USE OF LANDSAT THEMATIC MAPPER AND ANCILLARY DATA IN ASSESSING POTENTIAL AREAS FOR RAINWATER HARVESTING CROPPING SYSTEMS

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ABSTRACT

Rain Water Harvesting (RWH) is a system which can store and redistribute the moisture needed to enhance yields, in areas where rainfall distribution limit dryland crop production. In regions where rainfall is insufficient to produce even a minimum crop, water harvesting offers the potential to bring those areas under cultivation. However, in many areas, conventional planning data for selecting prospective sites for RWH cropping system is in most cases not easily available or not up to date. This study assess the possibility of using satellite images to improve and up-date the required data.

This study used a nested procedure, combining a coverage of a small sample area by Landsat Thematic Mapper (TM) satellite imagery, conventional photo interpretation and analysis of soil and topographic maps to identify potential areas for RWH cropping system. Computer pattern recognition techniques were used to discriminate soil information from the Landsat Thematic Mapper (TM) satellite data on a sample area. Soil mapping units from a conventional soil survey and aerial photo interpretation were matched to the classified soil spectral map for interpretation and description of the generated classes. Field investigations were done to confir the results of the sample area which was then extended to larger area by extrapolation using computer algorithms.

Results shows that combination of Landsat TM data an ancillary data can replace extensive field surveys i identifying suitable area for RWH especially where groun truth is available and the landscape is sparsely vegetated.

DECLARATION

I, **AMINI RABI KWEKA**, do here by declare to the senate of the Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor currently being submitted for a higher degree in any other University.

Date ....12/11/1996..........................

Signature....AKweka..........................

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This work is dedicated to my beloved wife

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CHAPTER ONE

INTRODUCTION

1.1 Definition and problem statement

Inadequate soil-water and restricted period of useful soil-water availability is a primary constraint to crop production in semi-arid areas. This problem is further aggravated by the low fertility of the soils. Intervention techniques are required to impart stability to crop production during sub - normal rainfall years and maximize yields in normal rainfall years. The intervention techniques should in general aim at maximizing soil-water available to crops as a result of each rainfall event and optimize crop yield per unit of this available soil-water.

Rain water harvesting is one such intervention technique which collects surface runoff from one area for use to increase soil-water content in a cropped basin. Thus identification of potential areas for application of this technique is an important step towards maximizing soil water available to crops. Information collected for identification of potential RWH area must be able to show the existence or inexistence of a catchment and cropping areas, also it must depict the amount of rainfall and runoff available for collection, the storage capacity of the soil and crop water requirement.

In many semi arid areas, up to date information on relevant parameters to rain water harvesting is not available through the conventional means. However, in recent years satellite imagery has been applied to suppliment information for discriminating land cover and earth's surface characteristics in many circumstances. We therefore examine the possibility of replacing some conventional means of obtaining information on relevant parameters to RWH by analysing satellite image of a study area described by the following characteristics.

1.2 Location

The study area was situated near Morogoro town, Tanzania (Fig. 3.1). Within this area a sample area of 420ha in Sokoine University of Agriculture farm (Fig. 3.2) was used for collection of sample data. The area has its centre approximately at longitude 37°39′ E and latitude 6°50′ S.

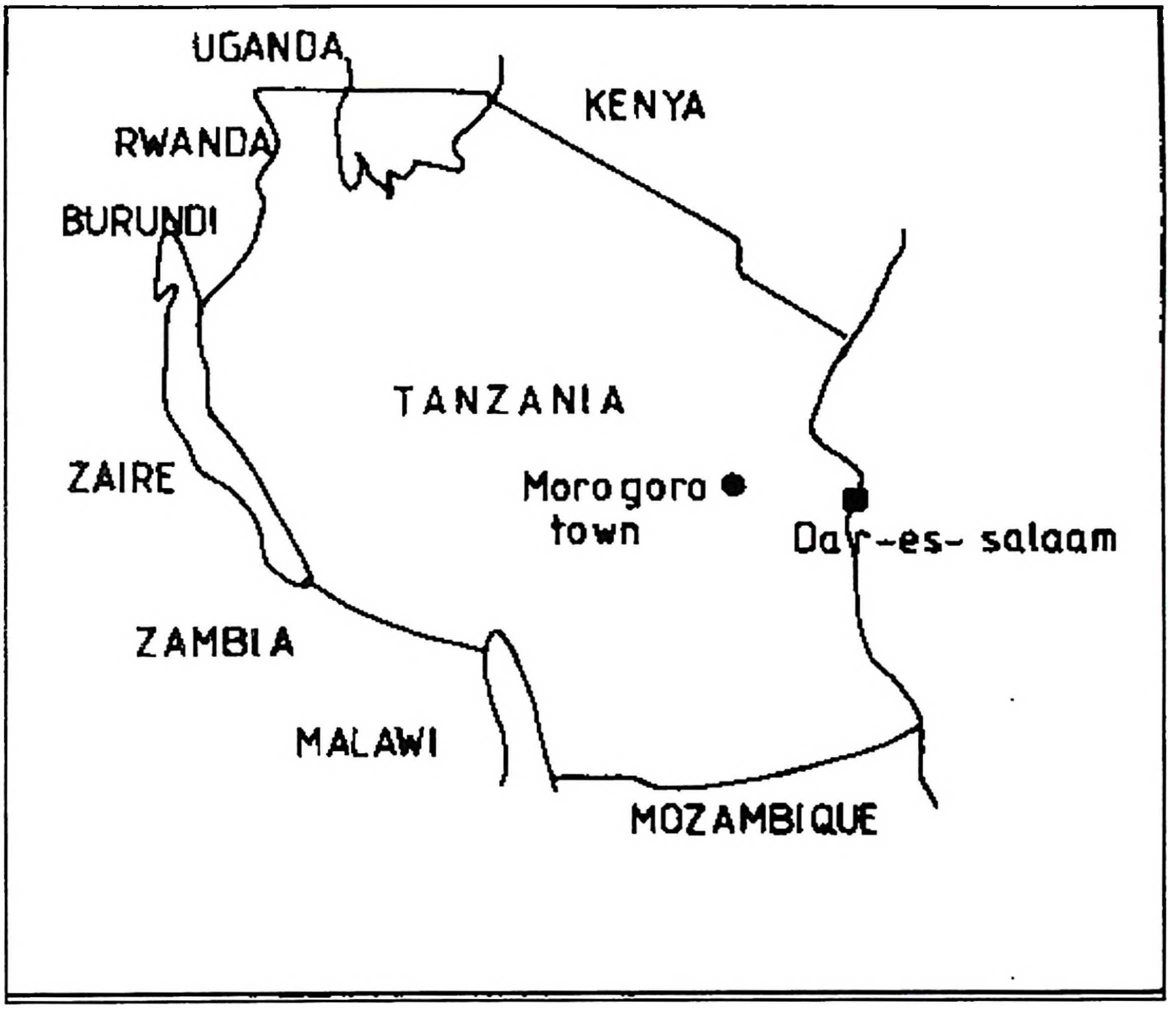


Figure 1: The map of Tanzania showing the position of Morogoro township

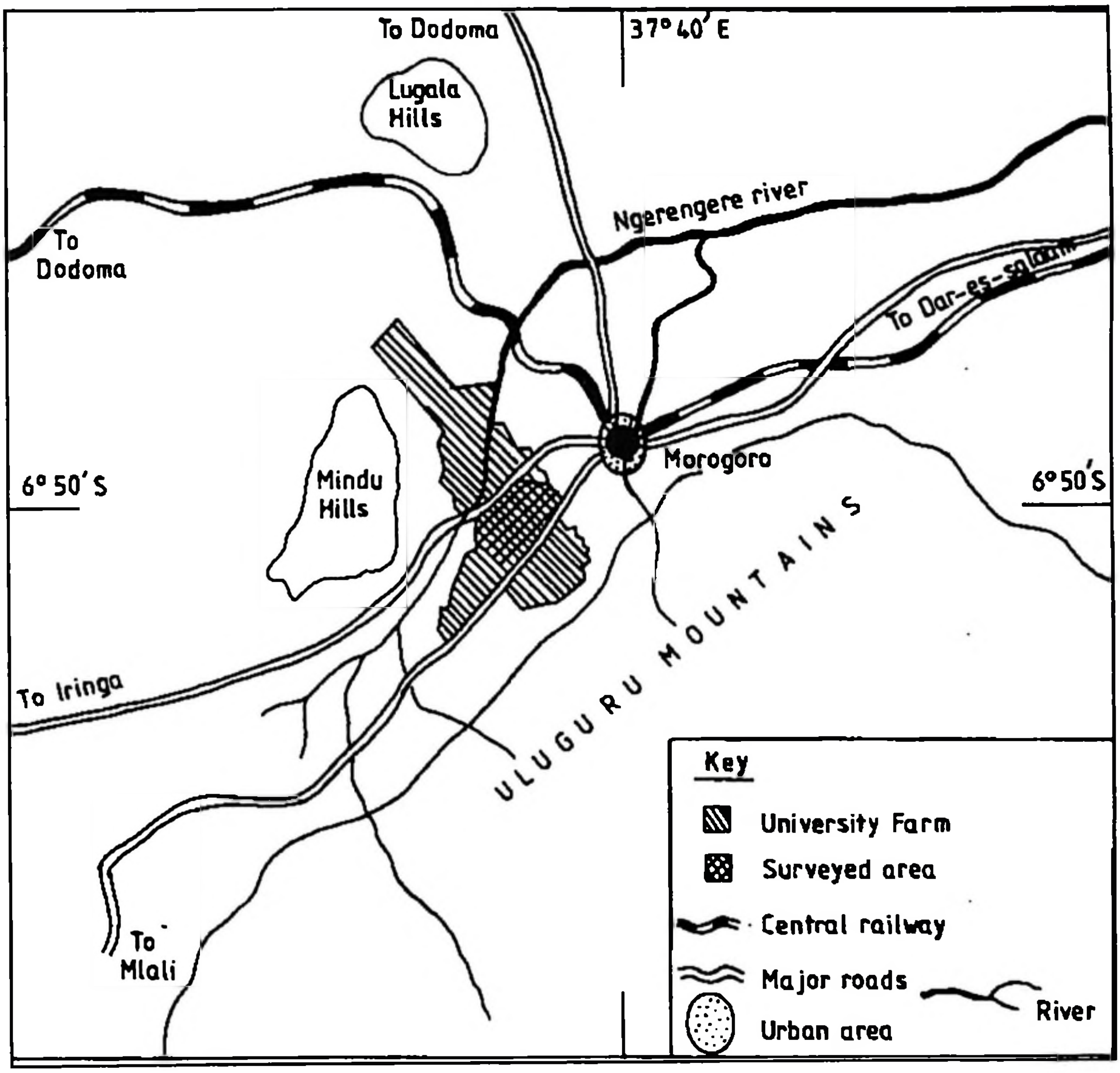


Figure 2: Sketch map showing location of the study area and the sample area in relation to Morogoro Township.

1.3 General characteristics of the study area

1.3.1 Climate

The climate of the study area is of sub-humid tropical type (Sharma, 1987) with the characteristics shown in Appendix 1 and described below:

1.3.1.1. Rainfall

The annual rainfall records show that rainfall in Morogoro varies between 587 mm and 1177 mm. The analysis was done on the basis of 24 years (1971 - 1994) of which 11 years had above average annual rainfall.

The area experiences bimodal rainfall characterized by two rainfall peaks in a year. The short and lighter rains last from November to January with their peak in December and longer and heavier ones last from March to May with their peak period in April.

The most important observation is the high values of standard deviation and coefficient of variation even during the months of high rainfall (Table 3.1). This shows that the distribution patten of long and short rains is irregular and therefore unreliable. Since most of the crops are cultivated under rainfed conditions, this irregularity and unreliability of rainfall has most often resulted in low yields or failure of crops because planting dates can not be predicted accurately and most often the rainfall period lasts for shorter period than the growing periods of many crops.

Table 3.1: Mean, standard deviation and the coefficient of variation of monthly rainfall at Morogoro.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Max	249	258	229	298	158	54	61	19	33	105	176	262
Mean	100	81	124	192	89	18	14	7	10	30	67	110
Min	11	1	41	87	13	0	0	0	0	0	11	0
S.D	67.4	66.7	51.4	64.0	37.1	15.5	14.3	5.9	10.5	27.1	54.0	71.8
C.V	0.67	0.82	0.41	0.33	0.42	0.86	1.02	0.85	1.05	0.90	0.81	0.65

1.3.1.2 Temperature

The mean monthly maximum temperature ranges from 27.4°C during the coldest month (July) to 32.3°C during the hottest months. The mean monthly minimum temperature ranges from 15.2°C to 21.1°C. The mean annual air temperature is 24.4°C for the period of 1971 - 1994. The average soil temperature is estimated as 25°C after adding 1°C to the mean annual air temperature (USDA, 1975) and therefore the soil temperature regime is isohyperthermic.

1.3.1.3 Relative Humidity

The relative humidity is medium. Early morning values may be in the range of 76 - 89% with a mean of 81%, but in the afternoon it decreases to a range of 42 - 67% with its mean at 52%.

1.3.1.4 Sunshine

The number of sunshine hours amounts to around 2500 per year in Morogoro. The area experiences an annual mean of 7.0 hours of sunshine per day. A maximum of almost 10 hours per day occurs during the months of November and January.

1.3.1.5 Wind speed

Wind speed is lowest in May. From June it starts to increase with highest value in December (147 miles per day).

1.3.2 Geology

Uluguru mountains, whose feet are the study area, belong to the Usagaran system of the Mozambiquian Belt (Saggerson, 1962).

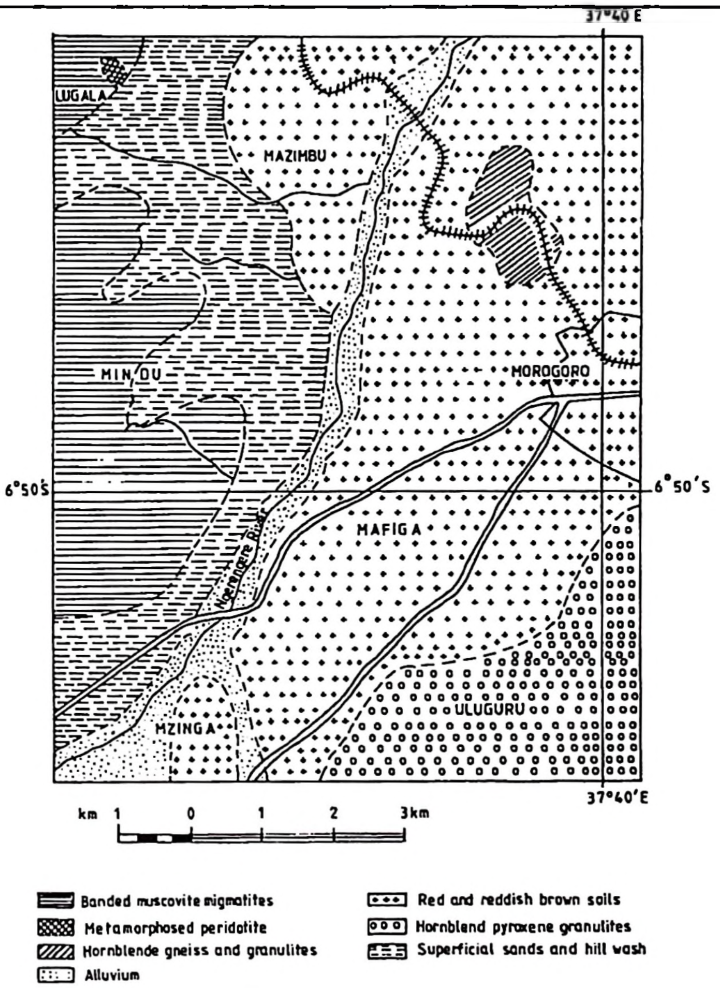


Figure 3: Geological Cover of the study area.

The rocks are metasediments of precambrian age and are mainly composed of pyroxene qranulites containing plagioclase and quartz-rich veins.

Most of materials at the foot are derived from the Uluguru mountains by fluvial erosion and deposit on the Ngerengere flood plain. It is most likely though, that some materials derived from the nearby Mindu hills have also affected this area. The Mindu hills also belong to the precambrian Usagaran system, but are intergrading from meta sedimentary to meta - igneous material rich in muscovite, biotite and hornblende gneiss (Sampson et al; 1961).

1.3.3 Geomorphology and drainage

At an altitude of 1140m a.s.l (point 1) the area has a linear but slightly convex slope form, down to about 915 m a.s.l (point 2) the slope is linear followed out by a convex slope at 560 m a.s.l (point 3), which downslope borders a alluvial fan. Point 4 is situated at 500 m a.s.l, on a linear slope running over the Ngerengere flood plain (Fig. 3.4 and 3.5). The gradients at the 4 points are 60, 62, 35 and 1 percent respectively. The area included in the study is that occupied by alluvial fans and Ngerengere flood plain.

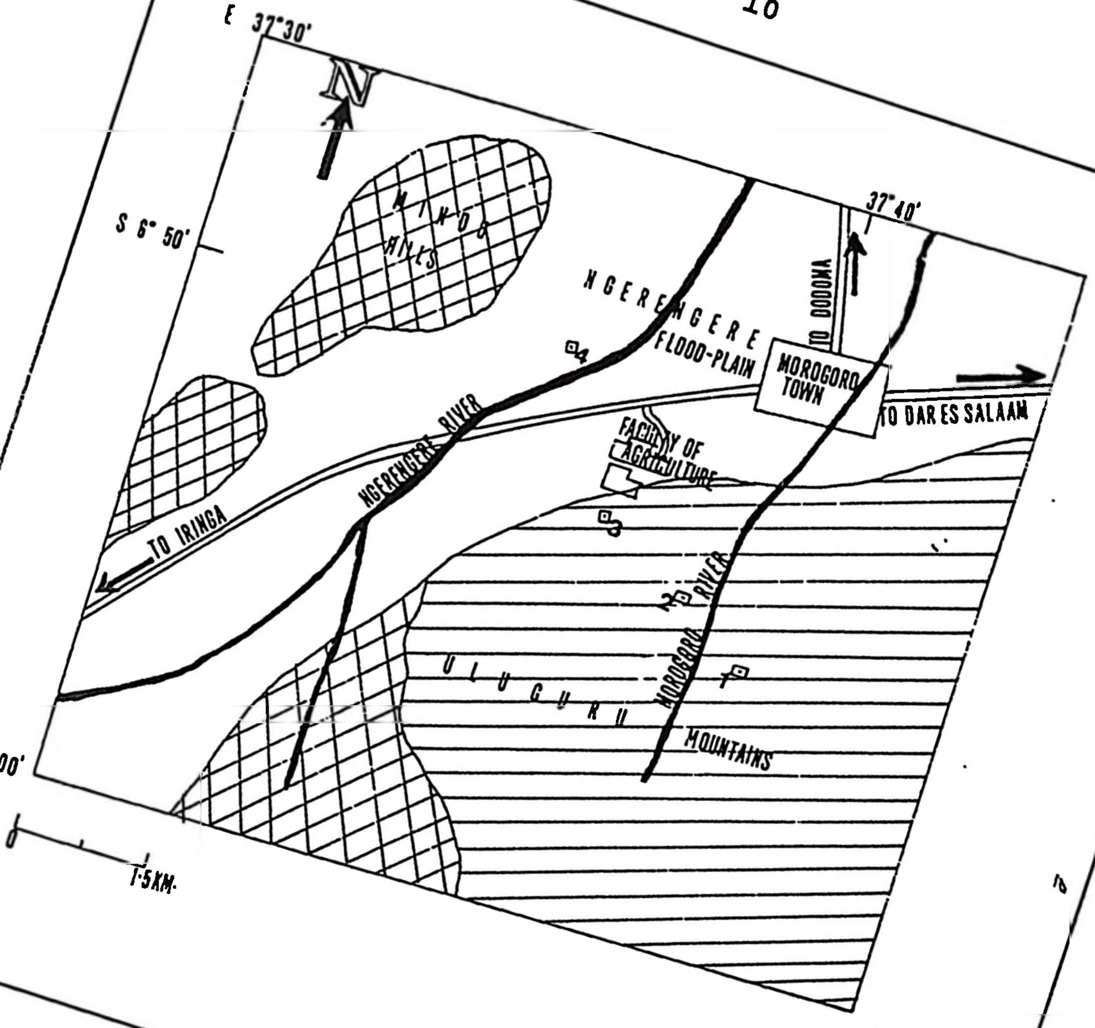


Figure 4: The sample points across the study area, source: Msanya (1980).

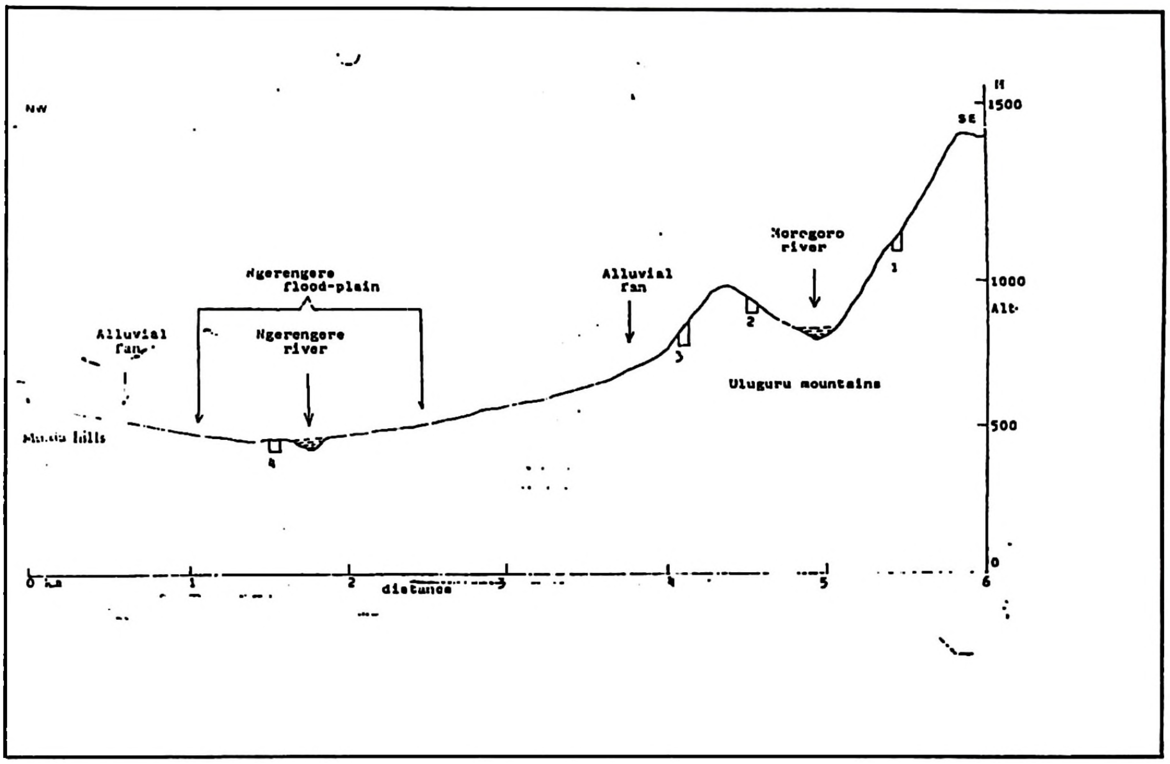


Figure 5: A cross-section of the sample area to show the main geomorphological features.

1.3.4 Vegetation and current land use

Point 1 is situated in an area almost at the border to a tropical highland rain forest, but the local vegetation is mainly a grassland dominated by *Hyparrtenis spp* (Msanya ,1980). Current land use in this area is mainly bean and maize cultivation. Terracing is widely used as a conservation measure against soil erosion.

At point 2 the area is dominated by bushed grassland containing *Themeda triandra* and *Hyparrhenia displantra*. Maize and sorghum cultivation is the main land use practice at the lower slopes.

Point 3 is in a bushland with few scattered trees and dominated by the grass species *Andropogon schirensis* and *Heteropogon contortus* (Msanya, 1980). The bushland is currently being used as a source of firewood. The area around point 4 is a grassland composed mainly of *Hyparrhenia spp* and the current land use include maize and rice cultivation.

1.4 Objectives

The main objective of this study is to examine the ability of satellite data combined with ancillary data in delineating potential areas for rain water harvesting application.

The specific objectives are:

1.4.1 To assess the contribution that the satellite images can make to planning a RWH agrisystem, 1.4.2 To assess how the contribution in 1.2.1 can be integrated with land and soil survey data to planning a RWH agrisystem.

CHAPTER TWO

LITERATURE REVIEW

2.1 Land evaluation and planning

Various survey and evaluation methodologies have been developed in recognition of the need for data in land use planning. The USDA land capability classification (Klingebel and Mortgomery, 1966) and its derivative is one of a number of interpretative groupings of land made primarily for agricultural purposes. In this classification system, the arable soils are grouped according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specialized site conditioning or site treatment. Non arable soils are grouped according to their potentialities and limitations for the production of permanent vegetation and according to their risks of soil damage if mismanaged.

The capability grouping of soils is designed to help land owners and other users to interpret soil maps, to introduce soil map users to the details of the soil map itself and to make possible broad generalizations based on soil potentialities, limitations in use and management problems.

Four physical characteristic which are used to determine land capability classes include the dominant texture of the soil profile, natural drainage, slope of the landscape and amount of erosion. The capability classification places all the soils in eight capability classes. The risks of soil damage or limitations in use become progressively greater from class I to class VIII (Klingebel and Mortgomery, 1966).

The major advantage of the USDA land capability classification is its versatility. It can be adapted to any physical environment and to any level of farming technology. The concept of limitations and its application via conversion tables calibrated by individual land characteristics is simple and the results can be presented with straight forwardness. It leads itself to local ad hoc modifications (Dent and Young, 1981).

The main limitation of this classification system is that, it is designed primarily for soil conservation rather than for economic purposes. Also, its assessment criterion puts more emphasis on environmental factors or physical features than chemical characteristics which equally affect the land use. Its assumption that the best land for one use is also best for another and vice versa is practically not always true.

To improve upon USDA classification system the land capability classification of the UK was developed (Bibby and Mackey, 1969) followed by that of Iran (Mahler, 1970 in Dent and Young, 1981). The system has a slight deviation from the USDA system by putting weights on a few land characteristics that have a greater diagnostic value for specific kinds of land use. The rating is of a qualitative nature, where each rating is weighted according to the importance that the characteristic has on a defined land utilization. Unlike the USDA system where the starting point is optimum usage, the standard land classification system of Iran is based on the existing soil and land conditions while the irrigability of land classification is based on uncorrected limitations.

With the advance of technology and agricultural production, another school of thought on land evaluation evolved. This emphasized that, it is desirable to consider social and economic factors in addition to physical in land evaluation so as to ensure that the assessed suitability corresponds with economic realities.

Among the early land evaluations system in which economic factors play an important role is the United States Bureau of Reclamation (USBR) irrigation suitability land classification system (USBR, 1951). In this system, land classes are based on the economics of production, the system has four basic classes used to identify the arable lands according to their suitability for irrigation agriculture, one for provisional class and one class to identify the non arable lands. Major disadvantage of USBR land evaluation system are that the inventory of soil resources is not important, and the fact that the system is based on the land suitability for irrigation development in general but not for crops.

In the FAO's Framework for land evaluation' (FAO, 1976) and in related publications land use practices (management practices) are mixed with typical socio-economic aspects like availability of labour and capital, education and prices in the 'land utilization type' (LUT). In this way the reasons underlying the farmer's choice for a particular set of cropping practices are disguised rather than elucidated. Furthermore, the framework restricts the human intervention in the bio-physical process to the choice of a crop or a livestock species. As rightly criticized by Stomph et al (1994) this completely ignores the fact that the essence of agriculture is human intervention in bio-physical processes to obtain more of a desired product.

According to Burrough (1986) the generalized qualitative methods of classification and mapping were unavoidable given the huge quantities of complex data that most land surveys generate. Quantitative land descriptions was hindered not only by data volume but also by the lack of quantitative observations. Furthermore, there was a lack of appropriate mathematical tools for describing spatial variation quantitatively.

2.2 Development of computer-assisted land evaluation methods

The first developments in appropriate mathematics for spatial problems began to be developed in the 1930s and 1940s in parallel with developments in statistical methods and time series analysis. Effective practical progress was blocked, however, by the lack of suitable computing tools. It is only since the 1960s, with availability of the digital computer, that both the conceptual methods for spatial analysis and the actual possibilities for quantitative mapping have been able to blossom (Cliff and Ord, 1981, Webster, 1977).

During the 1960s and 1970s new trends arose in the ways in which mapped data were used for resource assessment, land evaluation and planning. Owing to the realization that the different aspects of the earth's surface did not function independently of each other, people began to evaluate them in an integrated, multidisplinary way. Hopkins (1977) attempted to do this by finding 'naturally occurring' environmental units that can be recognized, described and mapped in terms of the total interaction of the attributes under study. Within these 'natural units' there is supposed to be a recognizable, unique, and interdependent combination of the environment characteristics of landform, geology, soil vegetation and water. This is termed as the 'correlative complex'.

The main problem with using the results of this approach for land use decisions is that for many purposes they are too general and it is often very difficult to retrieve specific information from them about particular attributes of landscape. Thus the more conventional monodiscipline survey, such as those of geology, landform, soil, vegetation and land use, seems to be more useful, particularly so as surveys have tended towards larger scales.

Monodisciplinary resource survey and mapping can be done for a wide range of land attributes, thus the user must seek a way in which the information from each map can be combined to give an integrated overview as needed. It has been realized that (McHarg, 1969) data from several monodisciplinary resource surveys can be combined and integrated simply by overlying transparent copies of the resource maps on a light table and looking for the places where the boundaries on the several maps coincides. In so doing decisions can be made on suitability of land for specific use.

However, visual interpretation techniques have disadvantages in that they require extensive training and are labour intensive. In addition spectral characteristics are not always fully evaluated in visual interpretation efforts. This is partly because of the limited ability of the eye to discern tonal values on an image and the difficulty for an interpreter to simultaneously analyze numerous spectral images. Spectral patterns are highly informative especially in distinguishing monodiscipline land resources, it is therefore preferable to analyze digital, rather than pictorial, image data.

The acquisition of digital data involves remote sensing and geocoding of measurements and observations about the land qualities. The geocoded data may be derived from a soil survey map, geological map, or an aerial photograph. They may also stem from 'field check' on the identity, extent, and condition of agricultural crop, land use etc. Reference data may also involve field measurements of physical and chemical properties of various land features.

In the past quarter century three major approaches have been used in developing techniques of image interpretation for land resource survey, these are 'pattern analysis', 'element analysis' by Buringh (1960), 'physiographic analysis' by Vink (1963) and Goosen (1967). An excellent and practical guide in satellite image interpretation is the work of Sabins (1978) though it deals mainly with geo-sciences, particularly geology.

Using Sabins' guidance a methodology for the interpretation of carefully selected Landsat data and aerial photos for inventories of natural resources by integrating static and dynamic image interpretation elements was developed. Among the element to be used for assessment, the following are the most important:

2.2.1 Drainage Pattern

Drainage patterns are an important aid in image interpretation because they can be used as criteria for identification of hydrological, structural, lithological and topographical phenomena. Drainage patterns can be further sub-divided into erosional, depositional and special patterns (Hilwig, 1979). In addition to the patterns described above, combinations may occur in various degrees of integration, density and uniformity, which is indicative of different area characteristics. Daels and Antrop (1977) distinguish some fifteen principal drainage patterns as an indicator of lithology and landform. In geological interpretation some ten main drainage patterns have been recorded. However, the image interpretation procedure proposed in this study will distinctively differentiate drainage pattern from drainage condition, the former one being independent of seasonal changes.

2.2.2 Alignments

An alignment or lineament is defined as a mappable simple or composite linear features of a surface, whose parts are aligned in a straight or slightly curving relationship. It can be clearly distinguished from the patterns of adjacent features and probably reflects a subsurface phenomenon (O'Leary et. al., 1976). The surface features making up a lineament may be geomorphic (caused by relief) or tonal (caused by contrast differences). The surface features may be landform boundaries, the linear boundaries may be between different types of terrain, or breaks in a uniform terrain. Straight stream valleys and aligned segments of valleys are typical geomorphic expressions of lineaments. A tonal lineament may be a straight boundary between areas of contrasting tone or a thin strip within a background of contrasting tone. Differences in vegetation, moisture content and soil or rock composition account for most tonal contrasts. Alignments may be continuous or discontinuous. In discontinuous lineaments the separate features are aligned in a consistent direction and are relatively closely spaced. Alignments may be simple or composite. Simple lineaments are formed by a single type of feature, such as a linear stream valley or aligned topographic escarpments. Composite lineaments are defined by more than one type of feature, such as an alignment of linear tonal features, stream segments and ridges.

Alignments are well expressed on Landsat images because of the oblique illumination, suppression of distracting spatial details and the regional coverage. Linear features caused by topography may be enhanced or suppressed on Landsat images depending upon their orientation relative to the direction of the solar irradiance as given by the sun azimuth. Linear features trending normal or at a high angle to the sun azimuth are enhanced by shadows and highlights. Those trending parallel with the azimuth are suppressed and difficult to recognize, as are linear features parallel to the MSS/TM scan lines (Sabins, 1978).

The presence of faults, folds, joints and certain physical rock characteristics may be deduced by analysing Landsat imagery of the alignments or lineaments. In this research, this static image interpretation element leads to an understanding of the structural geology of the study area. With the element drainage pattern it forms the skeleton for a sound interpretation of the various landform.

2.2.3 Landform

Landform can be used as an image interpretation element; it is related to the general morphology of the terrain. The morphological expression of the relief in conjunction with drainage pattern and supplemented by structural geologic deductions from the alignment pattern form the backbone of a systematic physiographic Landsat analysis.

The possibilities of stereovision are limited to areas with side lapping Landsat imagery. Therefore transparent overlays of small scale topographic maps with contour lines or use of aerial photographs may be of great help to the interpreter for the primary delineation of this image interpretation element.

2.2.4 Drainage Conditions

'Drainage condition' as reflecting moisture status, belongs to a group of elements based on 'converging evidence' (Vink, 1963) in modern aerial photo-interpretation techniques. Open water is much more clearly indicated than subsurface water, where a certain amount of deduction is allowed based upon correlating factors such as: a) nearness to waterlogged soils, b) colour of the earth's surface, c) natural vegetation/land use etc.

Element drainage condition represents all water and soil moisture close enough to the surface to be detected by remote sensors. In the case of Landsat imagery, it is frequently reported that band 7 in the infra-red (0.8-1.1 um) is the best band. Open water canals and rivers sufficiently large to be detected come out well on Landsat imagery, but for multitemporal analysis of the soil moisture regime near the surface, false colour composites composed of band 4, 5 and 7 or 4, 5 and 6 are preferable.

2.2.5 Vegetation and Land Use

Natural vegetation and agricultural land used and cropping patterns are strongly season dependent. Because of their changing character they are grouped with dynamic interpretation elements to distinguish them from static elements such as drainage pattern and landform.

At the time of the pre-selection of the imagery a crop calendar must be used because it offers information on the various seasons, giving clear indications as to which one would be most appropriate for interpretation purposes (Hilwig, 1979).

False colour composites of MSS/TM bands 4, 5 and 7 are most suitable for the analysis of vegetation and land use. This leads to a representation in various colours ranging from red through orange, yellow and green to blue. An increased intensity towards red on the false colour composite generally means a denser vegetation cover. Depending upon its spatial distribution and the type of vegetation and crops or association of crops, a pattern emerges of which the colour and texture are the most important parameters.

2.3 Application of Digital Data in Selecting Potential Areas for Rain water Harvesting (RWH) Cropping System

2.3.1 Definition of rain water harvesting cropping system

Rain water harvesting for supplementary irrigation is that practice of capturing and concentrating rainfall water to irrigate crops. In arid and semiarid regions, where rainfall distribution limit dryland crop production, water harvesting can store and redistribute the moisture needed to enhance yields. And in regions where rainfall is insufficient to produce even a minimum crop, water harvesting offers the potential to bring those areas under cultivation. According to Flug (1981), some simple water-harvesting systems collect 20% to 40% of the precipitation for later beneficial uses, while a more elaborate system can collect more than 90%.

Collecting surface runoff during periods of excess rainfall and using it during subsequent dry periods in the rainy season or early in the dry season, markedly decrease the risks involved in rainfed agriculture. A particular example is the response observed in India on an alfisol, when a 30-day period coincided with the grain-formation stage (ICRISAT, 1975). A supplemental irrigation of only 5 cm on sorghum and maize in operational-scale research watersheds maintained yields near optimum levels, which were double the yields of the rainfed crops. Thus the direct effect of improved water utilization technology becomes substantial in years of ill-distributed rainfall or in producing a second crop in the dry seasons. Also reduced risk provides the basis for greater and assured responses to other inputs such as improved seeds and fertilizers.

2.3.1 Types of water harvesting

The systems have two parts. The catchment area where runoff is collected and the field where the water is concentrated. Of the great number of types in existence with various names, four forms are generally recognized for water harvesting techniques for agriculture.

2.3.1.1 Inter-row Water Harvesting

Inter-row water harvesting is applied either on land or on gentle slopes of up to 5% having soil at least 1m deep. The annual rainfall should not be less than 200mm/year. On flat terrain (0-1% inclination) bunds are constructed, compacted and, under higher-input conditions, treated with chemicals to increase runoff.

2.3.1.2 Microcatchment Systems

Microcatchment water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin which may be planted with a single tree, bush or with annual crops (Boers and Ben-Asher 1982).

2.3.1.3 Macrocatchment Water Harvesting

Water harvesting from macrocatchment (1,000m²-200ha) is referred to by some authors as "water harvesting from long slopes" or as "harvesting from external catchment systems" (Pacey and Cullis, 1988; Reij et al. 1988).

2.3.1.4 Large Catchment Water Harvesting

This uses catchments of many square kilometers in size, from which runoff water flows through major ravines or valleys, necessitating more complex structures of dams and distribution networks.

2.3.2 Potential areas for rainwater haversting

Performance of rainwater harvesting involves two main areas:

(i) The catchment; and
(ii) Storage and utilization area.

2.3.2.1 Catchment area

This is the area where rainfall runoff is induced and directed to storage or utilization areas. The success or failure of rain water harvesting depends to a great extent on the quantity of water that can be harvested from an area under given climatic conditions.

The threshold retention of a catchment is the quantity of precipitation required to initiate runoff and it depends on various components such as surface storage, rainfall intensity and infiltration capacity. Some times natural surfaces that can yield a good run-off are available, e.g rock outcrops, rock slopes, tarmac road, and root tops.

Also areas with slopes which are steep enough to maximize runoff and minimize surface storage but flat enough to prevent erosion, and have a tendency to crust during rainfall are also considered as natural catchments, since infiltration is low in such areas.

However, in most cases natural surfaces do not exist. It is in these cases that measures can be taken to induce runoff. Considerable research (Dutt et. al., 1981) has been done in other countries on methods to reduce surface storage and lower infiltration capacity, which are the main parameters determining threshold retention and runoff efficiency.

2.3.2.2 Storage.

Water storage techniques for holding the water collected from a catchment area can be separated into two general groups

(i) The soil profile or monolith, and
(ii) Tanks, ponds or dams.

The type of storage selected will depend on many factors, such as the ultimate use of the water, availability of construction materials and site topography.

According to Hatibu (1989), the soil monolith storage uses the profile of the soil within the crop-growing basin. The primary factors that must be considered in designing soil monolith storages are the depth of the soil profile, water holding capacity of the soil and the infiltration rate of the soil surface.

External water storage is necessary component for water supply systems for domestic and animal use. In many water harvesting systems, the storage facility is the most expensive single item and may represent up to 50% of the total lost (Cooley et al in Dutt et al, 1981).

2.3.3 Use of Satellite and ancillary data for selecting potential area for RWH cropping system

In semi arid tropics, conventional planning data is in most cases not available or not up to date. In such cases use of satellite images is of tremendous help. A nested procedure, combining a coverage of an area by satellite imagery, conventional photo interpretation and analysis of maps is the best way of conducting such studies and up dating the information base (Dent and Young, 1982).

A satellite imagery is composed of a two dimensional array of cells or picture elements (pixels). Associated with each pixel are values of earth surface radiance as measured in seven bands of the electromagnetic spectrum. Digital classification of these data requires that representative samples of object classes on the Earth's surface (eg. types of vegetation, soils, geology, land use) be carefully selected and described because without accurate reference data, the whole classification process become voids.

Digital classification of satellite data seeks to recognize earth objects using multiple observation of one attribute. When considering the spectrum as a whole different objects have different patterns of reflection and emission. It is assumed that these patterns are sufficiently unique to make objects consistently distinguishable from one another using statistical clustering techniques.

Since the satellite imagery is a record of land attribute radiance and these are the same elements which determine the potentiality of an area for RWH cropping system, then the physical potential of an area to yield sufficient runoff for supplementary irrigation can be assessed by classification of the satellite imagery.

2.3.4 Landsat satellite characteristics and imagery

The Landsat satellite whose data are the basis of this study, circles the globe in a near polar sun-synchronous orbit at an altitude of 912 Km. The satellite passes over the same area on the earth every 16 days. The Thematic Mapper (TM) aboard Landsat 4 and 5 is a seven band multispectral high resolution scanner, replacing the Return Beam Vidicon (RBV) camera of the Landsat 3, an earlier versions. The TM records reflected energy from the earth in seven distinct spectral bands whose wavelengths, resolutions and features/applications are shown in table 2.1

Table 2.1 The bands of Landsat Thematic Mapper

Landsat Thematic Mapper

Band	Spectral Range (Micrometers)	Resolution	Features/applications
TM 1	0 45 - 0.52 visible blue - green	30m	Bathymetry in less turbid waters. soil/vegetation differences. deciduous/coniferous differentiation (Chlorophyll absorption). soil types
TM 2	0 52 - 0 60 Visible green		Indicator of growth rate/ vegetation vigor.sedimentation concentration estimates. turbid water bathymetry
TM 3	0 63 - 0 69 Visible red	30m	Chlorophyll absorption/species differentiation. crop classification. vegetation cover and density. geological applications
TM 4	0 76 - 0.90 Solar near infrared	30m	Water body delineation. biomass and stress variations
TM 5	0.76 - 0.90 Solar mid infrared	30m	Vegetation moisture/ stress. minerals
TM 6	10.4 - 12 5 Emitted thermal infrared	120m	Surface temperatures. urban versus non urban land use separation distinguishing burned areas from water bodies
TM 7	2.08 - 2 35 Solar mid infrared	30m	Hydrothermally altered zones. mineral exploration. soil type discrimination

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials and methods

3.1.1 Data acquisition

Materials used for the study are satellite and ancillary data of the study area for characterisation of the soil spectral classes and geomorphology. Landsat Thematic Mapper (TM) satellite digital data were acquired on 30 september 1992 with cloud free imagery. Among the available scenes this was the best because in september most fields are bare due to drought. The satellite digital data were processed using the Earth Resources Data Analysis System (ERDAS) software.

The main study area covers over 10000 ha while the sample area which is part of the study area covers an area of 420 ha. Ancillary data used are soil map of the 420 ha sample area published by Kaaya et al (1994). Other information sources used are field investigations, topographic and geological maps and aerial photographs. The sample area provides the ground truth for interpretation of the satellite data.

3.1.2 Methods

The study was conducted in two stages. The first stage involves detailed analysis of the sample area.

Several transformation techniques were tried to see which define the soil mapping units. The principle component transformation was found to give the best results and thus it was used throughout the study.

Principle components transformation which is a linear combination of the original digital numbers was applied to the subscene to remove redundant information. The spectral properties for classification were defined using training fields. One or more training fields were identified from the study areas for each soil type or land cover class with the assistance of ancillary data.

Transformed divergence, which is calculated from the means and covariance matrices of each spectral class or training site was used to measure the statistical distance between class pairs. This separability is an indirect estimate of the likelihood of correct classification between groups of different band combination (Swain and Davis, 1978). This analysis also provides a quick and inexpensive indication of the classification accuracy (Haack et al., 1987).

Mean vector and covariance matrices were developed for each principal component and input into a Gaussian maximum likelihood classifier algorithm. The data set was then classified using the second and third components of the transformed reflective spectral bands.

A classified spectral soil map of the sample area was produced and compared with the conventional soil survey map and other ancillary data using visual extraction methods.

Finally, ancillary data were used to identify which spectral classes are potentially suitable for rain water harvesting cropping systems basing on catchment and cropping basin requirements.

In the second stage, computer pattern recognition techniques were applied to identify areas with characteristics similar to those mapped as suitable for RWH cropping system. The method involves the use of computer algorithm which uses the means and variance of the signatures derived from the sample area to generate spectral classes for the whole of the study area. This process locates and assign the pixels to the classes similar to those of the sample area. In so doing potential area for RWH cropping system were also identified on areas with no ground truth.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Spectral response of cover types

The spectral response of the cover types of the study area can be seen in Fig: 4.1 while Fig: 4.2 shows the sample area.

In the near-IR band (TM 4), the green vegetation shows much higher reflectance than any other cover type (Fig. 4.3). Fallow fields appear in light gray tones, grass in dark tones, and medium vigour vegetation in nealy white tone. In band 5 (Fig. 4.4) the pattern of soil variability is clearly displayed in vegetation-free fields; in particular on the central and north east part containing drying grass and ultsol, areas with light soils appear bright on the image while those with dark soils appear as dark. The thermal band (TM band 6) reveals low response for areas of green vegetation, similar to that for the chlorophyll-absorption bands, but this is due to lower temperatures because of high evapotranspiration rates (Fig. 4.5).

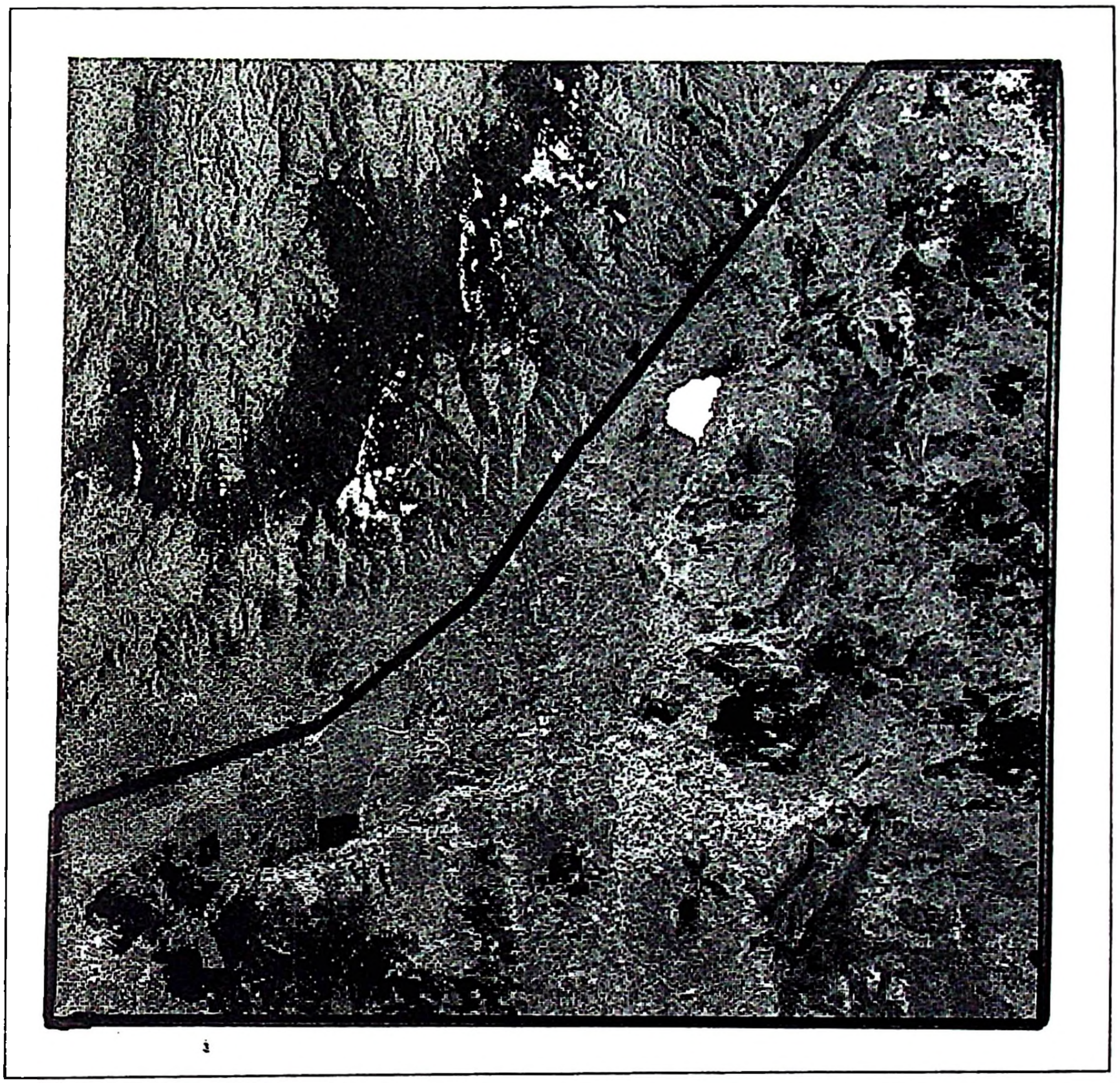


Figure 4.1 Spectral response of the study area

Note: For all printouts, the printer assigned white colour to supposedly black pixels

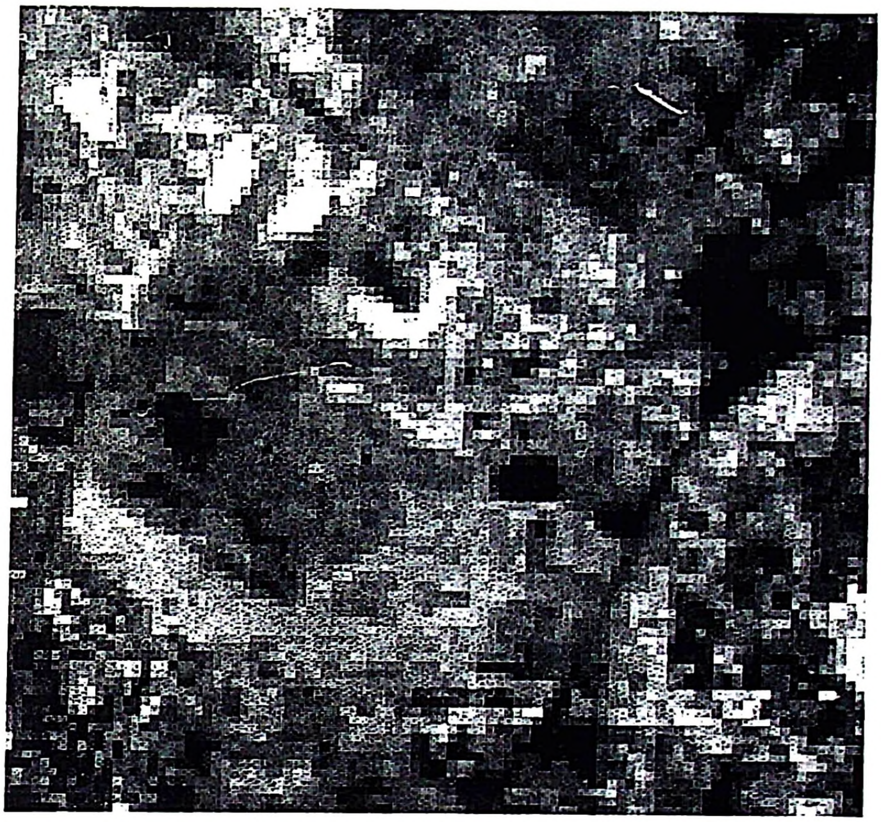


Figure 4.2 Spectral response of the sample area

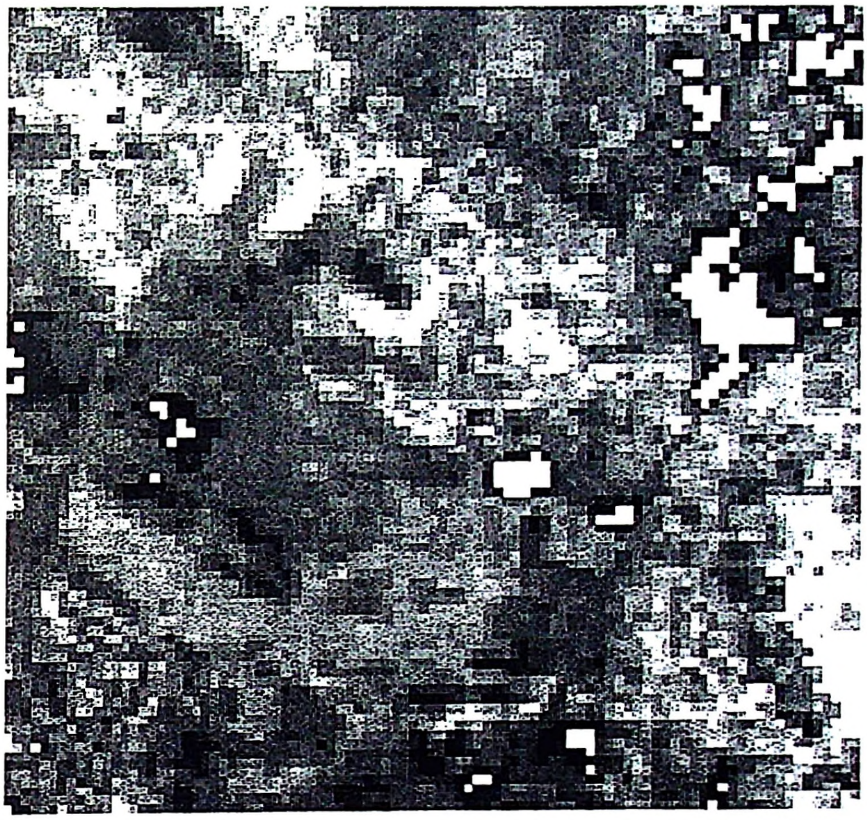


Figure 4.3 TM band 4 of the sample area (spectral range 0.76 - 0.90 μm).

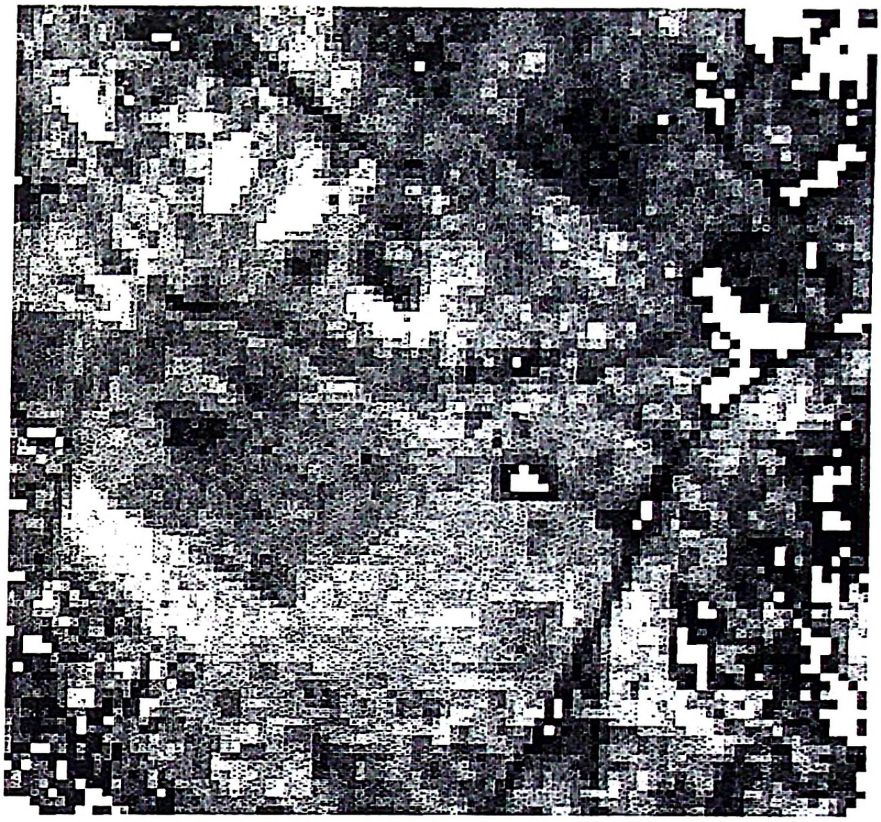


Figure 4.4: TM band 5 of the sample area (spectral range 1.55 - 1.75 μm).

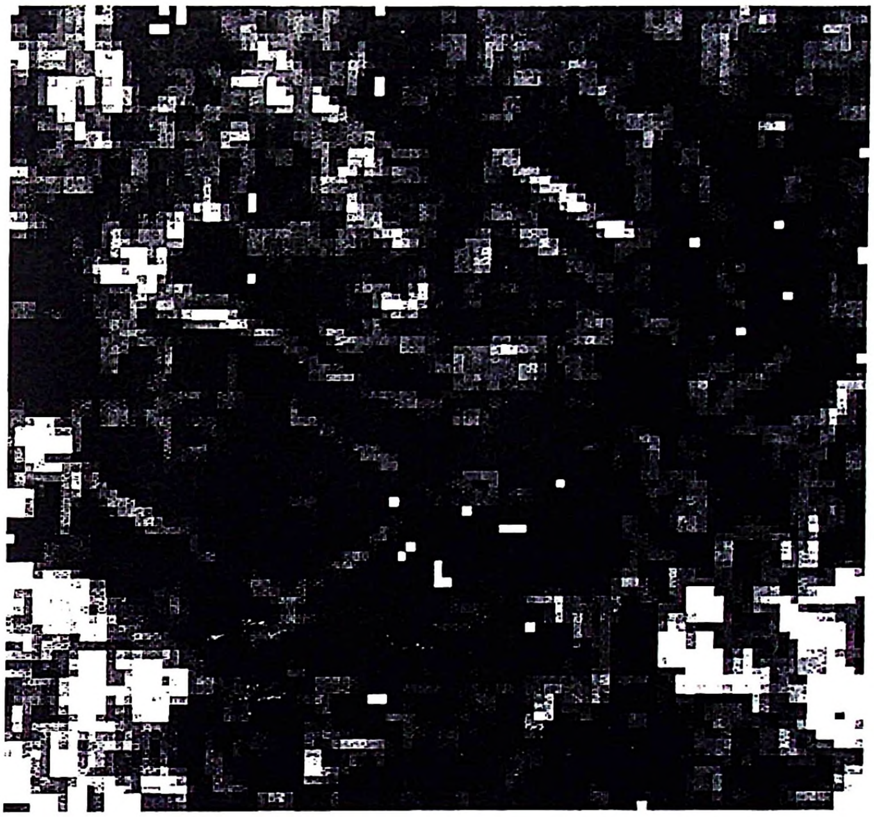


Figure 4.5: TM band 6 of the study area (spectral range 10.4 - 12.5 μm).

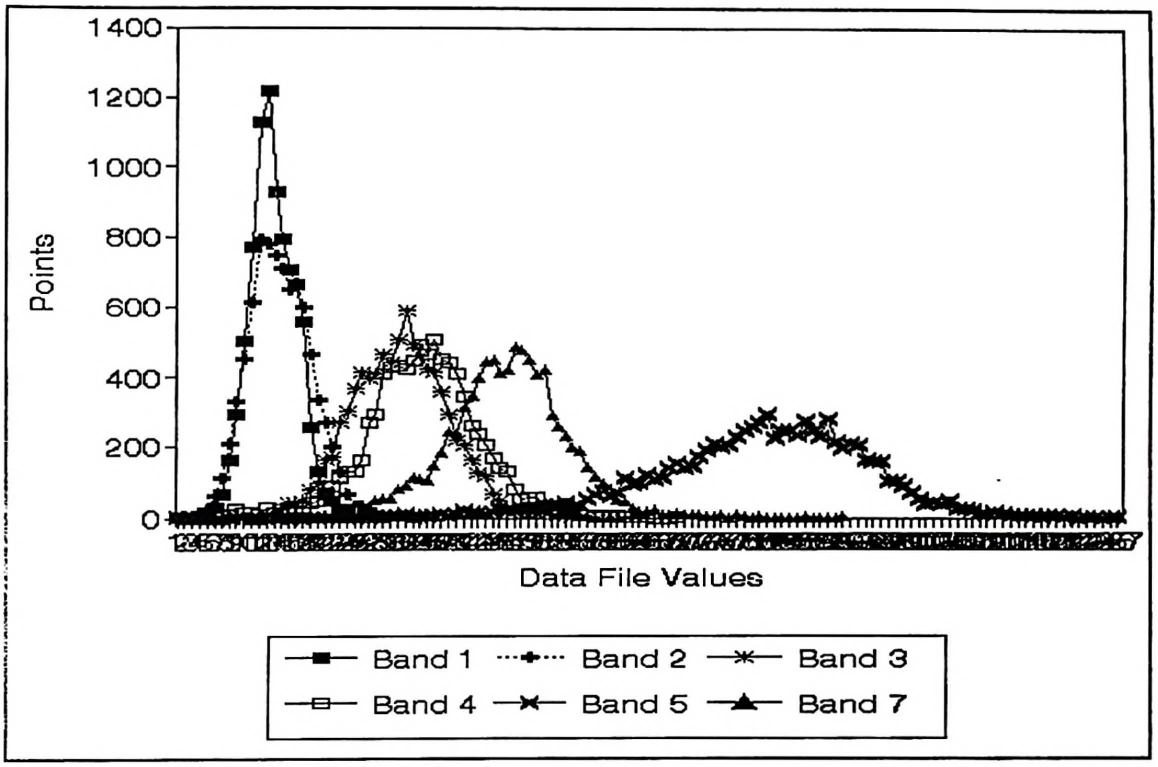


Figure 4.6: **Histograms for the subscene.**

It is however apparent from visual examination of the images in Fig. 4.2 that several of the bands display marked inter correlations. This is graphically shown in Fig. 4.6, which gives the histograms for six bands (excluding the thermal band) of the whole sub scene. Moderate to strong overlaps are found between the visible bands. To eliminate this effect, principle components were derived from the original data.

4.1.1 Derivation of principle components

The PRINCE algorithm of ERDAS image processing program was used to create an image file, whose bands are the principle components of the spectral bands of the sample area. The output principle component file contains the six reflective bands of the input file, these bands contain information for the reflective bands but no longer match the original bands since their distribution has been transformed. The variance within the original data was used to put out principal component bands, where

1. each band contains non redundant, independent data and
2. most of the variance is in band 1, with decreasing amounts in the subsequent bands.

Automatic polarization and scaling options were chosen in the transformation process as these gave component images with better visual dynamic range and it was felt that they would not prejudice the subsequent interpretation.

Table 4.1 Covarience Matrix, Eigen vectors and eigenvalues

Covariance Matrix

	1	2	3	4	5	7
1	18.00	11.47	22.84	16.33	36.76	8.72
2	11.47	9.67	18.11	14.89	29.61	8.74
3	22.84	18.11	42.87	25.00	74.00	-1.35
4	16.33	14.89	25.00	59.46	52.95	46.98
5	36.76	29.61	74.00	52.95	202.75	-50.41
7	8.72	8.74	-1.35	46.98	-50.41	674.30

	Eigenvalues	Var. %	Total %	Angle	Scale
1	682.57	67.78	67.78	86.96	1
2	262.48	36.06	93.84	19.68	1
3	36.91	3.67	97.51	82.05	1
4	20.31	2.02	99.53	78.99	1
5	3.80	0.38	99.90	103.56	1
7	0.99	0.10	100.00	90.61	1

Eigenvectors

	1	2	3	4	5	7
1	0.01	0.19	0.11	0.53	-0.78	-0.26
2	0.01	0.15	0.12	0.32	-0.03	0.93
3	-0.01	0.35	0.01	0.65	0.62	-0.26
4	0.07	0.31	0.91	-0.26	0.05	-0.07
5	-0.10	0.85	-0.37	-0.35	-0.09	0.03
7	0.99	0.06	-0.10	-0.02	0.00	0.00

Calculation of the eigen values indicates the underlying dimensionality of the data (Ready and Wintz, 1973). Essentially the data are three dimensional with 97.51 percent of the variance being explained by the first three components

(Table 4.1); there is some indication of a four-dimensional structure with the fourth component explaining just over 2 percent of the variance. None of the remaining components explains even 1 percent of the total variance.

4.1.2 Discrimination between cover types by Principle components analysis

Some of these eigenvectors and eigenvalues allows relatively easy interpretation of the resultant images. The first component tantamount to a total brightness image, whereas the later components highlight land covers. It is the second, third and fourth component which give a view of the cover types (Table 4.1). The second component has positive loading for band 7 hence most effectively distinguishes between soil types and other cover types. Component three and four are dominated by near- and mid-infrared radiation and hence, there is strong discrimination between areas of actively growing vegetation. The rest of the components do not display any features of significance to the study.

4.1.3 Classification of principle components imagery

Supervised classification based on maximum likelihood classifier was applied to the second, third and fourth principle component. The SEED (IP) program of ERDAS was used to extract training data from the subscene. Suitable sets of training pixels for each of the 8 classes were identified visually in the image data.

4.1.3.1 Training samples and their quality

The overall quality of the data contained in each of the original candidate training areas was assessed and the spectral separability between the data sets studied. A measure of the spectral separability between the category response patterns was computed for all pairs of classes and is presented in form of a matrix (Table 4.2). Using the divergence, which is a covariance-weighted distance between the signatures representing future classes, it can be seen that the combination of bands 1 & 3, and 2 & 3 gives a low probability of correct classification of classes. However, band 1 & 2 when used in classification have larger divergence and hence higher probability of correct classification of classes. Consequently, only these two bands were used for classification.

Table 4.2 The spectral separability of the training signatures

Band	AVE	MIN	Class Pairs						
			1:2	1:3	1:4	1:5	1:6	1:7	1:8
			2:3	2:4	2:5	2:6	2:7	2:8	3:4
			3:5	3:6	3:7	3:8	4:5	4:6	4:7
			4:8	5:6	5:7	5:8	6:7	6:8	7:8
1:2	1397	1305	1410	1305	1414	1414	1414	1405	1412
			1382	1414	1414	1414	1414	1414	1391
			1414	1414	1398	1380	1409	1315	1414
			1373	1340	1414	1414	1414	1413	1396
1:3	1298	786	934	1322	1414	1414	1414	984	1404
			983	1414	1414	1414	1147	1355	1399
			1414	1414	1336	1127	1345	1381	1414
			786	1170	1414	1341	1414	1380	1394
2:3	1295	624	1412	946	724	1410	1298	1409	1412
			1377	1389	1290	1398	1414	1414	624
			1406	1318	1308	1372	1401	1200	1222
			1359	1395	1414	1414	1402	1411	1128

Another evaluation was provided by generating a contingency table (sometimes called a confusion matrix) as shown in Table 4.3. This table is prepared by classifying the training pixels. The known category types of the pixels used for training are listed versus the categories chosen by the classifier. From this information, classification errors of omission and commission were studied. In an ideal case, all non diagonal elements of the contingency table would be zero, indicating no misclassification. The results show that there is no significant confusion between the sample areas. Thus they were used for classification of the subscene.

Table 4.3 Contingency table for the training sample.

Sign. Name	Training polygon names															
	1	%	2	%	3	%	4	%	5	%	6	%	7	%	8	%
1	25	96.2	0	0	7	1.4	0	0	0	0	0	0	0	0	0	0
2	0	0	7	100	4	0.8	0	0	0	0	0	0	0	0	0	0
3	1	3.8	0	0	472	97.5	2	1.5	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	135	98.5	0	0	1	7.1	0	0	2	2.4
5	0	0	0	0	0	0	0	0	33	97.1	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	1	2.9	13	92.9	0	0	0	0
7	0	0	0	0	1	0.2	0	0	0	0	0	0	27	100	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	97.6
	26		7		484		137		34		14		27		84	

4.1.3.2 Signature development and Evaluation

The signatures developed from the training data were input in the MAXCLAS program of the "Image Processing Module" of ERDAS to form a GIS Image presented as Fig. 4.9. ELLIPSE program of

ERDAS was used to evaluate how distinct the signatures are. ELLIPSE allows to view graphs of signature statistics of the intended classes in spectral space, i.e one band against another, so that the signatures can be compared. The graphs appear as sets of ellipses. Each ellipse is based on the mean and the standard deviation of one signature in two bands.

By comparing the ellipses for all signatures of one band pair, it was observed that, no two or more signatures represent similar groups of pixels. However it is rare that all classes are totally distinct, that some overlap must be expected and thus was accepted as shown in Fig. 4.7.

4.1.4 Interpretation of the computer-produced pattern

At the time when the used satellite image was taken, on the 30 september 1992, maize had already been harvested from the fields, if any, because the rains were very little that year. From the meteorological data, the rains were below average by 105 mm. Due to the drought in september fields had dried or no vegetation at all, except in very few areas along the seasonal streams. This effect is revealed by the Normalized Difference Vegetative Index (NDVI) image figure 4.8. From NDVI image more than 70% of the study area is bare surface or

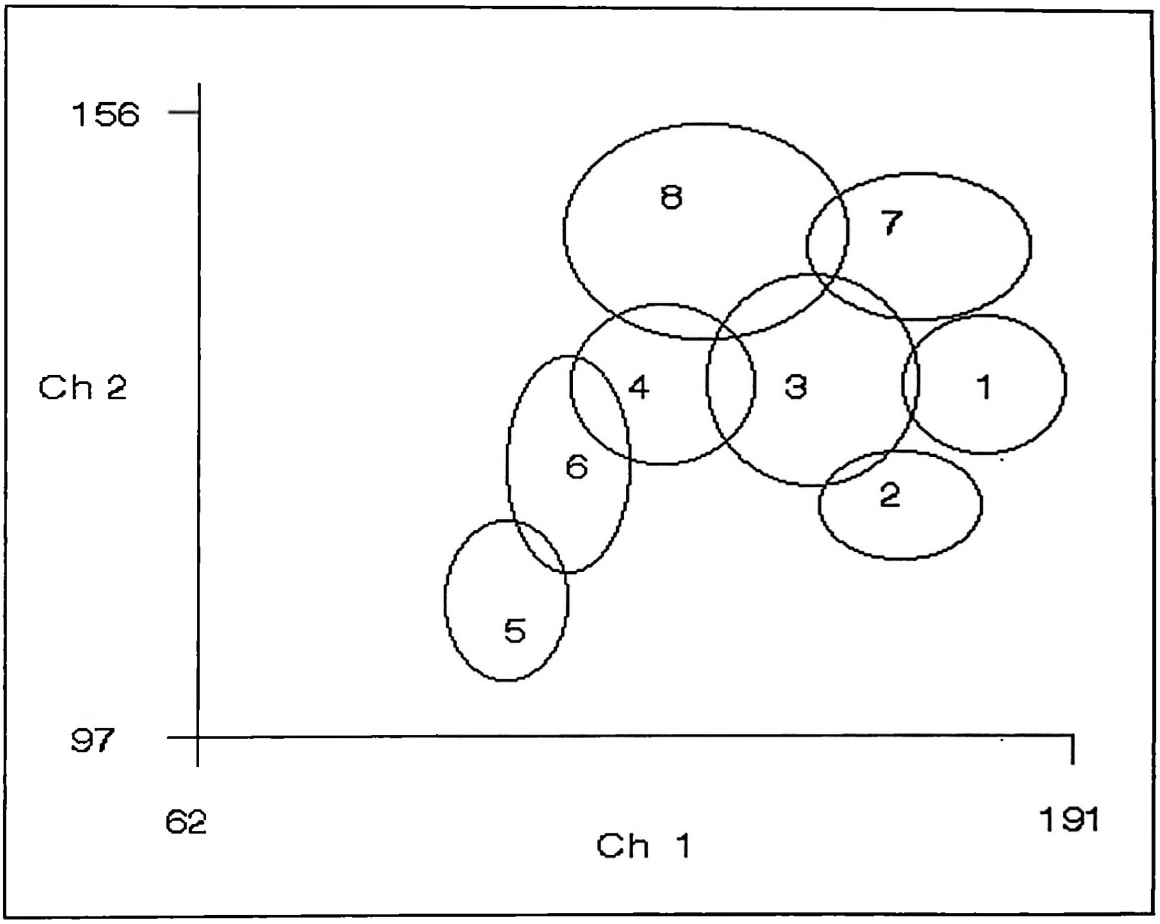


Figure 4.7 Ellipses of all signatures

non vital vegetation as indicated by the pixels with light blue and bluish colour, while the rest is occupied by vital or half-dry density vegetation (light yellow, yellowish and green pixels).

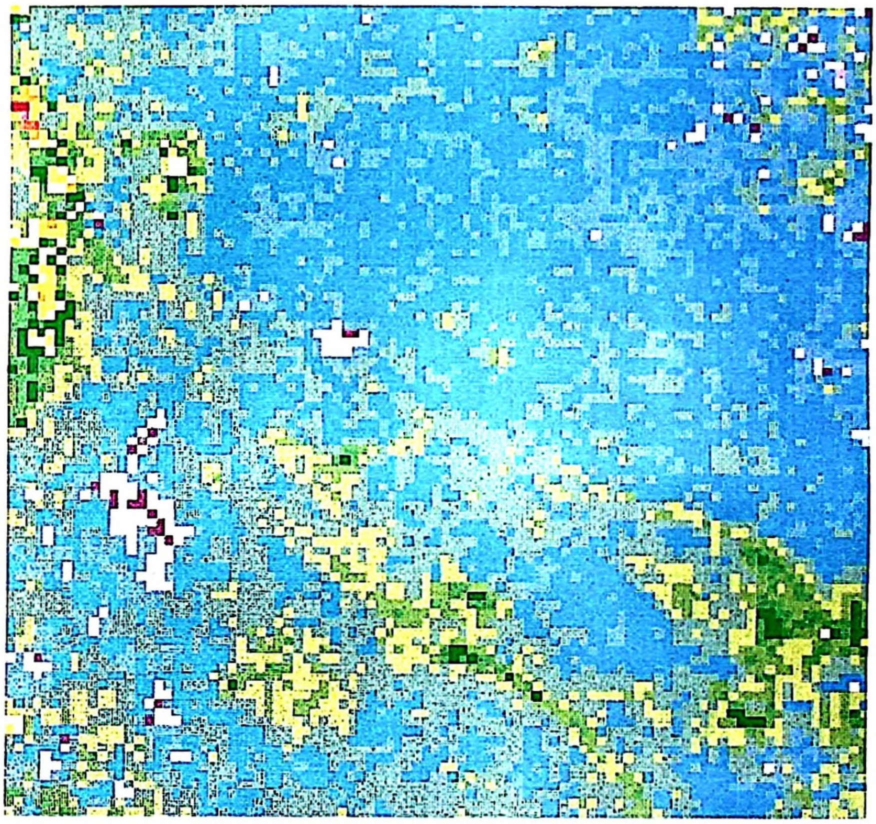


Figure 4.8 NDVI of the sample area

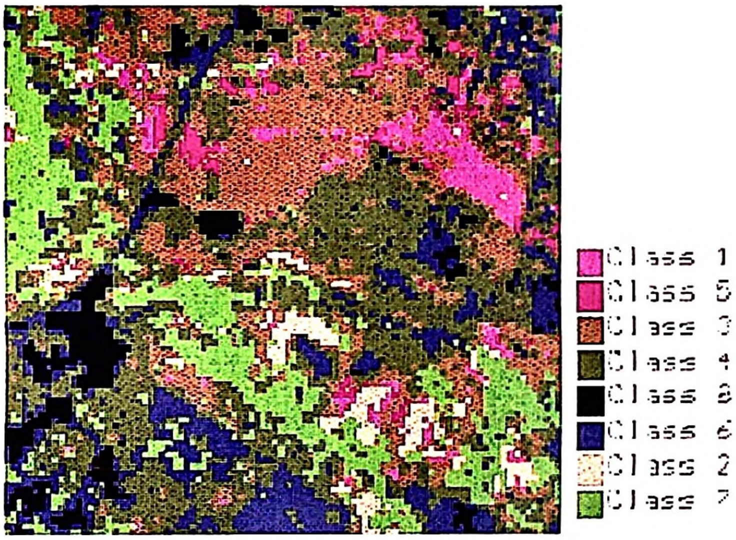
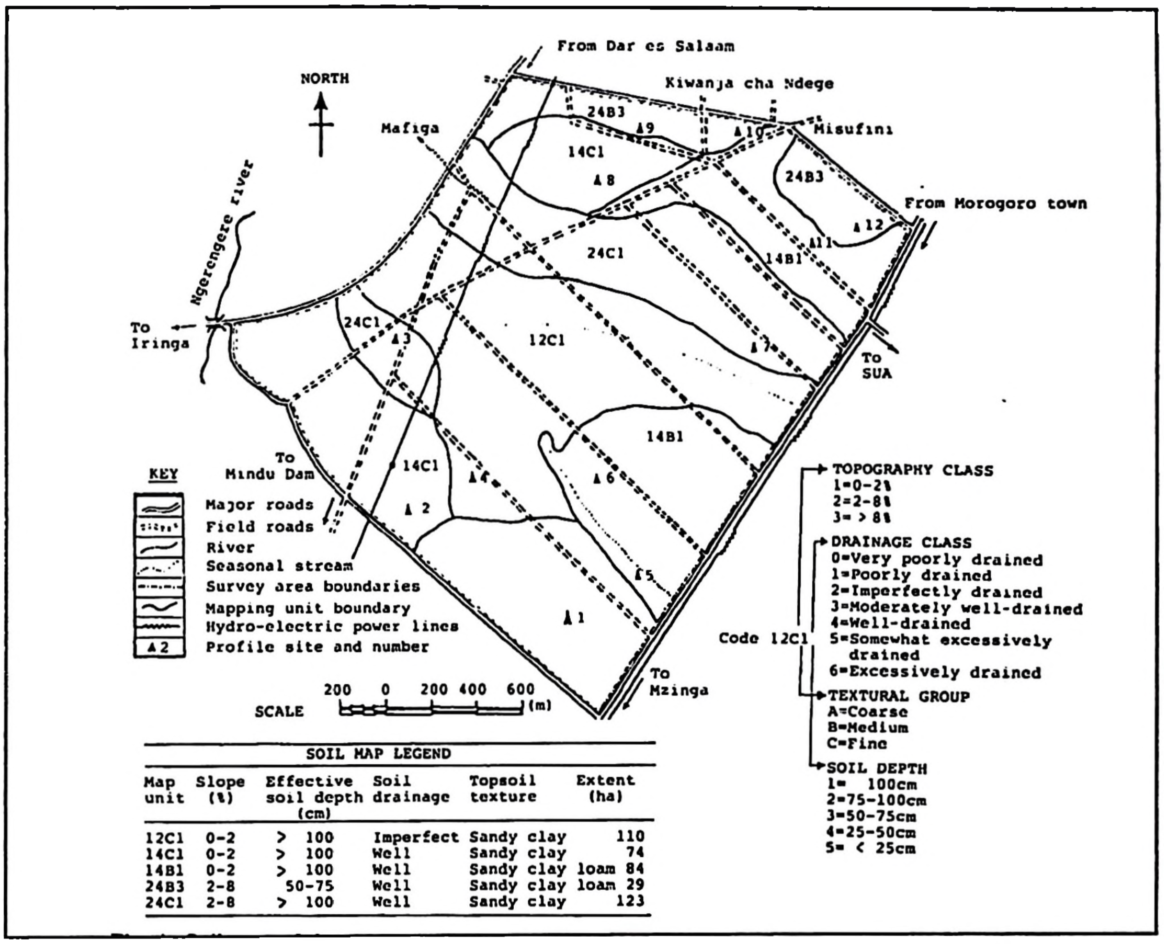


Figure 4.9 Classified PC image of the sample area



SOIL MAP LEGEND

Map unit	Slope (%)	Effective soil depth (cm)	Soil drainage	Topsoil texture	Extent (ha)
12C1	0-2	> 100	Imperfect	Sandy clay	110
14C1	0-2	> 100	Well	Sandy clay	74
14B1	0-2	> 100	Well	Sandy clay loam	84
24B3	2-8	50-75	Well	Sandy clay loam	29
24C1	2-8	> 100	Well	Sandy clay	123

Figure 4.10 Soil map of the sample area (Source: Kaaya et. al. 1994)

When the classified Principle Components Image in Figure 4.9 is compared to the aerial photographs and the NDVI image, 6 of the spectral classes describe the bare surface or non vital vegetation areas. Within the vegetated portions of the area, the spectral properties of the soils could not be observed. In these areas little effort was made to relate soil cover to soil types.

Digital mapping of soils using Landsat data is based solely upon the surface reflectance properties of the various soils. Thus distinguishing soil characteristics as parent material, profile development, and landscape position are only observable using advanced GIS - technology, which can not yet be done at Sokoine University of Agriculture. Often widely different soils exhibit similar spectral responses and cannot be differentiated from one another using satellite data alone. However, appropriate ancillary data used in conjunction with the Landsat data can greatly increase the informational content of a spectral soil map.

Kaaya et. al.(1994) conducted soil survey of this sample area and identified five mapping units based on the topography of the land, effective soil depth, drainage class of the soil profiles and the texture of the top soil. Each mapping unit is represented in the soil map Fig: 4.10 by a code which is explained in the legend.

They used the morphological and physicochemical characteristics of the soils in each mapping units (Table 4.4 and 4.5) to classify the soils of the sample area according to FAO - Unesco (1974) and the USDA (1975) Soil Taxonomy System. These results together with field observation and aerial photo interpretation were used to interpret the computer - produced pattern (Fig. 4.9).

Table 4.4. Soil physical properties of the sample area

Dedon 1:									
Ap	0 - 11	1.44	24.7	14.2	10.5	43.5	3.5	53.0	SC
B21t	11 - 36	1.58	26.9	6.3	10.7	63.2	3.5	33.3	C
B22t	36 - 82	1.57	30.2	15.6	14.6	66.2	3.5	30.3	C
B23t	82 - 152+	1.57	29.9	15.5	14.4	68.0	4.8	27.2	C
Dedon 2:									
A_p	0 - 15	1.11	30.1	15.0	15.1	55.9	4.8	39.3	C
B_{21t}	15 - 49	1.14	31.2	14.0	17.2	64.5	4.7	30.8	C
B_{22t}	49 - 95	1.21	31.1	14.5	16.6	67.7	6.1	26.2	C
B_{23t}	95 - 130	1.29	33.3	15.5	17.8	68.9	4.8	26.3	C
B_{24t}	130 - 155+	1.33	33.6	15.5	18.1	68.0	4.8	27.2	C
Pedon 3:									
Ap	0 - 17	1.24	29.9	15.1	14.8	46.7	7.5	45.8	SC
B21t	17 - 43	1.29	27.5	16.4	11.1	60.7	5.0	34.3	C
B22t	43 - 83	1.30	24.9	14.0	10.1	64.3	4.9	30.8	C
B23t	83 - 115	1.38	29.6	16.2	13.4	70.1	5.8	24.1	C
B24t	115-153+	1.41	31.1	16.9	14.4	69.6	6.3	24.1	C
Pedon 4:									
Ap	0 - 10	1.22	35.9	20.5	15.4	45.9	5.7	48.4	SC
B1	10 - 32	1.36	40.1	27.4	12.7	55.7	10.7	33.6	C
B21g	32 - 65	1.57	31.8	24.5	7.3	43.7	5.6	50.7	SC
B22g	65 - 115	1.42	32.4	26.2	6.2	50.5	5.7	43.8	C
B23g	115-152+	1.47	32.1	26.1	6.0	50.2	5.6	44.2	C
Pedon 7:									
Ap	0 - 16	1.18	17.6	10.5	7.1	40.9	5.2	53.9	SC
B21t	16 - 40	1.29	17.3	12.1	5.2	52.8	7.4	39.8	C
B22t	40 - 88	1.28	15.4	9.3	6.1	56.8	6.2	37.0	C
CB23t	88 - 158+	1.33	16.8	10.7	6.7	59.7	3.7	36.6	C
Pedon 8:									
Ap	0 - 13	1.38	22.8	10.2	12.6	36.3	3.7	60.0	SC
B1t	13 - 44	1.34	22.4	12.0	10.4	49.0	2.5	48.5	SC
B21t	44 - 76	1.35	30.1	15.3	14.8	56.0	4.9	39.1	C
B22t	76 - 152+	1.36	34.4	18.0	16.4	59.5	3.7	36.8	C
Pedon 9:									
A_p	0 - 8	1.54	24.6	13.2	11.4	30.1	4.9	65.0	SCL
B_2	8 - 20	1.51	26.6	16.6	10.0	36.8	3.7	59.5	SC
B_3	20 - 80	1.54	17.4	11.6	5.8	40.5	5.4	54.1	SC
C	80 - 122+	1.63	n.d.	n.d.	n.d.	34.8	6.2	59.0	SCL
Pedon 10:									
A_p	0 - 17	1.54	19.8	9.2	10.6	19.8	6.2	74.0	SL
B_{2t}	17 - 46	1.49	24.3	12.7	11.6	38.1	8.7	53.2	SC
B_3	46 - 102	1.57	14.8	8.6	6.2	37.2	4.9	58.0	SC
C	102-124+	n.d	n.d.	n.d.	n.d.	n.d	n.d.	n.d.	n.d.
Pedon 12:									
A_p	0 - 12	1.43	23.6	13.0	10.6	34.4	7.4	58.2	SCL
B_2	12 - 51	1.40	27.0	17.1	9.9	40.2	8.7	51.1	SC
B_3	51 - 60	1.63	19.1	12.3	6.8	45.4	7.4	47.2	SC
C	60 - 125+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Source: Kaaya et al, 1994.

Table 4.5 Chemical properties of the sample area

Soil sample and depth (cm)		pH H_2O	pH $CaCl_2$	P (mg kg^{-1})	C %	N %	Ca	Mg	K	Na	NH_4Oc CEC	BS %
							me/100g soil					
Pedon 1												
Ap	0-11	5.8	4.5	1.3	1.1	0.21	1.70	0.86	0.90	0.08	13.72	25.8
B21t	11-36	5.3	4.3	1.3	0.7	0.11	1.12	0.58	0.35	0.15	16.68	13.2
B22t	36-82	5.3	4.3	1.4	0.5	0.08	0.47	0.66	0.10	0.08	17.84	7.4
B23t	82-152	5.3	4.2	1.1	0.3	0.05	0.70	1.36	0.09	0.27	15.68	15.4
Pedon 2												
Ap	0-15	5.6	4.6	4.4	1.6	0.22	3.85	1.56	0.67	0.08	18.62	33.1
B21t	15-49	5.6	4.4	3.5	0.5	0.14	1.88	1.23	0.18	0.16	15.68	22.0
B22t	49-95	5.8	4.5	3.5	0.4	0.09	0.94	0.82	0.10	0.29	20.56	10.4
B23t	95-130	5.7	4.5	3.5	0.4	0.08	1.52	1.56	0.0.8	0.30	19.60	17.7
B24t	130-155	6.2	5.0	3.5	0.2	0.06	4.56	2.10	0.08	0.47	20.09	35.9
Pedon 3												
Ap	0-17	6.6	5.6	5.3	1.4	0.15	5.03	2.18	1.04	0.18	20.09	42.0
B21t	17-43	6.1	5.0	3.6	0.8	0.12	2.23	1.93	0.35	0.21	16.17	29.2
B22t	43-83	6.0	5.0	3.5	0.6	0.11	1.29	2.22	0.21	0.24	16.17	24.5
B23t	83-115	7.0	5.3	3.5	0.4	0.08	1.33	2.59	0.18	0.53	19.11	24.2
B24t	115-152	6.3	5.5	2.4	0.4	0.08	2.04	2.10	0.10	0.73	11.66	29.8
Pedon 4												
Ap	0-10	7.1	6.4	10.5	1.6	0.20	13.00	3.70	0.44	2.35	31.38	62.1
B1	10-32	7.3	6.3	8.8	0.8	0.14	22.93	5.14	0.48	0.72	30.87	94.6
B21g	32-65	7.2	6.2	5.3	0.7	0.10	13.70	3.40	0.25	0.55	25.48	70.3
B22g	65-115	7.5	6.7	5.3	0.5	0.08	20.11	5.25	0.21	1.48	33.32	81.1
B23g	115-152	7.8	7.0	5.3	0.3	0.08	19.18	7.61	0.21	2.20	32.34	90.2
Pedon 5												
Ap	0-14	7.7	6.6	18.4	1.0	0.13	6.67	1.89	0.58	0.15	15.68	59.2
B21	14-46	7.6	6.4	3.5	0.5	0.11	8.20	2.18	0.18	0.16	14.21	81.5
B22	46-58	7.6	6.4	2.6	0.4	0.09	3.62	1.85	0.18	0.22	10.29	55.1
B23	68-72	7.6	6.3	2.8	0.4	0.06	6.20	2.78	0.18	0.24	14.70	63.9
B24	72-96	7.7	6.8	2.2	0.2	0.7	2.45	0.99	0.07	0.21	7.84	47.4
B25	96-110	7.7	6.2	2.6	0.2	0.07	7.14	3.09	0.18	0.36	16.17	66.6
B3g	110-152	7.7	6.3	3.5	0.2	0.07	10.42	0.12	0.21	0.67	21.07	73.2
Pedon 6												
Ap	0-19	7.2	6.3	12.3	0.8	0.14	5.96	1.03	0.58	0.15	11.27	68.5
B21t	19-33	7.2	6.4	8.8	0.7	0.10	8.55	1.69	0.51	0.21	15.19	72.2
B22t	33-70	7.0	6.3	3.5	0.4	0.09	9.25	2.26	0.21	0.18	15.68	75.9
B23t	70-150	7.4	6.4	2.6	0.4	0.08	4.56	1.07	0.11	0.39	6.86	89.4
B24t	150-160	8.0	6.6	1.8	0.3	0.10	9.76	4.22	0.28	1.63	26.46	60.1

Pedon 7												
Ap	0-16	70	6.2	3.5	1.1	0.17	5.03	1.56	1.00	0.18	8.33	93.3
B21t	16-40	8.1	4.9	2.6	0.4	0.12	2.21	1.48	0.38	0.13	7.27	57.8
B22t	40-88	8.3	4.8	1.8	0.3	0.10	1.51	1.56	0.25	0.16	7.27	47.9
B23t	88-158+	6.6	5.2	1.8	0.3	0.08	1.51	1.65	0.25	0.27	7.27	50.6
Pedon 8												
Ap	0-13	6.4	5.5	1.8	1.3	0.16	5.03	1.73	0.71	0.10	10.29	73.6
B1t	13-44	5.6	4.2	1.8	0.8	0.12	3.15	1.52	0.18	0.13	16.68	29.9
B21t	44-76	6.0	5.0	0.9	0.5	0.12	2.68	2.35	0.09	0.16	11.76	44.9
B22t	76-152+	6.4	5.3	0.9	0.4	0.08	2.91	2.43	0.08	0.22	10.29	54.8
Pedon 9												
Ap	0-13	6.4	5.5	1.8	1.3	0.16	5.03	1.73	0.71	0.10	10.29	73.6
B2	13-44	5.6	4.2	1.8	0.8	0.12	3.15	1.52	0.16	0.13	16.66	29.9
B3	44-76	6.0	5.0	0.9	0.5	0.12	2.68	2.35	0.09	.016	11.76	44.9
C	76-152+	6.4	5.3	0.9	0.4	0.08	2.91	2.43	0.08	0.22	10.29	54.8
Pedon 10												
Ap	0-17	6.8	5.6	7.6	1.0	0.12	4.79	0.92	0.77	0.13	6.86	94.9
B2t	17-46	5.5	4.6	2.6	0.6	0.11	2.91	0.62	0.25	0.15	9.80	42.1
B3	46-102	6.2	4.8	1.8	0.4	0.09	3.39	1.15	0.18	0.24	10.78	46.0
C	102-124	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Pedon 11												
Ap	0-17	6.4	5.6	1.8	1.1	0.14	4.32	1.48	0.81	0.13	12.74	52.9
B21t	17-42	6.1	5.1	1.8	0.6	0.11	2.68	1.98	0.18	0.18	13.73	36.6
B22t	42-100	6.6	5.4	0.9	0.4	0.10	1.96	2.72	0.09	0.16	14.21	34.8
923t	100-121	6.8	5.5	0.9	0.4	0.08	2.21	2.67	0.13	0.24	25.00	21.0
B24t	121-146	6.9	5.6	0.9	0.3	0.08	3.39	2.98	0.12	0.45	28.42	24.4
C	146-153+	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Pedon 12												
Ap	0-12	7.8	6.8	3.5	1.0	0.18	34.18	0.99	0.48	0.10	44.59	8.02
B2	12-51	7.8	6.9	1.8	0.4	0.10	36.69	1.32	0.21	0.16	39.20	97.9
B3	81-60	7.9	7.0	1.8	0.3	0.09	39.59	2.06	0.21	0.18	42.14	99.7
C	60-125+	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

Source: Kaaya <u>et</u>. <u>al</u>. (1994).

It is readily observable from the soil map that there is not a direct one-to-one correlation between spectral classes and soil series or family. But the spatial distribution patterns of classes and soils are very closely correleted. In some instances one spectral class may represent two or more soil series, and in other cases a single soil series may be represented by one or more spectral classes. This occur due to the fact that different soils may have the same spectral reflection or a very similar. The spectal classes were correlated to the soil mapping units as follows.

4.1.4.1 Spectral class 1, (mapping unit $24B_3$)

The soils of this class, to a large extent correspond to the mapping unit $24B_3$ described as having two taxonomic units of the USDA Soil Taxonomy, namely Typic Ustorthent which is represented by pedon 9 and 12, and Rhodic Paleustalfs represented by pedon 10. Using the FAO - Unesco (1974) System, these soils are classified as Eutric Cambisols and Dystric Nitosol, respectively.

The soils are found on a gently sloping land of 2 - 5 % slope and have been developed from parent materials composed of biotite Schists and pyroxene granulates, which contain quartz and feldspar -rich veins (Saggerson, 1962).

The three pedons dug by Kaaya (1989) in this mapping unit reveal that the soils are generally shallow (50 - 75cm) but well drained. The mapping unit has pedogenic B horizon and argillic B horizon for Typic Ustorthents and Ultic Paleustalfs respectively. Above the B horizons lies an Ochric A horizon.

The texture of the topsoil ranges from sandy loam to sandy clay loam and it generally changes with soil depth to sandy clay loam in the whole mapping unit $24B_3$. From field observations and Kaaya's results, the topsoil moist color is dark reddish brown. The surface horizon organic matter content ranges from 1.69 to 2.02 and the structure of the topsoil is moderate medium granular and crumb which change with increase in clay content to angular and subangular blocky.

4.1.4.2 Spectral class 2 (mapping unit $12C_1$)

This spectral class correspond to the mapping unit $12C_1$ described by Kaaya (1989) and verified by field observations and aerial photo interpretation.

The soils are classified as Vertic Ustifluvents (USDA, 1975) and corresponded to Eutric Fluvisols (FAO - Unesco, 1974). The soils are on flat to almost flat topography with < 2% slope. The soils have developed from recent alluvial deposits from the Uluguru mountains (Kasseba *et al*, 1972; Moberg *et al*, 1982) which were brought by two seasonal streams draining into the sample area.

These soils which are represented by pedon 4, are deep but imperfectly drained and the profiles do not have clearly developed horizons probably because the alluvial materials were deposited at a faster rate than the profile could develop (Norman *et al*, 1984). The color of the topsoil is black (moist) and the structure is medium granular. The textural class of the top soil is sandy clay. The organic matter content decreases with profile depth with surface horizon containing 2.83%.

4.1.4.3 Spectral class 3 (mapping unit 14C1 and 14B1)

The soils of this spectral class were classified under two taxonomic units of the USDA Soil Taxonomy namely Oxic Paleustalfs and Typic Paleustults as represented by pedon 8 and 2 respectively. Using FAO - Unesco (1974) system, they are both classified as Eutric Nitisol and Dystric Nitisols.

The soils of this class are found on flat to almost flat land with < 2% slope. The soils have been formed from colluvial materials from Uluguru mountains (Kesseba *et al*., 1972) . The soils are deep and well drained. According to Kaaya (1989) they are characterized by the presence of an ochric A horizon and argillic B horizon. The textural class of the topsoil vary from sandy clay for Oxic Paleustalf to clay or Typic Paleustalf. In both taxonomic units, there is a steady increase of clay with depth to maximum level in the lower B subhorizons. The structure of the topsoil is granular which changes to subangular and organic matter is generally low with values ranging from 1.94% to 1.98% in the surface horizons and decreases with profile depth.

4.1.4.4 Spectral class 4 (Mapping unit $24C_1$)

The soils of this class are classified under taxonomic units, Paleustults, Typic Haplustults and Kandiustalfic Eutrustox using USDA (1974) Soil Taxomony system or as Dystric Nitisols and Rhodic Ferralsols under FAO - Unesco (1974) system and are represented by pedons 1,3 and 7 respectively.

The soils are situated on gently sloping land of 2-5% slope and have develop from the underlaying rocks which extend from the Uluguru mountains. The soils are deep and well drained with a characteristic Ochric A horizon, argillic B horizon in Oxic Haplustults and an Oxic B horizon in Tropteptic Eutrustox.

The soil texture in this mapping unit changes with depth from sandy clay in the surface to clay in the subsurface horizons. The dark red and dusk red moist colors of the surface horizons changes to dark brown moist from both units.

The organic matter content of the surface horizon changes from 1.86 - 2.47 % and is described as low to medium range by Landon (1984) and ILACO (1985). The soil structure is moderate medium and course crumbs at the surface.

The soils can be considered of low fertility as they have low available water content, low organic matter and nitrogen content, very low amount of phosphorus and CEC.

4.1.4.5 Spectral classes 5, 6 and 7

The classes represent the areas covered by vegetation of varying intensity. The shrubs and trees of class 5 and 6 are the kind of vegetation expected on imperfectly drained water course. Thus, it is presumed that, the soils of this class are the same as those of class 4. Class 7 represent ares occupied by tall grass and shrubs but little effort was made to relate this cover type to the soil type.

4.1.4.6 Spectral class 8

This class represents salt affected areas especially in the mapping unit $12C_1$.

4.2 Determination of classes suitable for RWH cropping system

The ultimate goal of this study was to separate mapping units that are potentially useful for RWH cropping systems on the sampled area and then to extrapolate the results to the whole of the study area, by using computer pattern recognition techniques.

In pursuit of this goal the characteristics of the soil spectral classes were compared to the requirements of the two parts of the RWH cropping system which are the catchment and the cropping basin. This was possible due to high correlation that exists between the soil spectral classes and the soil mapping units.

4.2.1 Suitability of the soil spectral classes for use as catchment.

One requirement for soils to be suitable for untreated catchments should be relatively impermeable, shallow or have a tendency to crust during rainfall. Our ancillary data shows that soils of spectral class 1 which corresponds to the mapping unit 24B1 are sufficiently shallow to be a good catchment. Furthermore, all the first four soil spectral classes were found to have high clay percentage in Ap and B horizons which suggest are good in crusting. According to Flug (1981) soils best suited for crusting are fine textured and have clay content greater than 20% and 30% in Ap and B horizons respectively.

Table 4.6 Comparison of the desired features for catchment area and the soil properties of the soil spectral classes

FEATURE		DESIRED	CLASS			
			1	2	3	4
			Mapping units			
			$24B_1$	12C.	$14C_1$ & $14B_1$	$24C_1$
SLOPE %		2 - 6	2 - 8	0 - 2	0 - 2	2 - 8
TEXTURAL GROUP		Fine	Medium	Fine	Fine - Medium	Fine
Depth in cm		< 75	50 - 75	>100	>100	>100
Clay content	Ap Horizon	> 20%	30.1 - 34.4	45.9	30.2 - 36.3	43.5 - 46.7
	B Horizons	> 30%	36.68 - 40.2	55.7	46.1 - 49.0	63.2 - 60.7

However, due to the morphology of soil spectral classes 2 and 3, they can not be used for natural catchments. The slope which range from 0-2% is too flat, thus can not encourage runoff neither minimize surface storage. Shanan and Tabmor (1976) write that "gently sloping land (2 - 6% gradient), without gullies, channels and local depressions are ideal for catchment".

Since spectral classes 1 and 4 fulfil most of desired features of a catchment, they were judged as suitable for use as catchment basing on their physical characteristics.

4.2.2 Suitability of the soil spectral classes for use as cropping basing

Common limitation for growth of maize, sorghum, rice and field beans in the sample area is low soil fertility status and low levels of organic matter, total N and available P (Kaaya *et al*, 1994). None of the four soil spectral classes fall under highly suitable class (S_1) because of low soil fertility status. However, with application of fertilizers spectral classes 3 and 4 may be upgraded to the highly suitable class for maize, sorghum and beans. Oxygen availability to plant roots (w) is a limitation only class 2 which correspond to mapping unit $12C_1$ where soils are imperfectly drained. However, this class is suitable for growth of paddy.

Shallow soils reduce the ability of plant roots to exploit their environment because of physical barrier to root development (Sanchez, 1976; Landon, 1984). Rooting conditions (r) is therefore a limitation in soil spectral class 1 corresponded to mapping unit $24B_3$ where soils are shallow. This class has earlier been shown to be ideal for catchment thus, since we can not do much to improve the soil depth, the best use it to make it a catchment.

Table 4.7 Soil spectral classes suitability for maize, sorghum and field beans growth

Spectral class	1	2	3	4
Mapping unit	$24B_3$	$12C_1$	$14C_1$ & $14B_1$	$24C_1$
Maize	S_{3rfm}*	S_{3-f}	S_{2fm}	S_{2fm}
Sorghum	S_{3rfm}	S_{3fm}	S_{2fm}	S_{2fm}
Field Beans	S_{3rfm}	S_{3fm}	S_{2fm}	S_{2fm}

*Land suitability class symbols

S1 = Highly suitable S2 = Moderately suitable

S3 = Marginally suitable N1 = currently not suitable

Land suitability subclass symbols:

w = oxygen availability limitation

f = soil fertility limitation

t = soil texture limitation

r = rooting condition limitation

e = erosion hazard limitation

m = moisture availability limitation

v = land preparation limitation

Basing on the foregoing argument, it was concluded that spectral classes 1 is only suitable for catchment while class 4 can be both a catchment and a cropped area. Since, soil spectral class 3 is only good for cropping and not suitable for catchment, thus in those parts of the sample area where the slope of the spectral class 1 lead itself into class 3, microcatchment water harvesting can be applied where by surface runoff is collected from a small catchment area (class 1) and stored in the root zone of an adjacent cropped area. In Class 4 , in situ water harvesting techniques can be applied where the patches of catchment alternate with cultivated plots inside the field boundary.

4.3 Extending the results of the sample area to the rest of the study area using landsat TM data

The choice of the study area was made to conform with the characteristics of the sample area because digital mapping of landscape is based solely upon the surface reflectance properties of the soils and other land covers. The area chosen has similar geomorphology, topography, land cover and vegetation as the sample area.

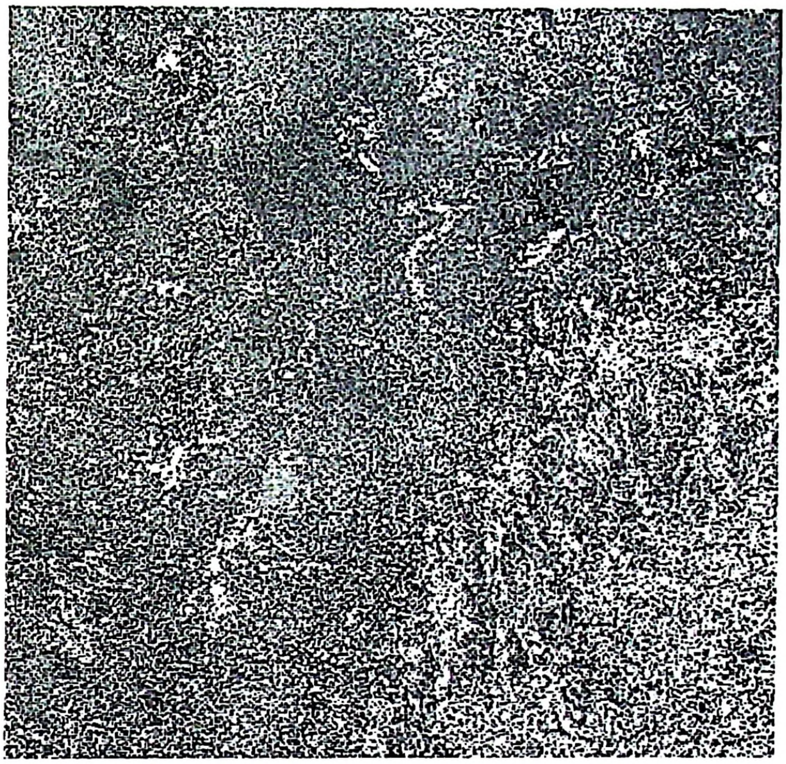


Figure 4.11: NDVI of the study area.

As seen in Fig. 4.11, the area with very high vigour vegetation (represented in red and yellow) and the steep slopes of the mountains Fig. 3.5 can not be expected to reflect solar energy of the same characteristics as the sample area Fig. 4.2. Therefore, the results of the sample area were only extended to the area shown in Fig. 4.12 which has similar morphology and land cover.

For the results of the extrapolation to be valid, all the pre-classification processes done for the sample area were performed prior to the extrapolation process.

4.3.1 Generation of the principle components for the study area

The principle components of the six reflective bands were generated using the covariance data previously created and applied to the sample area. This was to allow the same transformation to be applied to the whole of the study area. The first four principle components of the spectral bands contain 99.57% of the total scene variance. As was the case with the sample area only the second and third components were used for classification. Reasons for this have been explained under section 4.1.2.

4.3.2 Classification of the study area

The primary multispectral classification program of MAXCLAS (IP) was used. This program generates spectral classes from signatures, the signatures may be a result of another classification or clustering process. In our case signatures generated from supervised classification of the sample area using the principle components were input in to the MAXCLAS (IP) algorithm to generate spectral classes of the study area. The result of this process is a GIS image (Fig. 4.12) with the same classes as those of the sample area.

4.4 Potential areas for RWH cropping system in the study area

To confirm whether the classes of the study area resemble and represent the same characteristics as those of the sample area the classes of both images were given similar colours using COLORMOD (IP) program, enlarged to same scale and then compared (Fig. 4.13 and 4.14).

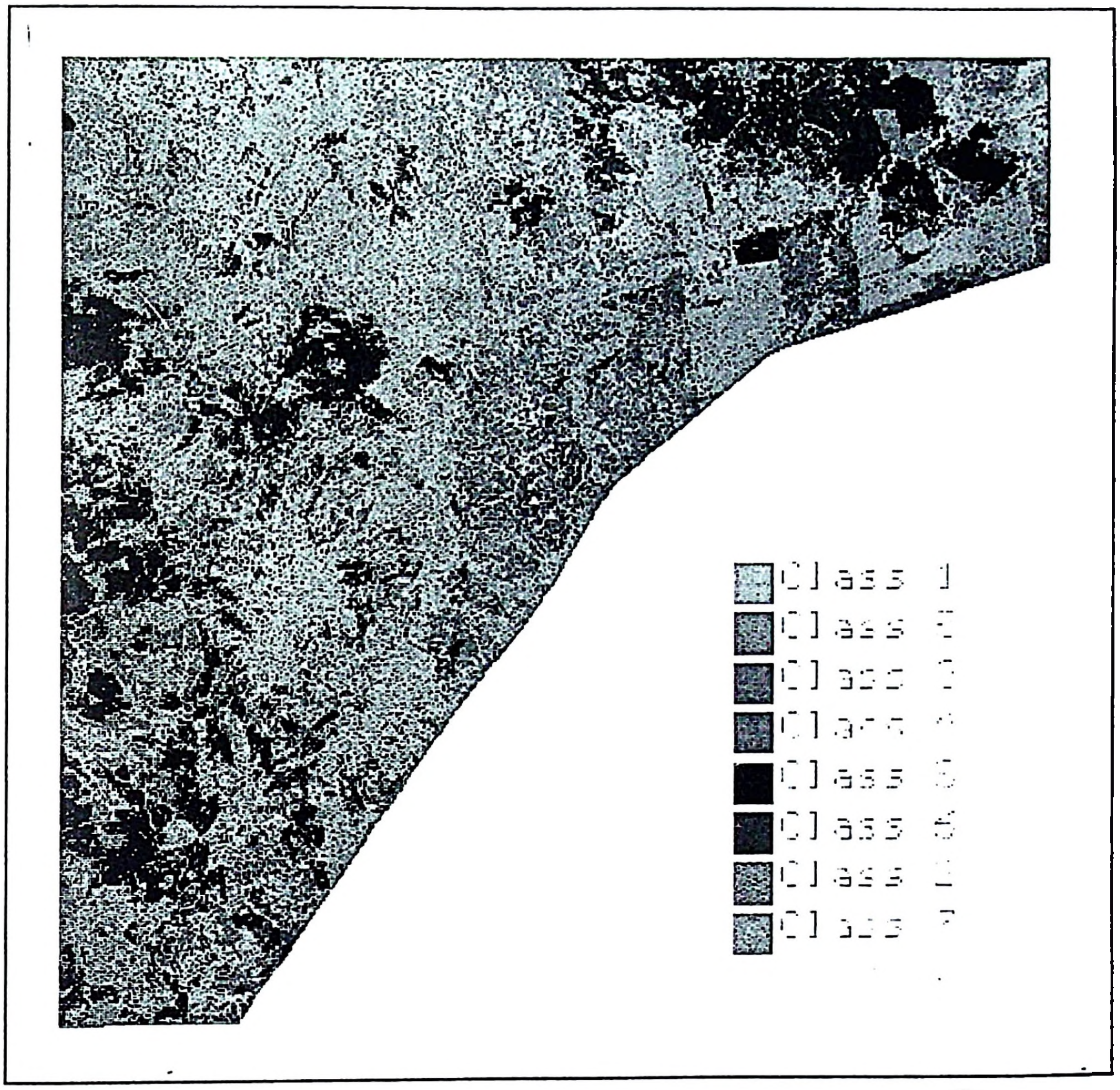


Figure 4.12: The spectral classes of the study area.

Figure 4.13: Part of the classified study area showing the sample area.

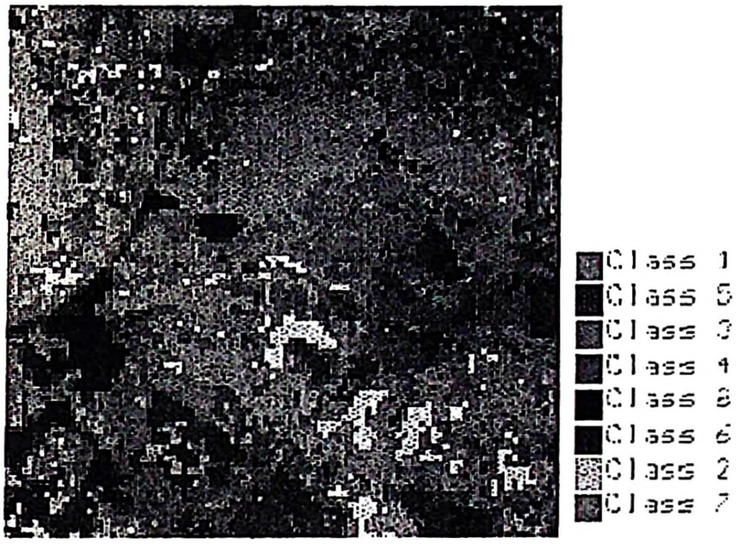


Figure 4.14: Spectral classes of the sample area.

Although there are minor differences, the classes of the study area represent the same patten of soil variation as those of the sample area. This confirm that the information content of the spectral classes of the study area is the same as that of the sample area. This lead to the conclusion that class 1 of the study area represent the areas suitable for catchment, class 3 areas for cropping basin and class 4 area suitable for both.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

1. In planning and designing RWH agrisystems Landsat TM data can contribute the information on drainage pattern, alignments, landform, drainage conditions, vegetation and land use.

2 The information obtained through Landsat TM imagery can only be useful if integrated and used together with land and soil survey data such as
   a) soil physical and chemical properties, and
   b) climatic data.

3. The use of Landsat TM improves the planning and design process because:
   a) each scene covers such a large area that a synoptic view of land features is possible. An area of up to 3.5 million hectares can be studied when sun angle, condition of soil, stage of vegetative growth and other features are recorded at nearly the same moment. The influence of climate and vegetation, soil parent material and topography on land use can be detected.

b) Landsat scenes fit controlled base maps such as geologic, topographic, soils, cultural and other features, can be superimposed as transparencies over Landsat scene or processed in the computer. Moreover, the scenes are near-orthographic. Thus Landsat scenes join one another with very little distortion so that mosaics can be constructed.

c) since Landsat passes occur every 16 days, scenes can be selected for the time of the year best suited for the determination of areas suitable for rainwater harvesting. Planers of RWH agrisystems have had very little control as to flight scheduling for acquiring aerial photographs and have to accept photographs taken for other uses.

4. It is recommended that more work be carried out to refine this technique and to include other pertinent ancillary data like socio-economic factors will continue to increase the usefulness of satellite data as an aid in selecting potential areas for RWH cropping system.

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