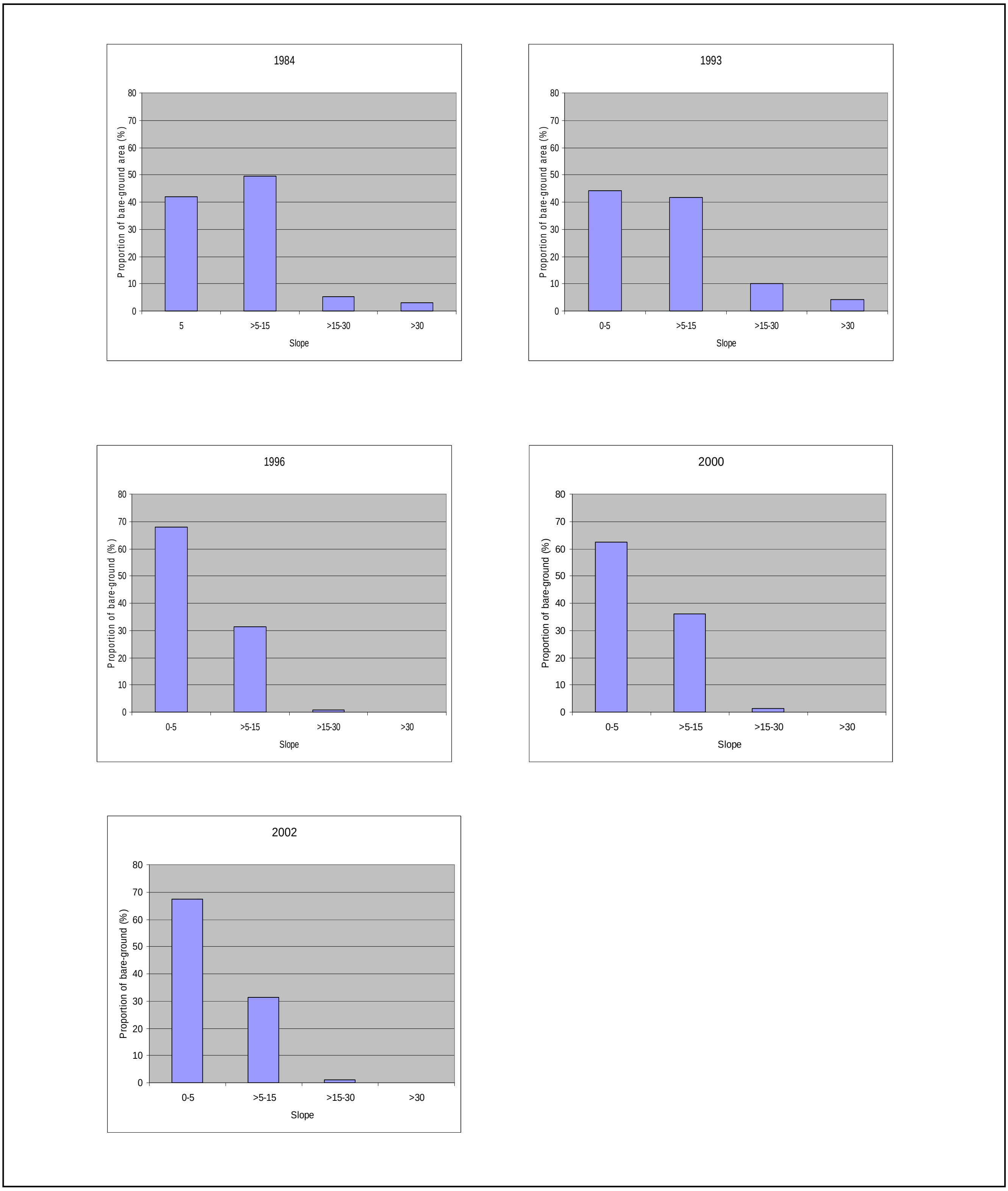


Figure 29: Proportion of bare-ground on different slope categories at each date

5.3.2 Geomorphology

The geomorphology of the study area (refer to Figure 30) is essentially controlled by the dolerite sills and rings (Jurassic in age) that are intruded into the red and greyish mudstone and yellowish sandstone of the Triassic Burgersdorp and Moletno Formations of the Beaufort Group (Hancox, 1998 and Groenewald, 1996). These dolerite sill/rings systems have a typical saucer shape structure with a flat lying inner sill at the base and a sub-circular inclined sheet on the rim (refer to Figure 31) according to the model proposed by Chevallier *et al.,* (2004).

The entire middle part of the Qoqodala ring is however overlain by recent alluvial deposits that can reach several meters in places and covered with a layer of organic soil. All erosional features in Qoqodala (dongas) are well developed in the loose deposits of the alluvial or soil profile. The geological map (1:250 000) of the study area mapped the underlying and sub-cropping rock and not the alluvium deposits. This has therefore led to the limitation of identifying the relationship of land degradation indicators relative to geology.

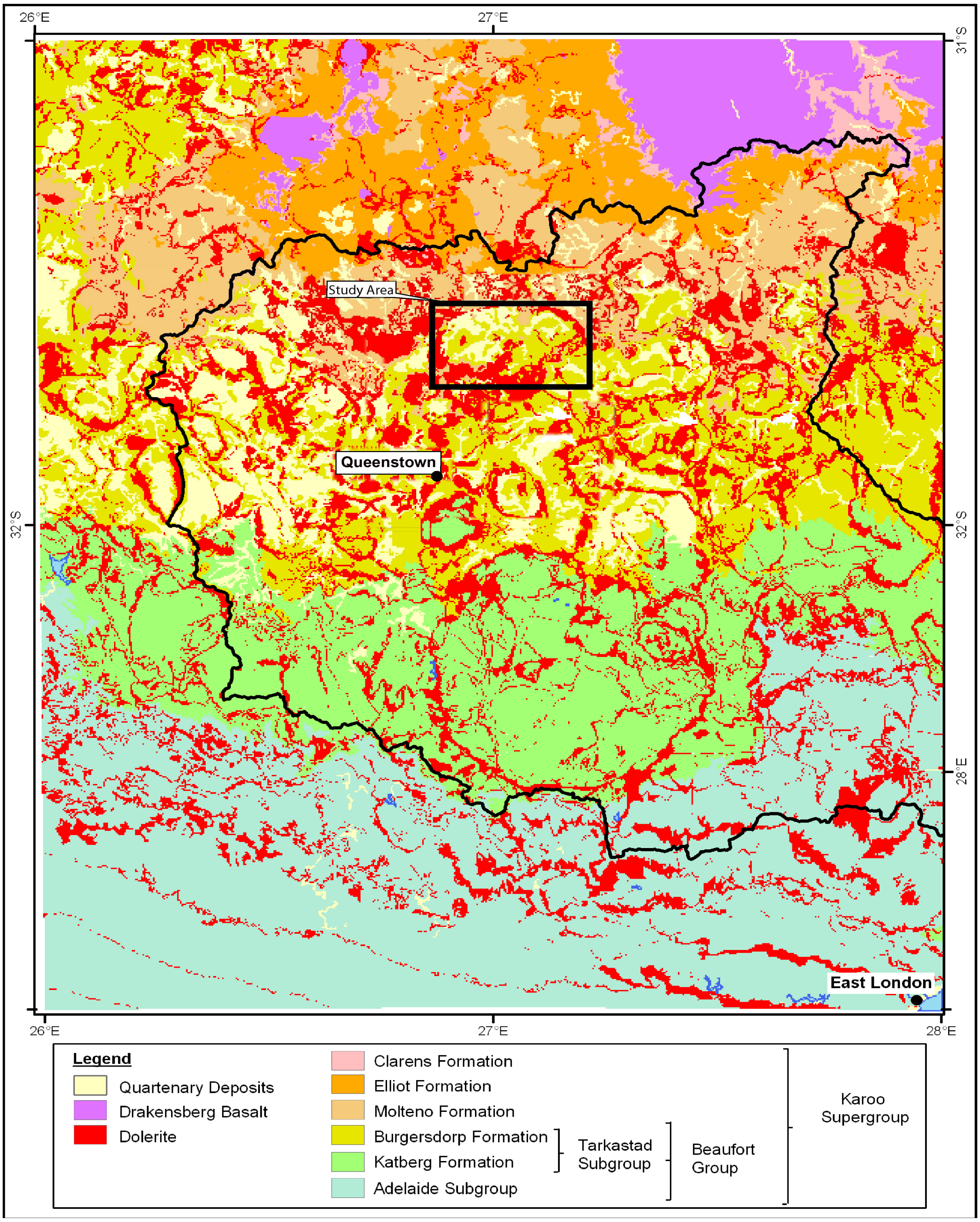


Figure 30: Geology of the study area (Source: Chevallier *et al.*, 2004)

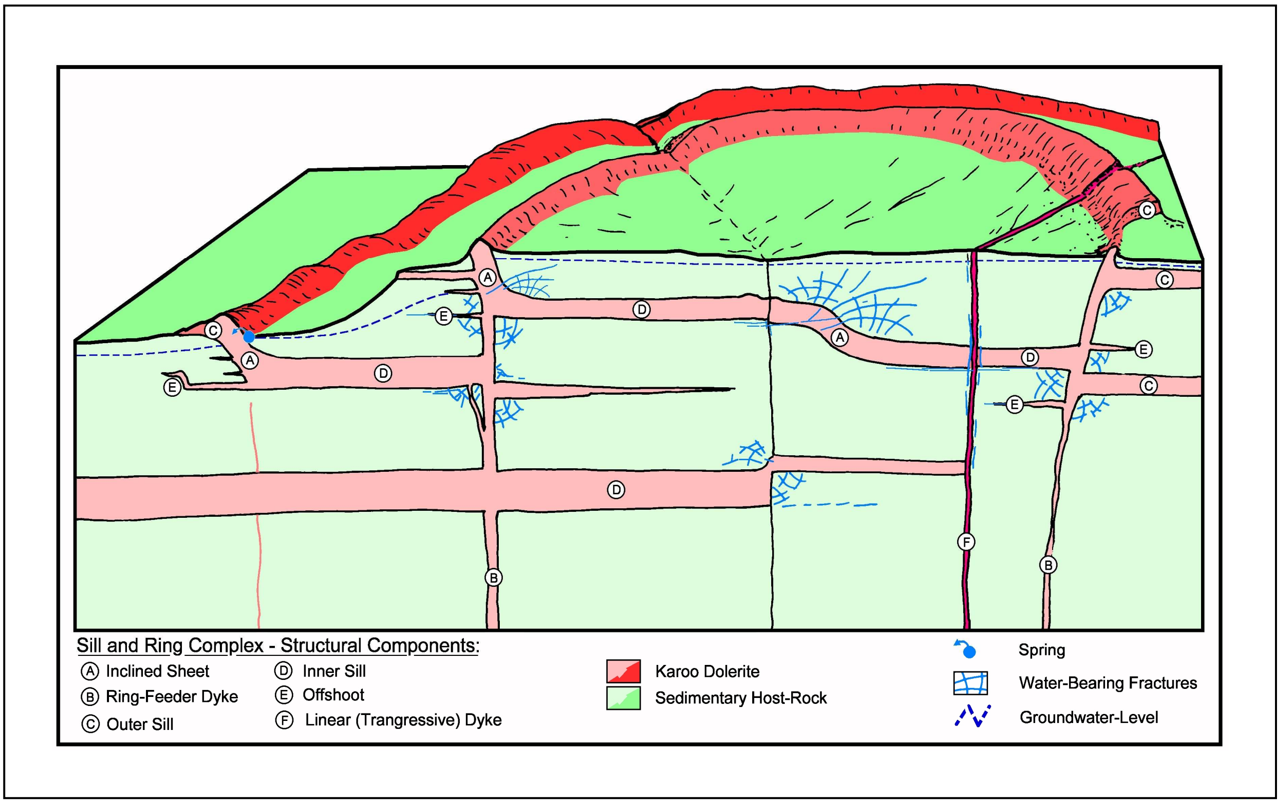


Figure 31: Hydro-morphology tactic model of Karoo dolerite rings and sills (Chevallier *et al.*, 2001) showing the relationship between inclined sheets, sills and rings.

5.3.3 Rainfall

The rainfall data for the study have been captured at Queenstown rainfall station. Figure 32 shows yearly rainfall in the study area from 1984 up to 2002. The years in which the 1984, 1993 and 2002 images were captured had relatively low yearly rainfall while year 1996 and 2000 had higher yearly rainfall. Figure 33 shows the monthly rainfall for each year in which an image was analysed (refer to Table 3 for image dates).

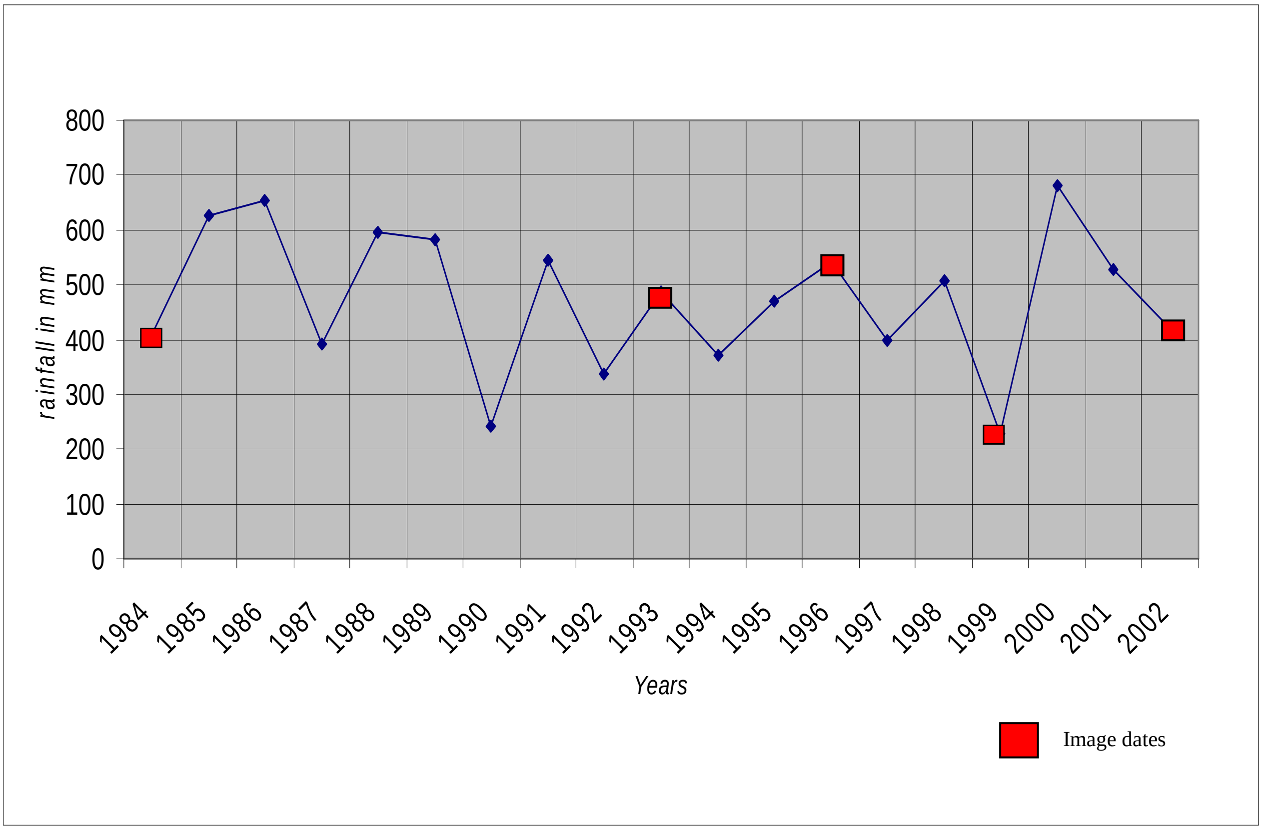


Figure 32: Yearly rainfall of Qoqodala for the period 1984 - 2002

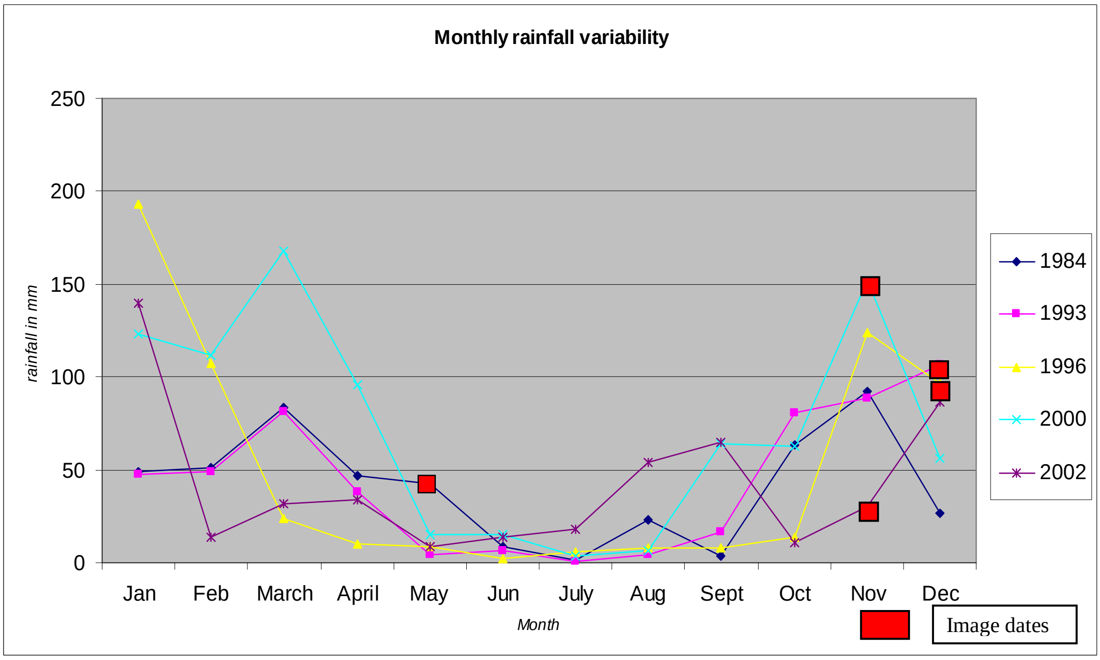


Figure 33: Monthly rainfall variability

The relationship of rainfall with vegetation cover and bare-ground of TCA and unsupervised classification techniques have been analysed and discussed in the discussion chapter.

Figure 34 shows relationship of vegetation cover and bare-ground of TCA technique with regard to yearly rainfall while Figure 35 show the relationship of dense vegetation cover and bare-ground of unsupervised classification technique.

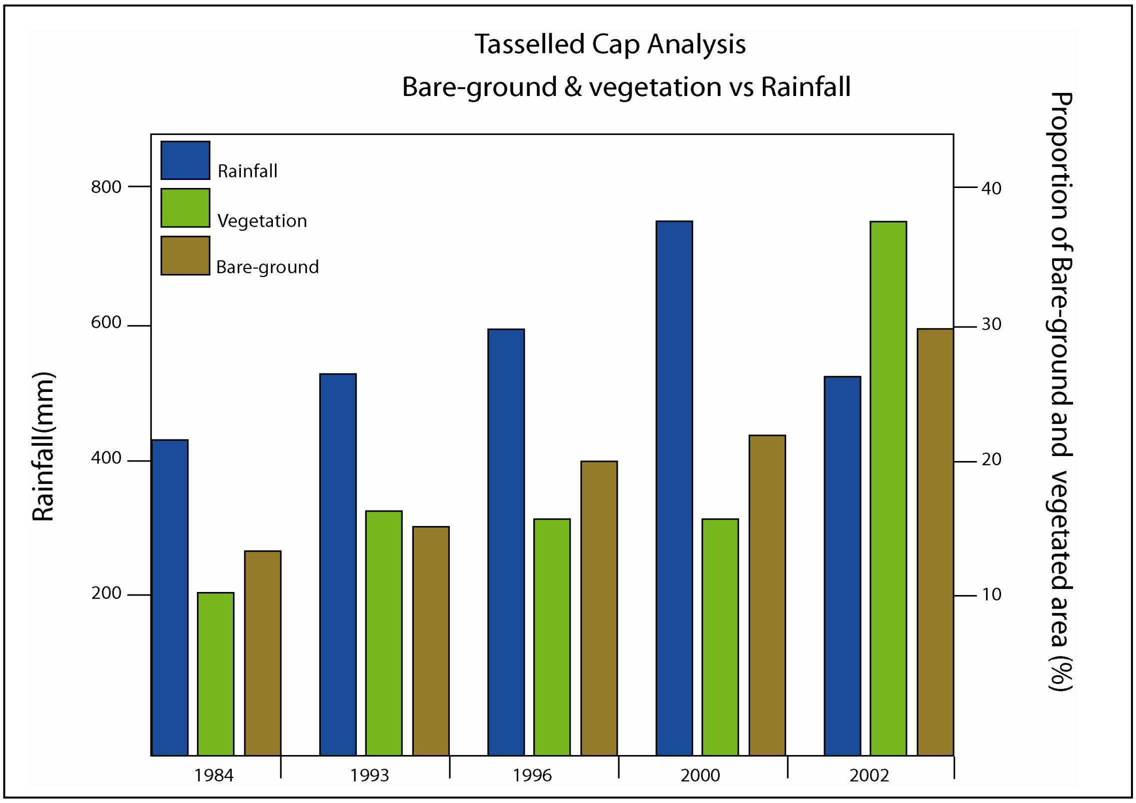


Figure 34: Relationship of yearly rainfall with the map results of vegetation cover and bare-ground produced by TCA technique

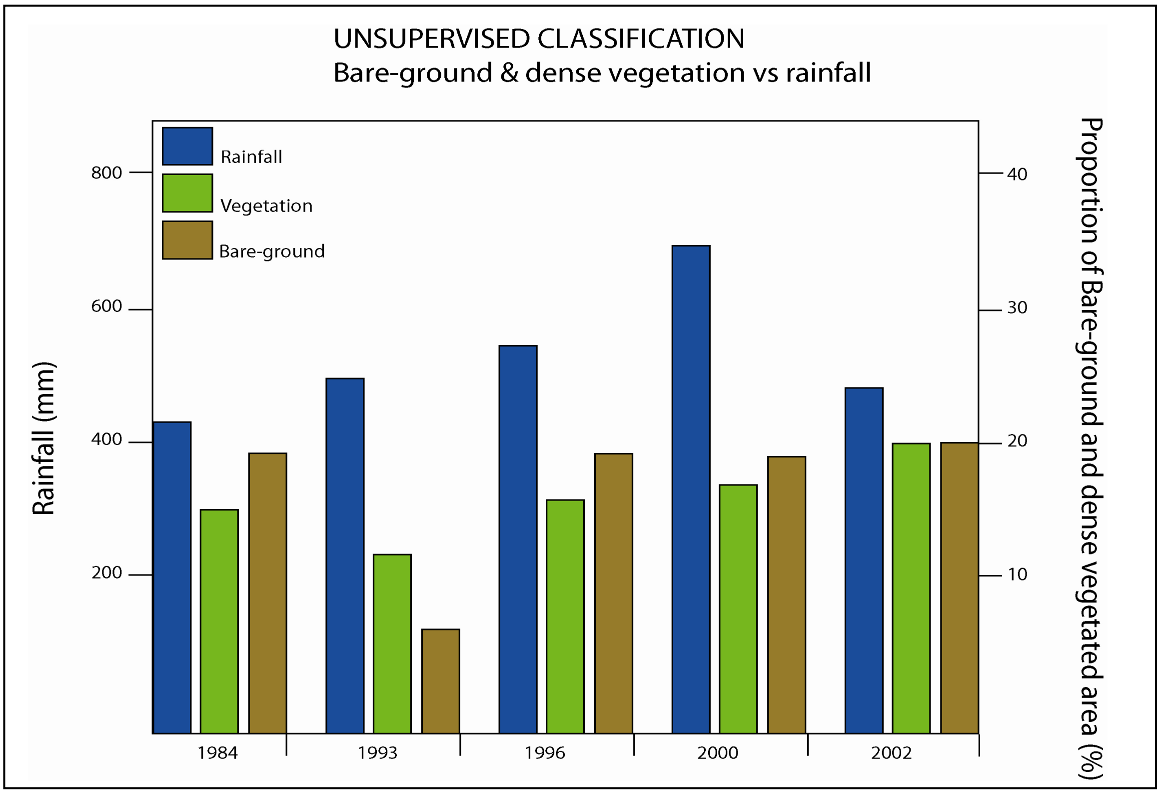


Figure 35: Relationship of yearly rainfall with the map results of dense vegetation cover and bare-ground produced by ISODATA unsupervised classification technique

5.4 Evidence of land degradation as observed in the field

Visual observation is also important for ground-truthing and verifying interpretations made in the desktop study. Indicators of land degradation observed in the field were erosion features such as rills and dongas and also anomalies such as dense vegetation which turned out to be an invasive species.

Ground observation points together with photographs were taken for the observed degradation feature. Points A, B, C, D, E and F were observed land degradation features which best represented examples of erosion and are further explained through photographs. The observed points were overlaid with 2002 image classification for analysing the relationship of the degraded features with regard to the classified image (refer to Figure 36).

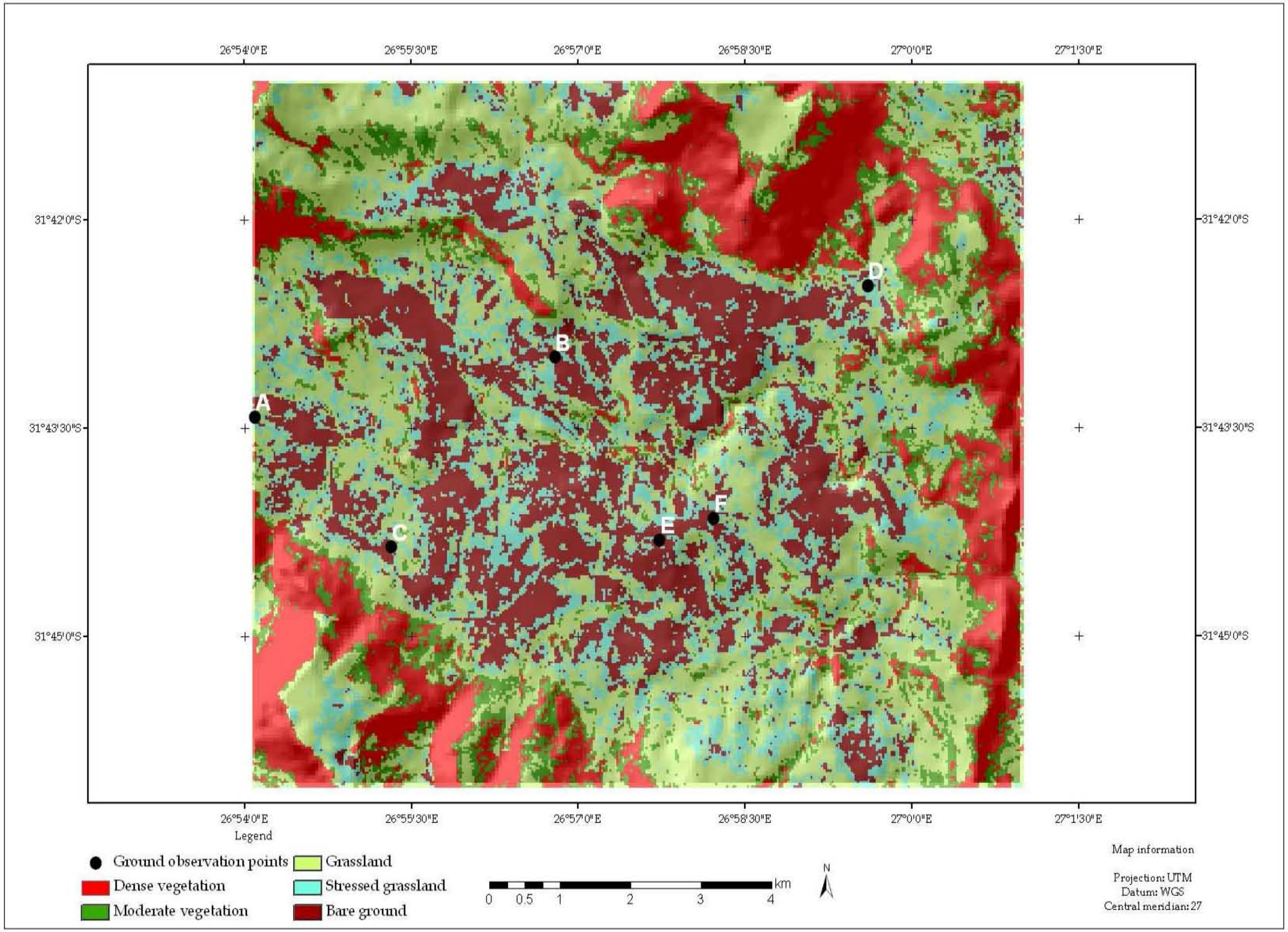


Figure 36: Ground observation points overlaid with 2002 image classification

Photographs that illustrate the observed points

The study focused on mapping of land degradation by remote sensing with reference to surface features, together with field visits and household interviews. Figure 37 shows land degradation points (from A to F) which were observed in the field and are further explained in Table 10.

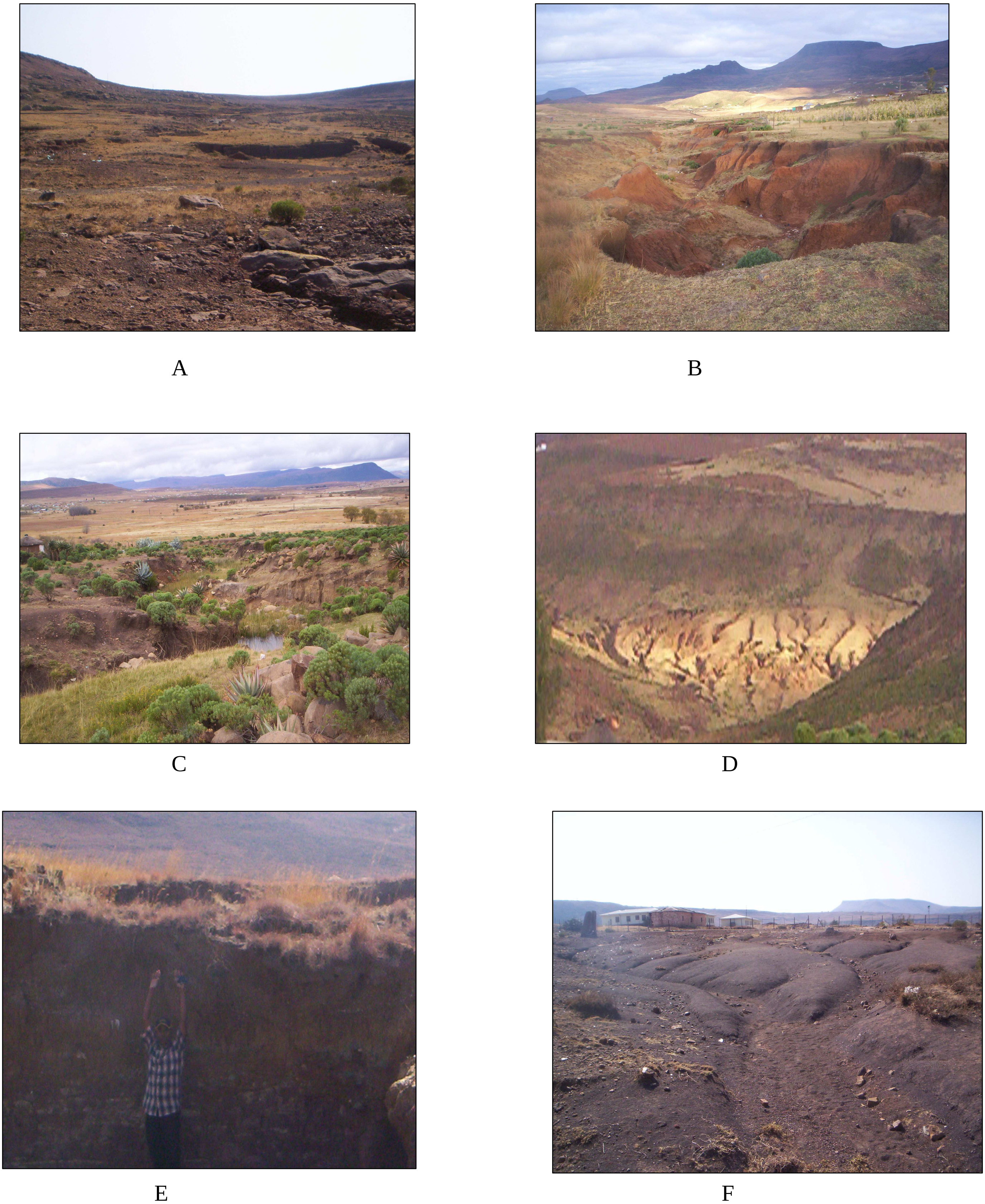


Figure 37: Observed land degradation features

Table 10: Ground observation points for land degradation features.

Ground observation points	Description
A	Sheet erosion on reduced grassland
B	Donga with some stabilised surface and some currently eroding surface.
C	Stream with bank erosion having gully development potential
D	Expanding gully network
E	Wall of donga showing depth of erosion
F	Early signs of gullying

5.5 Local perceptions on the history and extent of land degradation

In order to understand the overall environmental and socio-economic problems related to land degradation in the area, interviews were conducted to establish perceptions about land degradation and its current status.

A total of 14 interviews were carried-out with 32 people in isiXhosa and the majority of respondents were female (refer to Table 11). The interviews were held with individuals or groups of people who fell within a specified age range. The research covered the period from 1984 up to 2002 with image analysis (Landsat data). To establish a historical perspective from 1984 up to 2002, people in the 25 year age group and above were interviewed.

The semi-structured nature of the interviews allowed people to expand on certain issues which they regarded as important. All the respondents were friendly and their own perceptions on various issues were brought forward.

Table 11: Profile of the respondents

Age (years)	**Gender**		**Level of education**			
	Male	**Female**	**Informal education**	**Primary**	**Secondary**	**Tertiary**
25 - 30	2		1			1
30 - 35		1		1		
35 - 40	3	11	6	2	2	4
> 40	9	6	11	2		2
Total	14	18	18	5	2	7
Percentages	43.8%	56.3%	56.3%	15.6%	6.3%	21.9%

56.3% of the study sample population is largely illiterate or has only an informal education and cannot read (refer to Table 11). It has also been noted that not all interviewees were born in study area. 15% of the females came to the area after they got married. Females were the predominant respondents, due to the migration of males to the cities in the hunt for jobs. However to get different opinions teachers from Tyulu primary school and Lawini secondary school were also interviewed.

Different subsistence agricultural activities are practised in the area (refer to Table 12). 68.8% of the respondents recognised that land degradation is occurring in their area.

Table 12: Agricultural activities practised by respondents

Crop farming	**Stock farming**	**Both Stock & crop**	**None**
12.5%	18.8%	37.5%	31.3%

Mr Mqwathi highlighted the problem of donga expansion. He pointed out the problem he faces with a donga expanding into his yard, illustrated in Figure 38. All the crop farmers and those who stopped ploughing claim that their crop yields have declined. They argue that this is a result of several factors, one being a lack of government assistance, which was in place in the past (before 1994 elections). Mrs Hoho states that the government used to supply tractors and fertilisers to assist the community in the preparing phase of the soil for planting, but after 1994 this support ceased. This is said to have led to a decline in the volume of produce harvested compared to that planted.

37% of respondents who were involved in stock farmers were asked for their views on land degradation. The type (whether cattle, sheep or goat) and number of stock owned by an individual family was not considered, due to the sensitivity of such a question. Other questions though, related to how and what the stock was grazing on, were considered. The main problem cited by all the stockowners was that of encroachment of the grassland by the shrub *Euryops* also known to the local community as Lapesi (refer to Figure 39).

Figure 38: Mr Mqwathi shows us the donga which is slowly expanding towards his yard

Figure 39: Typical grassland in the study area, encroached by *Euryops* (Lapesi)

The summary of awareness of land degradation status by the community was based on their awareness of physical change in the area, soil erosion and vegetation change (refer to Table 13). Most of the respondents (84.4%) acknowledge that there is a decline in the physical status of their environment, while 68.8% are aware of soil erosion. Vegetation change was also considered as an important issue by the community. The increase of *Euryops* has been seen as a degradation feature by the respondents due to its invasive nature and its tendency to out-compete indigenous vegetation for growth.

Table 13: Overall land degradation awareness

A. Awareness of detectable features of land degradation

Awareness of physical change		
Decline	**Improvement**	**Unnoticed change**
84.4%	0%	15.6%

B. Awareness of soil erosion

Erosion		
Yes	**No**	**Not aware**
68.8%	0%	31.3%

C. Awareness of vegetation change

Depletion	**Increase**	**Not aware**
56.3%	34.4%	9.4%

D. Nature of land degradation

Natural	**Human-induced**	**Not sure/ no comment**
21.9%	6.3%	71.8%

CHAPTER 6: DISCUSION

The main aim of this study was to investigate the extent and nature of land degradation within the study area over time. To address the mentioned aim, vegetation and bare-ground have been the chosen indicators of land degradation to be assessed and their results are presented in the previous chapter. In this chapter the results from the Remote Sensing processing, GIS analysis, ground truthing (field investigation) and interviews of the local community are discussed in an attempt to explain the findings of land degradation in the study area.

6.1 GIS and Remote Sensing

To achieve the objectives of the study the visual analysis of the images (1984, 1993, 1996, 2000, and 2002) was first carried through RGB band combination.

The analysis of vegetation was first through RGB band combination 321 true colour composite and 432 false colour composite. It was observed that through true colour composite, visual portion indicating vegetation have been shown by a green colour (refer to Figure 17). This band combination however did not clearly reveal for visual analysis all the vegetated areas hence a false colour band 432, which is suggested as a good combination to indicate vegetation (Jensen 1996) was computed. A vegetation increase from 1993, 1996, 2000 and 2002 as compared to 1984 is seen to increase from one time period to the next.

The true colour composite 321 and false colour 573 have also been analysed in order to establish bare-ground. The importance of using colour composite in detecting bare ground is acknowledged by Van Trinh *et al.*, (2004) and Gobena (2003). True colour composite resulted in brown to bright colours within the images being detected as bare-ground. False colour composite of 574 which is also suggested as a good combination to indicate bare ground (Jensen 1996) was computed (Band 5 and 7 are said to be good indicators of soil while band 4 is good for vegetation (Mather, 2003)). The green colour within the images shows areas of bare-ground while blue indicated vegetated areas (refer to Figure 18). To enhance the information obtained from the RGB band combination technique, Tasselled Cap and image classification techniques were computed.

6.1.1 Tasselled Cap Analysis (TCA)

Better understanding of vegetation cover and bare-ground status has been achieved through the TCA technique. As mentioned in the results chapter TCA results in three bands, brightness, greenness and wetness. The greenness band was analysed in order to gain further understanding of vegetation cover as an indicator of land degradation while the brightness band was used to gain better understanding on bare-ground. The results of TCA are shown by Figure 22.

The results showed an increase in vegetation cover from 1984 to 1993, a slight decrease from 1993 to 1996, further increase from 1996 to 2000, with a vast increase from 2000 to 2002 (refer to Figure 22). The yearly vegetation cover change analyses have also been calculated. Each year from 1984 to 1993 vegetation cover has increased by 0.5%, while from 1993 to 1996 each year experienced a decreased of -0.3. The vegetation cover experienced an increase of 0.25% in each year during the 1996 to 2000 period and further experienced a vast increase of 10.5% per year during 2000 to 2002 period (refer to Table 5 and Figure 40).

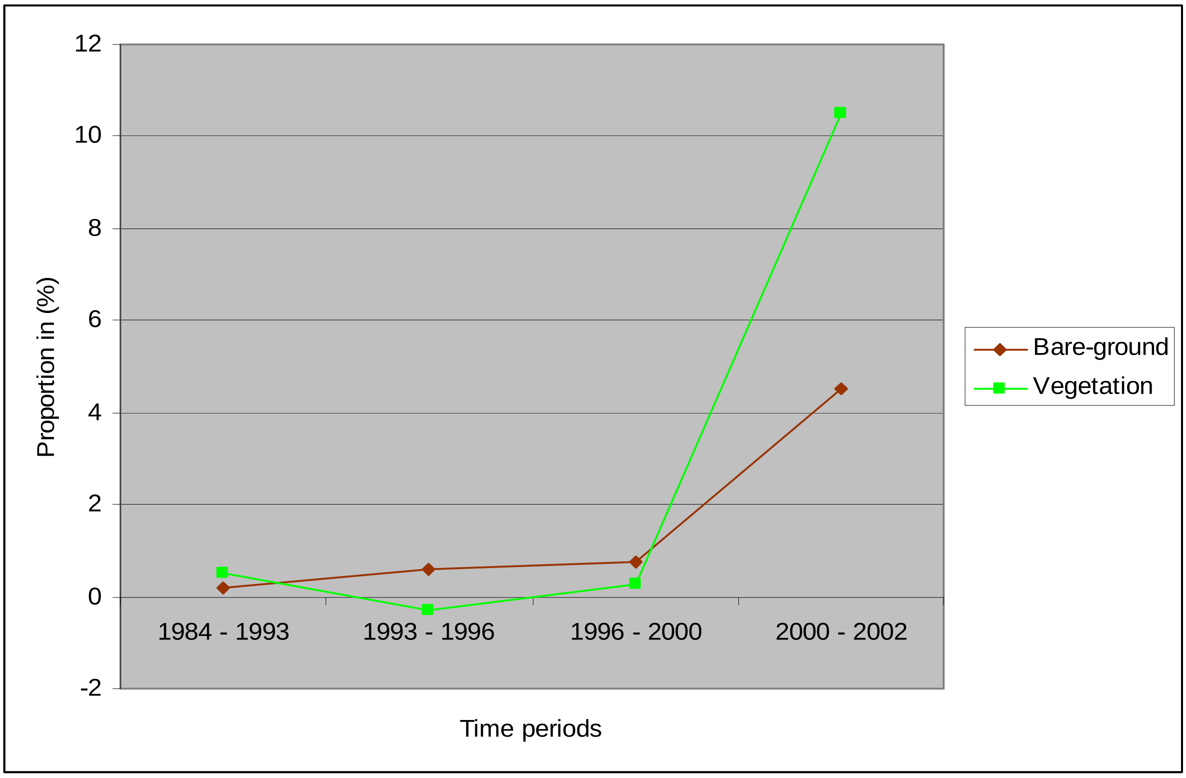


Figure 40: Average annual rate of change

It has been mentioned by several authors (Florencia 2003, Meadows and Hoffman 2002 and Stocking and Murnaghan 2000) that a vast vegetation decrease or increase are signs of land degradation. De Baets *et al.,* (2006) further argue that removal of vegetation cover may lead to the acceleration of soil erosion as the soil shear strength is reduced. Acknowledging this however other authors (Palmer *et al.,* 1999, Evans and Geerken 2004, Kakembo *et al.,* 2007 and Hoffman *et al.,* 1999) also mentioned that vast increase of vegetation may be the result of invasion of indigenous vegetation by shrubs. In this study the cause of the vast vegetation increase in vegetation during the period of 2000 to 2002 could not be explained by TCA. However information obtained from interviews explains that the increase of vegetation is the result of E*uryops* invasion. Kakembo *et al.,* (2007) argues that there is no simple explanation as to why some biomes and regions are more susceptible to invasion.

The brightness band as mentioned has been used to study bare-ground. The results revealed that there was a bare-ground increase for all the years from 1984 up to 2002 (refer to Figure 22). The yearly increase rate from 1984 to 1993 was 0.2%, from 1993 to 1996 was 0.6% , 1996 to 2000 was 0.75% and 2000 to 2002 experienced a vast increase of 4.5% (refer to Table 5 and Figure 40). Kakembo (1997), Florencia (2003) and Stocking and Murnaghan (2000) argue that increase in the proportion of bare-ground is a sign of land degradation and further mentioned that (Stocking and Murnaghan 2001) the rate of soil erosion on bare-ground is faster than the rate of soil formation causing irreversible degraded features. Acknowledging this Bakker *et al.,* (2005) argue that soil erosion reduces productivity on average of about 4% for each 10cm of soil lost. Photographs from the field visits give evidence of the current degradation features in the study area which are extensive.

Bakker *et al.,* (2005) further argues that soil erosion is the process that strongly varies in space. Therefore to further investigate one of the objectives of the study which is to determine the spatial characteristics of degraded land, vegetation cover and bare-ground occurrence in relation to slope was analysed (refer to Figure 28 and Figure 29). The vegetation cover show change from occurring on flat and moderate slope in 1984, 1993 and 1996 to occur on steep slopes in year 2000 and 2002, while bare-ground was found to occur on a moderate to flat slopes in all the images. Hoffman *et al.,* (2001) argue that there are still conflicting and inconclusive results as to whether erosion occurs more on short steep slopes or on long flat slope. In this study the decrease of vegetation cover on flat and moderate slopes to steep and very steep slope led to an increase of bare-ground (which is an erosion indicator) from flat to moderate slope. Hoffman *et al.,* (1999) further argue that the relationship of the rate of erosion with regard to slope is also affected by whether the land has been disturbed or not. He argues that disturbed lands erode faster than undisturbed lands on any slope. It has been mentioned through interviews that in this study area moderate to flat slopes have been used for ploughing in past while steep and very steep slope have been left unaltered and only utilised for grazing. This has resulted in the development of erosion features (such as rills and gullies) on flat and moderate slope (refer to Figure 37). Chevallier *et al.,* (2004) mentioned that the steep to very steep slopes of the study area is controlled by dolerites which are not susceptible to erosion while moderate to flat slopes are characterised by thick alluvium which is easy to erode. The interviewed respondents have also acknowledged the increase of bare-ground on flat to moderate slope. They argue that the reason for high occurrence of bare-ground on moderate to flat slopes is due to the lack of ploughing (on such slopes) by same community members which was happening in the past. They also mentioned that heavy rains which occur in the area remove the loose top soil. Photographs from field visit (refer to Figure 37) give evidence of degradation features occurring on moderate to flat slopes. Kakembo *et al.,* (2007) acknowledges this and states that gully erosion targets deep soils in hallow or concave lower slopes.

"In the past, much of the blame for land degradation has been placed on the people's use or abuse of soil and vegetation resources, without recognising the often subtle interactions that exist between climate patterns and land use" (Hoffman *et al.,* 1999, p65). Climate change plays an important role in land degradation due to its effects on hydrological cycles and temperature changes. It is argued by the WMO (2005) that the extremes of either too much or too little of rainfall can affect soil erosion, hence rainfall of the study periods has been analysed. The rainfall records of the study area show fluctuation in average rainfall with low rainfall of 400mm in 1984 and 2000 and higher rainfall in 1993 and 1996 reaching a high of 680mm in year 2000 (refer to Figure 32).The monthly rainfall for each year was also analysed. The capturing dates of images are shown in Table 3 and its relation to monthly average rainfall further shown by Figure 33. Image 1984 has been captured in a low rainfall month as compared to the other image dates. This is because it has been captured during winter season. This is drawn from the fact that vegetation cover increase with increasing rainfall. An anomaly is observed in 2002 where vegetation cover increased drastically with a vast decrease of rainfall (refer to Figure 34). To gain further understanding of rainfall relationship with vegetation cover, a monthly rainfall was analysed. The monthly rainfalls of 2002 showed a high rainfall during the month when the 2002 image was captured. This may explain the increase of vegetation cover despite the low annual rainfall average.

The bare-ground relationship with rainfall was also analysed. The bare-ground showed a positive relationship with rainfall. The bare-ground increased with the rainfall increase from 1984 to 2000 except in 2002 where bare ground experienced an increase while rainfall decreased (refer to Figure 34). The reason for such an anomaly is the same as for the vegetation cover mentioned above. It has also been mentioned by WMO (2005) that in areas where there is little or no vegetation cover, rainfall erodes the soil. In this study bare-ground result from TCA increase is related to yearly rainfall increase.

6.1.2 Image classification

The use of a post-classification technique in land degradation studies through detection of land use and land cover change is recommended by Weismiller *et al.*, (1977) and Wickware and Howarth (1981) cited by Tardie and Congalton (s.d). The post classification within the study area is derived from comparing unsupervised ISODATA classification of different dates (1984, 1993, 1996, 2000 and 2002, refer to Figure 24). Unsupervised classification of each image resulted into 5 classes (Dense vegetation, Moderate vegetation, Grassland, Degraded grassland and Bare-ground). Dense vegetation and Bare-ground land cover type results were compared with those of TCA (refer to Figure 41). The results are similar, with bare-ground from unsupervised classification showing a decrease in 1993 and further increased from 1996 to 2002, while bare-ground from TCA shows a steady increase through out the study years. The dense vegetation cover from unsupervised classification shows a decrease in 1993 and an increase in 1996 to 2002. However the vegetation cover from the TCA shows an increase in 1984 to 1993 and a decrease in 1996 with further increase in 2000 and 2002. The results of these analyses (unsupervised ISODATA classification and TCA) both characterised an overall increase of bare-ground and vegetation cover (refer to Figure 41). Florencia (2003) and Stocking and Murnaghan (2000) have been mentioned stating that the increase of bare-ground is an indicator of land degradation. In this study through interviews and field visit the bare-ground increase also highlights land degradation increase. The increase of bare-ground in this study therefore indicated the high chances of soil loss and gully development. Photographs from field visit also show gullies occurring on bare-ground areas.

De Baets *et al.,* (2006) argue that vegetation cover reduces soil erosion by intercepting raindrops, enhancing infiltration and provides soil shear strength. In this study vegetation increase does not mean more soil is protected but rather acts as a sign of degradation. This is a result of invasion of indigenous vegetation by *Euryops*. Mr Frikkie Coetzee (an environmental rehabilitator in the neighbouring catchment) argues that an invasion by *Euryops* depletes natural vegetation cover. This therefore results in bare-ground patches which further increase over time. Acknowledging this Kellner and Bosch (1992) cited by Van de Berg *et al.*, (2005) states that degradation generally starts with the formation of small areas or patches that expands and join together to form a large bare and denuded areas in the long term. The respondents from the local community also acknowledge that the *Euryops* reduces natural vegetation cover. Kakembo *et al.,* (2007) have argued that invasive species out-compete the indigenous vegetation for growth, which explains such an increase of *Euryops.*

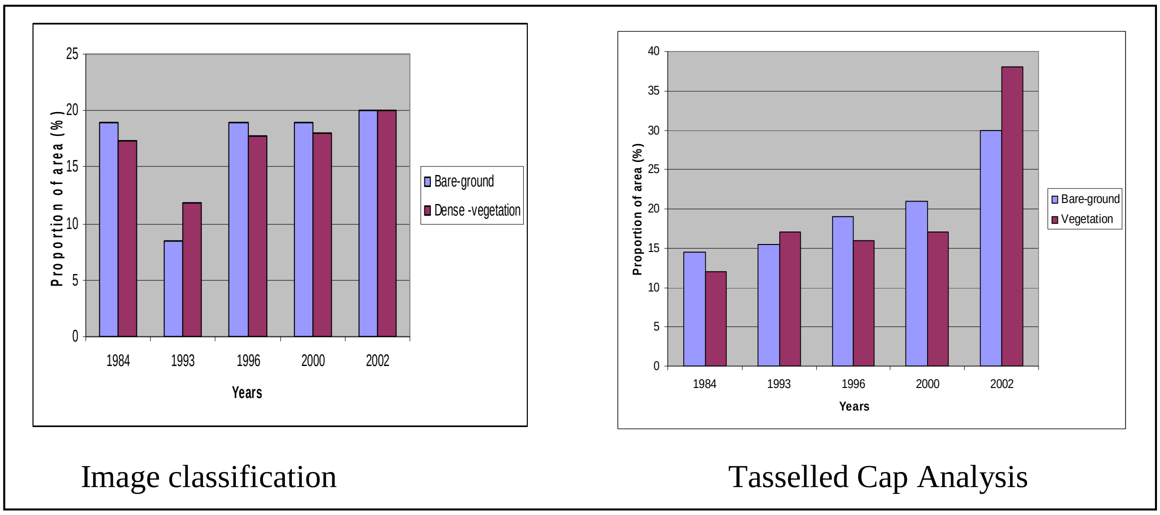


Figure 41: A comparison of differences in bare-ground and vegetation cover of TCA with the bare-ground and dense vegetation. cover of unsupervised classification

The relationship of dense vegetation cover and bare-ground from the unsupervised ISODATA classification with rainfall were analysed. The dense vegetation cover showed a negative relationship with rainfall. In 1993 dense vegetation showed a decrease with an increase in rainfall and in 2002 dense vegetation cover showed an increase with a decrease in rainfall (refer to Figure 35). This result is similar with the relationship of rainfall and vegetation cover of TCA, where vegetation cover increase in 2002 with decrease in rainfall. However Van de Berg *et al.*, (2005) argue that vegetation changes generally occur unpredictably in short term (years) in response to rainfall and episodically in response to long term (decades). The increase of rainfall from 1984 to 2000 explains the increase of vegetation in 2002.

Bare-ground relationship with rainfall was also analysed. The results revealed a negative relationship of bare-ground and rainfall. Bare-ground showed a decrease in 1993 in relation to the rainfall increase and further showed an increase in 2002 in relation to the rainfall decrease (refer to Figure 35). However WMO (2005) argue that the value of surface runoff is also important in determining soil erosion. It is argued that without surface runoff the amount of soil erosion by rainfall is relatively small. Due to time and financial constraints the study could not analyse surface runoff. The overall increase of bare-ground by unsupervised ISODATA classification is similar to the results by TCA.

6.2 Field observation and local perceptions on the history and extent of land degradation

Field survey and household interviews were conducted in order to gain holistic information on local knowledge, history and nature of land degradation within the study area. Ground observation points together with photographs of the observed degradation features were captured (refer to Figure 36 and Figure 37). Some of the observed features of degradation were sheet erosion, rills and expanding gully networks (refer to Figure 37) which were occurring on bare-ground. Poesen (2003) cited by De Baets *et al.,* (2006) have been mentioned arguing that gullies are great in bare-lands than covered lands. Bare-ground have been detected by both TCA and unsupervised ISODATA classification techniques. The deterioration of healthy vegetation cover as the sign of vegetation degradation mentioned by Kakembo *et al.,* (2002) could not be mapped by TCA. This is due to the fact that the green band of TCA only detects healthy vegetation and the results of the time series analysis showed an increase in vegetation cover (refer to Figure 22). Horta (2003), Kakembo *et al.,* (2007) and Wessel *et al.,* (2004) argues that changes in vegetation degradation are revealed gradually, sometimes not only in terms of biomass decrease in an area but through loss of species diversity, increase in invasive species and reduction of woody species. During a field survey an invasion of *Euryops* have been observed (refer to Figure 39). The *Euryops* have the same spectral reflectance as the natural vegetation and therefore could not be separately detected by Landsat images. It therefore contributed in results revealing vegetation increase in the study area.

To gain local perception on the history and extent of land degradation in the area questionnaires were conducted (refer to annex 1). Dzivhani (2001) however argues that a variety of factors influence how people consider and perceive degraded conditions. Acknowledging this, Kinlund (1996) argue that various factors lead to some degraded lands (although they are visible) being overlooked at, except by those who are directly affected.

The questionnaires were therefore designed to stimulate conversation rather than elicit precise response in order to gain holistic perception of the interviewees on land degradation. First requested information was about establishing the background of the interviewees in order to obtain as much knowledge about them. The next section of interviews was to get general information about the knowledge of an area and land use practices. The questioners then asked in more detail about land degradation particular soil erosion and vegetation loss.

Respondents identified land degradation as the decline of food production, increase of dongas, decline of grasslands, vast increase of *Euryops* and high rainfall during rainy seasons which washes crops and top soil away. The understanding of land degradation by the respondents incorporates both vegetation and bare-ground which are chosen land degradation indicators to be assessed and monitored in this study.

Most of the respondents recognized that there has been a decrease of grassland with an increase of *Euryops*. Awareness of this situation came from 56.3% of the sample group, while 34% did not recognize *Euryops* as an encroaching species depleting grassland and natural vegetation in the area. Then 9.4% of the respondents were not aware of such changes to their environment (refer to Table 13). The respondents further recognised that there have been dongas ever since they have been in the area, and that they have expanded over the years. Figure 38 highlights one of the donga expansion as observed by Mr. Umqwathi. The reduction of grassland and in some cases complete decline has been noted as the one factor that led to donga expansion in the area. Mrs Desemile stated that some people have stopped ploughing (because of various reasons) and this has also led to the slow expansion of dongas in the plough fields. Some of the reasons to stop ploughing were said to be lower production relative to the input, and lack of government support towards maintenance of the fertility of the soil. 68% of the respondents are aware of land degradation. They argue that heavy rains in the area cause floods that leave new donga developments (especially in the fields were ploughing have been stopped) which expands every time the process repeats. The remaining 31.3% of the respondents are still not aware of land degradation in the area.

6.3 Summary

Land degradation through vegetation and bare-ground indicators have been assessed and monitored by the three techniques used in this study. The bare-ground increase identified by TCA and unsupervised ISODATA classification has been assessed as an increase in extent of bare-ground, rills and donga by the respondents. In addition to this areas which showed bare-ground increase by unsupervised ISODATA classification were observed as rills and dongas during field visits (refer to Figure 36 and Figure 37). The occurrence of dongas on flat and moderate slopes was because of the soil disturbance through ploughing on such slopes.

The increase of vegetation assessed through TCA and unsupervised ISODATA classification techniques have been related to *Euryops* encroachment in the study area. Respondents argue that *Euryops* out-competes indigenous vegetation species for growth in the area. This has been noted by Kakembo *et al.*, (2007) as a major characteristic of invasive species. The results of these three techniques complement each other. This study acknowledges what have been mentioned by other authors (Dzivhani 2001, Kinlund 1996 and Florencia 2003) who studied land degradation that human memories, experience and perceptions together with remote sensing techniques are important source of information towards land degradation studies.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

It has been mentioned that land degradation is complex and need a multi-disciplinary approach in order to obtain a holistic picture towards its assessment and monitoring. Acknowledging this Florencia 2003, states that an increase in information of land use and land cover dynamics is important in order to achieve land use sustainability.

To understand more the challenges of the aim of the study, four objectives were highlighted (refer to page 3). A literature review was conducted in order to get some insight into the problem of land degradation. Literature showed that the current problem has many different dimensions and aspects. Through this, two main indicators of land degradation were focused on, namely

1. Changes in bare ground and
2. vegetation cover

The colour composite (RGB band combination) tasselled cap analysis, unsupervised ISODATA classification, and household survey were used techniques towards land degradation in Qoqodala.

The RGB band combination gave the overview of land degradation through visual analysis of land degradation indicators (vegetation cover and bare-ground). The results of the RGB band combination could not quantify the change of the assessed degradation indicators and therefore led to the choice of TCA and unsupervised ISODATA classification techniques.

TCA technique as mentioned in chapter 5 (5.2.2) reduces the six Landsat bands into three bands namely: brightness, greenness and wetness. The brightness band was used for bare-ground detection while the greenness band was used to detect healthy vegetation cover. The result of the brightness band revealed an increase of bare-ground from the assessed years of study (1984, 1993, 1996, 2000 and 2002). The vegetation cover showed an increase through the years from 1984-1993 and a decline from 1993-1996 and regained an increase from 1996-2000 and 2002.

To achieve one of the objectives which was to determine physical characteristics of the degraded areas, TCA in relation to slope was analysed. The assessment of vegetation cover in relation to slope showed a change of occurrence of vegetation cover from flat to moderate slope in 1984, 1993 and 1996 to steep to very steep slope areas in 2000 and 2002 while the bare-ground occurred on moderate to flat slopes throughout the period of the study.

Unsupervised ISODATA classification technique was also analysed. Five classes were provided by unsupervised classification namely: dense vegetation, moderate vegetation, grassland, degraded grassland and bare-ground. Dense vegetation and bare-ground have been further analysed and results were compared with against those of TCA. The results of bare-ground and vegetation cover land degradation indicators from both TCA and unsupervised ISODATA classification techniques complement each other, both showing bare-ground and vegetation cover increase from the period of study.

To further address one of other objective of the study which relates to the establishment of local knowledge, history and nature of practices with regard to land degradation, field visit and interviews of local community were conducted. A summary of the information about land degradation from the respondents highlights the decline of food production, increase of dongas, decline of grasslands, vast increase of *Euryops* and a damaging effect of high rainfall during rainy seasons which washes crops and top soil away. The understanding of land degradation by the respondents incorporates both vegetation and bare-ground which are chosen land degradation indicators to be assessed and monitored in this study. During field visits, photography highlighting sheet erosion, rills and dongas were captured. They complement what is observed on the field in relation to the desk-top results.

Although the study managed to achieve its objectives, there were limitations. One of these limitations was the challenges faced when conducting interviews. The interviewees did not want to participate citing that Government organisations which interviewed them in the past have made promises to improve their lives but never returned to honour their promises. Therefore they felt that the interviewer was repeating the same thing done by the Government officials, up until the clear purpose of the interviews was clarified, (which is a master's study). The other challenge which was experienced was related to time scheduled for the interviews. There were 2 funerals during the scheduled time for interviews which lead to the extension of interview time that carried unforeseen financial cost. Due to the distance to field site, time and cost constraints involved, it was only possible to conduct a limited number of interviews. An increase in interviewees would add more information to this research.

The spatial analysis of this study also had its own constraints. The unavailability of a December 1984 image would have improved the seasonal consistency of the study and may have improved the results. Due to financial and time constraints a 2007 image and aerial photographs were not incorporated in this time series study. Aerial photos would have provided a greater level of detail which might have added to understanding the type of land degradation or erosion which affects different areas. The current imagery would have provided a current image of the situation in the study area thereby adding greater understanding of the whole problem. Further limitation of the study is related to the small number and poor distribution of ground control points used for ground truthing of the classified images. A second round of ground observations over a wider area with better representation of the classes should have been conducted to improve the integrity of the classified images.

Despite these limitations the study managed to assess and monitor the nature of land degradation in Qoqodala. The land degradation indicators chosen in this study (bare ground and vegetation cover) revealed that there is an increase in land degradation in the study area. The use of GIS and Remote Sensing techniques together with interviews has therefore been a success towards a holistic study of land degradation. However in spite of the success achieved by the current study, recommendations to improve land degradation research are discussed in the paragraph below.

The incorporation of soil erosion models into future land degradation studies are recommended. However this will also require the quantification of soil erosion through detailed on-site studies investigating the characteristics of the different erosion features as input data for soil erosion models.

The use of high spatial resolution satellites like IKONOS and Quickbird are recommended to be used in conjunction with Landsat images which provides high spectral resolution. The IKONOS system from Space Imaging and the Quickbird system from Digital Globe offer multispectral imagery at resolutions of 3.2 and 2.88m respectively (refer toTable 14).

Table 14: IKONOS and Quickbird properties

Properties		**IKONOS**	**Quickbird**
Spatial resolution	Band 1	3.2m	2.88m
	Band 2	3.2m	2.88m
	Band 3	3.2m	2.88m
	Band 4	3.2m	2.88m
	Band 5 (Panchromatic)	0.82m	61cm (nadir) 72cm (off-nadir)
Temporal resolution (Repeat-coverage interval)		3 days	16 days
Radiometric resolution		11 bits	8 bits
Inclination		98.1°	97.2°

High spatial resolution satellites would enable the researcher to discriminate in detail between erosion types of bare ground degradation indicator. To enhance the use of recommended soil models, high spatial resolution data are essential. However the challenge with high spatial resolution lies in the image acquisition cost. High spatial resolution images are more expensive than medium resolution (Landsat) data.

The last recommendation is with regard to the Qoqodala community. The investigations of the social implications and issues surrounding land degradation would contribute greatly to developing an approach to understand and managing the problem in a sustainable manner.

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ANNEXE 1: QUESTIONNAIRES

Appendix A: (Information about the household)

1. Sex

Male	
Female	

2. How old are you?

25 – 30	
30 – 35	
35 – 40	
40 and above	

3. What are your education qualifications?

None/ informal	
Primary	
Secondary	
Tertiary	
Others	

4. Are you employed?

Yes	
No	

5. What is your employment status?|

Self employed	
Permanent employed	
Temporary employed	
Old age pension	
Other sources	

6. What do you do?

…………………………………………………………………………………………

…………………………………………………………………………………………

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7. How long have lived in this area?

Less than 5 years	
From 6 to 10 years	
From11 to 25 years	
More than 25 years	

8. Are you home all the time?

Yes	
No	

9. If not, specify number of day or month away from home?

…………………………………………………………………………………………

…………………………………………………………………………………………

……

10. What is your role in the family?

Head	
Wife	
Daughter	
Son	
Other (specify)	

Appendix B: (target is to establish the knowledge of an area)

11. Do you like living here?

Yes	
No	

Why (specify)?

………………………………………………………………………………………………

………………………………………………………………………………………………

……

12. What is your source of power (to cook and lighting at night, heater etc)?

………………………………………………………………………………………

………………………………………………………………………………………

…………

13. Do you own any stock?

Yes	
No	

14. If yes, number and type?

………………………………………………………………………………………………

………………………………………………………………………………………………

……

15. How are they grazing?

Open grazing	
Pastoral grazing	
Other (specify)	

16. Is there good grazing?

……………………………………………………………………………………………
……………………………………………………………………………………………
……

17. Are you engaged in any crop farming?

Yes	
No	

18. Are the crops growing well?

Yes	
No	

19. What do you think is the cause of them performing this way?

……………………………………………………………………………………………
……………………………………………………………………………………………
……

20. Is there any change with the land (specify)?

……………………………………………………………………………………………
……………………………………………………………………………………………
……

21. Comments

Appendix C: (target to establish the extent of land degradation)

22. Is there any change in the land since you arrived in this area?

Yes	
No	

23. If yes what is the change?

…………………………………………………………………………………

…………………………………………………………………………………

…………

24. What are the causes of these changes?

…………………………………………………………………………………

…………………………………………………………………………………

…………

25. Are there any problems experienced related to the changes in the land?

…………………………………………………………………………………

…………………………………………………………………………………

…………

26. Is there any soil loss in the area?

Yes	
No	

27. If yes, what do you think causes the soil loss in the area?

…………………………………………………………………………………

…………………………………………………………………………………

…………

28. Are there any gullies in the area (specify)?

Yes	
No	

………………………………………………………………………………………
………………………………………………………………………………………
…………

29. What is your understanding of the occurrence of the gullies?

………………………………………………………………………………………
………………………………………………………………………………………
…………

30. Are there any community activities to control soil erosion?

Yes	
No	

31. If yes, what are they or if not, why not?

………………………………………………………………………………………
………………………………………………………………………………………
…………

32. Is there any vegetation change in the area?

Yes	
No	

33. If yes what causes it or if no what is preventing it?

………………………………………………………………………………………
………………………………………………………………………………………
…………

34. Are there any adequately early warning symptoms and indicators of land degradation?

Yes	
No	

35. If yes what are they or if no what could be the problem?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………

36. What coping strategies used in response to land degradation?

…………………………………………………………………………………………

…………………………………………………………………………………………

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37. What is your opinion regarding vegetation change in the area?

…………………………………………………………………………………………

…………………………………………………………………………………………

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38. How does soil erosion and vegetation change impacts you?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………

39. Are there any physical changes in the neighbourhood locations?

Yes	
No	

40. If yes how are they affecting the structure and land use of your village

…………………………………………………………………………………………

…………………………………………………………………………………………

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41. Comments

Appendix D: (related to conservation)

41. Are there any traditional methods in place to reduce land degradation?

Yes	
No	

42. If yes what are they?

………………………………………………………………………………………
………………………………………………………………………………………
…………

43. Are the main on-site social and economic barriers prevailing to effectively rehabilitate the degraded land?

………………………………………………………………………………………
………………………………………………………………………………………
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44. Is the any role the government is doing to assist in the control of land degradation?

………………………………………………………………………………………
………………………………………………………………………………………
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45. Did the government ever launch any research on land degradation in this area?

………………………………………………………………………………………
………………………………………………………………………………………
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45. Are there any programs in place to enhance environmental consciousness?

………………………………………………………………………………………

………………………………………………………………………………………

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46. Comments

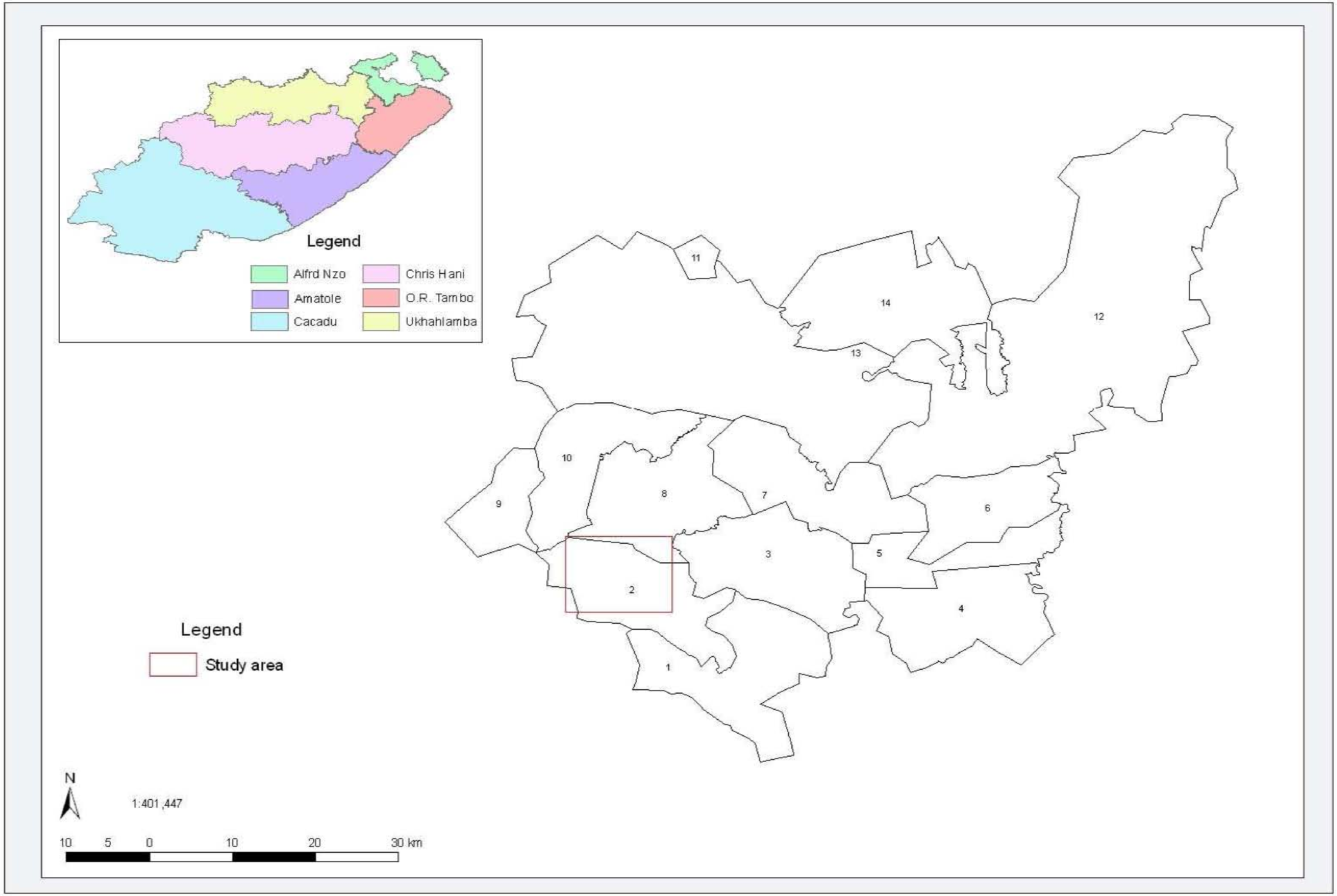

Figure 3: Study area ward number of Emalahlenni municipality

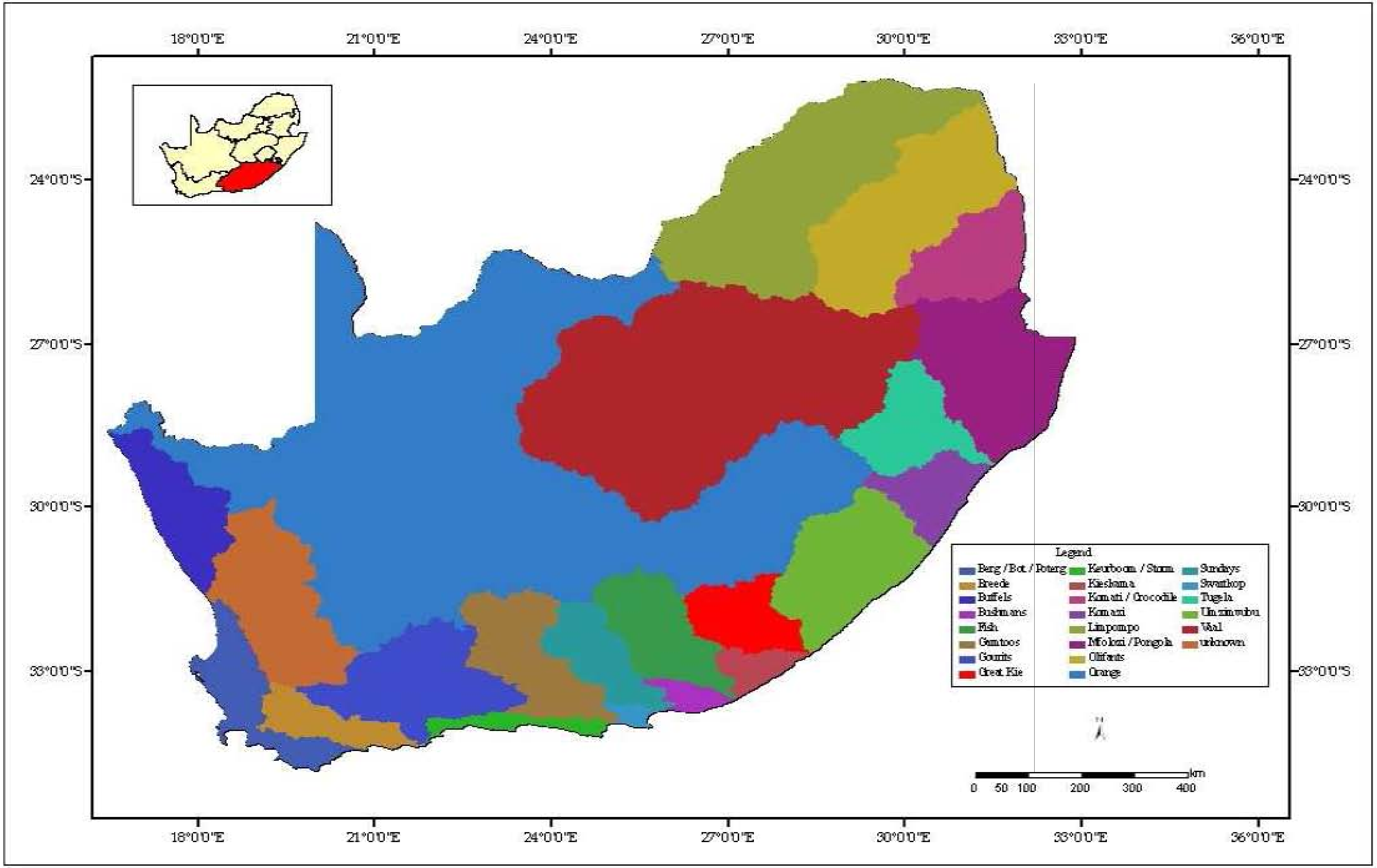

Figure 5: Primary catchments of South Africa with the Wit-Kei catchment highlighted.

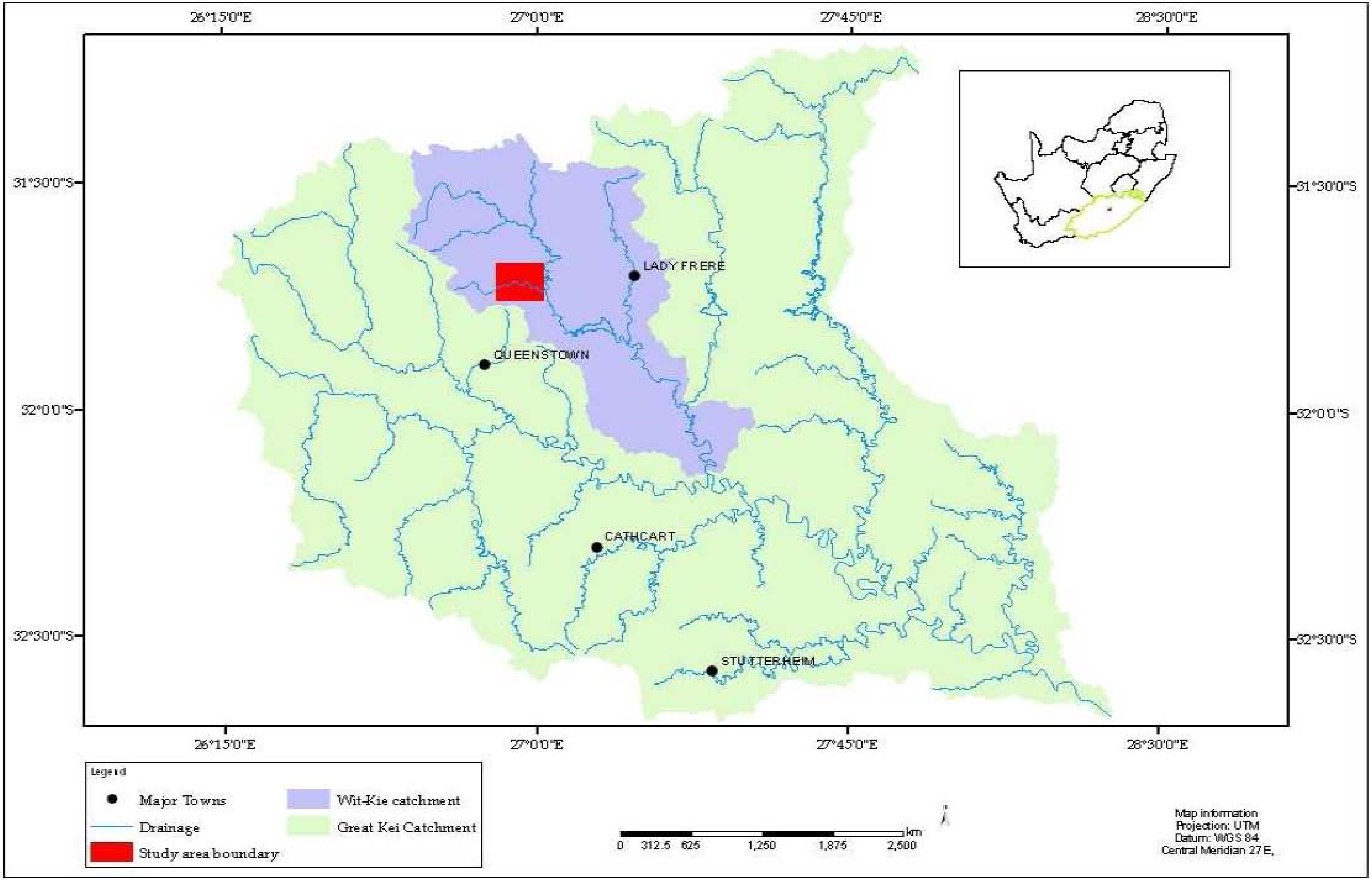

Figure 6: Study area within Great Kei Catchment in the Eastern Cape Province, South Africa

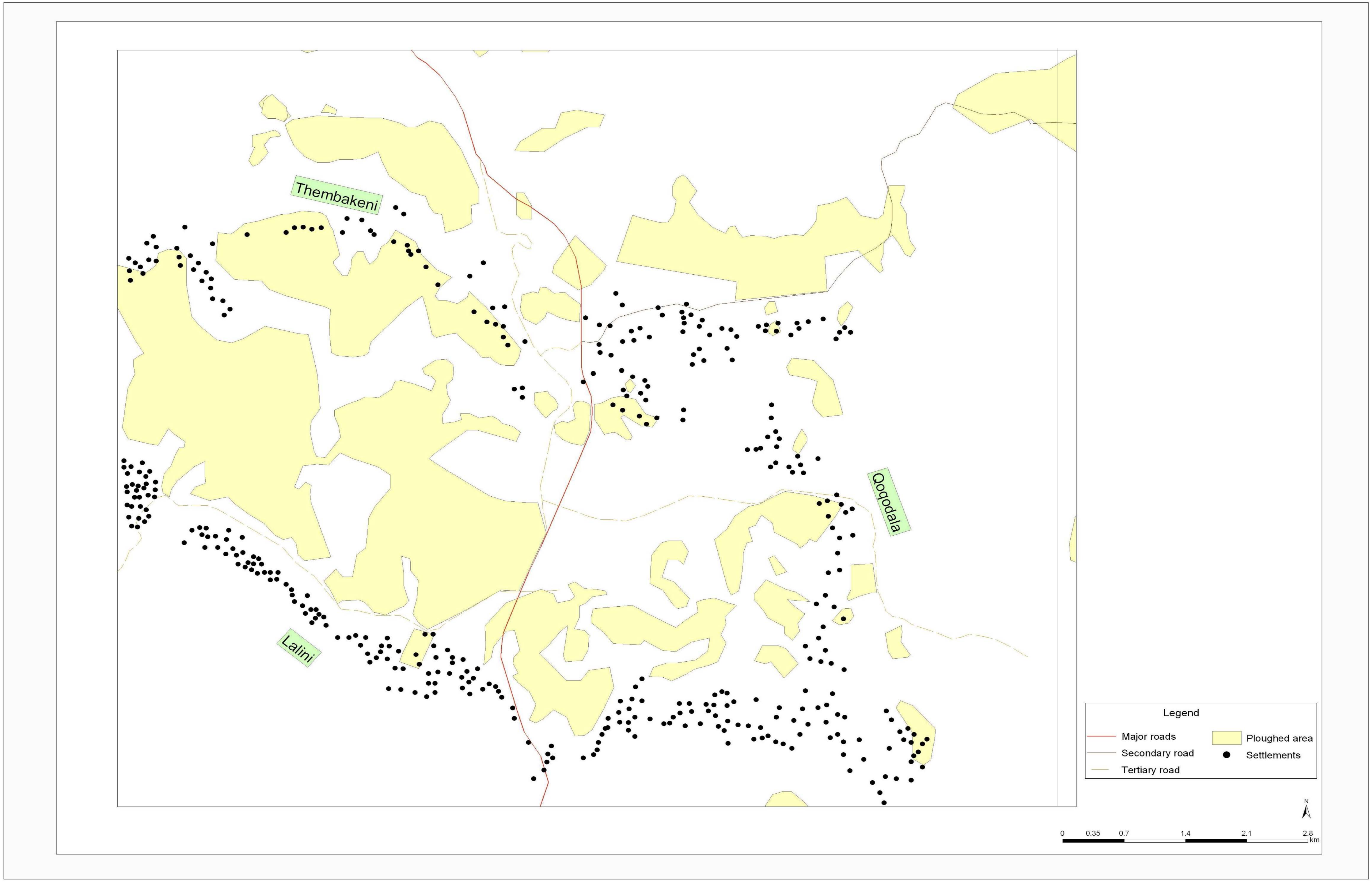

Figure 7: Map showing the location of the villages Qoqodala area within the Wit-Kei catchment

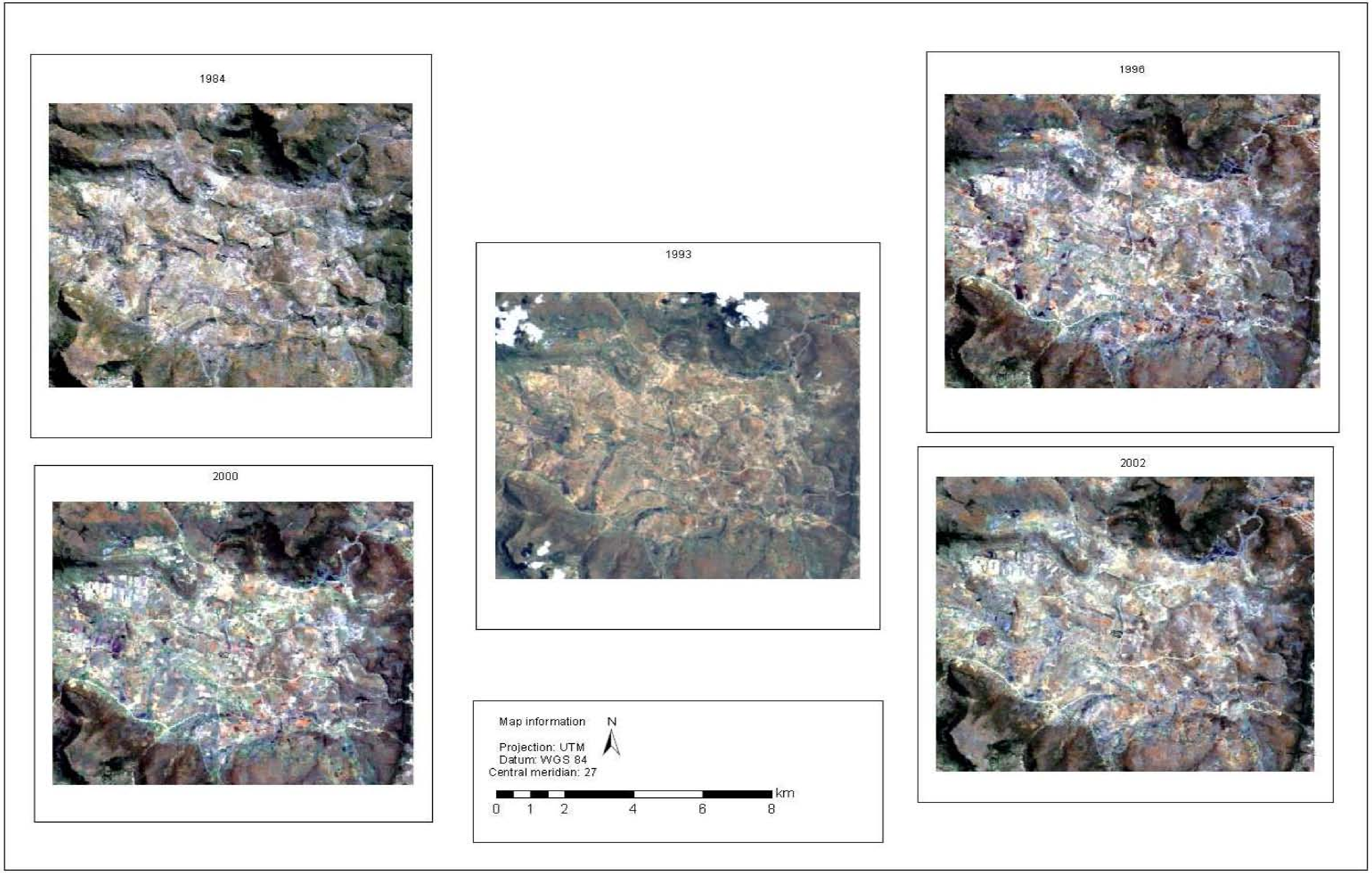

Figure 16: True Colour Band Combination

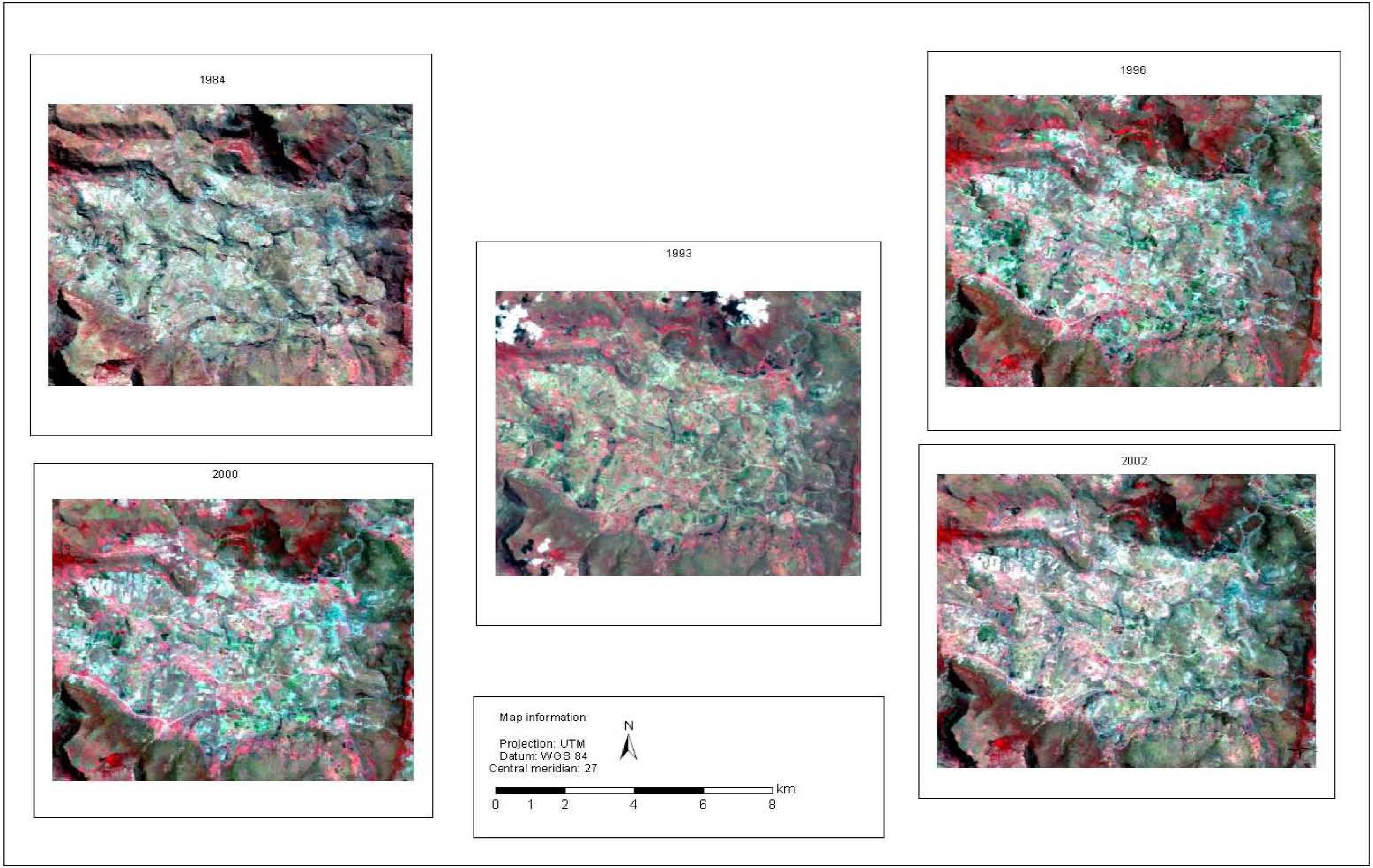

Figure 17: False Colour Band Combination R=4, G=3, B=2

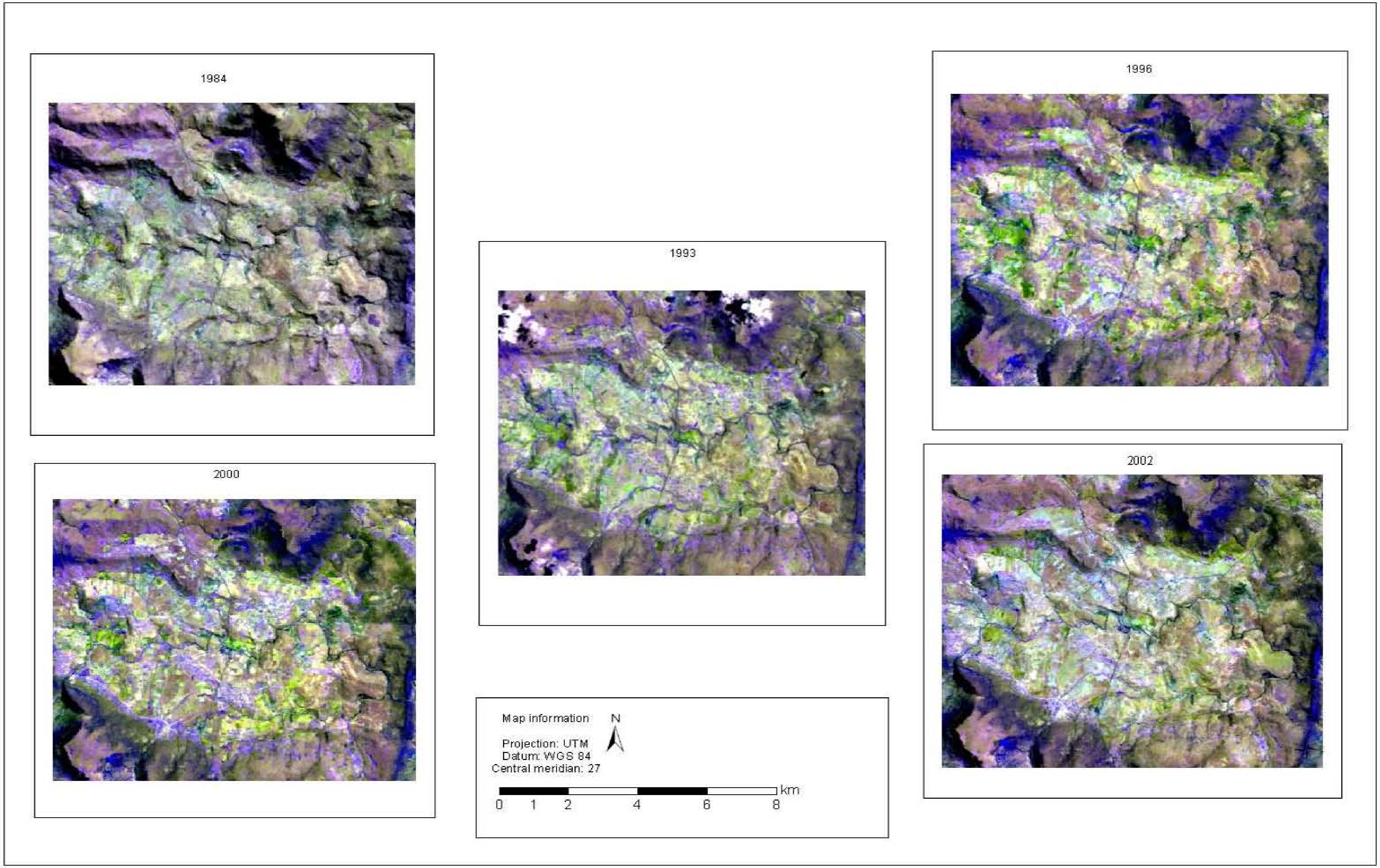

Figure 18: False Colour Band Combination R=5, G=7, B=4

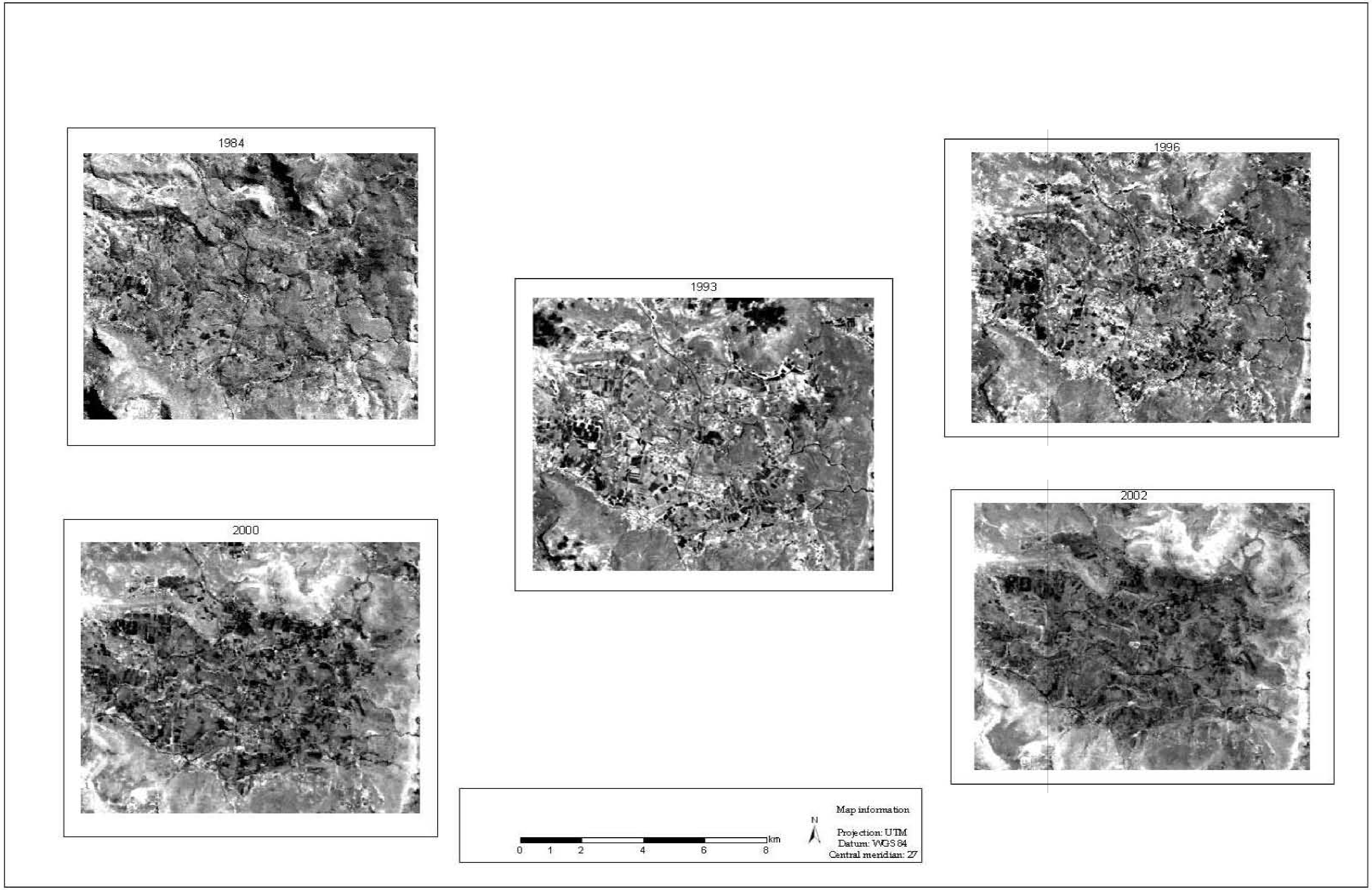

Figure 19: TCA of greenness band

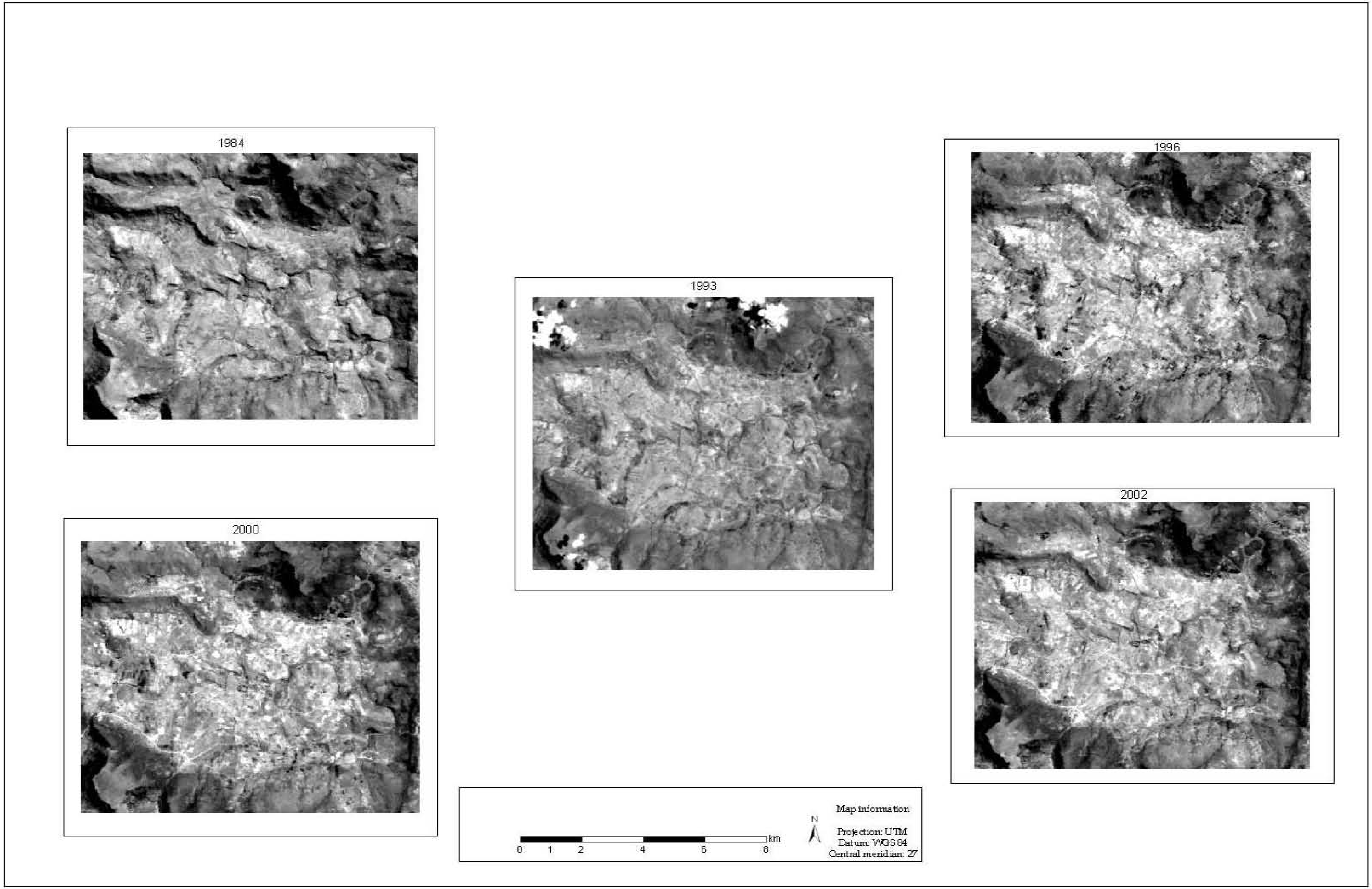

Figure 20: TCA of brightness band

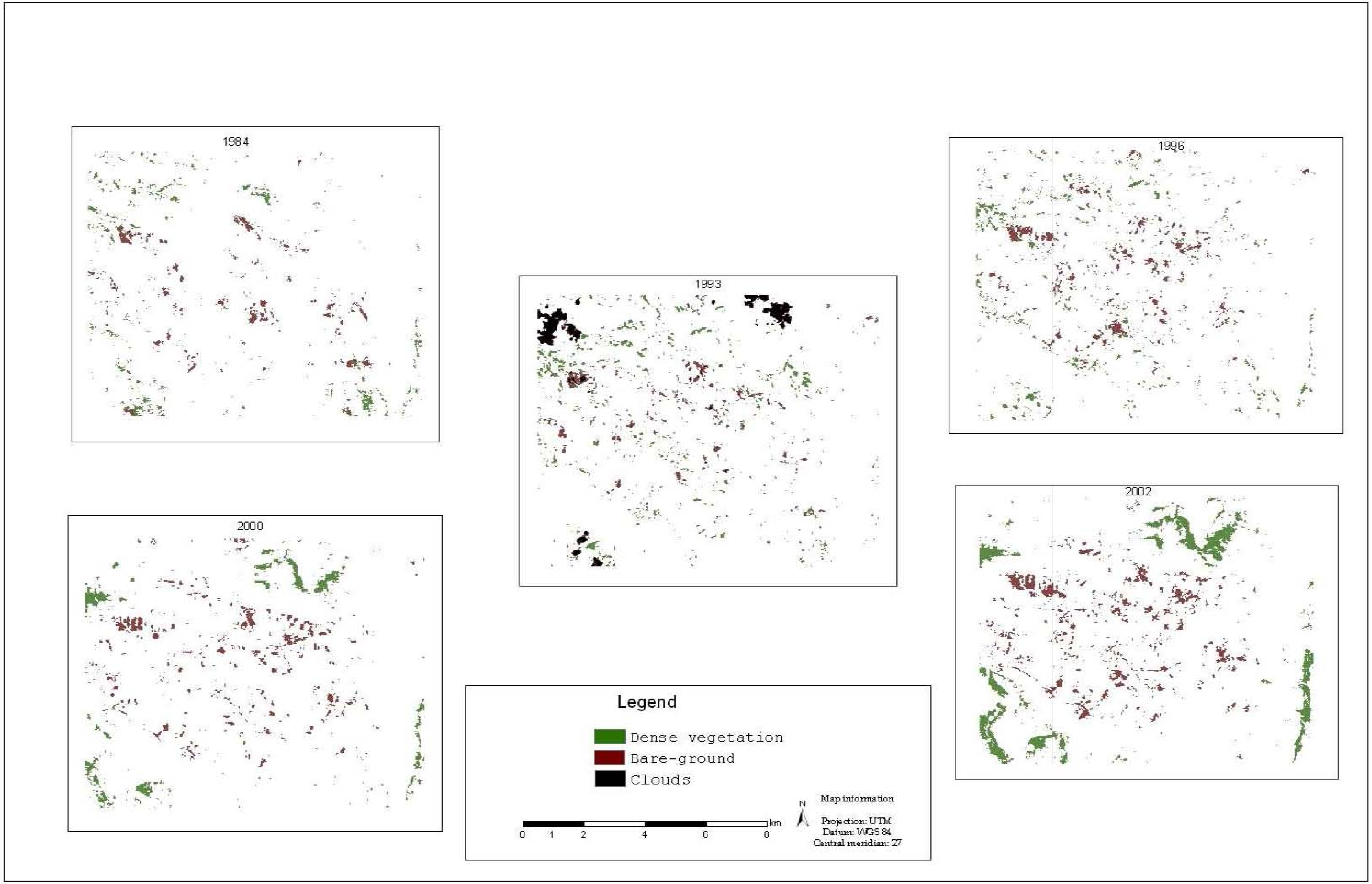

Figure 21: Density slicing of greenness band (showing vegetation) and of brightness band (showing bare-ground)

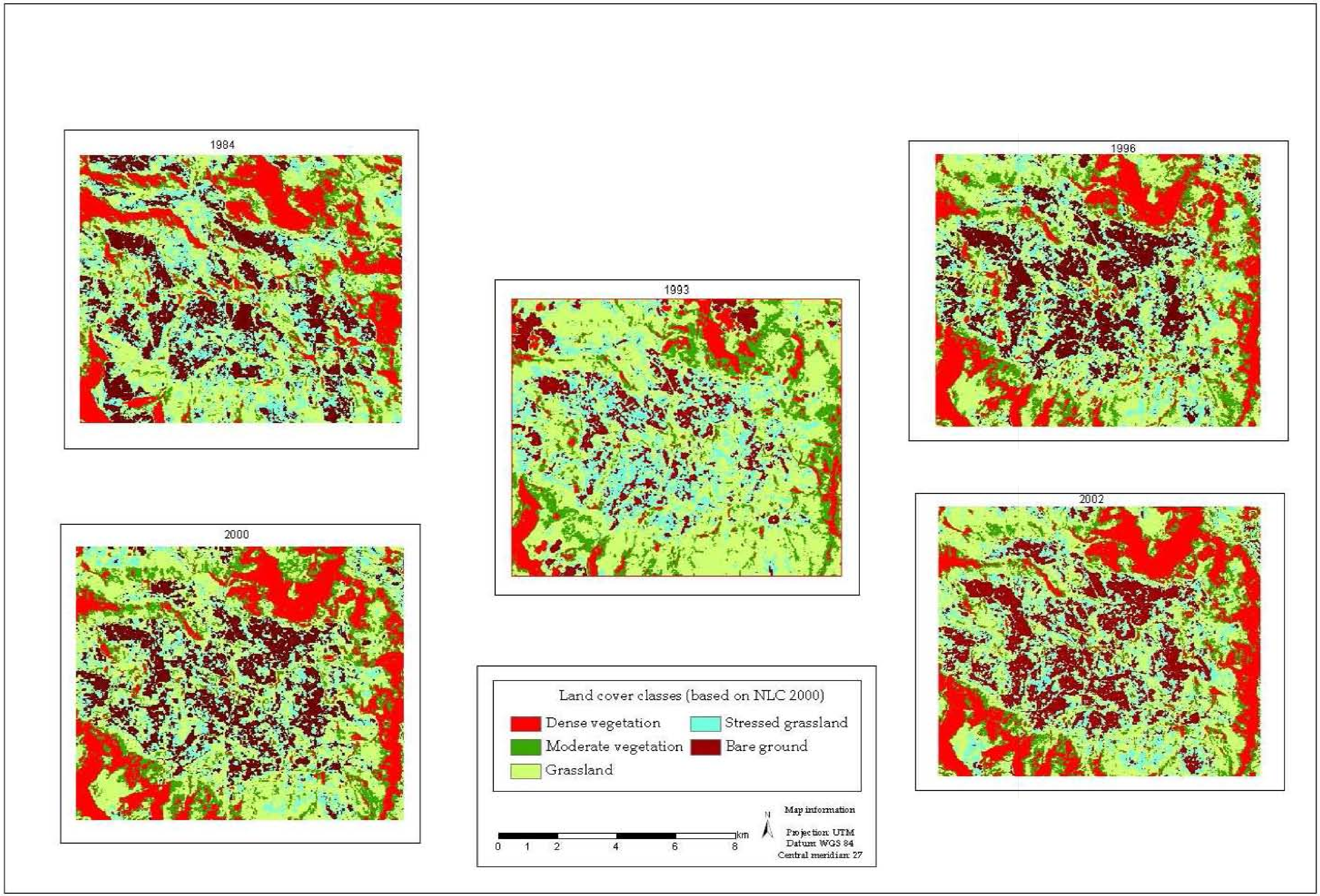

Figure 23: Land cover classes derived from the unsupervised classification technique

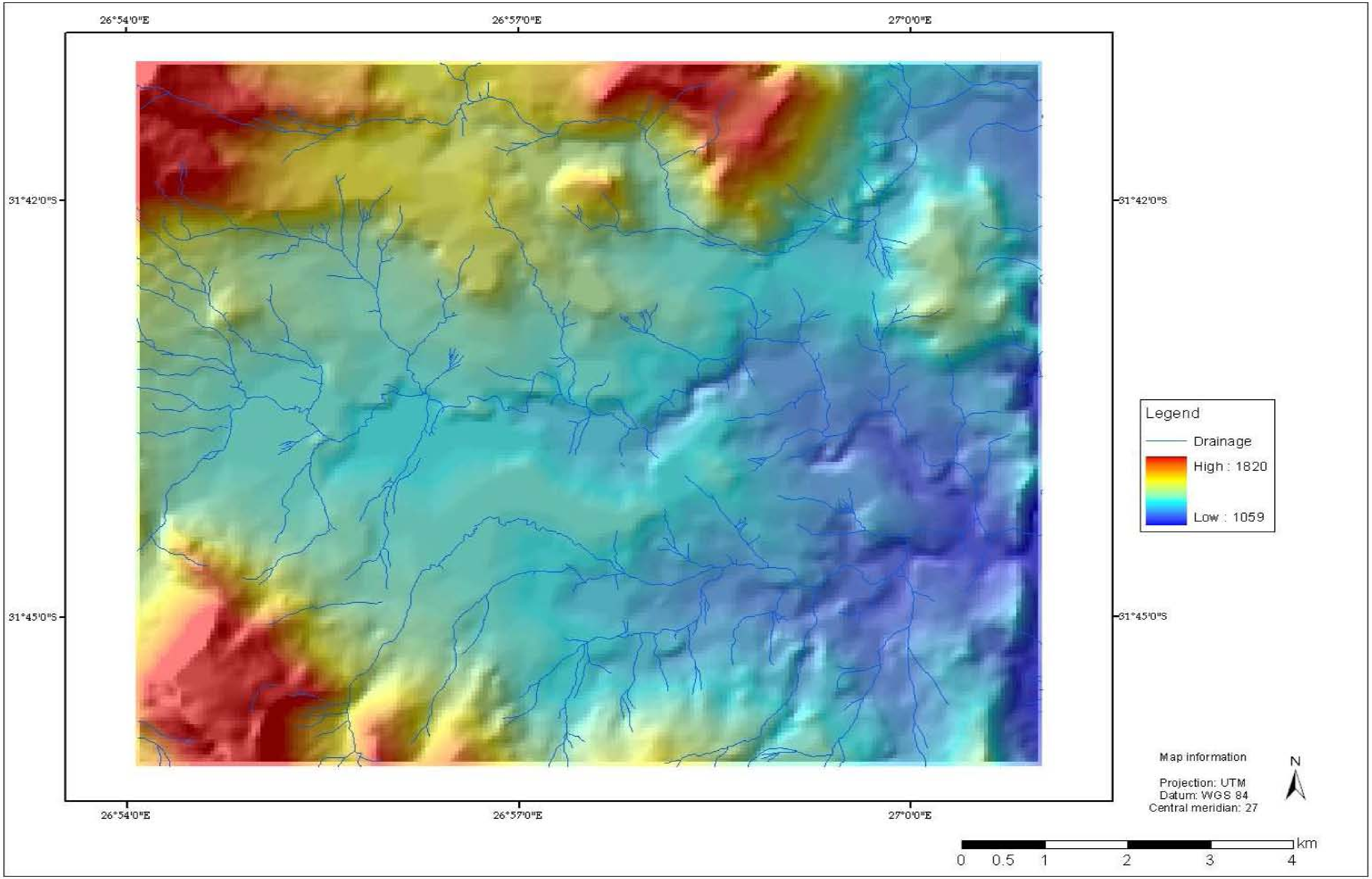

Figure 25: Drainage overlaid on 50m Digital Elevation Model of the study area

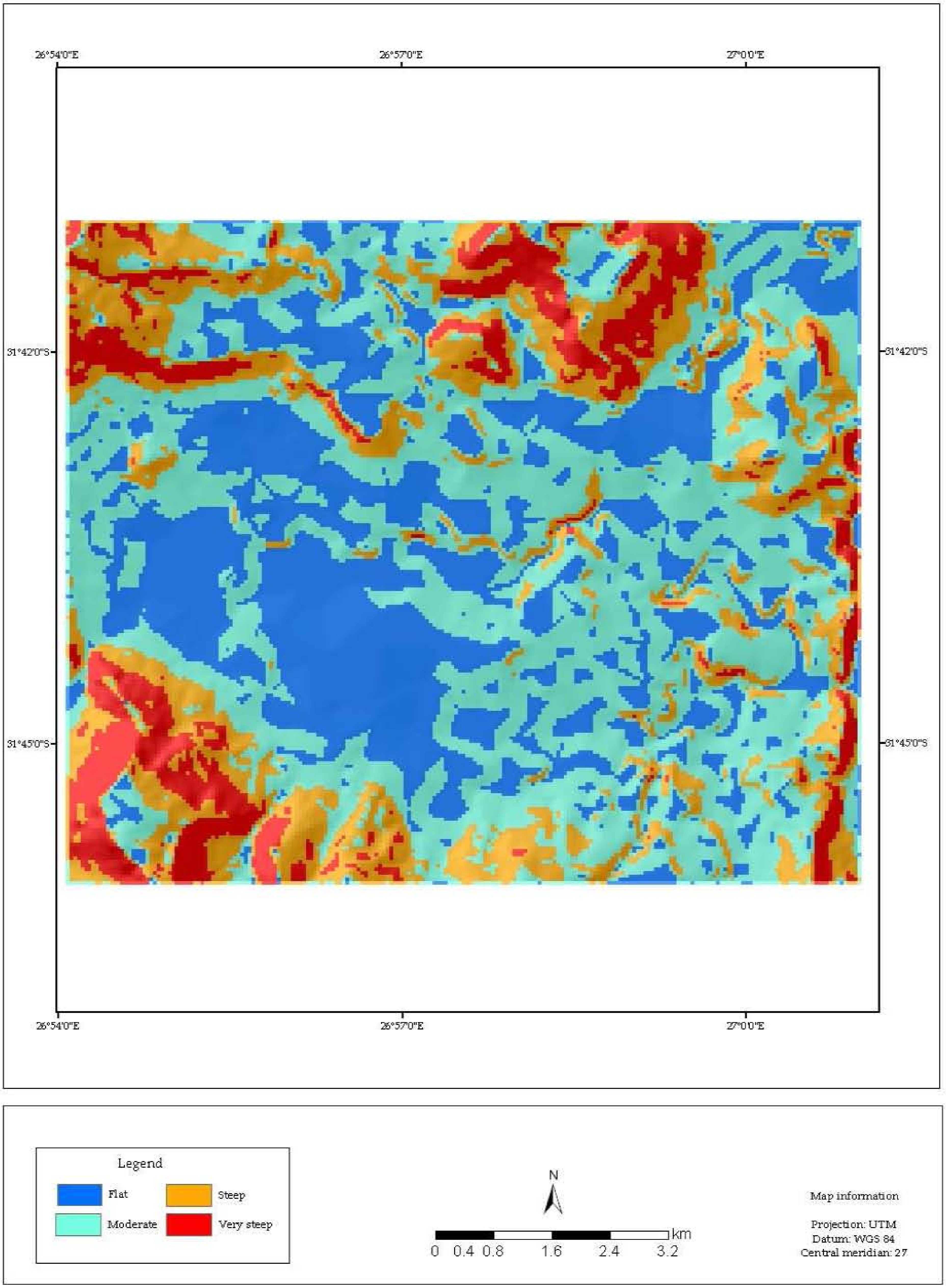

Figure 26: Slope map of the study area

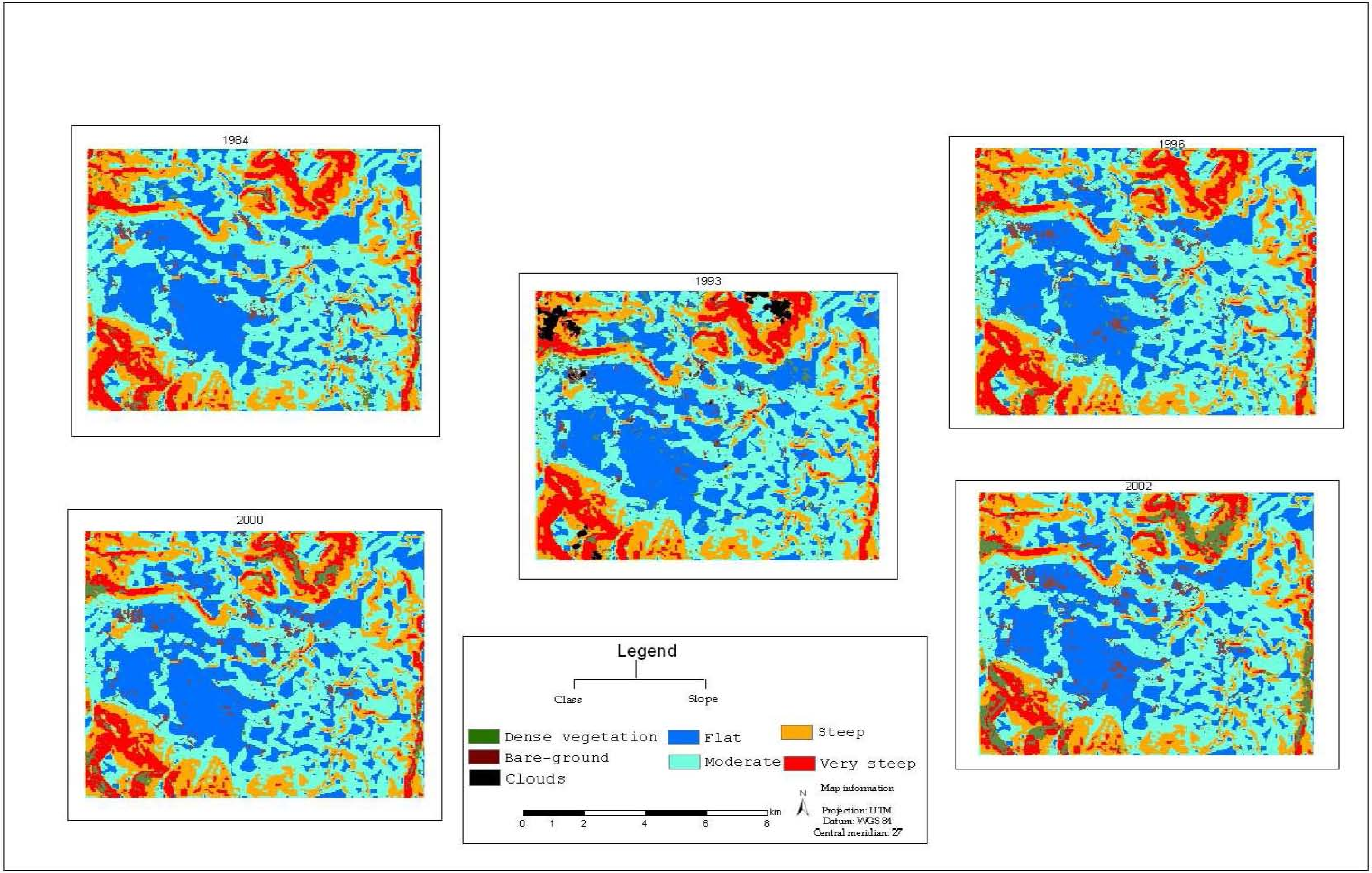

Figure 27: Slope map overlaid with vegetation cover and bare-ground from the Tasselled Cap Analysis

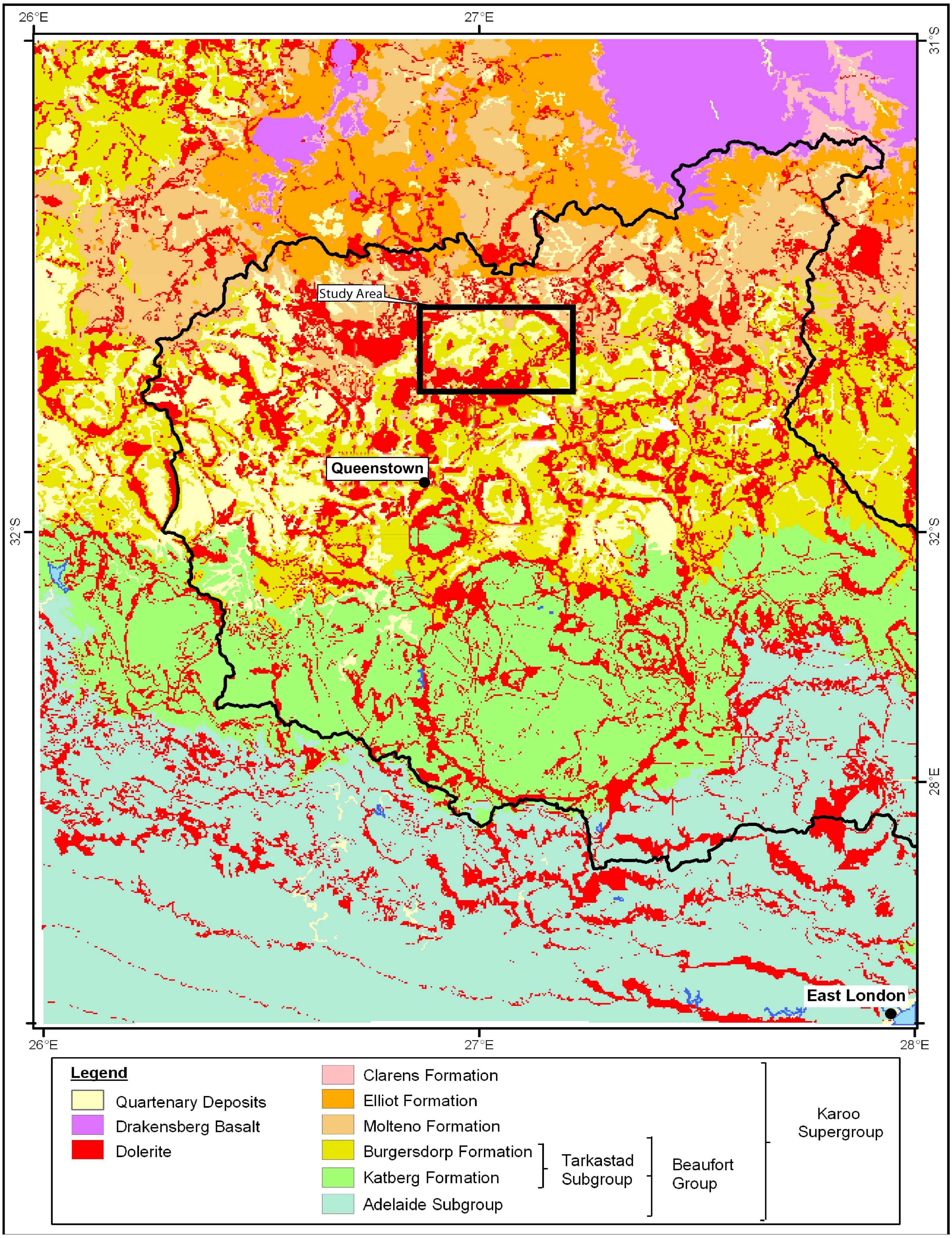

Figure 30: Geological map of the study area (Chevallier *et al., 2004*)

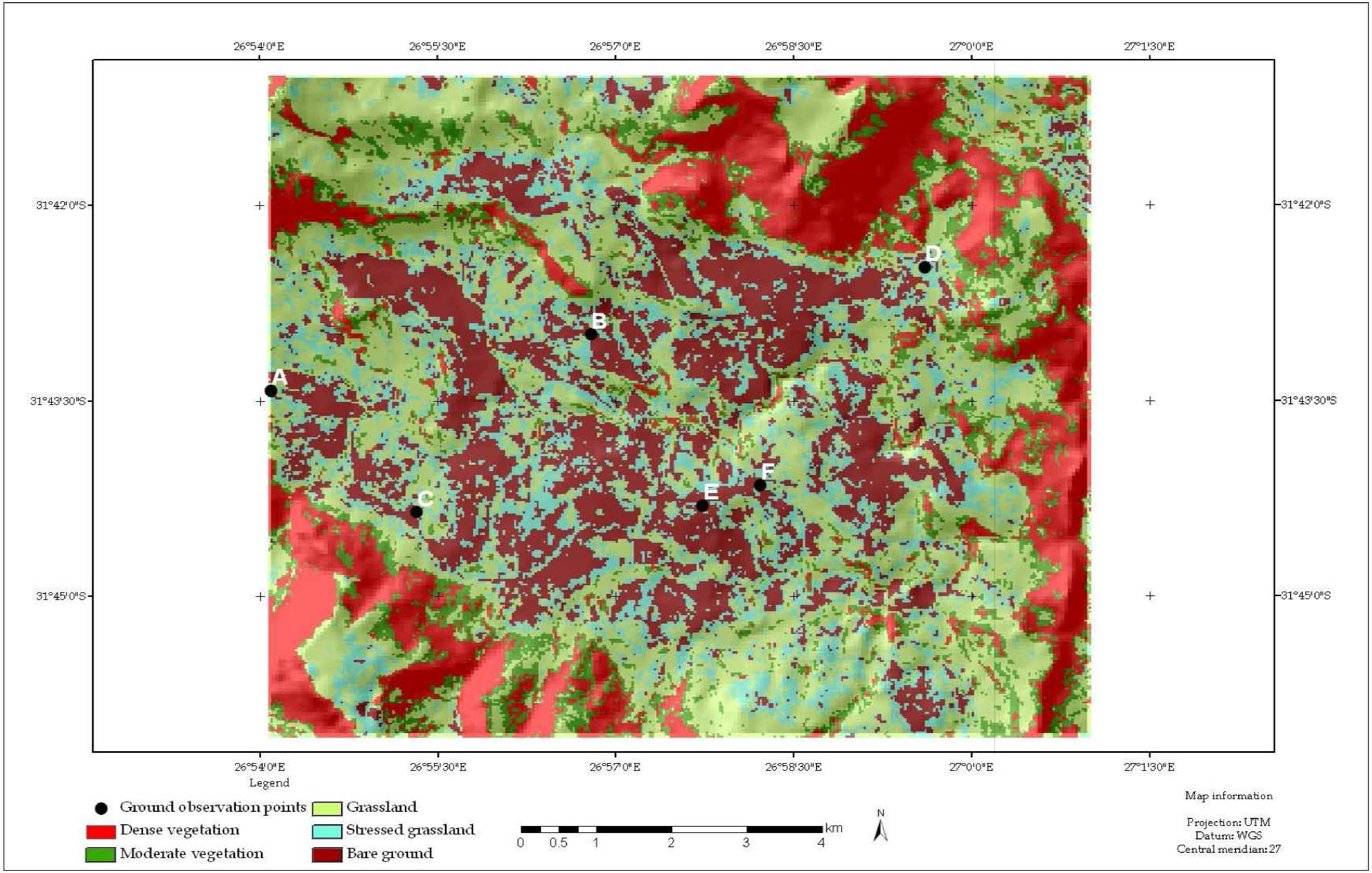

Figure 36: GPS points overlaid with 2002 unsupervised image classification