AN INVESTIGATION INTO LAND CAPABILITY CLASSIFICATION IN ERITREA: THE CASE STUDY OF ASMARA CITY ENVIRONS

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DEDICATION

This work is dedicated to those heroes and heroines who lost their lives in the struggle for independence and defending the national sovereignty of the country, Eritrea.

DECLARATION

This study was carried out in response to the misuse and land use competition in the pri-urban area of Asmara City environs, and was funded by the government of Eritrea.

The work described in this thesis was carried out in the Faculty of Science and Agriculture, School of Applied Environmental Science, Discipline of Geography.

This study represents my own original work. Where use has been made of the work of others it is duly acknowledged in the text.

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Date 23/03/04

ABSTRACT

The problems of land resources degradation as a result of misuse of arable land for non agricultural development and lack of appropriate methods and guidelines for land resources assessment are currently evident in Eritrea. These problems, have called for an urgent need for an appropriate land resources assessment in Eritrea. In response to this, a land capability classification in the areas around Asmara city that covers about 11742.7 ha was conducted.

The intended aim was to properly assess the potential of the land resources in the study area and classify the capability of the land so as to designate the land according to its capability and foster appropriate land use. All the available natural resources in the study area were carefully assessed. A detailed soil survey was conducted and soil units were examined, described, classified and mapped out. Several criteria for the limitations were selected from the reviewed literature mainly USDA and RSA Land Capability Classification systems and in consultation with the soil survey and natural resources experts of the Ministry of Agriculture in Eritrea.

Information on land and soil characteristics, and the specified limitations and criteria were captured in a spatial digital format and then analysed within a GIS. Based on the specified parameters, different land capability units, subclasses, classes and orders were identified and mapped out. Finally, the sub classes were grouped to create land capability classes ranging from Class I to Class VII and consequently the capability classes were grouped and mapped out at the level of land capability orders.

The results revealed seven land capability classes (class I toVII). Class III land in the study area covers 4149.43 ha (36.9 percent of the total area). The largest portion of this class is found in the central, southern and south eastern parts of the study area. However, classes I and II are very limited and cover 1562.95 ha (13.9 percent) of the study area. These classes are found mainly in the southern and central parts of the study area. Most of the gentle and steep sloping lands in the north and north eastern parts of the study area are classified as classes IV and VI.

These classes have an area of 2652.08 ha (23.6 percent) and 2594.87 ha (23.1 percent) of the study area, respectively. Classes V and VII are very limited. These classes cover 221.53 ha (2 percent) and 57.55 ha (0.5 percent), respectively. The largest portion of class V land is found in the central part of the study area. Class VII land is mainly confined to the north eastern, western and southern corners of the study area.

Four land capability orders were arrived at ranging from (high to moderate potential to non-arable land). The high to moderate potential arable lands are largely found in the southern and central parts of the study area. These lands cover 5715.39 ha (50.8 percent) of the study area. However, low potential arable (marginal productive) and non-arable lands have a considerable area of 2652.08 ha (23.6 percent) and 2652.42 ha (23.1 percent) of the study area, respectively. The largest portion of these lands is found in the north, north eastern and eastern parts of the study area. A small portion of the lands in the study area is classified as seasonally wetland. This land has an area of 221.53 ha (2 percent) of the study area and is mainly found in the central part of the study area.

It was concluded that nearly 50 percent of the land in the study area is classified as of moderately to high agricultural potential whereas the rest of the land is classified as marginal to non-arable land. However, the steady growth of demand for land for non-agricultural development due to the increasing population that depend on farm production in the study area, renders the prime arable lands as too limited to support the current population in the study area. Hence, protecting the prime arable lands and properly using such lands based on their sustained capacity can only secure the livelihood of the community.

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List of Acronyms

ACRS	Asian Conference on Remote Sensing
AEU	Agro-ecological Unit
AEZ	Agro-ecological Zone
APAO	Asmara Public Administration Office
ARDA	Agricultural Rehabilitation and Development Act
BRG	Bio-resources Group
BRU	Bio-resources Unit
CDE	Center for Development of Environment
CLI	Canada Land Inventory
CV%	Coefficient of Variation percentage
DEM	Digital Elevation Model
DPIWE	Department of Primary Industry Water and Environment
EAE	Eritrean Agency for Environment
ESRI	Environmental Systems Research Institute
FAO	Food and Agricultural Organization
GCP	Ground Control Point
GIS	Geographic Information Systems
GPS	Geographic Positioning System
HCl	Hydrochloric Acid
IAO	Instituto Agronomico per l'Oltremare
ICFRR	Institute for Commercial Forestry Research, Rhodesia
IDW	Inverse Distance Weighting
ITC	International Institute for Aerospace Survey and Earth Sciences
ITCZ	Inter-Tropical Convergence Zone
KZN	KwaZulu-Natal
LGP	Length of Growing Period
MAFF	Ministry of Agriculture, Fisheries and Food
MAP	Mean Annual Precipitation
MCPW	Ministry of Construction and Public Works (Eritrea)

Acronyms Cont.

MLWE	Ministry of Land, Water and Environment (Eritrea)
MOA	Ministry of Agriculture (Eritrea)
MTC/DCA	Ministry of Transport and Communication, Department of Civil Aviation
N-ASAWC	Non- Affiliated Soil Analysis Work Committee
NEMP-E	National Environmental Management Plan for Eritrea
NSO	National Statistics Office (Eritrea)
PET	Potential Evapotranspiration
RSA	Republic of South Africa
TIN	Triangulated Irregular Network
UN	United Nations
UNHCR	United Nations High Commissioner for Refugees
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programmee
UNESCO	United Nations Educational, Scientific and Cultural Organization
UK	United Kingdom
USDA	United States Department of Agriculture
USSCS	United States Soil Conservation Service
WRB	World Resources Base
WRD	Water resource Department (Eritrea)

CHAPTER 1

INTRODUCTION

1.1 Introduction

With the rapidly increasing population pressure and demand for land, the challenges concerning the proper use of land resource and improved land management are becoming important issues all over the world (FAO, 1993a). As the urban population grows, towns expand, eating into the surrounding rural areas (Ludorf, 1970). The rural urban migration has also increased urbanization density in the developing countries to affect the environment by the conversion of prime agricultural land and wetlands for housing and other non-agricultural use (UN Habitat, 2002).

As a result of the expansion of residential, commercial and industrial land use into rural areas, the protection of farmlands has become an increasingly essential aspiration of public officials in recent years (Kline and Alig, 1999). This is because whenever cities spread out into the countryside, land in the entire fringe be it farm land, grassland or forest is converted to urban use, which would result in the loss of quality agricultural land for residential development and other urban associated uses (Bryant *et al*, 1982).

The impacts of human settlement on the available land suitable for agriculture have become a serious problem in recent years at a global scale worsening its consequences on food security and environmental sustainability (Dunphy, 2000). Urbanization in Africa and Asia would increase the population growth of urban centers resulting in pressure on land for housing and shortage of food supply (UN Habitat, 2000). This pressure and the increasing and uncontrolled land use problems confronting urban areas in the Third World are today very evident in Asmara, Eritrea (FAO, 1997).

According to the Eritrean Land Proclamation No.58 (1994) the new land tenure system has been modernized and formulated to include the diverse traditional systems of

"Tselmi"[1], *"Quah-Mah-tse"*[2] , *"Dessa"*[3] and *"Dominale"*[4]. These diverse traditional land tenure systems created problems in land management. The most evident of these problems is land degradation due to misuse. The land around Asmara city has been traditionally cultivated to provide agricultural products to the local market. Production has been generally low due to lack of rigorous land assessment studies, misuse of land and use of ineffective methods. The rapidly increasing population of Asmara has increased the demand for land for residential, commercial and industrial development. The impact of this is that the traditionally cultivated land around Asmara is rapidly being transformed for other uses, hence reducing the supply of the already insufficient agricultural products (Figure 1.1).

Figure1.1. A new settlement expansion invading prime arable land in Kushet village in the outskirts of Asmara.

Tselmi[1]; equivalent to family ownership
Quah-Mahtse[2] ; village community owned land but the first occupancy has unlimited right to use
Dessa[3] ; equivalent to community owned land
Dominale[4] ; land owned by government

It has been estimated that within the past four decades about 1980 ha of the agricultural land around Asmara has been taken over by urban development. This translates into an average rate of about 49.5 ha per annum over the last 40 years. In reality, the increase is very fast as since independence in 1991. There has been a high demand for land for housing, industrial and other non-agricultural developments (MLWE, 2003).

The agricultural land around Asmara is currently vulnerable to urban expansion where agricultural land is being converted to non-agricultural development purposes. Although there is a will on the part of the government to exclude the arable land for agricultural use, the lack of adequate information on the potential productivity of the land is a major constraint where a considerable area of the arable land is currently being included for urban expansion and other non-agricultural development projects. Thus, this misuse of land has led to land resource degradation and use conflict in these urban fringes.

The land proclamation No. 58 (1994) repealed the previous land tenure systems. According to Article 9, of this land proclamation, the land administrative body shall adequately classify the land into arable and non-arable land for appropriate use. The inventory of available resources is the primary requirement, followed by determining as precisely as possible which specific land use can be put onto which area of land. The proclamation, based on the principle of sustainable development, aims at achieving an improvement in living standards without destruction or degradation of the environmental resources on which later generations will depend (Lassey, 1977).

However, despite this, almost all the land resources inventories carried out in the country are inadequate for land use planning. Moreover, as a proper land use policy in the country is not yet developed, and land resources assessment studies are not properly undertaken, the problem will remain as a kernel issue to the country, and it calls for an urgent need for land resources assessment. At this juncture a rational and sustainable land use is an issue of great concern to the government and land users interested in planning for the use of land resources for the benefit of present and future populations (FAO, 1996). Mbiba (2002) notes that, "it is critical that researchers, planners, and policy makers focus on the conflicts surrounding land in urban and peri-urban areas; as well as paying greater attention to conflict analysis, management and resolution". The increased pressure of urbanization and resource use is changing the face of rural areas where an apparent need grows for an informed and intelligent public to deal with decisions regarding the future of their land resources (Fabos, 1984). Hence, it is of vital importance that planners and administrators are aware of the best available resource data, including land capability information, for reliable development planning and informed decision making (DPIWE, 2002).

The primary objective of land capability classification is to assess the actual potential of land resources (Scotney *et al*, 1991). Such an assessment provides the essential land resources information which would be used as a basis for land use planning by indicating areas of high potential for agricultural development and protect them from non-agricultural development (Bryant *et al*, 1982).

The results of land capability classification can contribute to the proper resources allocation by indicating the most appropriate areas where particular development activities might be located (Whyte, 1976). The assumption is to use the survey findings to establish the optimum pattern of use for the limited land resources in the study area. The results will also help the decision makers to guide the location of urban development and draw attention to those areas where the most profitable agricultural activities can be expected to flourish.

A land capability classification study in the Asmara environs will, therefore, significantly facilitate planning of sustainable and environmentally sound land use systems that may contribute to the long-term strategy of food security and resource management in the country (FAO, 1993a; DPIWE, 2002).

1.2. Aims and Objectives

This study aims at classifying the land in the areas around Asmara, Eritrea, according to its capability and prepares land capability maps based on a detailed land resources assessment. The study also attempts to identify sustainable and optimum alternative uses of the land. To achieve the above-mentioned aims, the following are the specific objectives.

1. To identify and assess the land resources of the study area based on field surveys and verification of existing data sources.
2. To assess and determine the soil and land characteristics, and climatic factors that determine the capability class of the land.
3. To identify and set the parameters and criteria of the permanent limitations of the specified land resources for land capability classification.
4. To classify the land according to its capability based on the specified criteria of the limitations of soil, land characteristics and climatic variables and mapping out the different land capability classes and orders.
5. To establish detailed and valuable land resource information for the study area, which could be, used as base reference for decision-makers, planners and other land developers.
6. To draw valuable recommendations for optimum and appropriate land use options for the study area based on each identified land capability order.

1.3 Structure of the Dissertation

The purpose and objective of land classification, methods and approaches applied in land classification system and other relevant studies, and major factors that determine the capability class and criteria used in the assessment of the capability of the land are reviewed in chapter two. The current land policy in the study area and the need for land classification in the Eritrean context, and the role of Geographical Information Systems (GIS) technology in land capability assessment are also reviewed in chapter two. The biophysical and socioeconomic set-ups of the study area are described in chapter three. Chapter four describes the materials and methods employed during the data collection, the assessment of the land resources and subsequent analyse. The results of the assessment and the land capability categories are discussed in chapter five. Chapter six provides the conclusions of the study and draws relevant recommendations based on the findings.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Bennett (1948) notes that productive land is a critical resource, where good land or lack of good land always has been a vital factor in the progress or decline of any nation. Moreover, land as a limited and finite resource needs conservation and proper use (Simonson, 1974). Conservation of this limited land resource is, therefore, of paramount importance.

The recognition of the land for sustainable land use systems that also conserve the land has led to various land classification systems depending on the purpose and objectives of the studies (Hills, 1976; Olson, 1984; Davidson, 1992). Land can be evaluated and classified into different ways based on different factors for different purposes and objectives. Suitability and capability classifications are widely used to assess land resources as pertinent for land use planning activities (McRae and Burnham, 1981).

Land suitability classification considers the fitness of a given piece of land for a definite and specific use by identifying and grouping of land units that reflect relative suitability for sustainable use in a defined manner and for a defined purpose (Brinkman and Smyth, 1973; FAO, 1976b; Dent and Young, 1981). On the other hand land capability classification, which is reviewed in detail in this chapter, is used in a broader sense, to classify land into various uses (McRae and Burnham, 1981; Davidson, 1992).

Land capability assessment identifies the encountered potential limitations on land and provides base information for land use planning, where land use planning aims at putting the land under the appropriate use to secure the livelihood of a society (FAO, 1993a). Therefore, capability assessment, which is based on the actual potential of the land to support various uses, is significant where a proper land use plan can be drawn (Guy and

Smith, 1995). Consequently, it can be defined as the potential of the land for use in specified ways or with specified management practices (Dent and Young, 1981).

The capability potential of a land is determined mainly by the collective effects of soil, terrain and climatic factors, which are the permanent physical limitations of soil, land features and climate (Scotney, 1970). These permanent limitations are referred to as the parameters or criteria that determine land capability categories. Land capability categories are determined after the assessment of the adverse effects of these permanent limitations for the potential use of the land (Davidson, 1992). These categories are referred to as the land capability units, subclasses, classes and orders (Scotney *et al,* 1991). Therefore, the method is based on the concept of limitations to land use imposed by land characteristics (Mather, 1986). The permanent limitations of soil physical properties and land characteristics include soil effective depth, soil texture, permeability, wetness, erosion hazards, slope and surface rockiness and stoniness on which land capability classification is based (Ivy, 1977; Scotney *et al*, 1991; Smith, 2002). Their detailed description is discussed in section 4.2.3.

These limitations are generally analyzed and mapped out using a GIS (Burrough, 1986). For this reason the role of GIS technology for land resource assessment in general and in land capability assessment in particular with relevant case studies is discussed in detail in section 2.8 of this chapter.

2.2. Overview of Land Capability Classification

2.2.1 The Concept of Land Capability Classification.

Klingebeil and Montgomery (1973) defined land classification as grouping of soil mapping units on the basis of their ability to produce nearly uniform cultivars and pasture plants for a long period of time. Jack (1946) defined land classification as the grouping of land units according to their suitability for producing plants of economic importance. According to Davidson (1992) the subject of land classification is only the starting point in the land resource analysis, which is based on the carrying capacity, productivity, and environmental sensitivity of the area.

Some workers view land classification, in its broad term, as a process of dividing the land into units that reflect homogeneous natural features. Such a classification is designed to organize and simplify information that would be used for a variety of planning and management purpose (Hills, 1976). However, Olson (1984) has indicated that land classifications are widely used to evaluate potentials and problems in soil management. The procedures used for classification in different parts of the world are different as a result of different purposes and objectives (Olson 1984). For example, the irrigation suitability classification that is designed for irrigation development is based on soil properties. The storie index, which is intended to provide a numerical rating of soils, is aimed at defining the prime land and indicates those areas that should be preserved for agricultural use (Olson, 1984). The FAO system is designed to carry out an inventory on the production potential of soils of the world where the formulas used in calculating the productivity index use factors based on the efficiency of soil properties to meet crop needs.

2.2.3. Purposes and Objectives of Land Classification

Land classification based on the yield index is one of the land classification systems that indicate soil quality and the value of the land, which is mainly used for the assessment of fair taxation, for food production planning and as a basis for land use planning (Olson, 1984).

The agricultural land classification system that is used in England and Wales provides a framework for classifying land according to the extent to which physical and chemical properties impose long-term limitations (Brewer, 1997). In Jordan land is classified for different uses for example agriculture, residential, industrial and for other development programmes (Dalal, 2001). The Canadian land classification system is intended as a base for land use and resources planning for agricultural and other uses at a large scale with related information to establish a data bank that shows classes and subclasses according to their soil capability (Whyte, 1976). In the Netherlands the land classification as a discipline was formulated for agricultural land use planning (Beek and Bennema, 1972). Furthermore, Obeng (1968) devised a system for the classification of land in Ghana based on the soil productivity and land conditions and the system is aimed for mechanized and hand cultivation for crop and livestock production.

The USDA land classification is used for agricultural purposes to classify the land, based on the detailed soil properties of the survey report (Regan and Singer, 1978). Thus, according to Hartmann (1981) to classify farm activities arable soils are placed into groups according to their potentialities and limitations for sustainable production of cultivated crops in the USA. Based on the intended purpose and objectives, different systems and approaches of ecological and resources based land classifications have been developed and are being used in different parts of the world (Hills, 1976; FAO, 1996b).

2.2.4. Systems and Strategies of Land Classification

Land can be classified in a number of different ways depending on the objective and purpose of the classification, be it for a general or specific use (Olson, 1984). For simplicity land can be classified in its general use as agricultural and non-agricultural though agricultural land can be classified into a specific use based on the objective of the classification, where the objective of classification is to group land to show their most intensive and safe use (FRCE, 1985).

The grouping of land can be carried out either from the 'top down' or visa-versa (Hills, 1976). The process of dividing land from the top down separates larger units into smaller ones based on differences (Hills, 1976). This choice in land classification generally uses broad views of the landscape and natural resources to divide larger, heterogeneous units into smaller more homogeneous ones (FAO, 1996b). Such land classification strategy includes a hierarchy of units depending on size, scale and information available, where geographic areas are commonly divided into a series of landscape types or eco-systems that reflect overall patterns of landscape features (Hills, 1976).

The complimentary process of aggregating small, homogeneous units into larger units requires extensive and detailed information on the area being classified (Hills, 1976). For this rationale, where parts of an area are known in sufficient detail, the information will be used often as a check on the 'top down' process (Hills, (1976). Such a system of land classification involves the categorisation of land resources such as topography, climate, geology, natural vegetation and soil type. These natural or ecological regions are often referred to as bio-geographical land units, (Bailey *et al*, 1978), for example, the FAO Agro-ecological Zoning (AEZ) (1996b) and Bioresources Grouping (BRG) (Guy and Smith, 1995).

2.3. The Need for Land Capability Classification

Land is the most important and economic resource where all the development activities depend (Oli, 2001). Therefore, land capability classification is vital in regional and development programmes or land resource inventories to indicate the suitability of soil or land for specific uses (Rossiter, 1994).

To aid any development planning of the urban fringe an appropriate capability analysis that includes a map of soil capability for agriculture and the land factor limitations is essentially needed to designate marginal land for urban expansion and protect areas deemed best for agriculture (Dumaniski *et al*, 1979).

As natural resources are limited and scarce, and as human needs are infinite, the need for optimum land use as a goal of the land use planning process has become a great concern to the present generation when rapid population growth and urbanization are putting more pressure on the available land to make it a more scarce resource (FAO, 1983).

For this reason, the importance of land inventory as a prerequisite to land capability classification and planning was clearly recognised in developing land classification procedures where the land classification is based on a factual inventory of all the essential items on which the intelligent utilization of land should be based (Jacks, 1946).

As Thomas *et al*, (1976) indicated, the growing population and the corresponding rise in pressure on land could give a timely warning of the need for planned land use on the basis of rational selection. For this rational selection McRae and Burnham (1981) put more emphasis on the use of soil survey information (Whyte, 1976). Besides, in any planning effort a careful assessment and collection and analysis of a great deal of information concerning the natural resource base including surface and ground water and its ability to sustain rural and urban development before any major regional or urban planning takes place, is of vital important (Bartelli *et al,* 1996). Land capability assessment collects and analyse these information in combination with the inherent characteristics and permanent limitations of soil and land physical features (Smith, 2002).

2.4 A Review on Land Classification Studies

Several land evaluations systems have been used in land classification at local and national levels (Breimer *et al*, 1986). These include the FAO framework for land suitability classification (FAO, 1976b) and the USDA land capability classification (Klingiebel and Montgomery, 1961; Dent and Young, 1981; Sys, 1985; Scotney *et al*, 1991 Davidson, 1992; Smith, 2002). However, these systems have been found different in their applications. The different land classification studies carried out at different scope global, national and local levels are as follows:

2.4.1 The FAO Agro-ecological Zoning

The model of agro-ecological zoning emerged with the foundation of the FAO framework for land evaluation (FAO, 1976a) for determining the land utilization type as a necessary step to land evaluation and land use planning. It employs several thematic land resources maps to define agro-ecological boundaries with respect to the recognition of the heterogeneity of the real world (FAO, 1978). Climatic, soil and topographic information are used with crop requirements to produce agro-ecological zone maps.

This system classifies the land into different zones based on the broad natural resource and physical features of the land (FAO, 1996b). Land is divided into smaller units, which have similar characteristics related to land potential production and environmental impact based on similarities in their physical and ecological set up, which have a specific range of potentials and constraints for different land use activities. Hence, natural vegetation, climate, soil and the landform are the primary criteria for classification (FAO, 1996). The smallest unit of agro-ecological zoning is referred to as agro-ecological cell and is defined by a unique combination of landform, soil, and climatic characteristics (FAO, 1996).

Basically the FAO Agro-ecological Zones project was developed for worldwide use (FAO, 2000). The study of land potential and the methodology employed in the land resources assessment are the basis on which most large and small-scale land classification studies depend (FAO, 1996).

However, the Guidelines provided by the FAO for land resources assessment assist developing countries in applying and adopting the FAO methodology to their local conditions (FAO, 1996). For example, FAO has assisted various countries such as China, Brazil and Tanzania in developing AEZ studies for land resources information system at various scales following the Kenya approach (FAO, 2000). Hence, this system is currently largely employed with certain modifications in different countries to classify land according to its potential uses for agriculture (FAO, 2000).

2.4.2. Land Classification in KZN, RSA

The land capability classification of the Natal Region made by Ludorf (1970) identify the land on its potential use and classify the land into two major use categories as land suitable for cultivation and land not suitable for cultivation. This classification was based on slope. The capability classes were assessed based on soil and land characteristics. The main objective of the capability classification was to protect the arable land from urbanization and provide base information for land use planning in the Natal Region (Ludorf, 1970).

In KZN a more recent land classification system, which is referred to as bioresource grouping is a broad classification based on the homogeneity of the natural vegetation and climate of the area (Manson *et al*, 1995). The work of Camp (1999) in the Province of KwaZulu-Natal classifies the land into several bioresource units based on the environmental factors such as soil types, climate, terrain form and vegetation which are sufficiently homogeneous where uniform land use practices and techniques can be defined.

Guy and Smith (1995), following the broad resource distribution and using the frame work provided by the bioresources units, classified the land potential of KwaZulu-Natal into eight land potential classes based on climate, slope, and soil in combinations to determine the agricultural land potential of a site or a region. In their land potential classification both the climate capability classes and land capability classes are assessed in combination to classify the land to its respective potential.

However, bioresource units are broad and are not suitable for detailed planning in KwaZulu-Natal. Thus, detailed planning is possible using crop and veld ecotopes based on detailed information of soil and soil characteristics with a uniform production or management practices (Camp, 1999).

2.4.3. Land Classification in Eritrea

2.4.3.1 Land Policy

The government of Eritrea promulgated a land proclamation No.58 (1994), as land is State owned. According to the Eritrean Constitution Art.10/94 the State has a responsibility to regulate all land, water and natural resources and to ensure their management in a balanced and sustainable manner and in the interests of the present and future generations (Mengsteab, 2001). The policy guidelines are released concerning the best strategy for diminishing food insecurity in the short term and achieve food security in the long term through active participation of the government and enhancing various environmental programs, for example land use planning.

In this context, the Land and Housing Commission (LHC) in 1994 (which later Ministry of Land, Water and Environment in 1997) was established to administer, allocate and evaluate the land and land resources. On the other hand, the land use policy is still being formulated and land is still community-owned. However, the need for optimum and appropriate use of land both in rural and urban fringes is an urgent issue in the country.

Hence, the Legal Notice No. 95 (1997) identifies the Land Use Unit under the Department of Land as the sole responsible government body to prepare the appropriate land use plans at regional and national level, and provides the results for the land users and developers.

2.4.3.2 Land Classification Studies

Several agro-ecological, land use and land capability classification studies have been undertaken in Eritrea at national and regional levels.

The Ministry of Agriculture with the assistance of the FAO classified Eritrea into six major agro-ecological zones based on agro-climatic and soil characteristics. Climate and soil conditions of an area were assessed to determine the agricultural potential of the region in question (FAO, 1994a). Following this assessment the NEMP-E Technical Committee and Ministry of Agriculture (1995) conducted a land classification, which classified Eritrea into four eco-geographic zones based mainly on altitude, vegetation cover, soils and moisture status. The study was aimed at undertaking an environmental assessment for the preparation of an Environmental Management Plan for the country.

Furthermore, the Land and Housing Commission (1996) carried out a land classification study to prepare a provisional agro-ecological zones map for Eritrea. This classified the country into six major agro-ecological zones based on the similarity of natural vegetation, altitude, climate, broad soil classification and farming practice. About 55 agro-ecological units (AEU) were also identified based on similarities in landform, natural vegetation, climate, precipitation, soil types and land use practice. The study provided valuable information for agricultural development activities in general and guidelines and directives in the implementation of proper land use activities during the land reform in particular (LHC, 1996).

However, these three studies did not either adequately follow the FAO guidelines (1996) or sufficiently used detailed land use planning. Hence, they all lacked a detailed land resources survey. Thus, in both the systems, land classification was mainly based on the land use and land cover at the time of the survey (Scotney, 1970). This approach was very broad and insufficient to depict the actual potential of the land.

Meanwhile, the Ministry of Land, Water and Environment (1997), carried out a land capability classification and land use plan for the areas surrounding Asmara City, in *Zoba*[5] *Ma'kel*[6], and classified the land into seven classes. Several soil and land characteristic attributes were assessed to identify the capability of the land so as to arrive at a proper land use plan. However, despite the fact that the study followed the USDA system of classification it lacked detailed soil information, which made it superficial and of less quality. The Ministry of Agriculture (2000) prepared a land use-planning map for *Zoba Ma'kel* based on the parameters of soil type, natural vegetation, and land use practice. Soil information was taken from the surface and vegetation type was delineated from the old topographic maps of 1974. The methodology employed in both studies did not fully satisfy and agree with standard resource inventory methodologies for example those of the USDA (1961) and FAO (1996). As a result the products were generally of poor quality.

Recently the Ministry of Land, Water and Environment (2003) undertook a land potential assessment in the areas surrounding Asmara and several potential classes ranging from "high potential" to "marginal potential" were identified. During the study the parameters considered for land potential assessment were fully qualitative where the *stand of field crops* and the *soil type from the surface* were basic sources of information for the quality of the land in question (MLWE, 2003). Although the study aimed to classify the land based on its potential, the methodology employed during the classification of the land did not follow the standard procedures for land potential assessment.

Therefore, the provision of detailed information that could be used as base information for land use planning in Eritrea is urgently needed.

Zoba[5] *in this context is equivalent to the zone and Ma'ekel*[6] *is connotation of centre.*

Hence, the implementation of standard procedures in land capability classification can adequately identify the capability of the land leading to its appropriate and safe use.

2.4.4 Land Suitability and Land Capability Classification

2.4.4.1 Land Suitability Classification

As different literature reveals land can be classified in different ways for different purposes and objectives. The FAO system of land classification as explained in detail in the FAO *Framework for Land Evaluation* (1976) classifies land for a specific use where land is evaluated for its **fitness** for a given type of defined use (FAO, 1976). Hence, suitability classification is a practice of land evaluation for a single clearly defined use (McRae and Burnham, 1981).

Apart from the land capability classification system, the FAO (1976) land suitability classification has a distinctive focus by looking for sites possessing positive features associated with successful production (McRae and Burnham, 1981). This system is essential to compare land characteristics and land qualities with the specified crop requirements (Sys, 1985). Therefore, land suitability classification, which is a specific approach of land evaluation, looks at appropriateness of a certain area of land for a definite use (Vink, 1975; Young, 1976; Dent and Young, 1981; Davidson, 1992).

However, the degree of actual or potential suitability is determined by the relationship between inputs required and outputs gained, hence the assumption made is that land conditions reflect its actual and potential fitness (Vink, 1975). Based on this approach the FAO system classifies land into four levels namely **orders, classes, subclasses and units** (FAO, 1976), which makes it similar to the USDA land capability classification (Young, 1976).

2.4.4.2 Land Capability Classification

Land capability classification (commonly called the USDA land capability classification) is one of the most widely used systems for land evaluation or land classification and is based on a detailed soil survey (Olson, 1984). The system groups the various soil mapping units on the basis of their capability to produce common cultivated crops and forage plants for a long period of time (Klingebiel and Montgomery, 1973). Land is classified mainly on the basis of permanent limitations, which are the collective effects of climate and permanent land and soil physical properties (Dent and Young, 1981).

2.5 Methods of Land Capability Classification

There is no one or a single system or method of land capability classification, which is uniformly applicable, but there is a systematic way of assessing land capability (for example USDA system set by Klingebiel and Montgomery (1961) and later revised and modified in RSA by Scotney *et al* (1991)). These give a series of procedures for the assessment of land capability. The methodological procedures can be summarised as follows:

Collection of available information: This refers to all the relevant information on available maps, aerial photographs coverage, soils, terrain factors, climate, vegetation cover, and geology that need to be collected and carefully studied (Scotney *et al*, 1991). When sufficient information on these resources is not available further survey will be necessary (Dent and Young, 1981; Scotney *et al*, 1991). This stage includes an assessment of the permanent limitations of soil and land characteristics, and climate.

Ranking the permanent limitations: At this stage the assessed permanent physical limitations of the soil properties, climate, slope and other land characteristics are identified and ranked so as to evaluate the degree of the imposed limitations. The evaluation of the degree of limitation is based on the prescribed criteria and the functional relationship that exists between the quality of the land and the requirement of the land capability classification (Scotney *et al*, 1991). At this level land capability units are identified based on their uniformity.

Grouping and categorizing of the classes: This is the final stage in which the permanent limitations of equal rank are grouped and categorised into different classes to show their safe use. Based on the permanent physical limitations land is classified into several classes from the best to the worst (Dent and Young, 1981; Rossiter, 1994). Four levels of land capability classification are recognised. These include land capability units, subclasses, classes and orders (Scotney *et al*, 1991).

Although land capability assessment is aimed to group different land units the parameters and criteria used in the system are not similar for all countries. Thus, in the following section the parameters and methods used in different countries are reviewed.

2.5.1 The USDA Method of Land Capability Classification

This method has a long history since 1930; however, it came to effect after the work of Klingbiel and Montgomery (1961). This method was first developed by the USSCS and was aimed at assessing the extent to which limitations such as erosion risk; soil depth, wetness and climate hinder the agricultural use that can be made of land (Morgan, 1986).

Davidson (1992) notes that although soil assessment is a key factor in land classification in USA the system of land use capability assessment was developed in order to identify sustainable types of land use. Hence, the method is based on a broad range of characteristics such as percent slope, climate, and flood and erosion risk including soil properties (Ivy, 1977; Davidson, 1992).

The universal rule of the limitations in this method is of sufficient severity to lower the land capability to the classes below (Davidson, 1992), where the seriousness of a limitation is a function of the severity within which crop growth is inhibited (Sys, 1985). The main aim of this method is therefore; to assess the degree of limitations for the use of the land or the potential imposed by the permanent land characteristics and soil physical properties (Davidson, 1992). The objective of this classification is to reorganize an area of land into units with similar kinds and degrees of limitation (Morgan, 1986) on which the different land capability classes are graded. These limitations are that of soil and land characteristics and climatic conditions (Scotney, 1970; Ivy, 1977; Morgan, 1986; Scotney et al, 1991; Davidson, 1992; Smith, 2002).

Moormann (1973) note that the USDA land capability classification uses land characteristic limitations and soil survey maps as a basis and brings the individual soil map units into groups with similar management requirements. Thus the capability grouping is designed to help users of the land to understand the soils and make a decision based on potentials of soils and limitations on their use and management. Based on the potentials of soils and limitations the USDA method of land capability classification recognizes eight classes arranged from Class I, characterised by no or very slight risk of damage to the land when used for cultivation, to class VIII, very rough land which can be safely used only for wildlife, limited recreation and watershed conservation (Morgan, 1986).

In land capability assessment these classes are mapped to depict areas of different capability classes ranging from Class I (best) to class VIII (worst) (Rossiter, 1994) where their use intensity is decreased with increasing limitations and hazards (Davidson, 1992; Smith, 2000). According to Davis (1976) this system has been periodically updated and revised using a number of interpretative groupings for agricultural uses. Since then the USDA method of Land capability classification (Klingebiel and Montgomery, 1973) has been adopted for use in many other countries (Hudson, 1971) with various degrees of modifications (Beek, 1978; Mather, 1986).

2.5.2 Land Capability Classification in Britain

The Land Utilization Type Survey of 1940s graded the land into various classes (Stamp, 1962). Land was qualitatively ranked and graded on the basis of land use characteristics. According to Dawson and Doornkamp (1973) land is classified into given classes ranging from good quality (heavy land) and poor quality (light land) as grade I land with minor or no physical limitations to agricultural use and grade V land with very severe limitations for non agricultural development.

Based on the severity of the limitations, the Ministry of Agriculture, Fisheries and Food (MAFF) produced a land classification map for England and Wales in order to protect the good quality agricultural lands from urban encroachment (Mather, 1986). According to Bibby and Mackney (1969) land capability classification classified land into seven classes based on the permanent limitations. The parameters used in the classification of the land to the various capability classes were wetness (w), soil limitation (s), gradient (g), liability to erosion (e) and climatic condition (c); however, climate was given a higher consideration (Davidson, 1992).

Although the land capability classification method in Britain was based on the USDA module, it recognises only seven capability classes. However, unlike other systems gradient is assessed not primarily with respect to erosion, but for its effect on mechanization, which is different to the experiences in most parts of the world. In this method of classification the land class also becomes lower as rainfall increases (Dawson and Doornkamp, 1973).

This implies that adaptation to local conditions; a combination of specific guidelines with flexibility of applications, and simplicity and conciseness of presentation is required and vital (Hudson, 1971). These days, in combination with the USDA method in Britain under the agricultural land classification schemes land was graded into capability classes according to degree of limitations imposed by soil and climatic conditions on agriculture (Davidson, 1992). Based on this large-scale land classification maps were produced to assess planning decision concerning the release of agricultural land for urban purpose (Davidson, 1992). Hence, the agricultural land capability classification provides a framework for classifying land according to the extent to which physical and chemical properties impose long-term limitations on the agricultural use of the land (Brewer, 1997).

2.5.3 Land Capability Classification in Canada

In Canada land classification was initiated by the Canada Land Inventory (CLI) in 1963 as result of the Agricultural Rehabilitation and Development Act (ARDA) of 1961 (Mather, 1986; Davidson, 1992). The land inventory made was a broad survey of land capability designed to provide generalised land resource information for land evaluation and land use planning. Hence it was the most comprehensive national scheme of land evaluation (Dawson and Doornkamp, 1973). However, since the early 1970s the land capability classification method was divided into two capability schemes where the agricultural land capability were based on soil limitations to identify the good quality agricultural land (Davidson, 1992). Unlike the USDA land capability classification, the Canadian capability classification system recognises seven classes. These land capability classes were identified based on soil limitations for a wide range of uses similar to that of the USDA (Mather, 1986).

Although the system is similar to the USDA method some of the differences include the use of separate methods to identify land capability for forestry, recreation and wildlife use (Davidson, 1992). Thus, in this method land capability analysis is made based on the existing use of the land. Unlike to the USDA only the first three classes are considered as agricultural land, otherwise if none of them is to exist a class four land is added as agricultural land (Dawson and Doornkamp, 1973). Furthermore, the prime capability classes for each purpose are considered to be of equal value, thus land for forestry, recreation and wildlife are given equal value. This eventually leads to land use conflict (Dawson and Doornkamp, 1973).

2.5.4 Land Capability Classification in Republic of South Africa

In the Republic of South Africa, Loxton (1962) recommended the vital importance of the availability of standard land capability procedure by introducing the soil survey procedures. Edwards (1983) adopted a scheme where both land and veld were classified in terms of their productivity potential and erosion hazards. A system similar to the USDA land capability classification method was recognised to serve the local needs of the country after the work of Scotney *et al*, (1991). The main reason for the adoption of this method was that both categories of the classes and the parameters used during the classification are easy to understand, flexible and versatile to use (Dent and Young, 1981; Scotney *et al*, 1991; Davidson, 1992).

This revised and modified land capability classification was made with the emphasis to provide a sounding basis for the further introduction of soil productivity ratings and the reservation of high potential land for agriculture (Scotney, *et al*, 1991). The assumption made was that the collective effects of soil and terrain features and climate determine land capability

Land is classified into various capability classes based on the permanent physical limitations of the soil properties, soil surface and land characteristics (Sys, 1985; Mather, 1986; Scotney *et al,* 1991; Smith, 2002). Based on these factors a modified USDA land capability classification system is being used in the Republic of South Africa to classify land according to its capability for different agricultural uses (Guy and Smith, 1995) and for the allocation of land for residential, commercial, industrial or other utility purposes (Ludorf, 1970).

Although, the system is similar to that of the USDA Land Capability Classification, in the revised work by Scotney *et al* (1991) a fourth category, which is a capability order, has been introduced to facilitate use of the system for land potential assessment. In this revised work the capability class categories comprise four class levels, namely unit, subclass, class and order.

According to Scotney *et al* (1991) six major kinds of limitations are recognised at the subclass level and are applied when specific hazard is the dominant problem affecting land use. These are erosion hazard (e), excess wetness (w), excess flooding (f), root zone limitation (d), mechanical limitation (m) and climatic limitation (c) where the availability of water resources is considered to upgrade the capability class (Smith, 2002). The following section discusses the different natural resource factors that determine land capability classes.

2.6 Factors Determining Land Capability Classes

2.6.1 Terrain Factors

Terrain refers to the landforms or topography or the physical set-up and surface configuration of the land or an area and includes the associated land characteristics for example slope, erosion and flooding (Ivy, 1977; Scotney *et al*, 1991).

Slope plays an important role in determining the agricultural potential of land, which is used to identify areas of different capability units. Both erosion susceptibility of the land and the potential of mechanization in field operations are adversely affected by the steepness of the land (Schröder, 2002). Areas with steep to strongly steep slopes are prone to erosion; whereas flat to almost flat areas are exposed to flooding hazards. These combined effects of slopes result in differences in the capability of the land (Scotney *et al*, 1991). Therefore, slope determines the capability of the land for various uses (Murdoch, 1961; Smith, 2002).

Erosion hazard which is a threat to land use (Ivy, 1977) can be defined as the natural erodibility or susceptibility to erosion of a particular soil type (Loxton, 1962). The removal of the topsoil is referred to as sheet erosion, whereas the removal of the sub soils by developing run-off channels are said to be rill and gully erosion based on their depth and degree of severity. These erosion features affect the capability and hence determine the use and capability class of the land.

2.6.2 Soil Factors

Soil is a basic resource on which plant growth and other land use developments depend. However, soils by nature are with different physical and chemical characteristics that influence the land system. The most important soil physical properties, which adversely affect and determine the capability class of a given land, are the effective depth, texture of the soil, the status and conditions of internal drainage and other soil characteristics for example soil crusting (Loxton, 1962; Ivy, 1977; Scotney *et al*, 1991; Smith, 2002).

Effective soil depth for plant roots to obtain water, nutrient and air from the soils, is limited by the nature of the soil characteristics in the subsoil (Ivy, 1977; Scotney *et al,* 1991; Smith, 2002). These soil characteristics and conditions, and the encountered parent material such as the hard pans and prismatic structure or water- logged horizons hinder the downward root development of normal crops (Ivy, 1977).

Soil texture influences soil moisture supply and capacity and rate of erodibility of a respective soil type, hence it adversely affects the capability class of the land (Scotney *et al,* 1991). Soils of sand and sandy loam textures are more prone to erosion than the clay and silt clay texture classes (Schulze, 1995).

The internal drainage condition of the subsoil, which results in a temporary or permanent wetness of the soil, has an adverse effect on crop growth and some other land use developments (Ivy, 1977; Scotney *et al*, 1991; Smith, 2002). Permeability, which is the ability of the soil horizon to transmit soil water, affects the land in each horizon by exerting an important influence on the internal drainage of the soil profile as a whole to restrict the rooting zones of a particular crop (Loxton, 1962).

Therefore the rate of permeability of the surface soil and the nature of the internal drainage of the soil are the most important factors that hinder or facilitate the movement of water in the soil, hence determine the capability class of the land (Loxton, 1962; Ivy, 1977; Scotney *et al,* 1991; Smith, 2002).

Furthermore, the physical characteristics of the surface soil affect the behaviour of the soil surface under cultivation. Compaction and sealing at the surface lead to consequent reduction in aeration and penetrability by rain and seedlings (Ivy, 1977). Thus, the nature of crusting of the surface soil creates problems in tillage operations during the dry season that adversely affect the capability class of the land (Scotney *et al,* 1991).

2.6.3 Climatic Factors

According to Scotney *et al*, (1991) climatic features especially precipitation and temperature is the most important factors that determine the capability class of a land to produce crop. When precipitation is below a normal condition it results in moisture stress to the growing crops, and failure of the normally required average temperatures results in damage of the growing crops (Scotney *et al*, 1991; Smith and Camp, 2002). Therefore, information on slope, climate, and flood and erosion hazard as well as of soil properties is required to assess the capability classes of a respective land (Davidson, 1992).

2.7 Basic Definitions and Assumptions

2.7.1 Basic Definitions

Land: Is an area of the earth's surface the characteristics of which embrace all reasonably stable or predictable cyclic attributes of the biosphere vertically above and below this area. Such characteristics or attributes comprise those of the atmosphere, the terrain form and soil, underlying geology and hydrology, the *fauna* and *flora* populations and the result of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of land by man. Land is a broader concept than soil (Brinkman *et al*, 1973; Sys, 1985; Scotney *et al*, 1991; FAO, 1993a).

Land characteristics: Are those properties of land that can be measured or assessed with out excessive effect. These include wetness (surface characteristics), erosion hazard, slope and climate (Ivy, 1977).

Land capability: This refers to the extent to which land can meet the needs of one or more uses, under defined conditions of management, without permanent damage (Scotney *et al*, 1991) which is the potential of the land for use in specified ways, or with specified management practice (Dent and Young, 1981; Davidson, 1992; Smith, 2002).

Land capability classification: Is an appraisal and grouping of types of land into various capability categories based on the properties of the physical factors (Scotney *et al*, 1991).

Capability category: Is a level in a land capability classification to include for level of categories during classification namely units, subclasses, classes and orders.

Soil: A natural body consisting of layers or horizons of minerals and /or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics (Davidson, 1992).

Soil characteristics: These are the inherited physical properties of the soil, which comprise depth, texture, subsurface drainage capacity, and permeability (Ivy, 1977) that cannot be easily rectified.

Permanent Limitations: Are both soil and land characteristics that have an adverse effect on the capability of a land (Dent and Young, 1981; McRae and Burnham, 1981). Permanent limitations refer to the land and soil physical characteristics that cannot be easily rectified or corrected in land use, hence, remain as permanent limitations to hinder the use of the land (Scotney, 1970; Bibby and Mackney, 1973; Dent and Young, 1981; Scotney *et al*, 1991 and Smith, 2002).

Diagnostic criteria: Are the thresholds set to the encountered limitations in land capability assessment. These criteria are used to lower or down-grade the capability class. Each criterion is indicated as a suffix with a small letter to the respective land capability class (Ivy, 1977; Scotney *et al*, 1991; Smith, 2002).

Prime farm land: Is the land best suited to cereals, pasture and other crops to produce highest yield with minimum input energy and economic resource where farming results in the least damage to the environment (USDA, 2000).

Arable land: Is land suitable for various crop productions. In the land capability classification it is described at the order level that includes capability class I to Class IV (Scotney *et al*, 1991).

Non-arable land: Land areas not suitable for any crop production but useful for grazing, forestry, urban development or other non-agricultural activities (Davidson, 1992).

2.7.2 Basic Assumptions

The assumptions made during the land capability classification are as follows:

The classification has a series of land use options where choice of use is restricted by the potential limitations imposed on land (Davidson, 1992). The potential limitations are referred to as the collective effect of soil, terrain and climatic characteristics that have an adverse effect on capability McRae and Burnham (1981) where Land capability is determined. The later is useful to provide a realistic and consistent land capability classification only when climatic variation exists (Scotney *et al,* 1991).

Moreover, the land capability system has pedological significance since it is derived from soil units defined and mapped in terms of soil classification where it is assumed that the capability classification will be carried out by an appropriate soil survey and that the information will then be appropriately interpreted taking account of specified criteria (Scotney *et al*, 1991).

Land will be classified to different classes according to its present limitations, which are inherited, and permanent that cannot be rectified or corrected (Bibby and Mackney, 1973; Dent and Young, 1981; Scotney *et al*, 1991). Land that is allocated to any particular capability class has the potential for the use specified for that class and the classes below (Dent and Young, 1981). The capability of a land unit for crop growth is better when a wide range of crops can be cultivated on it than on other land units (Sys, 1985).

The capability classification will be applied to rain fed agriculture. However, if the need arises the associated detailed soil and climate inventories will contribute to the further investigation of the land for irrigated crops.

2.7.3 Levels of Classification

Three levels of classification namely units, subclasses and classes have traditionally been used and include areas of the same relative degree of limitations or hazards (Dent and Young, 1981). More recently a fourth level of land capability classification viz. order, was added for the application of a broader scale grouping of land capability classes as arable and non arable land (Scotney *et al*, 1991).

A) ***Land Capability Units***: These land capability units are the lowest categories in the system which include one or more soil mapping units with similar agricultural use potential and limitations where the sub classes are divided on the bases of potential productivity (Sys, 1985). The range of variations within land capability units is not significant, and further subdivision would not be meaningful to the land user (Scotney *et al,* 1991).

However, differences that occur between soil mapping units, which are of little or no significance in management are eliminated by grouping such units into capability units (Dent and Young, 1981). A land capability unit is therefore, grouping of different soil mapping units that reflect a high degree of uniformity in the soil and land characteristics.

B) ***Land Capability Subclasses***: These capability subclasses are places that have the same kinds of limitations, which put them into the same category (Dent and Young, 1981; Sys, 1985). These subclasses are grouped from the capability units with the same kind of limitations or problems, and six major kinds of limitations are recognised at a subclass level and are applied where a specific hazard is the dominant problem affecting the intended land use (Scotney *et al,* 1991); for example, land capability subclass indicated by the letter "w" depict wetness as a limitation.

Land capability classes are therefore, defined essentially based on the hazard or limitations encountered within each subclass (Ivy, 1977, Sys, 1985, Scotney *et al*, 1991). These limitations include either wetness or other soil properties, which adversely affect the land capability class to be down-graded (Olson, 1984).

C) ***Land Capability Classes.*** This level of classification comprise groups of capability subclasses that have the same relative degree of limitations where these limitations and hazards of use increase from class I to Class VIII (Scotney and *et al,* 1991). These land capability classes are, therefore, established with increasing limitation to restrict their use value (Dent and Young, 1981; Sys, 1985). Hence, the production potential and alternative use of the land decrease as the number of the capability classes increase (Scotney et al 1991).

This level of classification is the highest category in the USDA system which is mostly used for assessment purposes to designate all land in capability classes (Klingebiel and Montgomery, 1961).

D) Land Capability Orders. Land capability classes can be grouped into the higher level of classification to classify the land as arable and non-arable land where class I to class VI land are recognised as arable land and class V to class VIII land are considered as non-arable land (Scotney and *et al,* 1991). This level of classification is referred to as land capability order (Scotney *et al*, 1991). Hence, the highest category of land capability is usually the division of land into land suitable for cultivation and land not suitable for cultivation (Ludorf, 1970).

2.8 The Role of GIS in Land Resources Assessment and Case Studies

2.8.1 GIS and Land Resources Assessment

Rapid developments in computer technology in the last decade have facilitated the use of multi-purpose land resources information systems (FAO, 1996). GIS is the central element in the configuration of these land resources information systems (FAO, 1996). GIS is a computer assisted information system to collect, store, manipulate and display spatial data with the purpose of functioning as a decision support system (Kraak and Ormeling, 1996).

GIS is a powerful tool suited to the management and analysis of basic data and information that could be used in land use decisions (FAO, 1996). Combining different data layers such as soils, landforms, and climate data creates a land resources database.

Such data can be used to determine land capability and determine best possible land allocation based on the potential capability of the land in question (FAO, 1996). This GIS-based land resources information system has contributed to the effective management of land resources, efficient land use planning and land utilization practices (Haling, 2000).

The application of GIS technology in many countries of the world is growing where various projects have been set up and aimed to establish computerised land information systems to support the systematic and comprehensive evaluation of land resources in support of decisions for the rational utilisation of natural resources on a sustainable basis (FAO, 2000a). For example in Lithuania GIS-based land resource information was established to provide a resources information basis for national, regional and local level land assessment and land use planning (FAO, 2000b). In many countries of Africa such as Tanzania, GIS has been used in the establishment of land resource information systems for soil and land resource conservation (Antoine, 2000).

GIS technology has emerged as a powerful tool in management and analysis of the large amounts of basic data needed to generate various information products in forms of maps which would be used in linkage with agro-ecological zoning and other related models for land resource inventory, assessment and analysis (FAO, 1996).

2.8.2 The Use of GIS in Land Capability Studies

Yeh (1991) noted that as most GIS in the developing countries are used for regional resources and environment management based programmes, they are especially useful for implementing the sustainable development strategies. The application of GIS technology in land suitability analysis for certain crops in the agro-ecological study of Kenya assisted the resource appraisal program of the country, where several arrays of land qualities and environmental crop requirements were assessed and analysed within GIS to identify areas suitable for certain crops (FAO, 1993b).

Various criteria and parameters were selected and analysed using GIS to map out the several bioresource units in KwaZulu-Natal province, South Africa. The identification of the national resources and agricultural potential of areas in KZN were also achieved through the use of GIS (Camp, 1999).

Acharya (2000) used GIS in the collection, integration, analysis and extraction of land resources through a scientific survey of all resources for the production of land utilization and land capability maps in Nepal. Initially results of the survey were added to the GIS as spatial attributes. Based on these spatial attributes several thematic layers of land resources information maps were produced. Finally through overlay analysis of the thematic layers a land capability map was produced. Similarly in Vietnam a GIS-based land resources information system was used in various natural resources studies for land inventory and planning where remotely sensed data was incorporated into a GIS for agricultural monitoring and for the production of soil and land use maps (Han, 2000).

Kamanzi (2002) employed GIS technology in assessing and mapping the natural resources to identify sites suitable for grouped rural settlements of two study areas in Rwanda. Various criteria were selected and analysed in a GIS so as to arrive at maps that depict areas suitable for grouped settlement. Similarly, in Weerketya, Sri Lanka GIS was used to identify the ideal areas for cultivation. Variables such as water availability, erosion hazard, and temperature regime, ease of land use and land classification were assessed, and analysed using a GIS to produce a map identifying where cultivation was possible (Bitter, 1996).

2.9 Summary

Land is an important natural resource on which human livelihoods depend. Misuse of land leads to serious land degradation resulting in erosion, loss of productivity and other negative impacts. To protect land from misuse, detailed inventories on soil and land characteristics are important for providing information for informed decisions on the most appropriate land use plans. A major component of such plans are sustainable resource management strategy that ensures a wise use of land resources.

The land capability classification system classifies the land according to its capability to a range of uses without any damage to the land. The main objective of such classification is to direct agricultural endeavour to land of highest potential and preventing prime land from other non-agricultural development activities. This will help users and planners to direct their activities according to the specified capability classes.

The capability classes are determined by several factors such as terrain and soil characteristics including other climatic factors. To assess the effects of these factors and classify the land according to its capability several procedures need to be applied. These procedures include detailed soil and land characteristics surveys and other natural resources assessment.

Soil and land characteristic factors are basic concepts in land capability classification where the assumption is that land capability is determined by the collective effect of these factors including climatic characteristics and the permanent limitations inherited with soil and land characteristics. Theses permanent limitations and other natural resources are used as parametric criteria to classify land into different land capability categories (for example units, subclasses, classes and orders). These criteria are customarily analyzed using a GIS; as such a system has powerful functionalities most suited for natural resource assessment and the production of resources and land capability maps.

Eritrea has limited agricultural lands that are under threat from the ever-expanding urban centers. Although various land capability classifications have been carried out in the country, the adequacy of these studies is questionable as such studies were based on superficial data and no detailed soil surveys were ever carried out.

This study aimed at carrying out a land capability classification in the study areas around Asmara city, Eritrea based on a detailed land resources survey and preparing a land capability map which could be used as a baseline information and directive for the allocation of land for various uses.

CHAPTER 3

THE STUDY AREA

3.1. General Background

This study was carried out in Eritrea, which is a newly found nation in Africa located in the Horn of Africa along the Red Sea coast. The country lies between 12° and 18° N and 36° and 44° E. It is bordered by Sudan to the west, Ethiopia to the south and the Republic of Djibouti to the southeast. It has a total land mass area of about 121,320 Km^2 including about 360 Archipelagos (see Figure 3.1).

Of the total estimated land area of 12.2 million ha only about 2.033 million ha are arable and suitable for agriculture (MOA, 2000). This amounts to about 16.7 percent of the total area of the country. The population is estimated at about 4 million with a growth rate of 3.8 percent per annum (IAO, 2001). About 80 percent of the total population lives in rural areas (FAO, 1994b). One seventh of the total urban population lives in the capital city Asmara (FAO, 1994b).

Agriculture is the dominant economic activity in Eritrea where about 85 percent of the population in the country depends on both crop cultivation and livestock production. Ninety five percent of these are semi-subsistence farmers living on the central highland, which is a highly populated area (MOA, 2000). Therefore, land is the basic means of production; almost all the livelihood of the population depends on land. Hence land is the basic resource of material wealth in the nation.

Eritrea is divided into six *Zoba* administrative districts. *Zoba Ma'ekel* is one of the six administrative districts situated on the central highland of the country bordered by four administrative districts (see Figure 3.2).

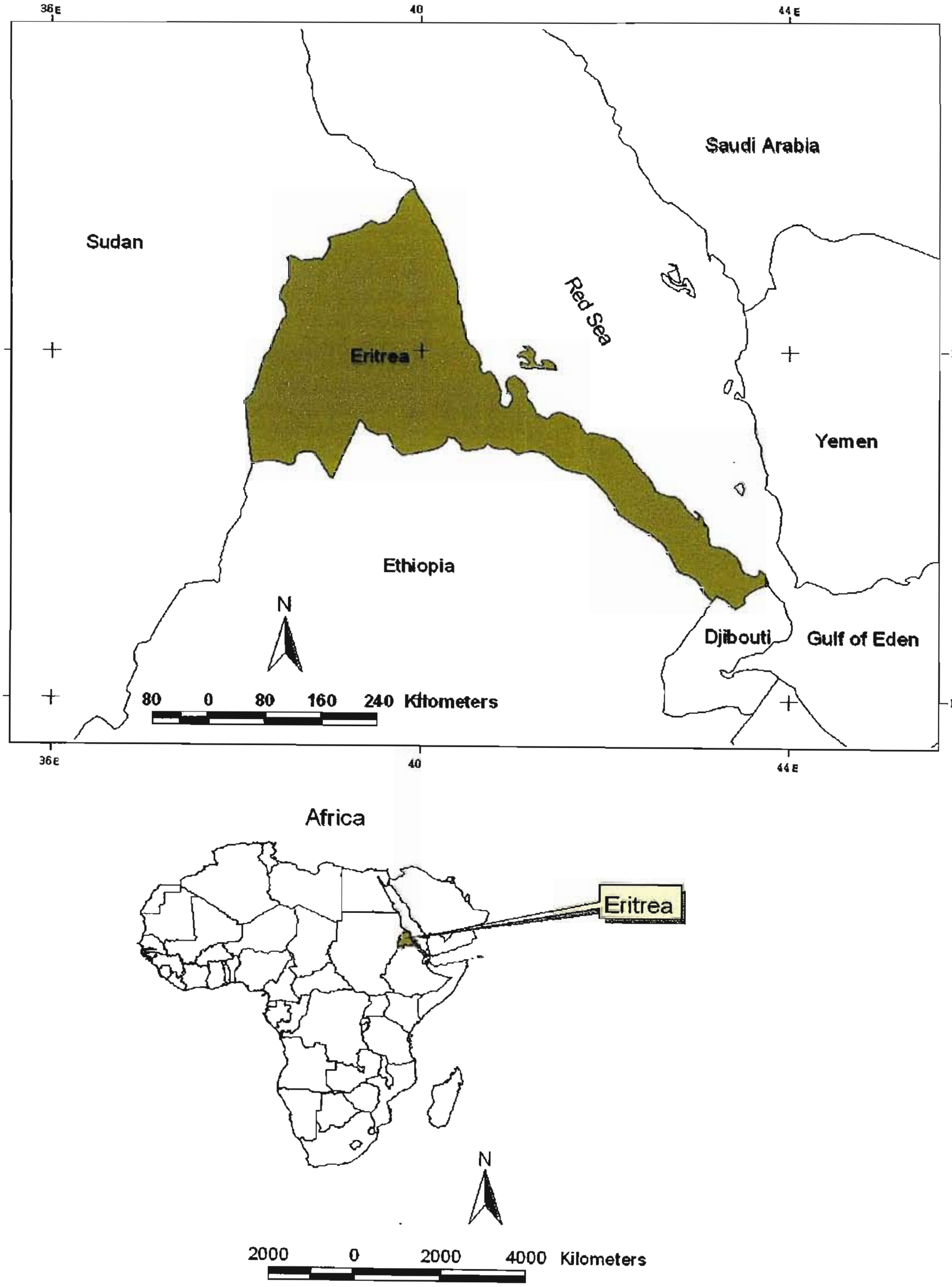

Figure 3.1 Location Map of Eritrea

Zoba Ma'ekel has a total area of about 107907.8 ha, which is about 8.09 percent of the total area of the country. Out of the total area about 54,448 ha are arable (MOA, 2000). Zoba Ma'ekel comprises 85 villages and the capital city Asmara.

The population is estimated at about 140,967 (MOA, 2000). This Zoba is the most densely populated where about 130.6 people live per Km^2, and is the region where the major economic activities of the country are situated (WRD, 2001).

3.2. Location

The study area is situated in the central part of *Zoba Ma'ekel* and surrounds the capital city Asmara. It extends between 15° 15' and 15° 25' North and 38° 48' and 38° 58' East (see Figure 3.2). It has a total area of about 11860 ha.

The total population of the study area is estimated at about 44,816 (ENS, 2003) where about 378 people live per Km^2. It is one of the highly populated areas in the country.

3.3. Topography and Lithology

3.3.1 Topography

Generally the landform of the study area is dominated by flat to undulating small rolling hills with an altitude range between 2200 and 2400m a.m.s.l. Altitude decreases from west to east where the slope is steeper in the eastern part of the study area. Rolling small hills and dissected undulating land are dominant land features in the northeast and south east of the study area. The central western and southern parts of the study area are generally flat. Cultivation is highly concentrated in these flat areas. The drainage pattern of the area is directed by the slope inclination where all streams flow westwards.

3.3.2 Lithology

Geologically the study area is dominated by well-preserved low metamorphosed supracrustal rocks of sedimentary and volcanic origin (Teklay, 1997). The geological material is composed of complex metamorphic rocks penetrated by granitoids and partly covered by the tertiary basalts of trap series.

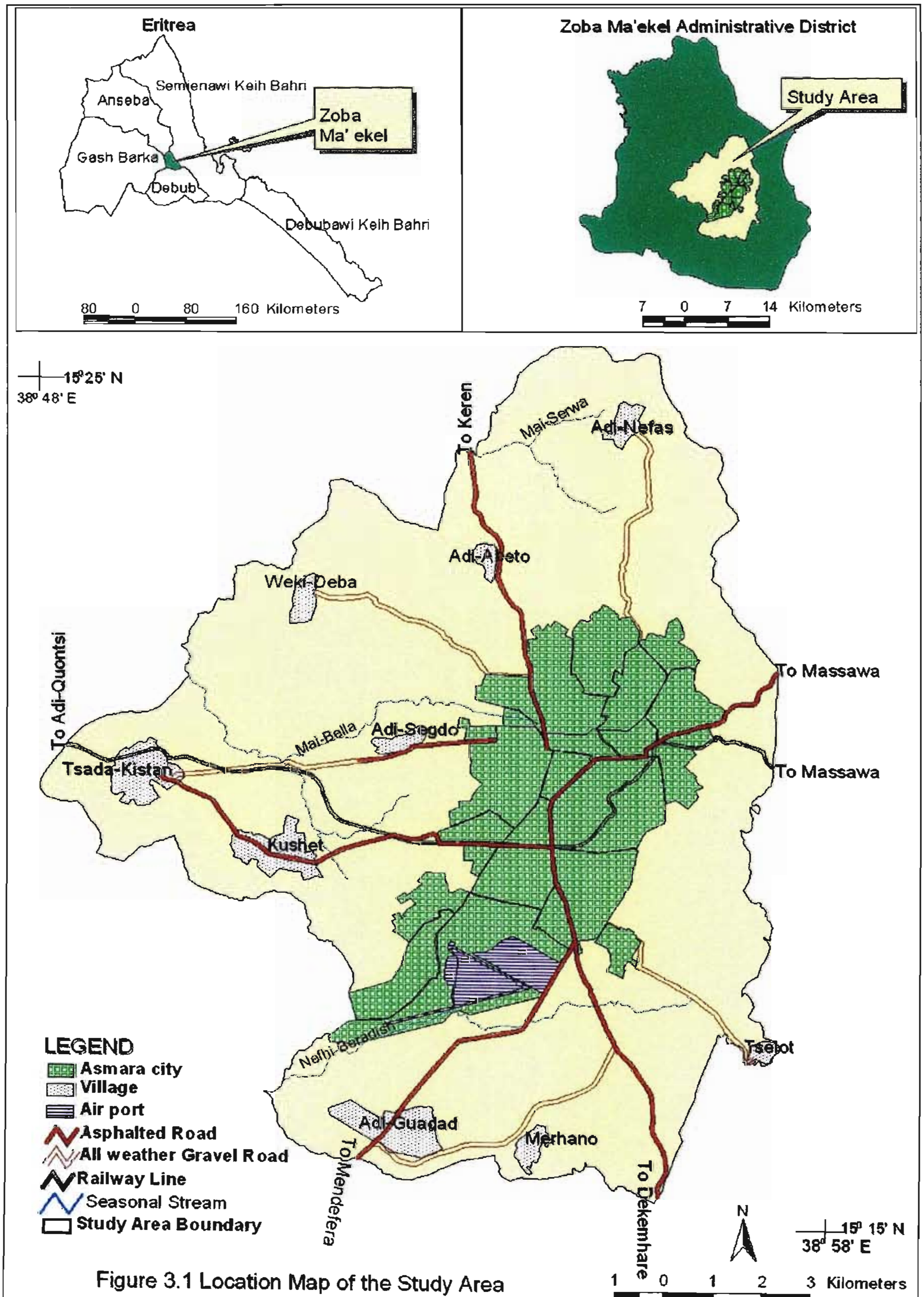

Figure 3.1 Location Map of the Study Area

The dominant metamorhoposed rocks are generally low degree, and represented by the chlorite, sericite-albite and quartz.

The Precambrian basement complex in the study area is of Tsaliet group, which is composed of thick series of low metamorphic volcanic rocks and sediments of grey wack. Within the Precambrian basement complex, dolerite dykes are located running northwest to southeast of the study area (Mohr, 1970).

The Tertiary volcanic rocks in the study area are represented by extrusive basalt defined as trap basalts, which cover almost all the southern part of the study area and underlie the lateritic soils (Pangnacco, 1968).

According to Teklay (1997) three main lithological units have been described. These comprise: (a) massive felsic meta-volcanic rocks interspaced with meta-sedimentary rocks and agglomerates. These occupy the northern, western and northwestern parts of the study area. (b) The meta- sedimentary and the basic meta-volcanic rocks which belong to the trap lava series. These occupy most of the southern, central and eastern parts of the study area. (c) The Basalts that are composed of Chlorite, carbonates and white micas of the Precambrian rocks. These are common in the northern part of the study area (Teklay, 1997).

3.4. Soils

The dominant soils in the study area are basaltic and cambic soils of eutric phase, and Lithosols or Leptosols of lithic phase and can be generalised as Luvisols of vertic or cambic types including patches of Lateritic soils. Although detailed information on soil resources in the study area is very scarce the report of the Land and Housing Commission (LHC) (1996) identify three major soil groups, namely: Eutric Cambisols, Chromic Luvisols and Lithosols (FAO, 1990).

In most of south and centre of the study area soils are dominantly chromic Luvisols and Cambisols and are the most intensive cultivated soils in the study area. Soil types those of Lithosols/Leptosols, which are known for their shallow depth, are widely associated with the undulating and steep slopes running southeast to northeast and north west of the study area.

3.5. Hydrology and Drainage.

Ground water distribution relates very much to the geological faults and lithological contacts in the study area (WRD, 2001). Faults in the central part of the study area are dominantly to occure running northeast to southwest directions. The lithological contact that separate the quartizite meta-sedments of the north and the basaltic rocks from the south occur in the central part of the study area. Hence, the central part of the study area is relatively very rich in ground water potential (WRD, 2001).

The study area is located on the watershed of the main drainage basin of the country where the major seasonal streams originate. Some of the major seasonal streams include *Nefhi Beradish, Mai-Bella and Mai- Serwa* (Figure 3.2). These seasonal streams are the main tributaries of the western river systems in the country. Hence, almost all the streams in the study area flow to the west and southwest direction creating a dendritic drainage pattern in the study area.

3.6. Climate

Climate in the study area is subtropical with distinct dry and rainy seasons. Winds that originate from the Atlantic Ocean and blow across equatorial Africa have a marked seasonal effect on the study area. Agro-ecologically the study area belongs to the moist highland agro-ecological zone unit where mean annual rainfall ranges between 500 and 600 mm. The mean annual temperature ranges between 16 to 18 °C, and the mean annual potential evapotranspiration (PET) is 1600 mm (LHC, 1996).

3.6.1. Rainfall

The resulting weather pattern provides the study area with most of its rainfall during a period that generally lasts from mid-June to mid-September. The atmospheric circulation in the study area is dominated by two zones namely the Inter-Tropical Convergence Zone (ITCZ) which brings greater rains in the study area where the air masses are equatorial maritime. Therefore, summer is the main rainy season with a mean annual rainfall ranging between 500 and 600 mm (Mohr, 1970). However, in the month of January the high-pressure system that produces monsoons in Asia crosses the Red Sea as Northeast Trade Winds bring rain to the coastal plains and the eastern escarpment. Thus, the study area receives a small amount of rain during the months of January and February in the winter season. However, the effect of the winter rains remains minimal and is not dependable for crop cultivation (Mohr, 1970).

3.6.2. Temperature

Due to the topographic location of the study area, which is adjacent to the eastern escarpment, the cool sea considerably modifies temperature during the dry winter season. However, the atmospheric circulation in the study area is dominated by two zones namely the Inter-Tropical Convergence Zone (ITCZ) and the Northeast Trade Winds. The former that brings greater rains in the study area are the air masses of equatorial maritime which raise the temperature to score maximum heat in summer season. Whereas, during the period from December to February the circulation of the air mass comes from the Northeast and is weak, dry and cold (FAO, 1994a). As a result air temperature is highly variable over the year ranging from 5 to 35 °C (Mohr, 1970).

Cloudiness in the study area is insignificant during the dry season, which is characterised by clear skies. The mean relative humidity for the study area is 66 percent. The dominant prevailing wind direction in the study area is east to northwest at an average speed of 8 knots. (MTC/DCA, 2003). The mean sunshine hours are high for most of the year except during the month of December when it exceeds 8 hours. Sunshine hours are longer in the winter season (MTC/DCA, 2003). Frost in the study area occurs during the months of December and January. According to LHC (1996) the length of growing period for the study area is between 60 and 90 days.

3.7 Natural Vegetation

Natural vegetation in the study area is highly deteriorated as a result of frequent clearing. In areas of undulating and steep slopes there are patches of highland vegetation of shrubs, bushes and scattered woodlots. These comprise *Olea africana* and *Junipers procera*, *Acacia thebica*, *Dodonea viscosa* and *Rumex nervosa* with *Cynodon dactylon* grass (LHC, 1996).

3.8. Land Use

3.8.1 Agriculture

Agriculture is the mainstay of the population where the predominant farming system is small scale mixed production (crops/livestock). Crop cultivation in the study area is predominantly subsistence based and rain-fed with very limited irrigation (MOA, 2002).

The main cultivars are cereals and pulses followed by small scale irrigated crops mainly vegetables with a very limited number of flower and fruit producing farms. The major growing cereals and pulses include barley, wheat, maize and vetch, chickpea, beans and fenugreek.

Irrigation

Although irrigation systems in the study area have a long history since the year 1952, in the period of the Italian occupation, however, it is still predominantly traditional with limited advanced systems. Almost all the irrigation lands are confined with the adjacent sewage water stream lines "*Mai-Bella*", down streams of some limited dams and patches of hand-dug wells water points (MOA, 2002). The major irrigated crops grown include dominantly vegetables with minor barley, maize and Alfalfa (*Medicago sativa main*) mainly for animal forage (MOA, 2002).

Livestock Production

Livestock production in the study area is generally practised as mixed farming produce (FAO, 1994b) at subsistence level with a very few and limited commercial cattle dairy farms. Sheep followed by cattle are the dominant farm animals with a very few number of goats, horses, donkeys and chickens in the villages in the study area (MOA, 2002). Most households are involved in traditional poultry farming of unimproved indigenous breeds, which are mainly used as a source of cash. More recently poultry farming of improved breeds has gained momentum (MOA, 2002).

3.8.2. Urbanization

Urban expansion of Asmara city into the study area has been increasing steadily in recent years (AMO, 1992). According to the annual report of the Ministry of Land, Water and Environment (2003), from 1997 to the end of 2002, about 350 hectares of land have been allocated for urban land use and other development projects in the study area. This translates to an average rate of 70 ha per year, which is higher than the average of the past 40 years of approximately 50 ha per year.

3.9. Summary

The land around Asmara city has been traditionally cultivated to provide agricultural products to the local market. Production has been generally low due to lack of rigorous land assessment studies, misuse of land and use of ineffective methods.

The rapidly increasing population of Asmara has increased the demand for land for residential, commercial and industrial developments. The impact of this is that the traditionally cultivated land around Asmara is rapidly being transformed for other uses, hence reducing the supply of the already insufficient agricultural products.

This study is aimed at conducting a land capability classification of the study area to identify areas of high agricultural potential and protect them from urban encroachment and other non-agricultural use. Capability classification will be done based on intensive resource assessment and soil survey to determine the actual potential of the land in this area and recommend its optimum and sustainable land use types.

CHAPTER 4
MATERIALS AND METHODS

4.1. Introduction

Land capability classification is one way of the methods in land evaluation (Sys, 1985), which gives more emphasis on the capability of land to support a range of uses on a sustainable basis (McRae and Burnham, 1981). This capability classification is mainly based on the assessment of the natural resources, where a detailed soil survey and collection of other resource information is of vital importance (Ivy, 1977; Scotney *et al*, 1991; Smith, 2002).

Assessment of land capability basically includes several stages of which data collection and data analysis are of crucial importance. Data collection comprises several stages such as obtaining of land resources information from recorded data source, remotely sensed images and field survey. If information on soil is not available a detailed soil survey is essential (Scotney *et al*, 1991). A field visit was made for delineating the study area boundary, examining the land physical features and identifying the land resources information using aerial photos. All the available resources for land capability assessment were interpreted and recorded on the working sheet including the representative pit sites for the soil survey. During soil survey both the soil and land characteristics were carefully assessed and the criteria for the limitations that determine the capability classes were simultaneously determined.

Moreover, land resources, which are important for land capability assessment such as topographic characteristics, climatic factors including water and geological information, were assessed and mapped. Mapping these resources was done in ArcView GIS (ESRI, 1996) following several procedures and techniques such as geo-referencing, digitizing and recording of attribute data, and spatial interpolation techniques. In the final analysis stage of the land capability classification several algorithms and arithmetic operations were carried out by ranking the limitations so as to group, categorise and order the capability classes. The following sections describe the methods used in producing the different land resources maps and the final land capability map of the study area.

4.2 Data Collection

Information at an adequately detailed level, which would be used as a basis for land capability classification and other development planning were not readily available. As a result, during the study much effort was made directly to collect essential land resource information in the field. The required land resources information was collected from recorded sources and field survey.

4.2.1. Land Resource Data from Recorded Sources

A topographic map at a scale of 1: 50000 that could be used as a base map was obtained from the Ministry of Land, Water and Environment. Climatic data on synoptic information for further climatic analysis was gathered from the Ministry of Transport and Communication, Civil Aviations Department. Furthermore, only rainfall data of several stations in the vicinity of the study area was available from the Ministry of Agriculture, Department of Early Warning. Water resource and hydrological information for the study area was obtained from the Ministry of Land, Water and Environment, Department of Water Resource.

A geological map at a scale 1: 50000 that includes the study area was obtained from the Ministry of Energy and Mine, Department of Mines. Although the map was extracted from aerial photographs interpretation in 1970, intensive ground verification was carried out in collaboration with geology experts from the Department of Mines during the study. Information on natural vegetation was compiled from the provisional agro-ecological map of Eritrea, and for soil references a geomorphology and soil association map at a scale of 1:1000000 was obtained from the Ministry of Land, Water and Environment. Data on the socioeconomic aspects of the study area was compiled from the documents of the *Zoba Ma'ekel* Administration and Ministry of Agriculture *Zoba Ma'ekel* Branch offices.

Aerial photographs at a scale of 1:15000 that were used as base maps and a Trimble GPS Explore for collecting ground control points were obtained from Ministry of Land, Water and Environment. A very recent Ikonos image captured in February 2001 at 1m by 1m resolution that was used in current land use verification was obtained from the Centre for Development and Environment (CDE) Institute of Geography, University of Berne, Switzerland.

4.2.2. Land Resources Survey

The only available information on soil resources in the country is the map of geomorphology and soil associations at a small scale of 1:1000000, which is inadequate for any development planning. Therefore, it has been found vital and crucial to carry out detailed land resources and soil survey on which the land capability classification could be based.

Aerial photographs taken in 1994 at a scale of 1: 15000 for use as field sheets and base maps for a detailed soil survey of the study area were obtained. As the aerial photographs were not geo-referenced, selecting easily identifiable areas in each aerial photo and determining their exact locations using a Trimble GPS Explore for further rectification of the aerial photographs collected a series of ground control points.

4.2.2.1. Interpretation of Aerial photographs

The nature of the terrain and drainage pattern of the study area was identified and different land features such as watercourses, eroded areas, rock outcrops, and areas of homogenous in terms slope and landscape position, vegetation cover and major soil types were identified and delineated using a mirror stereoscope (Ivy, 1977; Schröder and Camp, 2002).

Concurrently a ground truthing for landform and soil verification was made and the density of soil profile pits for detailed soil survey study was determined.

4.2.2.2. Soil Survey

A detailed soil survey was done based on the Free Survey Method following the techniques developed by Dent and Young, (1981) and Scotney *et al*, (1991). Based on the type of landforms and the complexity of the soil pattern most useful representative pit sites were selected. For wider and larger homogeneity in soil colour and slope characteristics at least one representative pit was opened for every 10 ha. However, in a few cases where the soil type tended to be complex extra, more sampling pits were made to clearly identify the soil types. Thus, the density of the profiles was determined by the heterogeneity of the soil forms.

For more accurate demarcation of soil boundaries, in areas with a complex soil type, an intensive augering of up to 10 m interval along transects was carried out. Pits were subsequently dug in order to examine the physical and chemical properties of the soils from the respective representative profiles

4.2.2.3. Description of Soil Profiles

Different soil properties, diagnostic horizons and depths of horizons were described and recorded carefully. Surface stoniness was estimated and recorded as percentage coverage of the areas. Slope percentage of the surface of the area was measured using clinometers. Permeability was estimated in the field by dropping water on a freshly broken surface and plough soil fragments, and the rate at which the water was absorbed by the soil was recorded.

Information on rock types and parent materials was identified in consultation with the geologic map and a geology expert. The occurrence of stones at each soil horizon was recorded in terms of abundance, form and size. Soil texture and structure were determined in the field and from the laboratory measurements. Soil concretions, thus the concentration of calcium carbonate deposits were checked in the field using 10% HCl. The colours of different soil horizons were recorded by matching a freshly broken soil fragment with the Munsell colour chart. Soil mottling or alternating wet and dry conditions existing within the respective horizons were recorded in the field.

Representative profiles for detailed analysis of the soils in each land unit were selected to ensure that it was as much as possible representative of the particular land unit. For some homogeneous land units in different localities two profiles were dug and geo-referenced. Furthermore, for some wider homogeneous land units two to three profiles were dug.

The width and depth of each profile was 1.5 m and 2 m respectively. All information on every profile was collected and recorded carefully. Diagnostic horizons were identified and the thickness of each horizon was recorded. Samples from each respective horizon were collected in plastic bags for laboratory analyses.

4.2.2.4. Laboratory Analyses

The soil samples were ground and air dried in the laboratory and passed through a 2mm sieve and then treating it with Calgon solution and ultrasound dispersed a 20g soil sample. The dispersed sample was washed through the 0.053 mm sieve to extract the very fine sand. The clay and silt fractions were measured with a pipette through sedimentation. The sand fractions were measured by dry sieving. Particle size fractions that were measured were clay (<0.002 mm), silt (0.002- 0.05 mm) and sand (0.05- 2 mm).

All the soil texture classes including percent of silt and very fine sand plus percent clay and texture class were determined in the laboratory measurements. The different chemical properties such as Nitrogen, Phosphorus, Potassium, Calcium and Magnesium of the soils were determined after employing the routine analytical methods (Landon, 1991). The results of chemical analysis of the soils are presented in Appendix A.3.

4.2.2.5. Classification of Soil Types

The soils of the study area were classified according to the system of the World Soils Reference Base Working Group (WRB, 1998), which is the latest revision of the FAO/UNESCO's Soil Map of the World (1989 revised legend), as recommended by Berhane (2000).

Generally, following this methodological procedure soils of the study area were classified into two higher and lower soils categorical levels namely soil groups and subgroups respectively. Accordingly the study area has five major soil groups and six sub groups. The five major soil groups are: Vertisols, Cambisols, Luvisols, Fluvisol and Leptosol. However, Cambisols and Leptosols followed by Vertisols are the most dominant soils in the study area.

The lower categories that are soil subgroups of the study area include Vertic Cambisol, Eutric Leptosol, Lithic Leptosol, and Rock-leptosol complex, Calcareous Cambisol with Carbonates and Plinthic Cambisol with Plinthic characteristics.

4.2.3. Determination of Soil and Land Characteristic Limitations

Based on the land surface and soil physical and chemical characteristics, eight physical limitations were identified. These characteristic limitations represent minimum requirements that must be fulfilled for land to qualify for a particular class (Smith, 2002a). These are the degree of severity of the existing erosion hazard, percent slope, and percent cover of surface rockiness and stoniness, and soil physical characteristics such as soil effective depth, percentage of soil texture, wetness and permeability rate of the soil (Loxton, 1962; Ivy, 1977; Scotney et al, 1991; Smith, 2002)

Effective Soil Depth

Depth of the soil that can provide a normal condition for root development, retain available water, and supply of available nutrients for the plant to grow is referred to as an effective soil depth (Loxton, 1962 and Ivy, 1977). It is, therefore, the most important soil property affecting moisture and nutrient supply to crops that greatly influence the capability of the land (Scotney *et al*, 1991) hence, carefully evaluated.

The effective soil depth was evaluated in the field from the representative soil profile pits. The presence of gravel, weathering rock, literate and/or hardpans, strong structures or water-logged horizons that retard the downward root development were examined and measured carefully, and recorded on the soil profile description sheet. The criterion of the effective soil depth was then determined with due consideration of the type of crops grown and other climatic factors in the study area.

Percentage Clay

Apart from the field assessment of soil texture, percentage clay was taken from the results of the laboratory analysis. A precise estimation of the texture classes and size and distribution of mineral particles was also obtained from the laboratory analysis (USDA, Soil Survey Staff, 1975 and Smith, 2002).

Permeability

This refers to as the ability of a uniform, isolated piece of soil such as a horizon within a profile, to allow water to pass through it (Mitchell, 2000). In other words it is the rate of water movement into and through the soil. Therefore; it refers in all classes to the permeability of both subsoil and the material limiting the effective depth (Loxton, 1962).

In the absence of precise measurements permeability was estimated in the field by dropping water on a freshly broken surface of soil fragment and observing the rate at which the water was absorbed by the soil (Loxton, 1962). As was not practical to measure this rate in every soil examined, permeability was assessed and described qualitatively by observing the texture, colour, structure, consistence, the absence and presence of rockiness and other properties of the soil as described by Ivy, (1977).

Some adjustments were made by comparing the results of the field assessment with the textural classes resulting from the laboratory analysis, with a particular reference to the guidelines provided by Loxton, (1962).

Wetness

The degree of wetness was determined in the field after careful examination of all layers of the profile and the existence of any signs of mottling, gleying and/or other horizons such as E and G and/or soft and hard Plithite B horizons were noted as described by Smith, (2002).

Furthermore, any other unconsolidated or undifferentiated materials with signs of wetness were assessed and recorded as described by Ivy, (1977). Finally from the results of the field observation the degree of wetness was determined.

Rockiness and Stoniness

This land surface characteristic was observed and determined directly in the field during the soil profile description. An observation was made at the centre of the land unit along the site of the representative soil profile. Five randomly located 400 m^2 quadrants were taken to evaluate and estimate the percentage of bed rock or rock exposure and stone cover on the surface and recorded on the profile description sheet as described by Smith, (2002).

Erosion Hazard

During the profile description erosion hazard was assessed by rigorous field observation with due consideration of land cover and land use practice and the slope characteristic along the representative pit, where the existing soil erosion status was recorded by rating from non apparent or slight to severe erosion on a qualitative basis.

Obviously soil erodibility is based on the inherent differences between soils in respect to their susceptibility to water erosion. These differences relate to soil resistance to **detachment** and to the **infiltration** characteristics (Wells, 1988). The former is largely dependent on soil texture and structure whilst the later is determined by the ability of a soil to absorb rain as it falls. In this study although information on soil rainfall acceptance is limited the estimation of soil erodibility based on the K-value is considered as suitable technique hence it includes the permeability and structure classes of the soils.

For this reason the soil textural erodibility class of the top soil of the respective soil types was estimated from the erodibility factor of the K-value based on the results of the laboratory analysis of the soil physical and chemical properties (for example percent silt, percent of very fine sand and percent organic mater) (Scotney et al, 1991; Lorentz and Schulze, 1995). Soil structure and permeability classes, soil structure class and permeability class rating were adopted from the work of Lorentz and Schulze (1995). In this case the value for the permeability class (P_s) was estimated from the permeability information given for soil textural classes by Renard *et al*, (1991). The value for the structure classes were taken from the soil description results related to the soil structure class (S_s) as described by Wischemeir *et al*, (1971). However, information on sand, silt, very fine sand and percentage for the organic matter (Om) were obtained from the results of the laboratory analysis. Concurrently to estimate the erodibility of the soils these variables were used in equation 4.1.

$$K= 0.01317(0.00021(12\text{-}Om\ \%)\ M^{1.14} +3.25(Ss-2) +2.5(Ps-3)) \quad \text{(Equation 4.1)}$$

Where: Om% is the percent of organic matter for the respective soil type

M is obtained from the equation M= (SS %*(SS% +Sa))

Where: SS% is percent silt plus percent of very fine sand

Sa = percent of existing sand
S_s = Soil structure class
P_s = Soil permeability class

Based on this, four erodibility classes were identified in the study area. These comprise very low erodibility, low erodibility, moderate erodibility and high erodibility. Although this assessment was based only on the soil physical and chemical properties erosion hazard is the combined effect of several factors such as slope, land use practice and land cover. Thus, both the field observations and textural erodibility classes were examined against the percentage slope, which was derived from a Digital Elevation Model (DEM) of the study area.

Slope class

Slope plays a fundamental role in land capability classification thus, within the capability classes factors such as depth, texture and permeability requirements are more strictly prescribed for the steeper slopes (Smith, 2002). Slope in its widest sense refers to steepness, length and shape; in land capability classifications it refers specifically to slope steepness (Scotney *et al*, 1991).

Although slope gradient, slope length and shape of slope affect the rate of soil loss (Welles and King, 1988), in this study data on slope shape and slope length were not used. However, percentage of slope classes for the slope gradient was determined from the topographic map of the study area after constructing a Digital Elevation Model (DEM).

4.3 Land Resources Assessment

4.3.1. Assessment of Soil Resources

Assessment of soil resources in the study area was based on the soil survey carried out. Consequently soils were identified and classified to the soil group that they belong. Results of the analysis of soil physical and chemical properties such as soil effective depth, percentage clay and the organic matter including the other soil physical characteristics such as soil permeability and wetness were added as attributes and base information for the soil capability evaluation of the land units. The results of the assessment are discussed in chapter five.

4.3.2. Assessment of Topographic Characteristics

Out of the topographic characteristics slope is the most important and easily workable parameter used in land capability classification. The assessment of slope was carried out based on the obtained topographic map where contour lines were digitized and readily converted into a Triangulated Irregular Network (TIN) and a Digital Elevation Model (DEM) using spatial interpolation. To consider a detailed slope representation of every land feature a 10 m grid cell size was selected to derive the slope.

4.3.3. Assessment of Climatic Resources

When the capability of a land is to be determined, it is of importance to assess the climatic limitation of the concerned land (Scotney *et al*, 1991; Guy and Smith, 1995).

Climatic elements such as precipitation, temperatures and potential evapotranspiration are the most important factors that determine climatic capability class of a land (Scotney *et al*, 1991). Hence, these variables are the major factors that govern the distribution of crops (FAO, 1978).

4.3.3.1. Precipitation

The availability of moisture in the soil is a critical factor for a normal plant growth. Precipitation usually forms the most important source of moisture not only directly to crop growth but also provides run-off which, when stored, can enhance productivity (Smith and Camp 2002). The amount of precipitation can be expressed as mean and median precipitation.

Although median precipitation can be more reliable, mean annual precipitation records with potential evapotranspiration are most often used in climatic capability assessment (Scotney *et al*, 1991; Smith and Camp, 2002). However, the deviation of rainfall variability about an average is also the most important to indicate agricultural productivity of an area (Schulze, 1997; Smith and Camp, 2002).

Variability of the median rainfall and coefficient of variation (CV %) recommended by Schulze, (1997), Smith and Camp (2002) were used to express precipitation in the study area. Although median rainfall eliminates the effect of extremes, which would be taken into account when mean, rainfall is calculated, the coefficient of variation which is expressed in percent (CV %) measures the variability of rainfall from year to year. In principle the amount of rainfall and the coefficient of variability are inversely related. Thus, this inverse relationship was assessed in the study area. The coefficient of variability is the percentage of the ratio of the standard deviation and the mean and is calculated using Equation 4.2 below:

$CV\% = SD/x * 100$ Where: CV% is coefficient of variability of the rainfall.......... (Equation 4.2)

X is the mean annual precipitation over 42 years (mm)

4.3.3.2. Evapotranspiration

Evapotranspiration (E_r) is the combination of transpiration from the leaves of growing plants and evaporation from the soil surface and the plant surface (Schulze, 1982; Smith and Camp, 2002). To ensure the availability of moisture in the soil for standard plant growth the amount of precipitation must exceed some lower threshold of plant evapotranspiration loss for sustained growth to continue (Schulze, 1997).

There are several methods to estimate evapotranspiration ranging from complex physical based equations to simple measurements (Schulze, 1997). FAO (1983) recommends that moisture availability in a given area is better estimated as a deficit or surplus of the difference between precipitation and potential evapotranspiration. However, these methods all yield different answers under different climatic conditions.

In the study area average moisture for the growing season was assessed according to the FAO (1996) and Guy and Smith (1995). The FAO (1996) assumes that during the period when precipitation is $\geq$ 0.5 E_r sustained plant growth can take place. Likewise when precipitation is $\leq$ 0.5 E_r it is difficult for a normal plant growth hence, moisture stress is likely to occur to hinder normal plant growth (FAO, 1996).

Similarly the amount of moisture for the growth period can be estimated from the ratio of the annual mean annual precipitation (MAP) to the annual potential evapotranspiration from the A-pan measurements (Guy and Smith, 1995). According to Scotney *et al*, (1991); Guy and Smith, (1995) when the ratio of these two variables thus mean annual precipitation to annual A-pan measurements is ≥0.5 the area is ideal for normal plant growth hence, crop production and grazing is possible. Otherwise when the mean monthly precipitation is less than the 1/3 A-pan value, it is unfavorable for growing crops (Scotney *et al,* 1991). However, when the ratio of the mean annual precipitation to the A-pan measurements is decreased consequently the climatic capability classes are down graded or changed to the respective lower class (Guy and Smith, 1995). Equation 4.3 was used to determine the capability class of the land based on the ratio of mean annual precipitation to potential evapotranspiration for the growing season in the study area. The prescribed criteria that place a land to its respective climatic capability class are presented in Table 1 of Appendix A.3

$$R = MAP/APAN \quad \text{.............................. } (\textit{Equation 4.3})$$

Where: R is the Ratio

MAP is Mean Annual Precipitation

APAN is potential evaporation

4.3.3.3. Temperature

Temperature is a basic parameter frequently used to indicate the energy status of the environment and determines the rate of growth of plants (Schulze, 1997; Smith and Camp, 2002). Mean annual temperature, monthly maximum and minimum are the major temperature indices used to assess the climatic capability of a region (Smith and Camp, 2002).

Frost, which is the output of a very low temperature, limits the choices of plant growth in land use and adversely affects the capability of the land by limiting the range of use (Smith and Camp, 2002). In this study the monthly mean, monthly mean maximum and mean minimum temperatures and the heat units (Degree days) of the growing season (see section 4.3.3.4) were assessed in determining the climatic capability of the study area. The criteria for climatic capability classification based on temperature limitations are given in Appendix C. However, these criteria were used with some modification considering the local temperature characteristic of the study area.

4.3.3.4. Heat Units

The growth of a particular crop may be identified more accurately in terms of the required amount of cumulative heat units (degree days) in the growing season (Smith and Camp, 2002). Similarly the range and types of crops grown in the field depend upon the amount of the required heat units available in the life cycle of the plant (FAO, 1980; Schulze, 1997). In other words the range of crops grown in an area is determined by the amount of heat units that can be accumulated to support the specified crops.

However, growth stops below certain level of temperature, which is referred to as a lower and upper threshold or base temperature (Smith, 1997). The base temperature is, therefore, used with the mean daily temperature to calculate the number of heat units (degree days) throughout the growing season (Smith and Camp, 2002). Although, heat units are calculated from the daily mean temperature on a daily basis, in the absence of the daily mean temperature heat units can be estimated using the monthly mean temperature (Smith, 1997). For example when the base temperature is 10°C and the monthly mean temperature is 16°C the 6°C degree days or heat units are accumulated from that day and multiplied by the number of days within the month and added to a previous total of the months of the growing period (Smith, 1997).

In this study a threshold daily temperature of 10°C was taken as an average to include a wide range of crops (Smith and Camp, 2002). Therefore, the monthly mean temperature for each meteorological station in the study area was used with the specified base temperature to calculate the heat units. The heat units were then multiplied by the number of days of the months and added to the previous months so as to arrive at the total heat units of the growing season in the study area. Based on this heat units were assessed for the intended growing period using the following Equation: 4.3.

$$\text{Heat Units} = \frac{Tx + Tn}{2} - \text{Base temperature} \quad \text{(Equation 4.4)}$$

Where: Tx = Mean daily maximum temperature for the month (°C)

Tn = Mean daily minimum temperature for the month (°C)

4.3.4. Assessment of Geological Resources

Geological data were assessed as a basis to investigate the parent material. Identification and assessment of the geological parent materials in the study area was done by intensive field verification.

Several types of rocks were assessed and identified from which the parent material was formed. The identified rock types and parent materials were used in describing the geological resources in the study area. Based on the assessment of the geological resources soils were described in terms of the parent rock.

4.3.5. Water Resources Assessment

Hydrological information is vital for any agricultural development and other related planning (Schulze, 1995). Water is a resource on which all agricultural land use must be based and is indispensable for the understanding and for the prediction of the future use of the land (Sys, 1985). Thus, where irrigation water is available, individual fields of land potential classes must be upgraded (Guy and Smith, 2002).

The availability of water resources in the study area was assessed. A thorough field assessment of the available water resources, which could be used for irrigation such as boreholes, streams and dams, was carried out. In addition to the field observation of the available water resources in the study area information on water resources were compiled from the hard copies of previous studies of the Water Resources Department (2001).

4.4. Rectification of Aerial Photographs &Production of Land Resource Maps

4.4.1. Rectification of Aerial Photographs.

Remotely sensed images and aerial photographs are efficient tools used in land resources inventory and mapping. Before the extraction of the land resources information, the scanned maps and aerial photographs in the form of images need to be rectified and geo-referenced (ER.Mapper, 1998).

The aerial photographs and maps collected for the study were scanned, geo-referenced and rectified. Geo-referencing of the aerial photographs in the study area was done based on coordinate readings of identifiable land features in the aerial photographs collected during the survey.

Image to image rectification was employed based on the Ikonos image as a reference. In few cases where GPS reading was missing for areas outside the boundaries of the available aerial photographs, the Ikonos image was used for generating reference points. Following this method the aerial photographs covering part of the study area were rectified (geo-referenced) and both the aerial photographs and the Ikonos image were brought to the same projection and used as a base map to produce the resource maps in the study area.

4.4.2. Production of Land Resource Maps

4.4.2.1 Geological Map

The different geological information was extracted from the original map through digitizing in ArcView GIS (ESRI, 1998). After cleaning and building topology in Erdas Imagine, the data was converted to shape file and all the attributes added in ArcView GIS so as to produce the geological map of the study area. Figure 4.1 presents the geological map of the study area.

4.4.2.2. Hydrological Map

Mapping of the hydrological information was done when all the dams and seasonal streams were digitized and added as a theme to the base map. Wells of the study area were extracted from the hard copy water resource inventory report of the Department of Water Resources (2001). The X and Y coordinates of water features were recorded in Excel format and had to be imported to ArcView GIS as dbf III file and added as Event Theme so as to locate them on the map after converting to shape file. Figure 4.2 illustrates the drainage pattern and hydrological information in the study area.

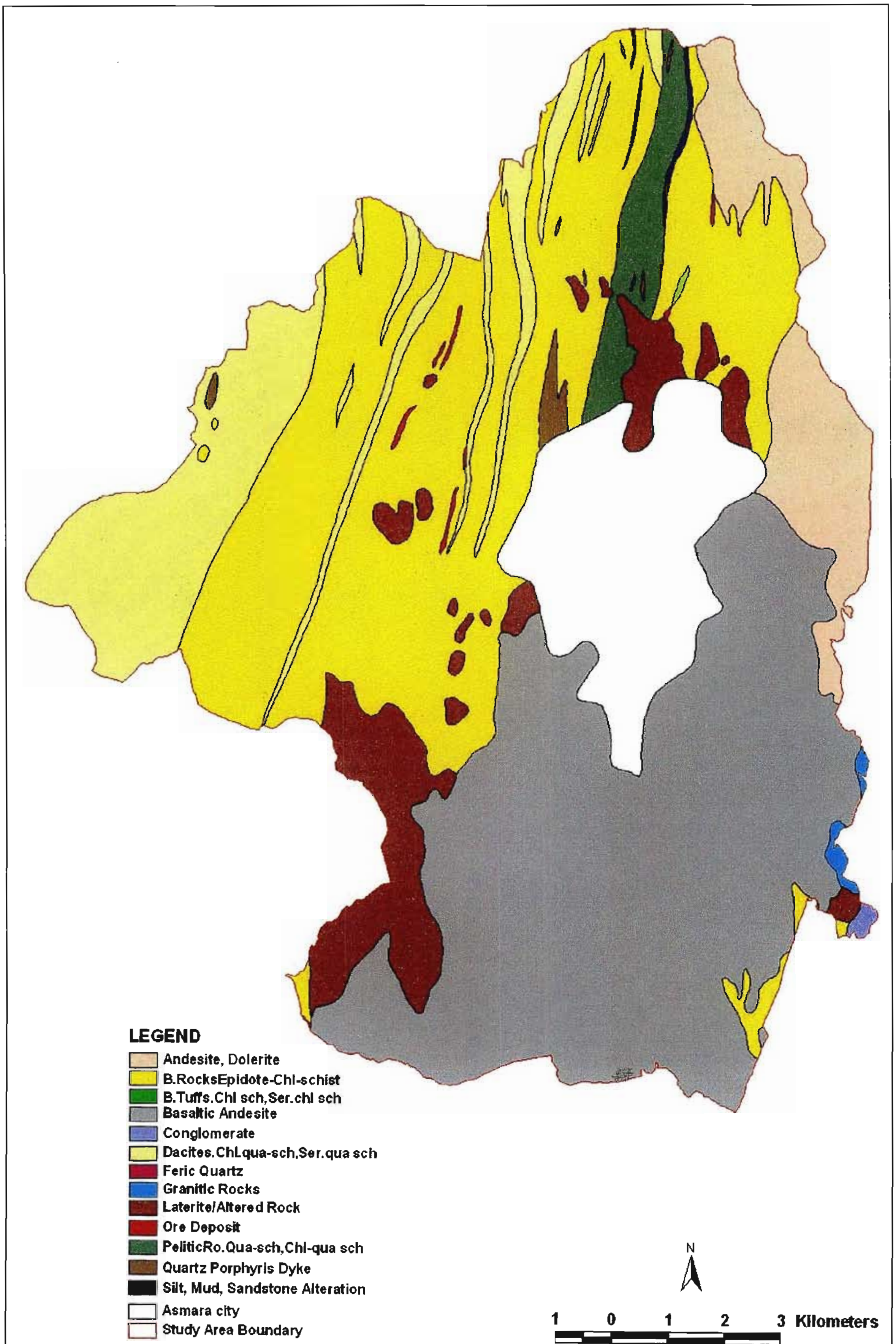

Figure 4.1 Geological Map of the Study Area

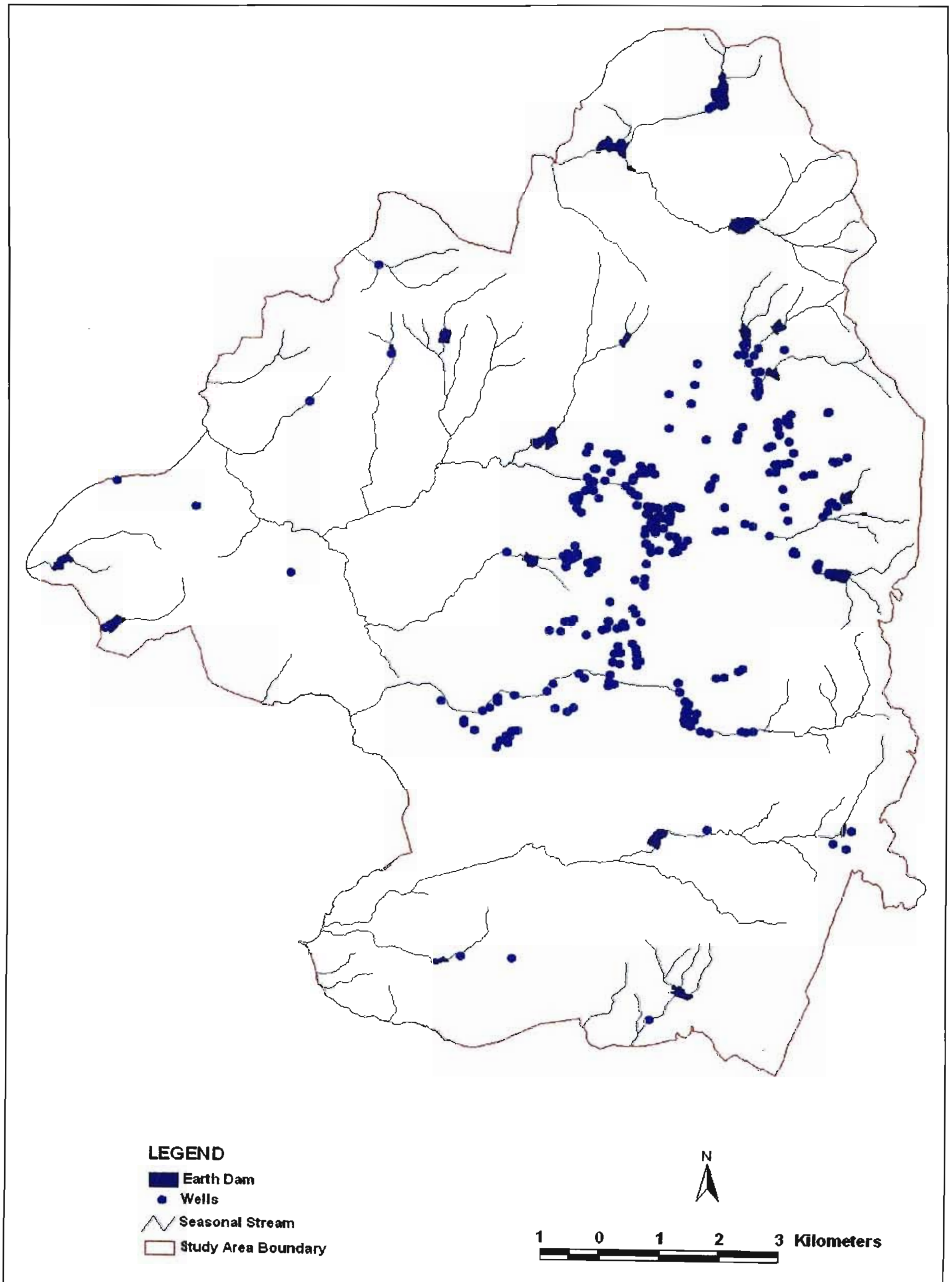

Figure 4.2 Hydrological Map of the Study Area

4.4.2.3. Soils Map

Digitizing

In the preparation of the digital soils map of the study area a high resolution Ikonos image and aerial photographs of the area were linked to ArcView GIS so as to perform the capture, edit and delineate the soil types and other spatial features. Soil type boundaries and other spatial features were digitized at an area threshold determined by the resolution of the images and saved as vector soil polygons in shape file format for further analysis.

Clean and built a topology

Once the relevant data in soil types and land characteristics in the image were digitized, it was necessary to clean and built a topology to remove any digitizing errors (ERDAS, 1999). The cleaning and building of topology were done when the ArcView shape file was converted to coverage in Erdas Imagine and then cleaned by selecting the "clean" and "built" topology commands. Then the coverage was converted back to ArcView shape file. All the errors were corrected and fixed manually by setting a snap tolerance of 5 m in producing the final product of the polygons representing soil mapping units.

Adding or Entering the Attribute data

All the attributes namely physical and chemical soil properties and the land characteristics were added and linked to the respective polygons of the mapping units using the keyboard. The land features and land use types associated with each individual polygon in the study areas were also identified and added as attributes to their corresponding polygons.

The geographic coordinate of each representative pits were added to the excel format and had to be imported to the ArcView as a dbf so as to show their geographical locations in the soil map. As a result the soil map database that shows the topology of the soil types and soil physical and chemical properties, land characteristics and other land features and land use types was created. The distribution of the soil types and the sampling sites is presented in Figure 5.1 of the next chapter five-subsection 5.2.1.

4.4.2.4. Mapping Topographic Features

In a conventional paper map topographic features are presented using contour lines placed at a fixed interval to depict the specific elevation and topographic features. However, in digital maps elevation and topographic features are presented with a digital point model. Such a representation of the topographic features is referred to as a digital elevation model (DEM). A Digital Elevation Model (DEM) can be constructed by using the data on the irregularly spaced points as the basis of a system of triangulation. This system refers to as a Triangulated Irregular Network (TIN). The (TIN) model provides a network of connected triangles with regularly spaced nodes or observation points with X, Y coordinates and Z values (UNEP, 1996).

In this study the production of the digital topographic feature maps were based on the topographic map at a scale of 1:50,000 with contour interval of 20 m that cover the study area. Initially contour lines were digitized with a snapping tolerance of 5 meters. The respective elevation values for the contour lines were added through the keyboard. A clean and built topology was employed to avoid any overshoot or undershoot errors during digitizing the contours. Once the data was cleaned and the topology was built the digitized contour lines were ready to be converted to a Triangulated Irregular Network (TIN).

For the construction of the TIN a spatial interpolation technique was used from the 3D Analyst extension of ArcView GIS. The Inverse Distance Weighting (IDW) method was used to produce a Triangulated Irregular Network (TIN) and slope maps.

4.4.2.4. Map of Climatic Elements

Climatic elements such as precipitation and temperature are not evenly distributed, hence their distribution vary over space (Bryan and Adams, 1999). These spatial variations in climatic conditions result in differences in the capability of the land when used for crop production (Scotney *et al*, 1991; Guy and Smith, 2002). Therefore, understanding of this spatial variability is a key issue in land capability classification.

However, most of the meteorological stations in the study area provide point data on climatic elements for discrete locations. Therefore, mapping will be essential to convert the point data into a spatial surface so as to represent the spatial variation of the climatic variables.

In this study a climatic data collected from sixteen climatic stations at discrete locations inside and around the study area was obtained from the ministry of Transportation and Communication, Department of Civil Aviation. These climatic datasets were provided as point data for the discrete locations in the Excel format. Therefore, in order to identify the spatial distribution of the climatic variables the point datasets need to be converted into a continuous surface. This can be done by adding the latitudinal (X) and longitudinal (Y) coordinates of the meteorological stations. Thus, the X and Y co-ordinates of the respective meteorological stations that were obtained from the GPS reading during the survey were added by editing in Excel format and had to be imported to ArcView GIS as a Dbf file and added as an event theme, and converted into a shape file for further analysis.

Converting of a point data to a spatial and continuous surface can be handled in ArcView GIS capabilities using different spatial interpolation methods (ESRI, 1995). The Inverse Distance Weighting (IDW) method is one of the methods that are recommended as efficient and works best with evenly distributed points and rugged surfaces (Anderson, 2001).

Although this method is influenced by the powers applied where higher powers resulted in the influence of the data points and lower powers over estimated the influence of the data points the power of distance controls weights, which are applied to data points (ESRI, 1996). For these reason in this study with the nature of the surface of the study area a weighting power of 2 at a neighborhood distance of 12 that resulted in better results both smoothing and retention of the original data was used in the production of the climatic element maps.

4.5. Land Capability Classification Procedures

Although there is no universal and standardized method for land capability classification, the USDA (Klingbiel and Montgomery, 1961) is widely used with some modifications in different countries (Loxton, 1961; Davis, 1976; Hudson, 1971; Mather, 1986; Davidson, 1992).

In this study the USDA land capability classification developed by Klingbiel and Montgomery (1961) as revised by Scotney *et al*, (1991) was used with some modifications to meet the aims and local conditions in Eritrea.

Initially the various land resources such as soil, topographic and climatic factors that determine the capability class of a land were carefully assessed. The assessment was based on a detailed survey of the physical and chemical properties of the soils and land characteristics. The boundaries of soil mapping units were carefully determined and drawn on aerial photographs. At this stage several soil and land characteristics, which are referred to as limitations that were used to place a land to a certain capability class were identified. The aerial photographs and images of the study area, which were used as base maps, were scanned and geo-referenced. Based on the aerial photographs polygons of soil mapping units were digitized and their pertinent soil and land characteristic limitations were added as attributes for further analysis.

The limitations were separately mapped out as soil and land characteristic limitations in the form of thematic layers suitable for analysis in ArcView GIS. Initially soil mapping units with uniform limitations of soil effective depth, percentage clay or permeability were grouped to establish soil capability units based on the prescribed criteria of the limitations (Appendix B.1). This was done in ArcView GIS using a Boolean overlay analysis where the different thematic layers of the limitations were overlaid to identify areas of uniform limitations. The intersection "AND" operation was used to identify the soil capability unit that posses uniform limitations.

A similar grouping of soil capability units was undertaken to arrive at soil capability subclasses based on uniform limitations that were ranked and grouped across the units. Finally limitations in the soil capability subclasses were grouped and ranked and the subclasses were eventually grouped into soil capability classes based on uniform limitations.

The same procedure was also applied to assess the topographic capability classes. Initially different thematic layers of the land characteristic limitations such erosion hazard, wetness, rockiness and stoniness were established. Based on the uniformity of the limitations several land characteristic capability units were identified based on the prescribed criteria shown in Appendix B.2. Land characteristic capability units were grouped to establish the capability subclasses. Grouping of these capability units to subclasses was based on the similarity of the kind of limitations encountered. These were then grouped to establish the capability classes. The land characteristic capability classes were established based on the degree of severity of the limitations of the subclasses. Land characteristic capability subclasses with uniform degree of limitation were designated to its respective capability class.

Slope was assessed separately from the topographic map of the study area. Initially the contours of the topographic map were digitized and interpolated to construct a Digital Elevation Model (DEM). Although the slope classes were derived from the DEM, class values were determined based on the prescribed criteria provided by Scotney *et al*, (1991). These slope classes were then used with the land characteristic capability classes to determine the final topographic capability classes. The intersection "AND" operation was used to identify areas that satisfied the specified slope and land characteristic class criteria and designated the land to its respective topographic capability class. Based on the soil and topographic capability classes the final land capability classes were established within a GIS by employing a Boolean overlay analysis. The intersection "AND" operation was used to identify areas that satisfy the specified criteria for determining the land capability classes.

To determine the final land capability classes in the study area climatic capability was assessed first. The assessment was done based on the point data of the climatic variables. Several thematic layers of climatic variables were produced from the point data through interpolation techniques. These thematic layers were overlaid using a Boolean overlay analysis to produce the climatic capability classes. The intersection "AND" operation was used to identify areas that satisfied the specified criteria of the climatic variables and designated the land to its respective climatic capability class.

The climatic capability classes were then compared with the land capability classes using an overlay analysis. The intersection "AND" operation was used to identify areas that could down-grade the land capability class based on the specified climatic capability and designated a land to its respective final land capability class. The final land capability classes were eventually grouped to produce the land capability orders. The grouping was undertaken based on the uniform land use potential of capability classes. The combination "OR" operation was applied to identify areas that satisfied the prescribed criteria provided by Scotney *et al*, (1991). Figure 4.3 presents the flow diagram of the operations followed in the production of the final land capability orders in the study area.

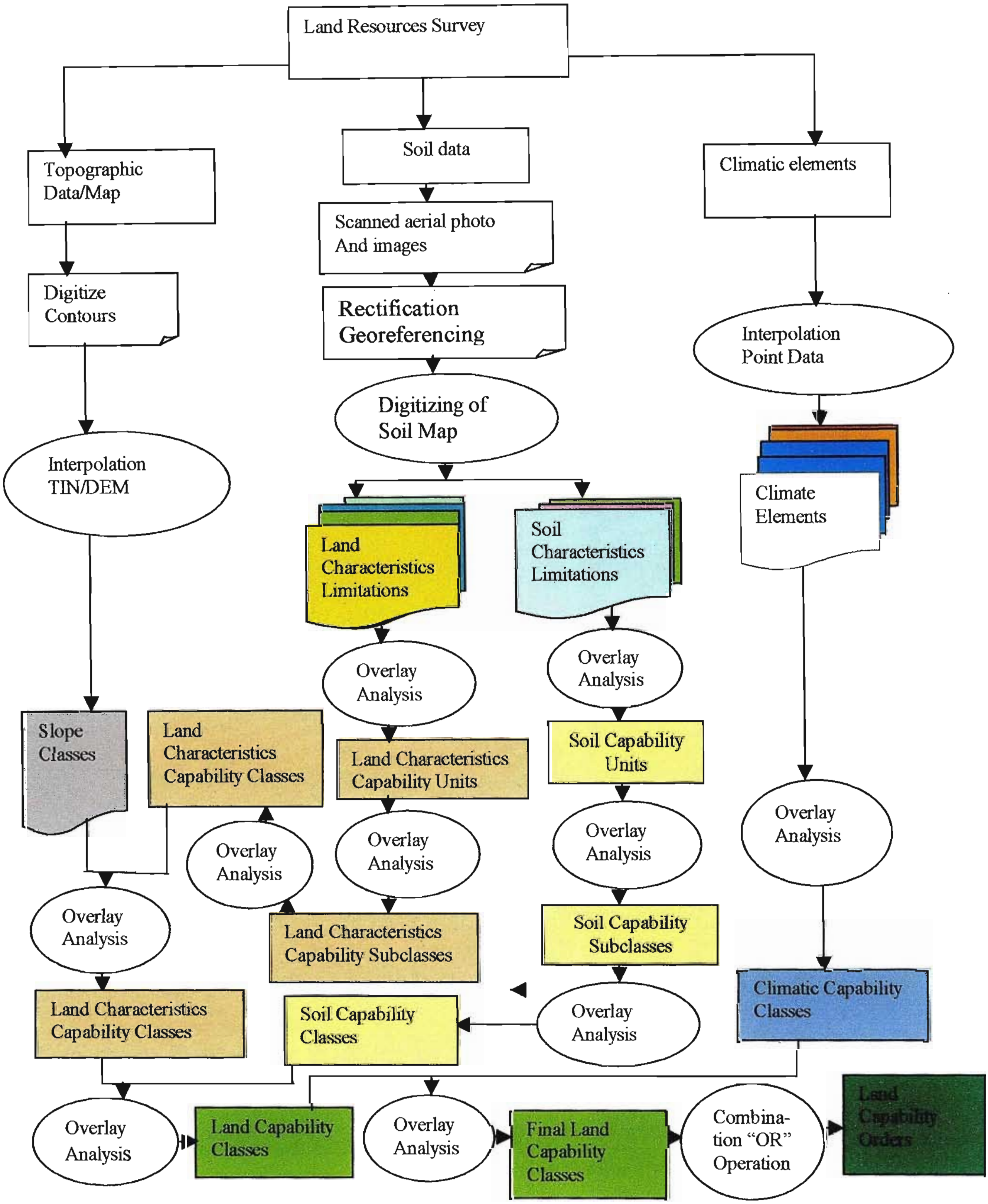

Figure 4.3 Flow diagram showing the process employed to create the final land capability class and order maps using the USDA and RSA land capability classification procedures in a GIS overlay analysis.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter presents and discusses the results obtained using the methodological procedures applied in the production of the land capability categories in the study area. Initially the soil and topographic limitations that appear to determine the capability category of the land were identified and mapped. Areas of uniform limitations and production potentials were identified as separate soil and topographic capability units. These units were grouped into separate soil and topographic capability subclasses by identifying the dominant limitations imposed on the land. Capability classes were produced by ranking and rating of the limitations to indicate uniform degrees of limitations shown in the subclasses. Eventually seven combined soil and topographic capability classes were identified in the study area.

Based on the assessed climatic variables, a climatic capability classification for the study area was prepared and examined against the soil and topographic capability classes to determine the final land capability classes. "Finally, land capability classes I- VII were identified in the study area; and in turn these were grouped into three major land capability orders according to their potential agricultural productivity". The land capability orders were: "high to moderate agricultural potential", "marginal agricultural potential" and "agriculturally non-productive" lands.

5.2. Land Resources Inventory

Land resources inventory in the context of this study was essentially an inventory or a spatial database of soil and land characteristics and climatic factors that determine the capability class of a given land.

5.2.1. Soil characteristics

Figure 5.1 presents the geographical distribution of the dominant soil groups in the study area including the representative sample sites of the survey. Five soil groups (Cambisols, Vertisols, Leptosols, Fluvisols and Luvisols) and eight additional subgroups (Calcaric Cambisols, Epileptic Regosols, Plinthic Cambisols, Rock-Leptosols Complex, Eutric Cambisols, Eutric Leptosols, Eutric Vertisols and Vertic Cambisols) have been identified in the study area based on the World Soil Reference (WRB, 1998).

The details of the soils characteristics included in the map of the study area are described in Appendix A.1 and their correlation to the USDA and RSA soil classification systems are provided in Appendix A.2. The details of the findings of these soils' physical and chemical properties from the soil survey and the results of the laboratory analyses are presented in Appendix A.3.

Generally on most of the flatlands of the central and southern part of the study area both Cambisols and Vertisols are widely distributed (Figure 5.1). These soils are the most intensively cultivated in the study area. These two soil groups cover 55.86 percent of the study area. Cambisols alone account for 40.43 percent of the total area. Leptosols, which are very shallow, predominantly occur on the steep slopes of the northeastern and eastern parts of the study area. This soil group covers 22.06 percent of the total area of the study area. Fluvisols are confined to the stream banks of the study area and these recently deposited soils are the most intensively irrigated. However, these soils are very limited to about 1 percent of the areal coverage of the study area. Soils of the Luvisol group are confined to pockets in the flat lands and are most probably results of past erosion depositions. This soil group covers 3.59 percent of the study area.

In the central part of the study area Calcaric Cambisols are very common covering 9.52 percent of the area. Epileptic Regosols that cover 2.92 percent of the area are commonly found in northeastern and southwestern parts of the study area. Plinthic Cambisols are more confined to areas adjacent to Mai-Bella stream basins and the northwestern part of the study area where the underlying material is highly gleyed. This soil subgroup covers

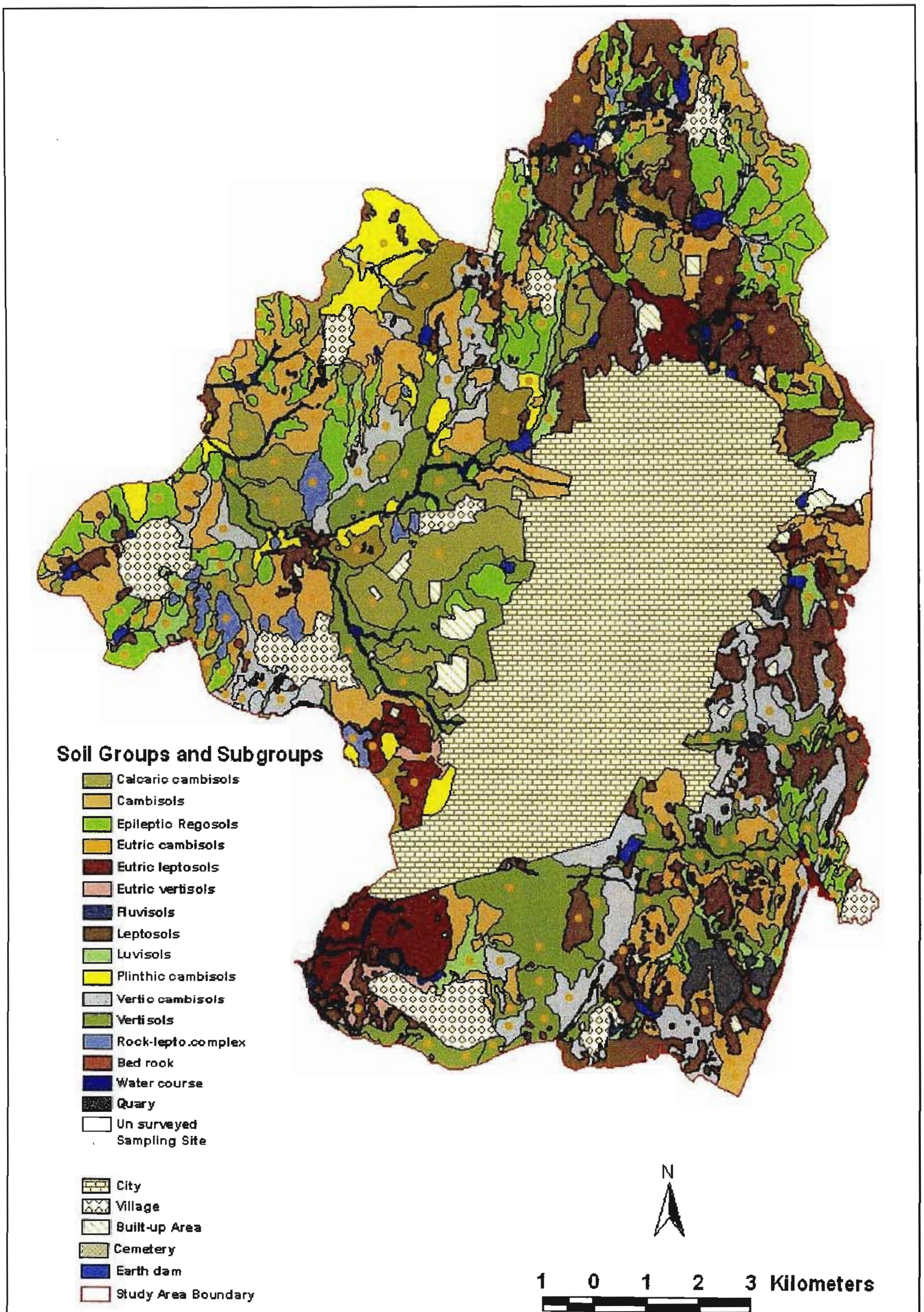

Figure 5.1 Soil Map of the Study Area

about 3.52 percent of the total area. The Rock-Leptosols Complex soils, which cover 1.53 percent of the study area, are widely distributed in northern and western corners of the study area.

Soil physical and chemical characteristics, e.g. effective soil depth, texture, permeability and organic carbon, had been assessed. Their geographical extent and characteristics are discussed in the following sub-sections.

5.2.1.1 Effective Depth

The results of the soil survey show that soils of the study area vary according to morphology and lithological of the substratum. The past erosion rate could have played an important role in determining the soil effective depth. Effective soil depth in this study area was rated into different classes that include very deep to very shallow soils.

Very deep or deep soils (effective soil depth greater than or equal to 100 cm) are very limited to the flat areas and stream basins in the study area. These soils are underlain by soft carbonates of Kaolinitic accumulations that show vertic properties Most parts of the colluvial and allvial deposits of the flat lands in the south and center of the study area show very deep, fine textured soils of slightly restricted permeability. Deep soils (effective soil depth between 80 and less than 100 cm) are more confined to the gentle sloping lands in the study area. Like the very deep soils these deep soils are underlain by the soft carbonates of kaolitic accumulation, but at a lower depth showing a cambic property. These soils are very common to the gentle sloping lands in southern, central and northern parts of the study area adjacent to the very deep soils.

Moderately deep soils (effective soil depth between 50 and less than 80 cm) are found on foot slopes, and on the surface of the gently and moderately sloping areas and in some plain areas of the study area. Most of these soils are fine textured with considerable sandy loams. The shallow soils (effective soil depth between 25 and 50 cm) of the study area belong to the steep slopes, and occupy the largest part of north and northeast of the study area. In western, southwest and southeast corners of the study area shallow soils are very common.

However, the very shallow soils (effective soil depth less than 25 cm) are mostly volcanic and cover the steep slopes north and east of the study area.

5.2.1.2 Percentage clay

The results of the soil laboratory analysis show that most of the soils in the study area have less than 30 percent clay. Such soils cover 72.8 percent of the study area. This indicates that soils in the study area are predominantly with low to very low moisture retaining capacity. The rest of the soils (28.2 percent coverage) have percent clay between 30 and 65. Taking rainfall characteristics and effective soil depth in the study area into account, the clayey soils are more importantly for crops than less clay soils, as they retain moisture which could be used during the early off set of rainfall.

Most of the soils with low clay percent (less than 30 percent clay); for example loamy sand and sandy loam, which occupy the largest part of north and northwest of the study area, have a low moisture holding capacity. As a result crops grown on such soils are heavily exposed to moisture stress during the growing season.

5.2.1.3 Permeability

The assessment indicates that soil permeability classes in the study area range from permeability class 2 (severely restricted) to permeability class 6 (rapid). However, permeability class 1 (impermeable) is not found in the study area.

The heavy textured clay soils of the Vertisols of the seasonal wetlands in the central and southern parts of the study area, which have permanent grey mottles at a shallower depths, have a permeability class 2 (severely restricted) for crop cultivation. Some drainage problems are also observed in the heavy textured clayey Vertisols of the plains, at the bottom of the valleys and stream basins mainly south and central part of the study area. These soils have a prismatic soil structure and experience drainage problems with a permeability class 3 (restricted permeability). As a result the growing crops in this part of the study area are very limited particularly when rain is frequent. Almost all crops suffer from the problem of permeability during the growing season.

However, the relatively deep Vertisols and vertic Cambisols in the south and southwest and in parts of the northwest of the study area are identified as having permeability class 4 (slightly restricted). The Leptosols and Cambisols north, northwest and eastern part of the study area where soil texture is ranging from sandy clay loam to sandy loam have a permeability class 5(good). Whereas the loamy sand texture classes in a limited area of the extreme north and south west of the study area have a permeability class 6 (rapid). Full description of the prescribed permeability criteria in the study area is shown in Appendix B.1.

5.2.14. Soil Organic Matter

It is generally accepted that organic matter and iron oxide stabilize soil aggregates and thus reduce erosion. Soil organic matter holds more water and nutrient than the same amount of soil minerals. Moreover, with adequate soil organic matter water infiltration rate increases and runoff decreases where soil structure is improved and becomes more stable and less prone to crusting and erosion. Hence, soils with low organic matter or iron oxides are poorly drained (Mitchell, 2002).

Two classes of soils were identified in the study area as far as organic matter is concerned. These include soils of low and moderate organic matter. Soils of low organic matter content (less than 2 percent organic matter) cover 63.6 percent of the study area. Soils of moderate organic matter content (greater than or equal to 2 percent organic matter) cover 36.4 percent of the study area. The organic matter content of the soils used in erosion assessment is presented in Appendix C.2. However, the assessment revealed that soils in the study area have moderate soil erodibility.

5.2.2 Land Characteristics

Land characteristics such as slope, erosion hazard, wetness, rockiness and stoniness of the land surface are the most important features considered in classifying the capability of the land in the study area. These land characteristics either in combination or independently can severely affect the use of the land. Hence, a thorough inventory of these limitations was carried out. The prescribed criteria and description of these limitations is given in Appendix B.1.

5.2.2.1 Wetness

As the results of the inventory reveal, most of the study area has no problem of wetness, where soils are well drained and free of any signs of wetness throughout their effective depths. However, four wetness classes class1 to class 4 (free of any signs of wetness to land which is permanently wet during the rain season) had been identified in the study area. Most of the land in the east, north and west of the study area, where soils are good and well drained within 80cm of the surface throughout their effective depth, the land is classified as wetness class 1(free of any signs of wetness). The flat and intensively cultivated land in the south, central and west of the study area including areas along Mai-Bella stream basin where the land shows a slight mottling at 50 cm depth has a wetness class 2 (slightly wet) and this is mostly due to frequent irrigation.

In parts of the flatland adjacent to watercourse in the south of the study area and the deep and heavy textured Vertisols of the valley bottoms of southeast of Asmara land is identified as a wetness class 3 (temporarily wet) during the rainy season where the surface is frequently wet for a considerable period. These lands are saturated at depths of 20 to 50 cm. Whilst close to the water courses and down stream of the earth dams of the study area including the deep clayey Vertisols down stream of the dam in the northwestern part of the study area, land is saturated within a depth of 15cm throughout the rainy season. This land is designated as wetness class 4 (seasonal wet) lands in the study area. Description of the results of wetness in the study area is presented Appendix B .2.

5.2.2.2 Rockiness and Stoniness

5.2.2.2.1 Rockiness

The results of the assessment of rockiness in the study area are presented in Appendix B.2. The results indicate that five ratings of rockiness are exhibited by soils in the study area. These are classes 1, 2, 3, 4 and 5. The percentages of rocks in these classes are 0-less than 2 percent, 2 to less than 10 percent, 10 to less than 20 percent, and 20 to less than 40 percent and greater than or equal to 40 percent respectively.

Lands of 0 to less than 2 percent (almost free) rockiness cover are found in the northern, central and southwestern parts of the study area. These lands have no rockiness limitation and are classified as rockiness rating of 1. Land of 2 to less than 10 percent (less sufficient) rockiness cover are common to the west, east and lower south east of the study area where rockiness has shown a smaller significance of limitation with tillage. These lands are identified as rockiness rating of 2. The extreme north and south east corner of the study area have 10 to less than 20 percent (sufficient) rockiness cover. These lands have enough limitations to obstruct tillage. However, such lands are only suitable for raw crops and are rated as rockiness rating of 3. Lands that have 20 to less than 40 percent (severe) rockiness cover are most common in the extreme north of the study area. In these lands rockiness is a serious problem to make all types of tillage. These lands are designated as rockiness rating of 4. Lands of greater or equal to 40 percent (very severe) rockiness cover occupy in the lower north and small part in southeast of the study area. These lands are identified as a rockiness rating of 5. These lands have a very severe limitation of rockiness for both type of tillage and mechanization.

5.2.2.2.2 Stoniness

The results of the assessment of stoniness in the study area are presented in Appendix B.2. The result shows that three stoniness ratings in the study area have been identified. These include rating 1, 2 and 3 (free to abundant). The percentage stoniness of these are 0 to less than 15 percent, 15 to less than 40 percent and greater than or equal to 40 percent.

In the lands north, northwest and most of the rugged terrain extending in a north-south direction of the study area the percentage cover of the stoniness is greater or equal to 40 percent (abundant). These lands have limitations for cultivation as a result of stoniness cover and are identified as stoniness ratings of 3. Lands of 15 to less than 40 percent (frequent) stoniness cover are found in southeast and southwestern part of the study area. These lands have stoniness ratings of 2 where stoniness cover has a moderate limitation as compared to rating of 3. However, in most of the central west and southern parts of the study area the lands have 0 to less than 15 percent (free to rare) stoniness cover. These lands have no stoniness limitation and are identified as stoniness rating of 1.

5.2.2.3 Erosion Hazard

Data on erosion hazard in the study area was based on two assessments. The first was a qualitative record of the observed status of erosion hazard, which was gathered during the soil survey. Three classes of soil erosion status were observed in the study area ranging from none and/or slight (E1) to severe sheet and rill erosion (E3). This qualitative information shows that the flatland in south and central part of the study area erosion hazard is identified as none or slight sheet erosion (denoted E1). In the gentle sloping lands east and southeastern corner, west and central parts of the study area erosion hazard is moderate (denoted E2). However, the intensively cultivated gentle to steep slopes northwest and north of the study area erosion hazard is high and severe (denoted E3).

The second assessment was based on the potential erodibility (K-factor) of the soils in the study area where a calculation of the K-factor was done based on the soil properties from the laboratory analysis (Lorentz and Schulze, 1995). Results of the assessment show that in soils with high clay and organic matter the risk of erosion is very low to moderate. This has the lowest values ranging between 0.08 (very low erosion risk) and less or equal to 0.5 (moderate erosion risk) (see Appendix B.2). The highest values between 0.5 and 0.63 reflect areas of low clay and high organic matter contents and susceptibility to erosion. The map (Appendix B.2) reveals that soils in the study area are generally moderately susceptible to erosion.

However, the results of the quantitative assessment (K-factor) did not fully match the qualitative results, especially for steep areas. This is most probably due to the fact that the K-factor was obtained based on chemical and physical laboratory analyses. Therefore, classification could reliably be based on this combined assessment of erosion. However, the assessment made based on soil properties could also be used as a reference to identify the potential erodibility (the inherent tendency of the soil to be transported by water) of the encountered soil types of the study area. Descriptions of the criteria and parameters used in identifying the soil potential erodibility classes are shown in Appendix C.1. The map in Appendix C.3 illustrates the erodibility classes of the soils in the study area

The results indicate that most of the soils in the northern and southeastern parts of the study area have a high and severe erosion hazard (E3). This land covers 34.5 percent of the study area where severe sheet erosion and rills developing into gullies are widely observed; more than 85 percent of this land is located in the north of the study area. Although bad farming practices and lack of soil conservation measures are common in the study area, slope has been observed as a predominant factor that accentuates erosion hazard in most of the eastern and northern parts of the study area.

Nonetheless 34 percent of the study area has moderate erosion hazard (E2). This land constitutes the clayey soils of the flatland in the south of the study area. However, only 21.5 percent of the study area has no to slight erosion hazard (E1); most of this land is in the south and central parts of the study area. Appendix B.2 provides the results of the erosion hazard in the study area.

5.2.2.4 Slope Characteristics

The Triangulated Irregular Network (TIN) and slope map of the study area in Figure 5.2 and Figure 5.3 respectively present the topographic characteristics of the study area. The TIN map shows that most of the higher ground lies east and northeast of the study area where altitude ranges between 2382 and 2454 m a.m.s.l. The altitude of the lowest ground to the west of the study area ranges between 2240 and 2264 m a.m.s.l.

Slope inclination in the study area is generally towards the west dictating the drainage pattern of the study area. Slope is one of the most dominant factors influencing both tillage practices and erosion, and is expected to exert some influence on soil profile (Ivy, 1977). Slope is the most important factor that affects the capability class of a concerned land (Scotney *et al*, 1991).

The slope map in Figure 5.3 indicates that most of the study area has a slope range between 0 and 1 degree that is from flat to almost flat or level land. However, the assessment results reveal six distinct slope classes in the study area ranging from class I that is 0 to less than 2 percent slope (flat or level) to class VII greater or equal to 30 percent slope. However the analysis shows class VIII is not present in the study area. The most dominant class is class I (flat or level) cover more than 80 percent of the study area. Slope classes II (gently sloping) and III (moderately sloping) which account for 15 percent of the study area are located in the north east extending to the south along the eastern edge of the study area. However, Classes IV, VI and VII including limited areas in the north, west and south of the study area, occupy the rest 5 percent of the land. Results of the slope assessment are shown in Appendix B2.

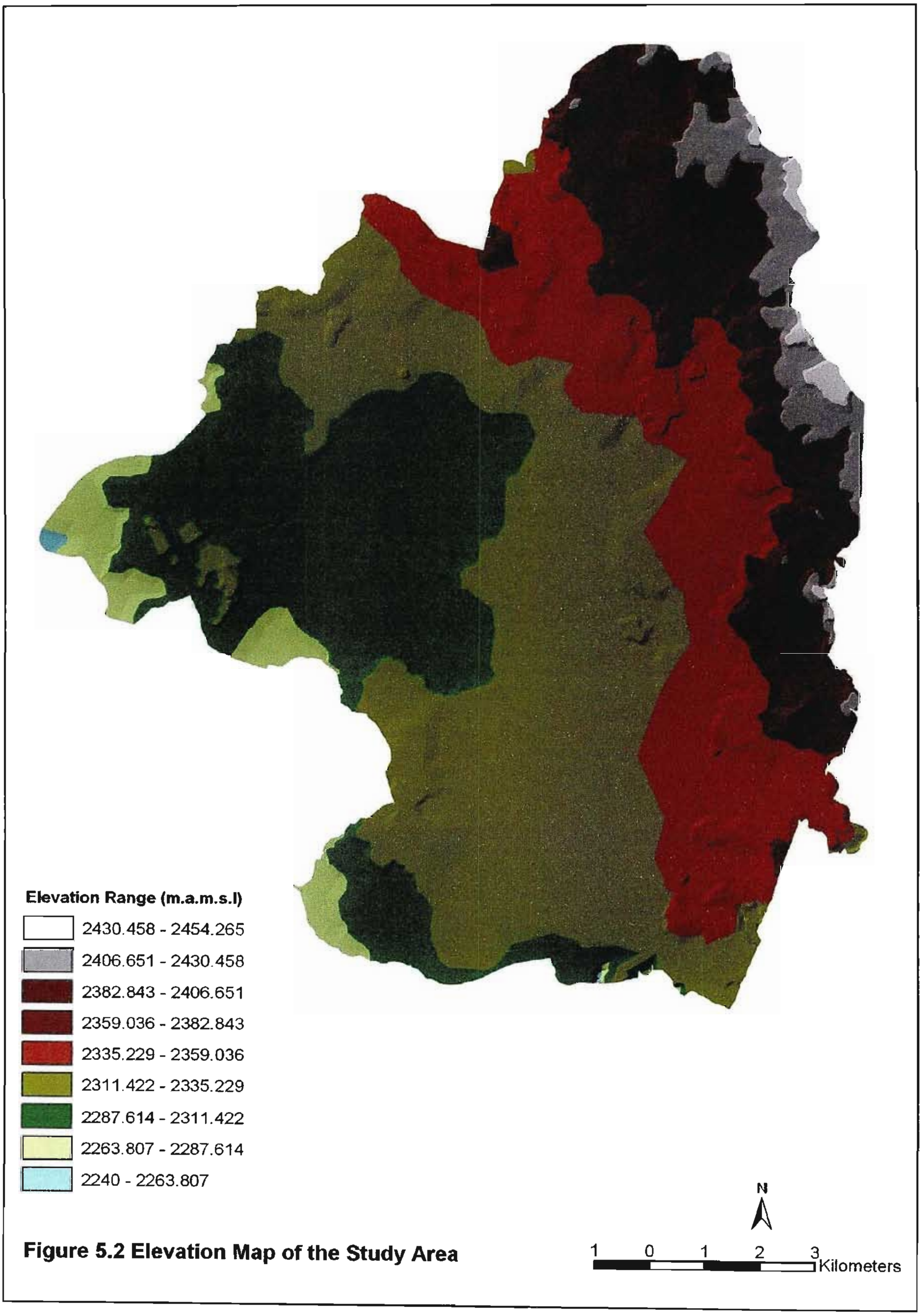

Figure 5.2 Elevation Map of the Study Area

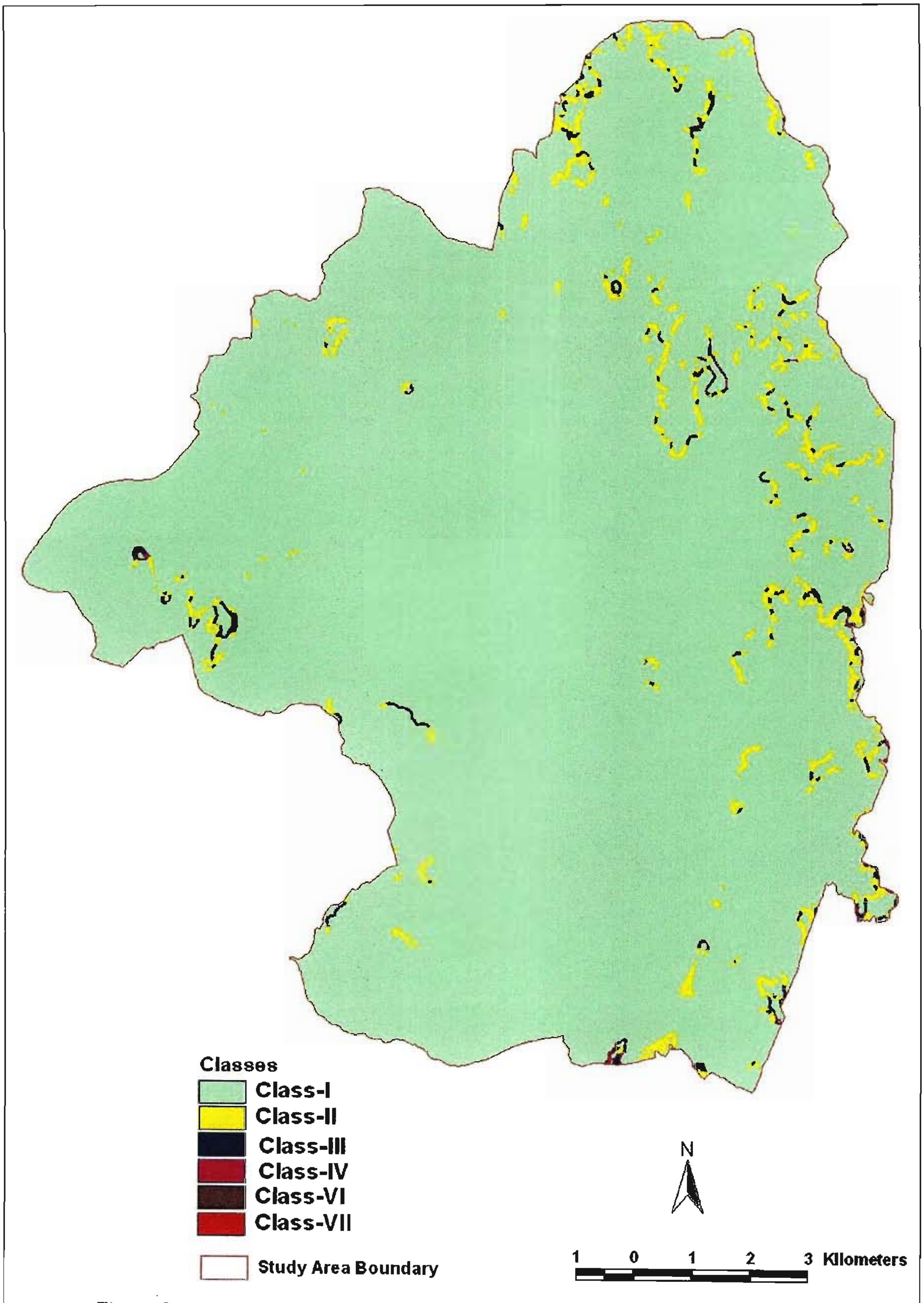

Figure 5.3 Map of Slope Classes in the Study Area

5.2.3 Climatic Resources

5.2.3.1 Precipitation

Precipitation refers to moisture obtained from rain, snow, hail, mist, dew and frost. Of these rainfall is the primary source of water for plant growth and the only form for which comprehensive records are obtainable (Camp, 2002). The mean annual precipitation was assessed with evapotranspiration for the evaluation of land capability in the study area (subsection 4.3.3.1). However, to express the nature of precipitation in the study area a comparison of variability of the mean, median rainfall and their coefficient of variation was done (Figure 5.4).

The comparison indicates that both the mean annual and median precipitation distribution in the study area as shown in the Figure 5.4 exceeds the total evapotranspiration except for two months. Indeed such a distribution creates a serious problem for most of the plants in the heavy clayey soils where waterloging results in crop failure or reductions in yield.

The annual mean precipitation in the study area is calculated 495.5 mm with an annual coefficient of variation (CV) of 37 percent over a 42 years period. This indicates precipitation is likely to vary by 183.3 mm. Hence the mean annual precipitation in the study area varies from 312.2 mm to 678.8mm for two thirds of the time. As indicated in Figure 5.4, the monthly coefficients of variation percentage are extremely high in the winter/dry season, but decline in the summer months. This is due to the fact that the precipitation within the summer months is higher and much more constant in contrast to the precipitation in the winter months. However, the 75 percentile of precipitation for the study area is 616mm; therefore 75 percent of the precipitation in the study area not exceeds 616 mm.

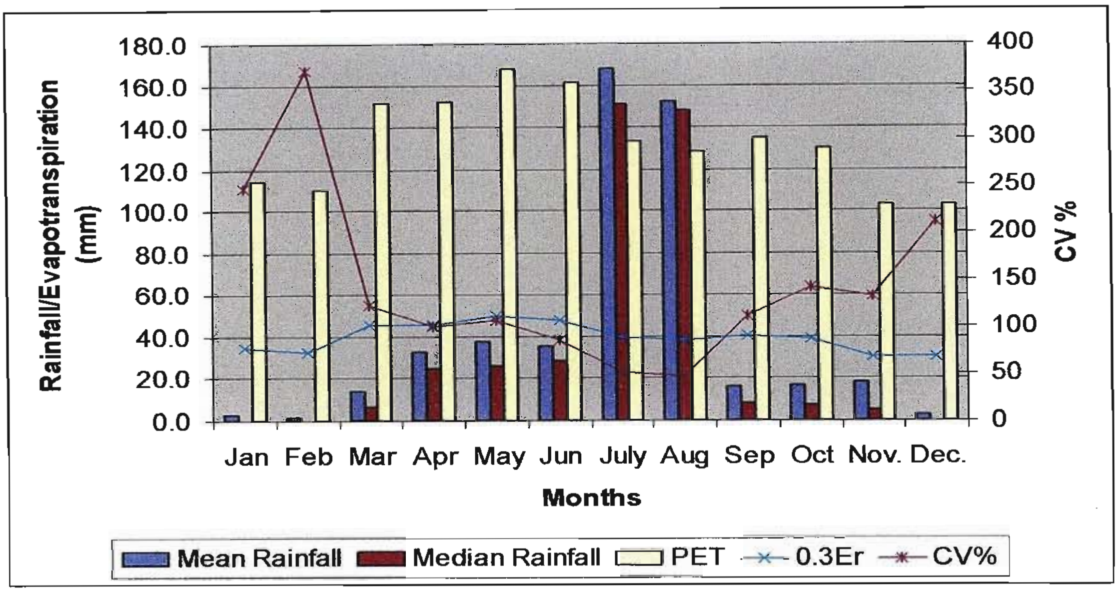

Figure 5.4 Distribution of three climatic statistics (mean rainfall, median rainfall, Evapotranspiration, and CV %) over months of years in the study area.

5.2.3.2 Evapotranspiration

For favorable conditions and normal plant growth the average monthly precipitation must exceeds (0.5) half of the evaporation values throughout the growing period (Scotney *et al*, 1991). However, evaporation in the study area is very high; it exceeds the rainfall for 10 months of the year, while precipitation exceeds the total annual evapotranspiration during the months of July and August (see Figure 5.3).

The effective growth for crops in the study area is to start from when the precipitation curve is to exceed the evapotranspiration curve. The growing period in the study area extends from the last week of June to the first week of September (see Figure 5.4). Annual precipitation is concentrated within the months of July and August where almost 70 percent of the precipitation falls in these two months only (see Figure 5.4). Although precipitation in these months of July and August shows higher peak the reset of 10 months precipitation is even below one third (1/3) of the monthly evaporation. As a result this period is very critical for a normal plant to grow and moisture stress is likely to occur in the month of September as displayed in Figure 5.4.

According to equation 4.2 (subsection 4.3.3.2) the ratio of mean annual precipitation to evaporation for the study area ranges between 0.23 and 0.34. The evaluation indicates that the ratio of mean annual precipitation to the annual evapotranspiration in most of the study area is less than 0.3. However, as is shown in the map Figure 5.5 in a very limited area in the center and north of the study area, the values range between 0.30 and 0.34, which are not very significantly different from the other areas of the study area. Descriptions for the range of the ratio values to their corresponding classes are presented in Appendix D.

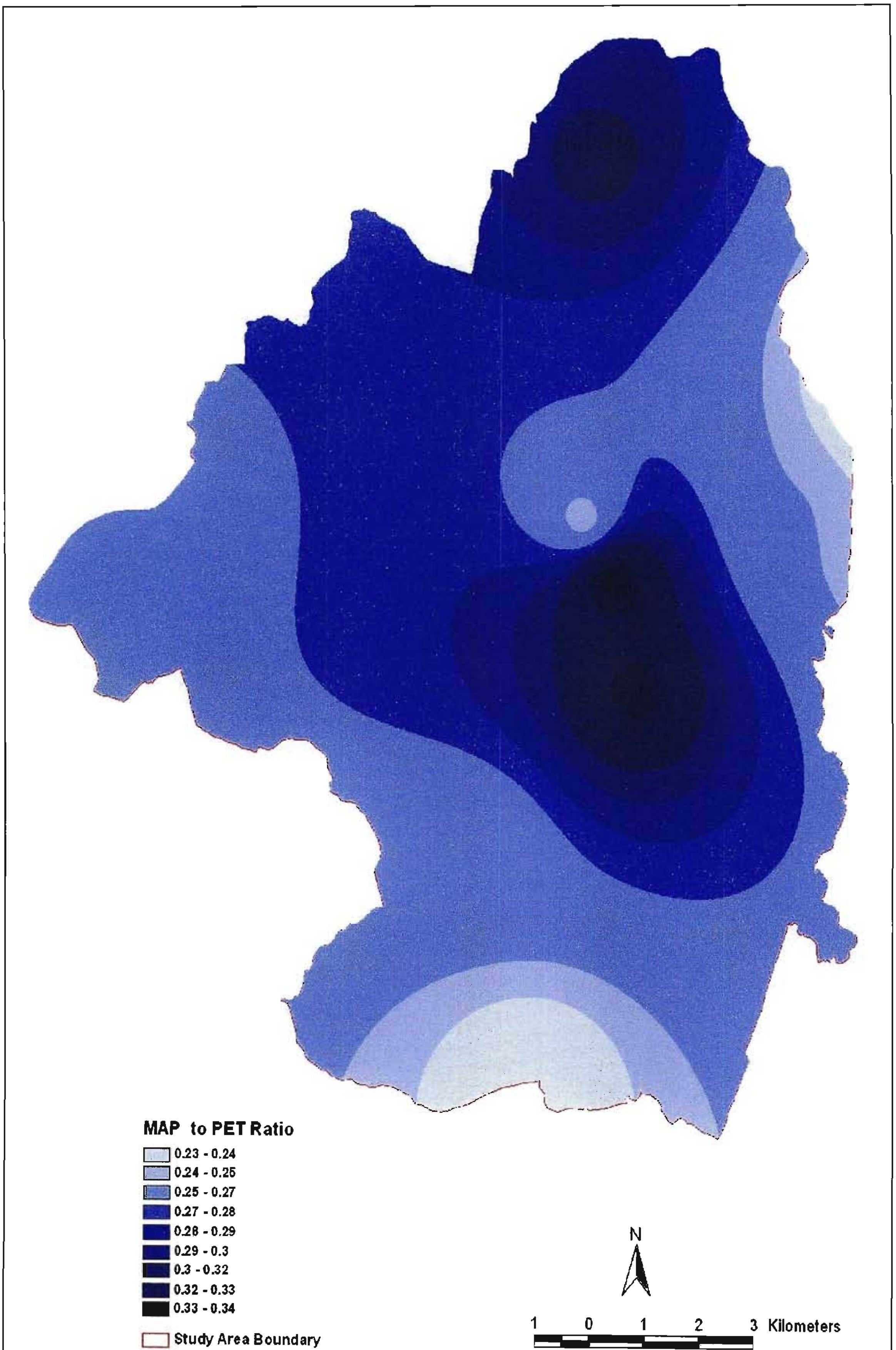

Figure 5.5 Map of ratio of MAP to PET in the Study Area

5.2.3.3 Temperature

Figure 5.6 presents the three temperature values (mean monthly maximum, mean monthly and mean monthly minimum) of the months over 42 years period in the study area. The mean monthly temperature in the study area varies from 22.41°C in July (summer) to 10.6°C in January (winter). For the warmest month (June), the mean temperature range between 20°C to 22.3°C while the coldest month (January) the mean temperature in the study area is between 10.12°C to 11.33°C.

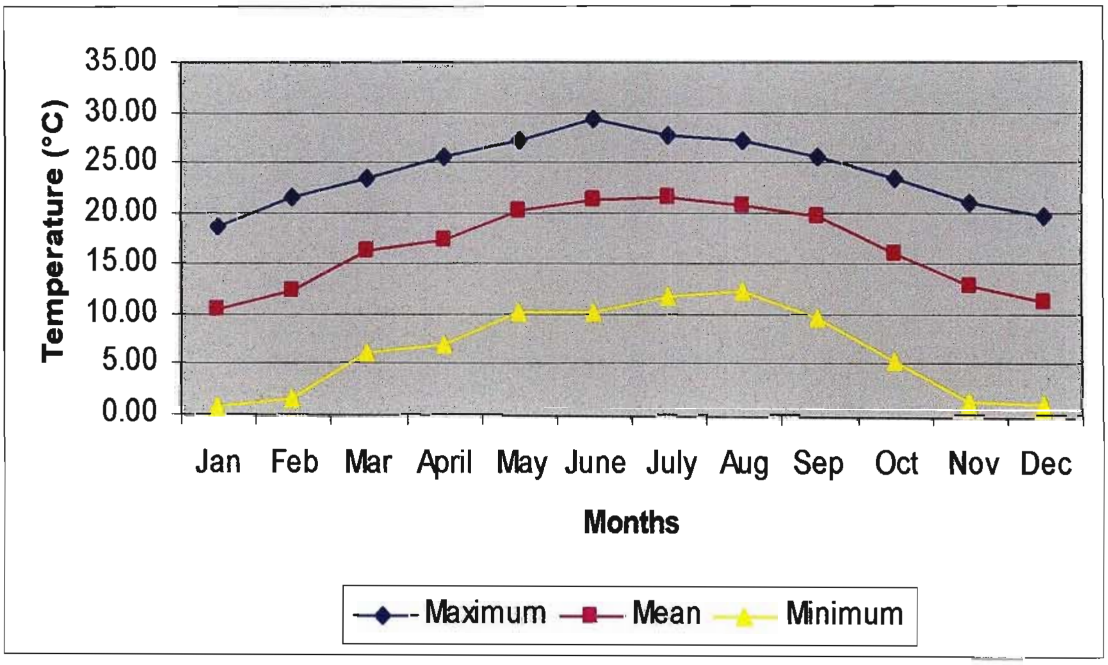

Figure 5.6 Mean monthly, mean monthly maximum and mean monthly minimum temperatures of the months of the years in the study area.

Figures 5.7, 5.8 and 5.9 display the spatial distribution of interpolated mean annual, mean annual maximum and mean annual minimum temperatures of the study area respectively. The mean temperature for the study area is between 16°C and 17°C. The higher grounds in eastern parts of the study area receive the lowest value of both mean monthly and mean monthly maximum temperatures in the study area. However, the eastern, northern and western parts of the study area receive the lowest values of the mean annual minimum temperatures.

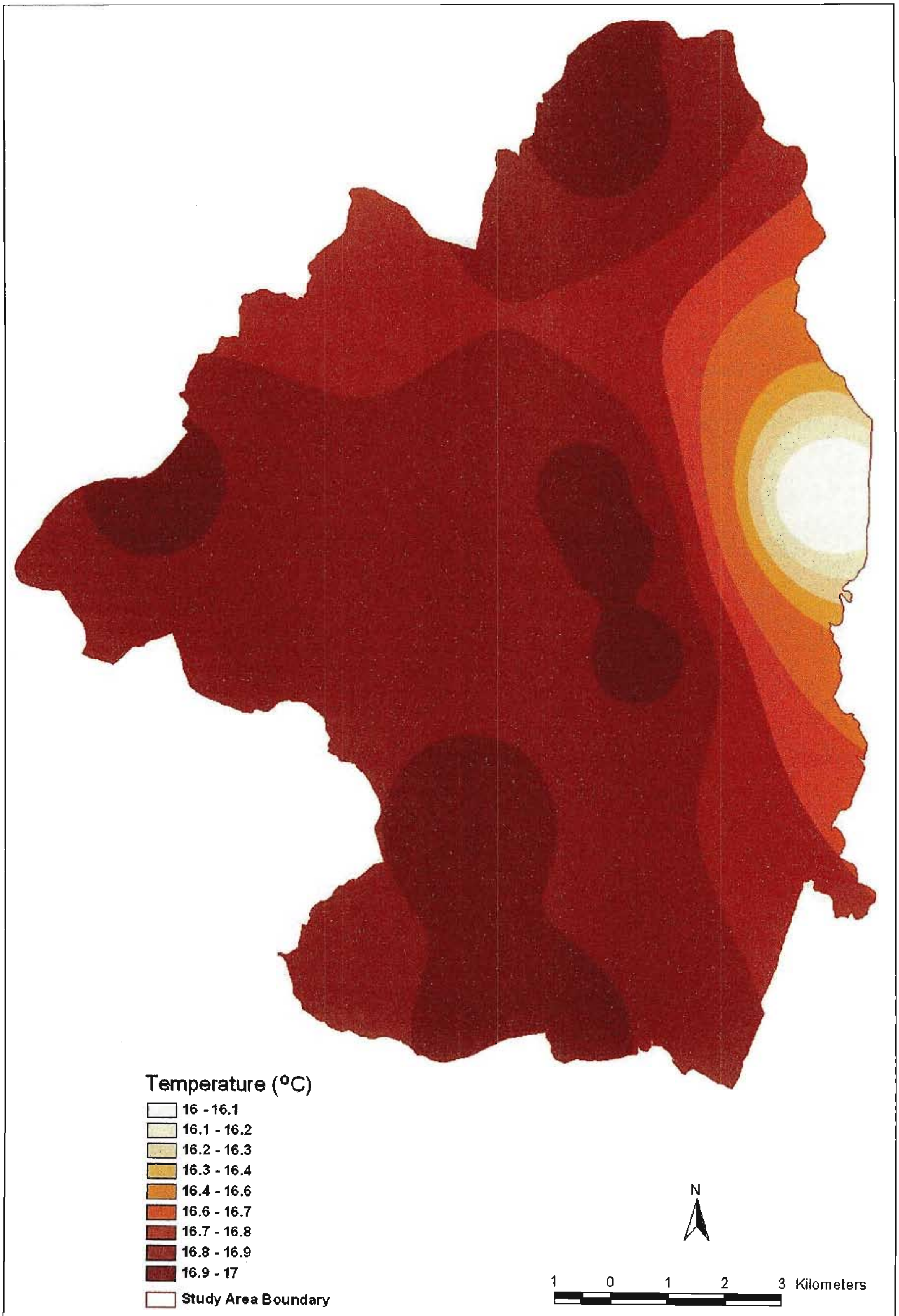

Figure 5.7 Map of Mean Annual Temperature

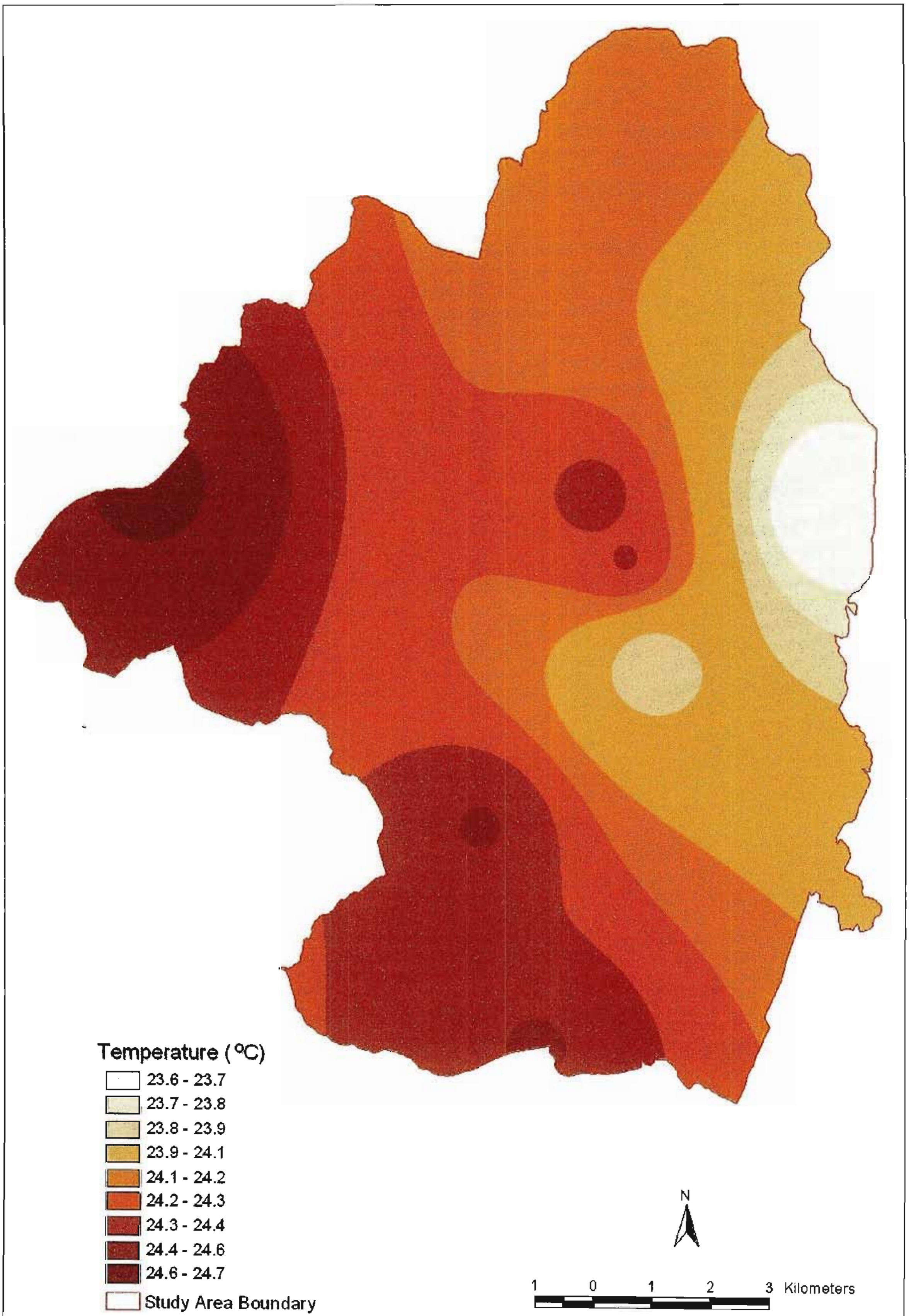

Figure 5.8 Map of Mean Annual Maximum Temperature

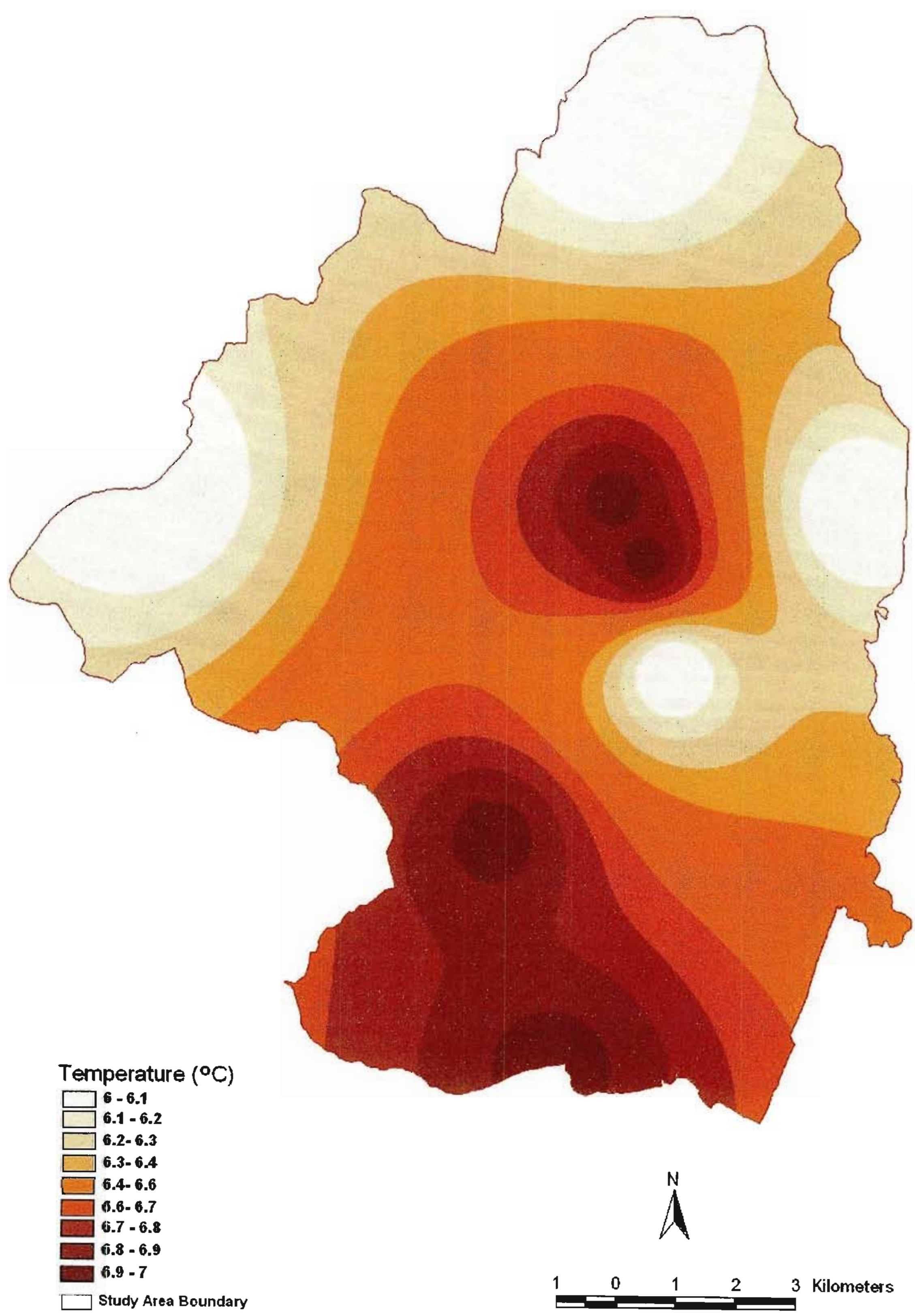

Figure 5.9 Map of Mean Annual Minimum Temperature

5.2.3.4 Heat Units (Degree Days)

Figure 5.10 provides the heat units (degree days) calculated for the growing season in the study area based on a base temperature of 10°C. Heat units in the study area vary from 1277 to 1362. Values of heat units are directly related to the temperature of the area where higher values are associated with higher temperatures. Most of the central and western parts of the study area have high heat unit values ranging from 1333.7 to 1362. However, in most of southern and northern parts of the study areas the values range between 1333 and 1333.7. Whereas, in the higher altitudes in the eastern parts of the study area the values are relatively lower ranging between 1277 to 1324.2.

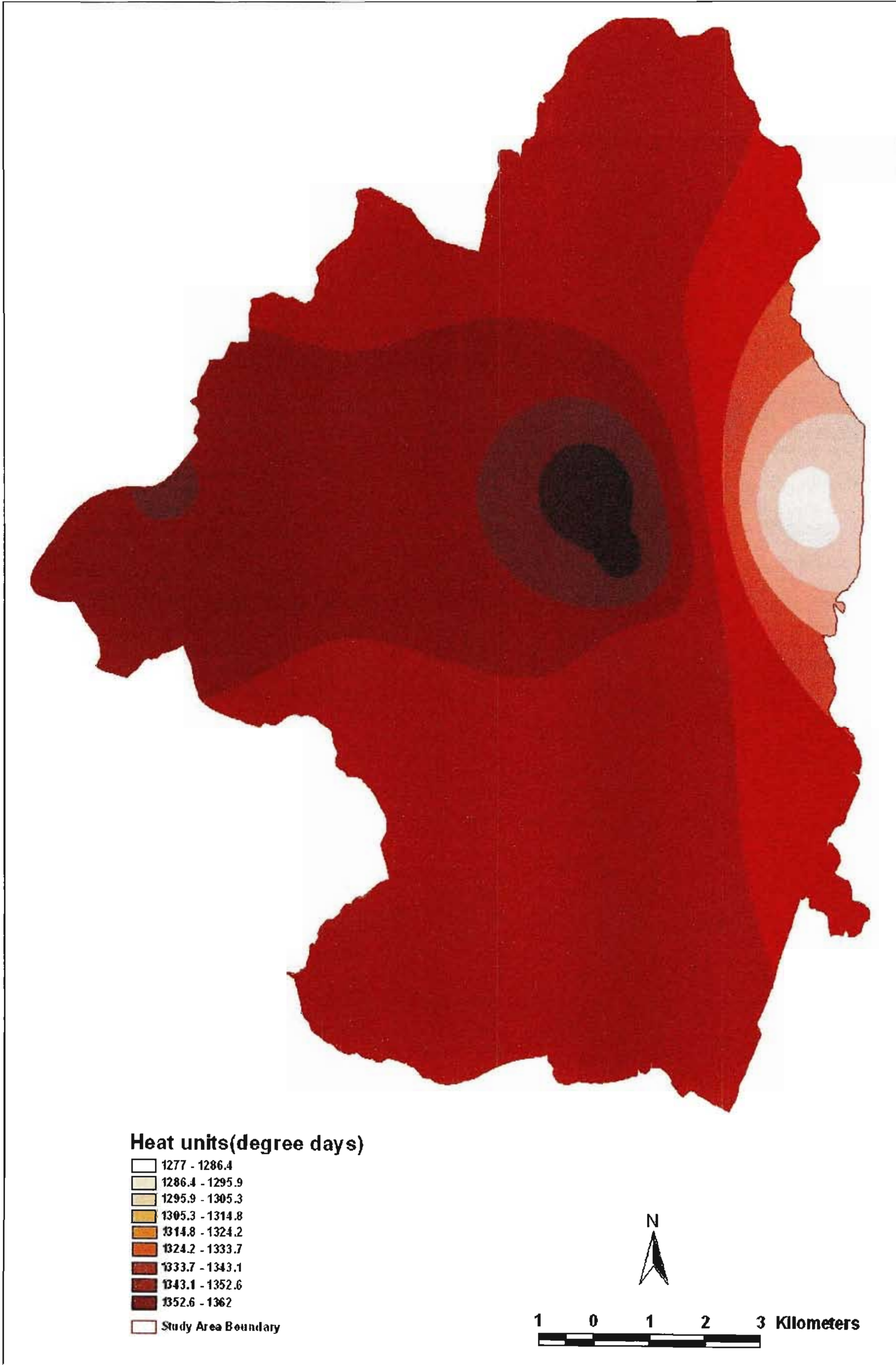

Figure 5.10 Map of Heat Units (degree days) of the Growing Season

5.3 Capability Categories

The key issue in determining both soil and land characteristics capability categories is to ensure a reasonable standard of uniformity (Scotney *et al*, 1991). In the USDA and the RSA land capability classifications; this has been achieved by specifying criteria and standard procedures. This study refrained from prescribing explicit criteria or minimum standards for each capability category based on the USDA and RSA land capability classification. These standards were obtained from the survey results. Based on these prescribed criteria and parameters the results reveal four land capability categories through soil and land characteristics capability categories in the study area.

5.3.1 Soil Capability Categories

The soil characteristics assessment in the study area was based on factors such as soil effective depth, percentage clay and soil permeability. The results revealed three capability categories namely units, subclasses and classes. Descriptions and results of these categories are discussed in the following subsections. A full description of the prescribed symbols and intensity of limitations of the factor is provided in Appendix B.2.

5.3.1.1 Soil Capability Units

The 648 soil mapping units were grouped into 31 soil capability units. The initial letter of the limitation or combinations of letters indicates a Limitation that places the soil mapping unit into a capability unit. For example a land capability unit I-D1T1P4 indicates that effective depth rating 1 (D1) in this capability unit is greater than or equal to 100 cm. The texture class 1 (T1) shows this capability unit has greater than 35 percentage clay and the permeability class 4 (P4) is slightly restricted. However, the capability unit VI-D5T3P3 implies to the land where effective depth rating 5 (D5) is less than 25 cm. The texture class 3 (T3) is between 15 to less than 30 percentage clay and the permeability class 3 (P3) is restricted. The prefix roman numbers I and VI indicate that these capability units belong to the capability class I and class VI respectively. The different soil capability units in the study area are shown by their respective color as given in the legend of the digital map of the soil capability unit in Figure 5.10.

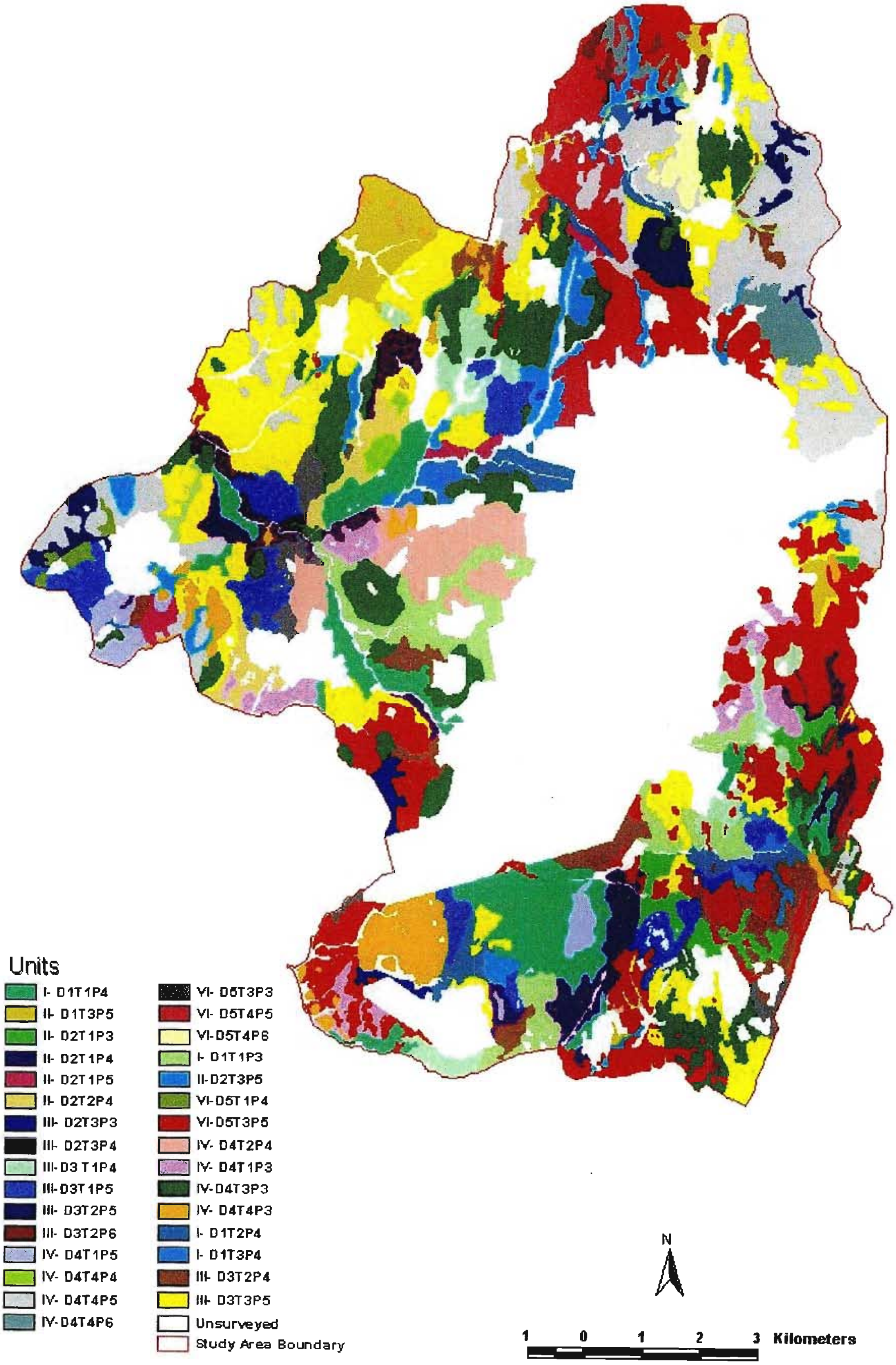

Figure 5.11 Map of Soil Capability Units

5.3.1.2 Soil Capability Subclasses

17 soil capability subclasses have been recognized in the study area. The major limitations that designate a land parcel to its respective subclass are as shown in the legend of the digital map in Figure 5.12. Soil effective depths followed by clay percent were the major dominant factors in determining these soil capability subclasses in the study area.

These limitations are either of equal value to influence the capability of the land or one of them is to appear as a dominant limitation. The dominant limitation appears next to the subclass and is indicated by the symbol of a capital letter of the limitation and the respective rating of the limitation indicates its degree of limitation. For example a subclass III-T3 indicates subclass III, the letter "T" indicates that the percentage clay is the dominant limitation. The number "3" indicates the rating of the percentage clay where percentage clay (15 to less than 30) is the dominant limitation. Such capability subclass lands are more confined to the northwestern corner of the study area. Subclass III-D3T2 indicates subclass III, the letters "D" and "T" soil effective depth followed by percentage clay of the soil are dominant limitations. The numbers preceding the letters indicate the rating of the respective limitation. However, soil effective depth rating 3 (D3) is dominant limitation that appears next to the subclass. Hence, lands in this land capability subclass have soil effective depth (15 to less than 80 cm) and percentage clay (30 to less than 35) with clay loam texture class. This capability subclass is dominantly found in the central part of the study area.

However, in capability subclass IV-D4T4 both soil effective depth rating 4 (D4) and percentage of clay rating 4 (T4) are dominant limitations. Lands in this capability subclass have soil effective depth (25 to less than 50 cm) and percentage clay (0 to less than 15) with sandy texture class. Although this capability subclass is limited to the northern and western parts of the study area it is very common in northeastern corner of the study area. The digital map in Figure 5.12 illustrates the geographical extent of soil capability subclasses.

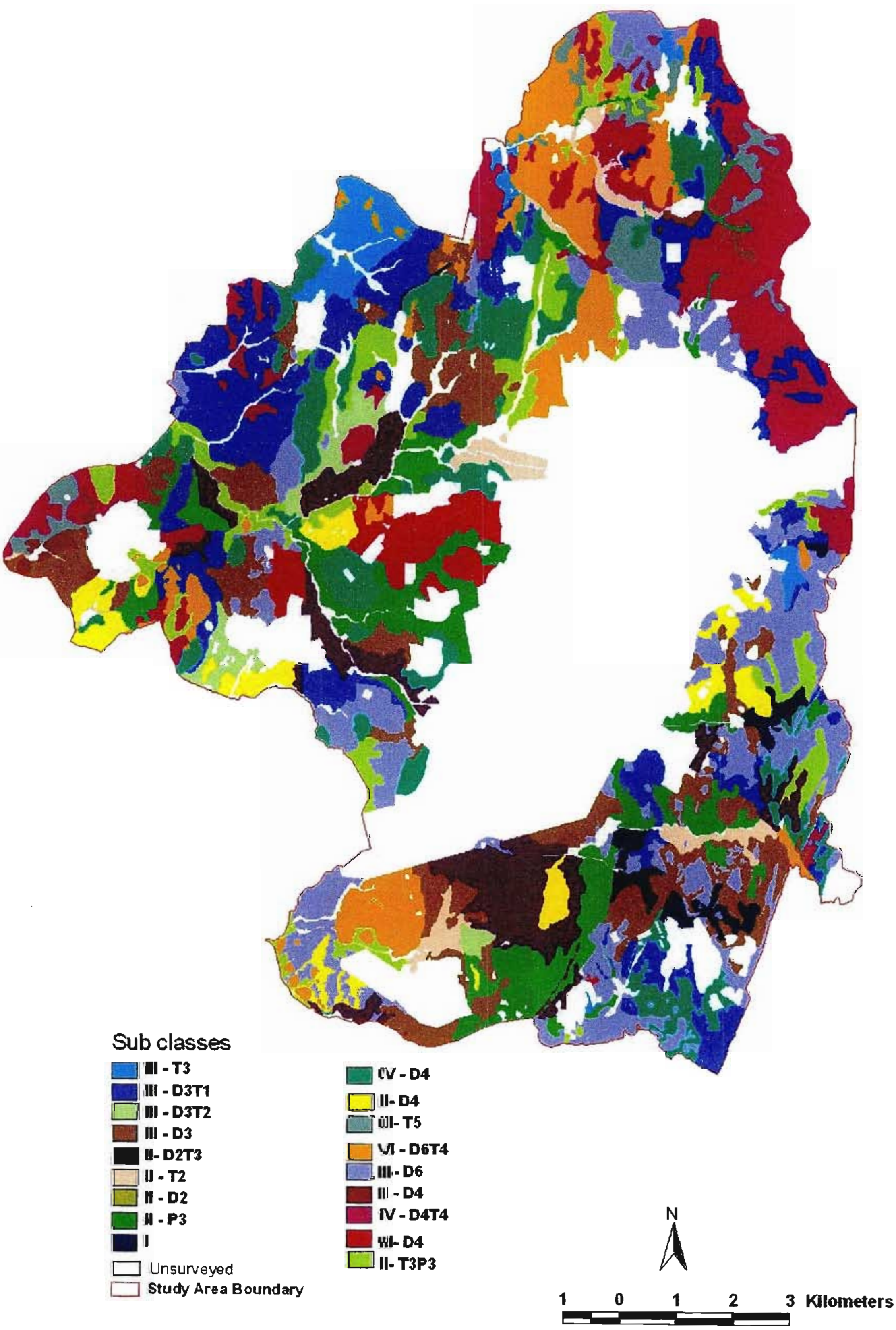

Figure 5.12 Map of Soil Capability Sub classes

5.3.1.3 Soil Capability Classes

The soil capability subclasses having the same relative degree of hazard or limitation were grouped and classified according to the prevailing potential limitations for a production of common cultivated crops. As compared among the three limitations related to soil physical properties, effective depth is dominant factor in determining the soil capability class in the study area.

Five soil capability classes were arrived at (class I to class VI). The spatial distribution and extent of each soil capability class is shown in Figure 5.13. The result indicates that class I soils are mainly found in the south of the study along the stream basins. The areal coverage of soil capability class I is 692.14 ha (6.2 percent of the total classified land). Most of the flat lands in the south and central parts and the lower valley bottoms to the east of the study area are classified as soil capability class II land. This class has an area of 1272.53 ha (11.4 percent of the study area). The extent of class III land is 3944.52 ha (35.4 Percent of the study area). Class III land is largely found in the western part of the study area. Soil capability class IV land has an area of 2893.13 ha (25.9 percent of the study area. The remaining 21 percent of the study area is classified as soil capability class VI (2354.45 ha).

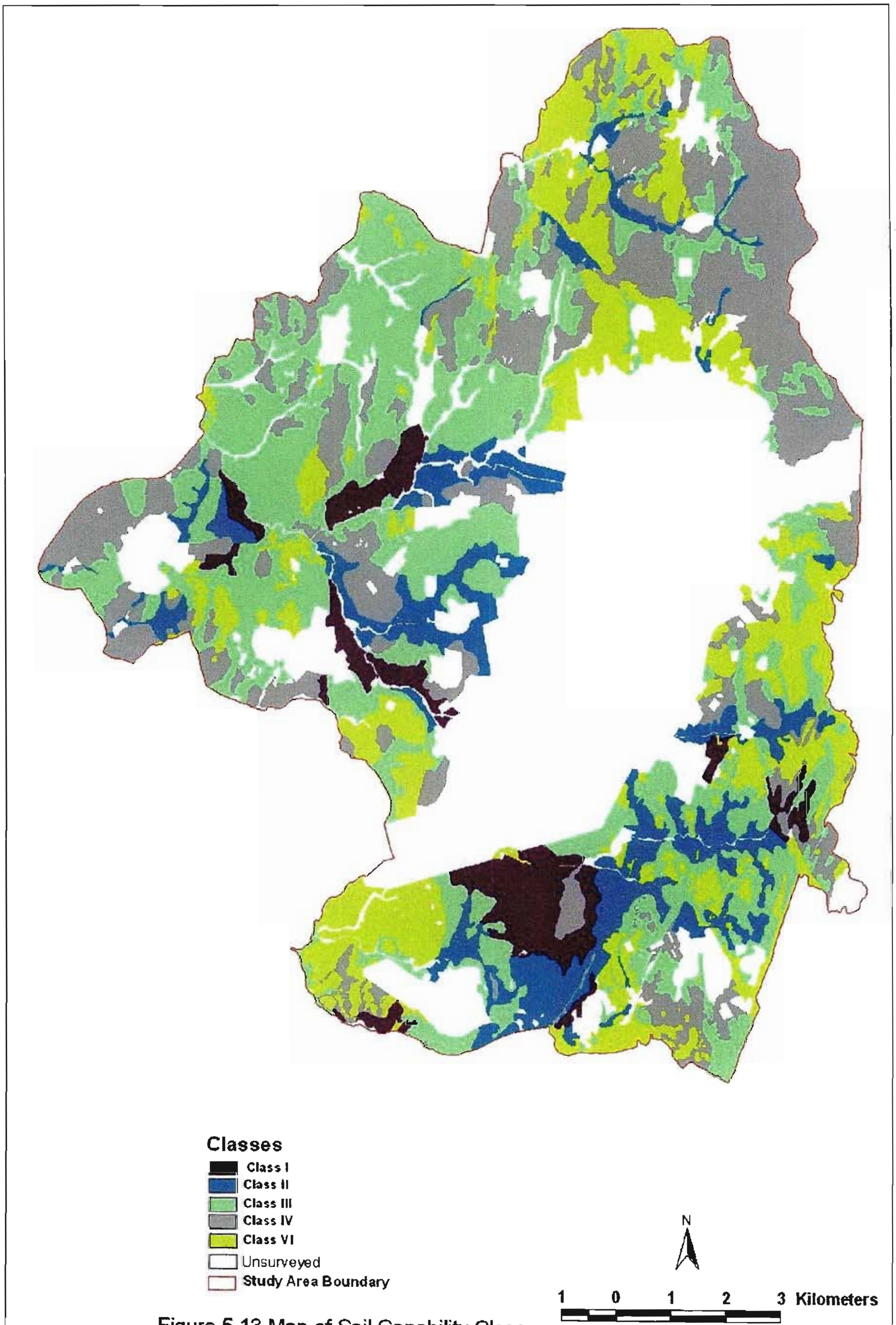

Figure 5.13 Map of Soil Capability Classes

5.3.2 Land Characteristics Categories

The land characteristics assessment in the study area was based on factors such as wetness, rockiness and/or stoniness, erosion hazard and percent slope. Limitations of these factors in relation to use, management and productivity provided the main basis for differentiating land into the respected categories. A detailed description of these categories is discussed in the following subsections. A full description of the prescribed symbols and degrees of limitations of the factor is provided in Appendix B.2.

5.3.2.1 Land Characteristics Capability Units

Soil mapping units that have a high degree of uniformity in each of the limitations were grouped to establish the land characteristics capability unit. 50 land characteristics capability units of uniform limitations were identified.

These 50 identified capability units and their geographic extent are indicated by their respective legend and shown in Figure 5.14. A full description for the symbols and degrees of limitations of the factors is presented in Appendix B.2.

The result indicates that in most of the soil units both erosion hazard and rockiness independently or in combination are the major contributing factors in designating these capability units. These capability units include one or more soil mapping units with similar agricultural potential and limitations. The initial letters of the respective limitation/s represents the limitations of the soil mapping units, which placed the land to the designated land characteristic unit. For example land characteristic unit II-W3E2R1S1 in the map of Figure 5. 14 indicates that the soil mapping unit/s in the study area has/have a land characteristic of wetness rating 3 (W3) where the land is temporally wet, erosion rating 2 (E2) moderate erosion, rockiness rating 1 (R1) free from rockiness limitation and stoniness rating 1 (S1) free to rare stoniness limitation. Land characteristic unit IV-E3W2R2S1 implies that this capability unit has erosion hazard rating 3 (E3) high and severe sheet erosion and rills, wetness rating 2 (W2) slight mottling within the top 50 cm soil depth, rockiness rating 2 (R2) which is less sufficient to cause limitation and stoniness rating 1 (S1) where stoniness cover is free or rare to cause limitation.

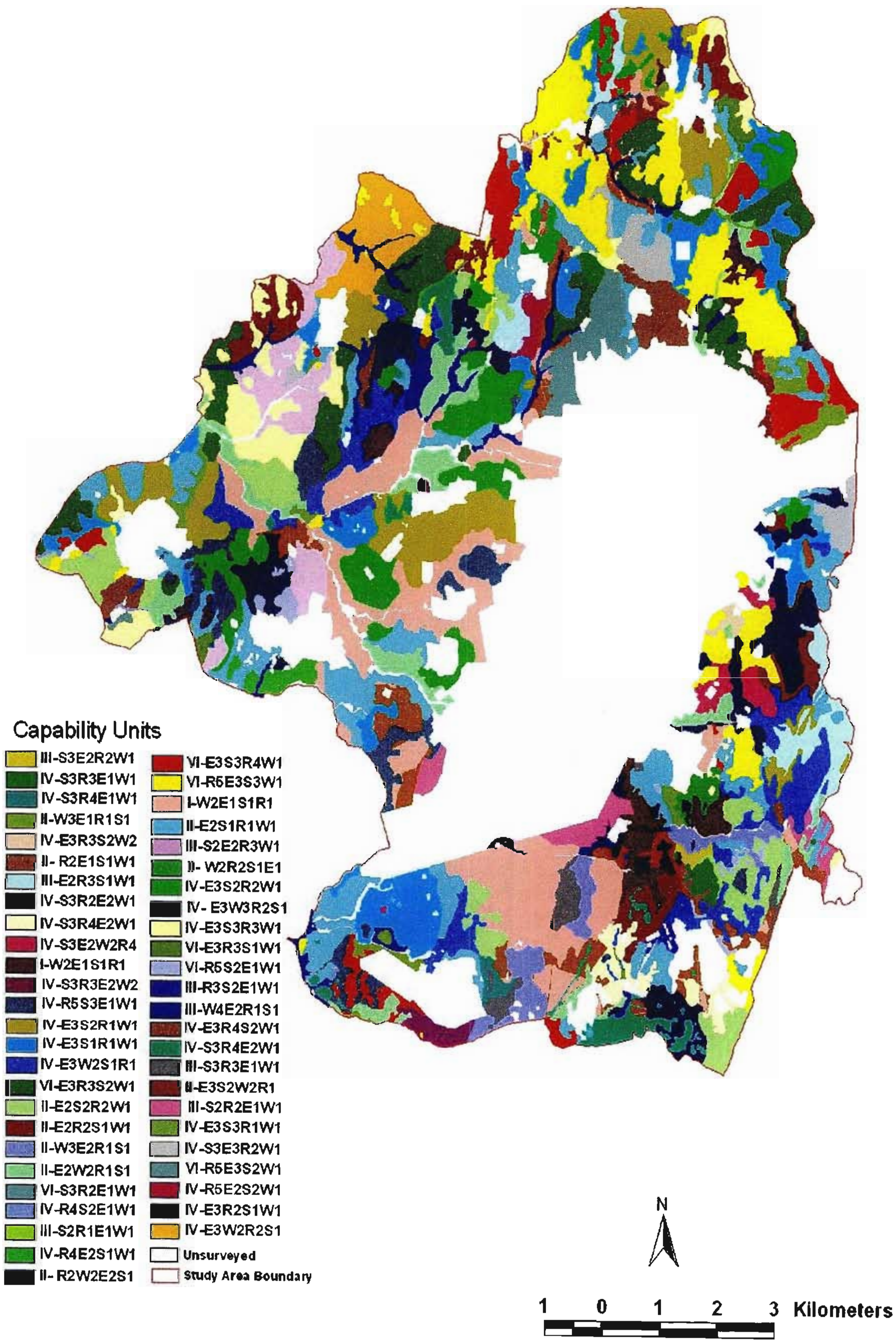

Figure 5.14 Map of Land Characteristics Capability Units

5.3.2.2 Land Characteristics Capability Subclasses

23 subclasses were arrived at. Figure 5.15 shows the spatial extent of each land characteristics capability subclasses and the dominant limitation/s that constitute the subclasses of the land characteristics in the study area. For example land characteristics capability subclass V-W4 indicates a subclass V, the letter "W" indicates that wetness is the dominant limitation. The preceding Arabic number "4" indicates the intensity of the limitation. In this case capability subclass V-W4 has a wetness rating 4 (W4) where land is seasonally wet through out the rainy season. Such capability subclass is very common in the adjacent watercourses of the northern part of the study area. However, when two of the limitations are of equal degree to affect land use; both are placed as a suffix after the respective class numeral. Hence the first letter is to indicate the type of encountered limitation where as the preceding number shows the intensity of the limitation to the use of the concerned land. For example land characteristics subclass IV-E3W3 indicates subclass IV, the letters "E" and "W" indicate that erosion and wetness respectively are dominant limitations where the preceding Arabic numbers show the rating of the limitation. This land characteristics capability subclass is found in southeastern part of the study area. Land characteristics subclass VI-R5S3 indicates subclass VI, the letters "R" and "S" indicate rockiness and stoniness respectively are dominant limitations. The Arabic numbers depict the rating of the limitation where rockiness rating 5 (R5) is very severe and stoniness rating 3 (S3) is abundant stoniness cover. This land characteristics capability subclass is dominantly found in the north and northeastern parts of the study area.

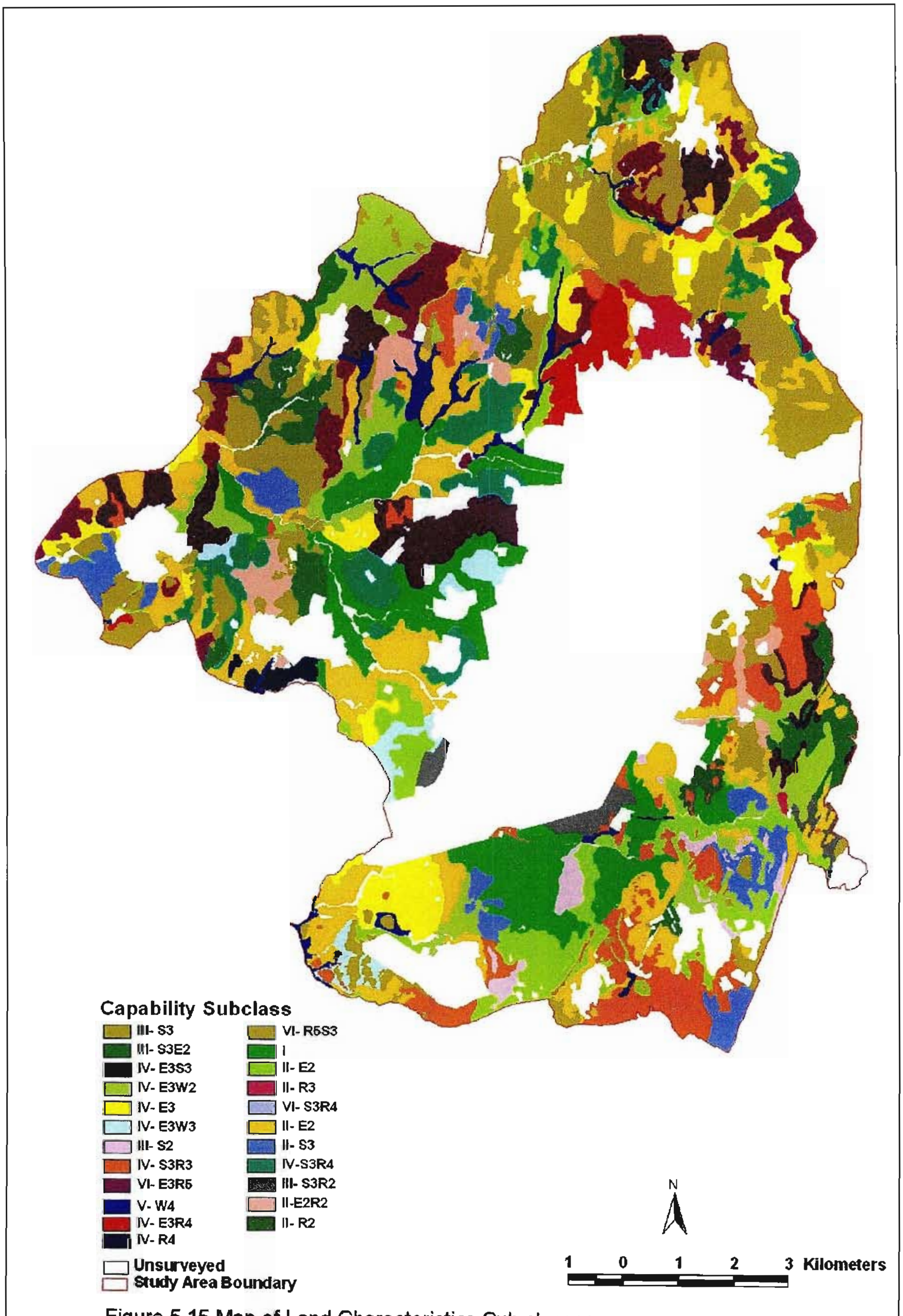

Figure 5.15 Map of Land Characteristics Sub classes

5.3.2.3 Land Characteristics Capability Classes

In determining these classes the intensity of the limitations encountered within each class was rated increasingly whilst the capability of the class was down-graded to the preceding lower class.

The subclasses that had either similar or different kinds of limitations but the same degree were designated to their respective topographic capability class. For example, the land capability subclass IVE2W2 was grouped with subclass IVE2S2 to produce land characteristic class IV hence, as both subclasses had the same degree of limitation.

The assessment resulted in seven land characteristics capability classes (class I through class VII). In determine the topographic capability classes these seven land characteristics classes were examined with the six independently assessed slope classes. The slope classes showed major effects in changing the land characteristics capability classes. Increases in percent slope resulted in most of the former land characteristics classes being down-graded to their preceding lower classes (e.g. some of the former land characteristics class IV in the north and north eastern parts of the study area were down-graded to class VI). The results indicate that both slope and erosion hazard were very much related to affect the capability class of the land as observed in the gentle to strongly slopping areas in the study area. Hence, the steeper slopes in the north and southeast of the study area have severe erosion hazard. The geographical distribution and extent of these classes is shown in Figure 5.16.

41.1 percent of the study area (4638.08 ha) are classified as land characteristics capability class IV. This class is found in the northwestern, east and northwest of the study area. Land characteristics capability class II (2543.47 ha) covers 22.6 percent of the total area. Land characteristics capability class I and III have areas of 1008.8 ha (8.9 percent) and 1028.87 ha (9.1 percent) respectively. Of the total area of the study area 1770 ha (15.7 percent) and 63.44 ha (0.6 percent) are classified as classes VI and VII respectively. A small area of 221.46 ha (2 percent) is permanently wet throughout the rainy season and is classified as class V.

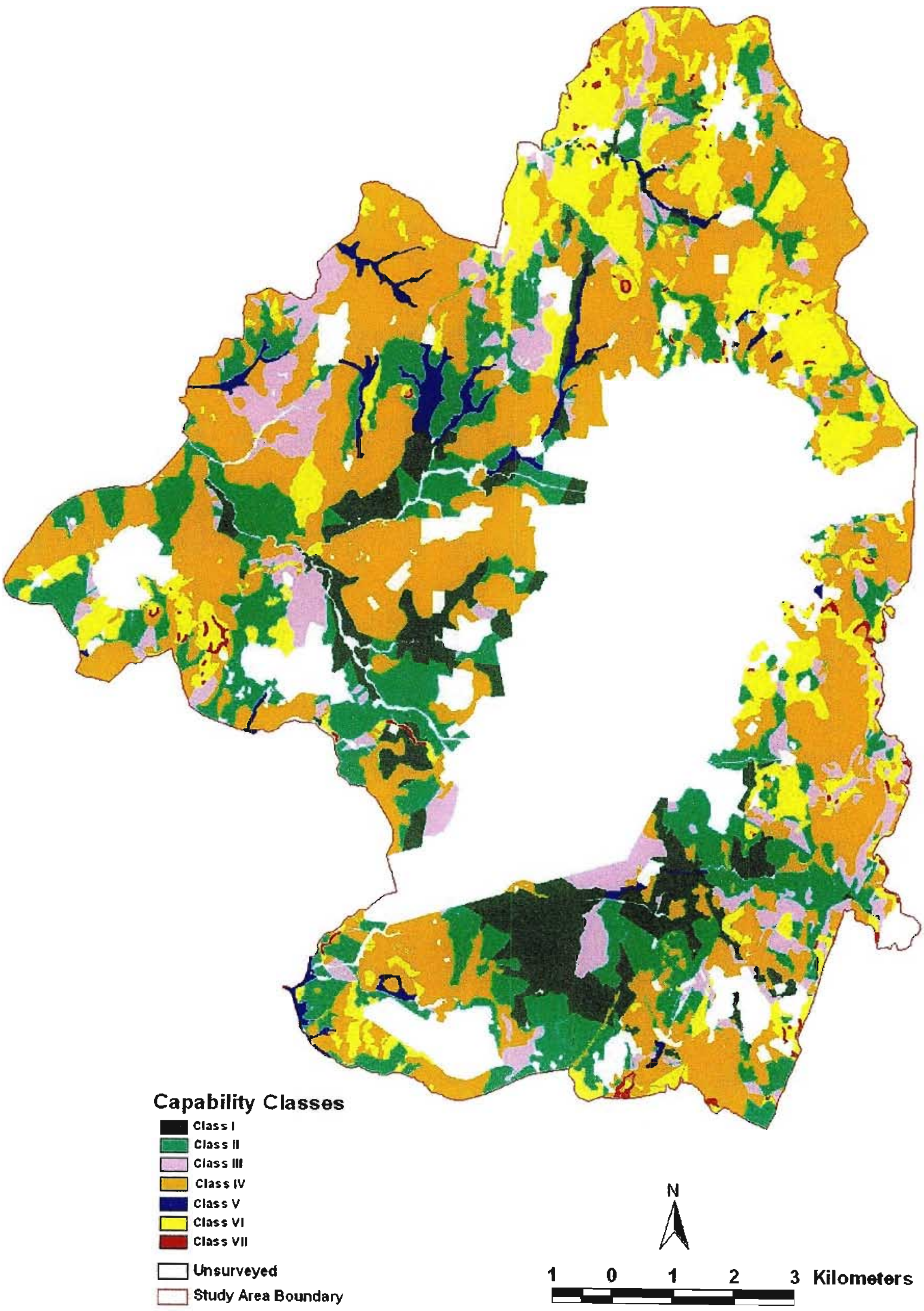

Figure 5.16 Map of Land Characteristics Capability Classes

5.3.3 Land Capability Classes

Figure 5.17 illustrates the soil and land characteristics parameters used in the land capability classification and the resulting land capability classes. Soil characteristics such as effective soil depth, percentage clay and permeability of the soil mapping units resulted several soil capability units and subclasses as discussed in subsections 5.3.1.1 and 5.3.1.2 respectively. Five soil capability classes arrived at class I to Class VI from the land capability subclasses as discussed in subsection 5.3.1.3. The assessment of the land characteristics limitations revealed seven land characteristics capability classes through land characteristics capability units and subclasses as discussed in subsections 5.3.2.1, 5.3.2.2 and 5.3.2.3. Eventually the assessment of the land capability classes was based on these five soil capability classes and seven land characteristics capability classes.

Seven land capability classes were arrived at (classes I to VII). The geographical extent of each land capability class is shown in Figure 5.18. The result indicates that out of the land capability classes, class III land is the dominant class in the study area. This class alone covers 4149.43 ha (36.9 percent) of the total areas of the study area. The largest portion of this class is found in the central, western and southeastern parts of the study area. Class IV and class VI land are the largest classes identified in the study area next to class III. These classes have an area of 2652.08 ha (23.6 percent) and 2594.87 ha (23.1 percent) of the study area respectively. The largest portion of these classes is found in the north and eastern parts of the study area. Class II land in the study area occupy 1158.11 ha (10.3 percent) of the total area and the largest portion of this class is found in the southern and central parts of the study area. Class I land is mainly found in the flat lands of the southern and adjacent stream basins of the central parts of the study area. As compared to class II and III lands class I land is very limited only 407.85 ha (3.6 percent). The largest portion of this class is found in the southern part of the study area. Class V land in the study area is confined to the flooded watercourses. This class covers 221.53 ha (2 percent) of the study area. This class is mainly found in the central part of the study area. Class VII land in the study area is very limited only 57.55 ha (0.5 percent) of the study area is classified as class VII land. This class is found in the northern, eastern, southern and western corners of the study area.

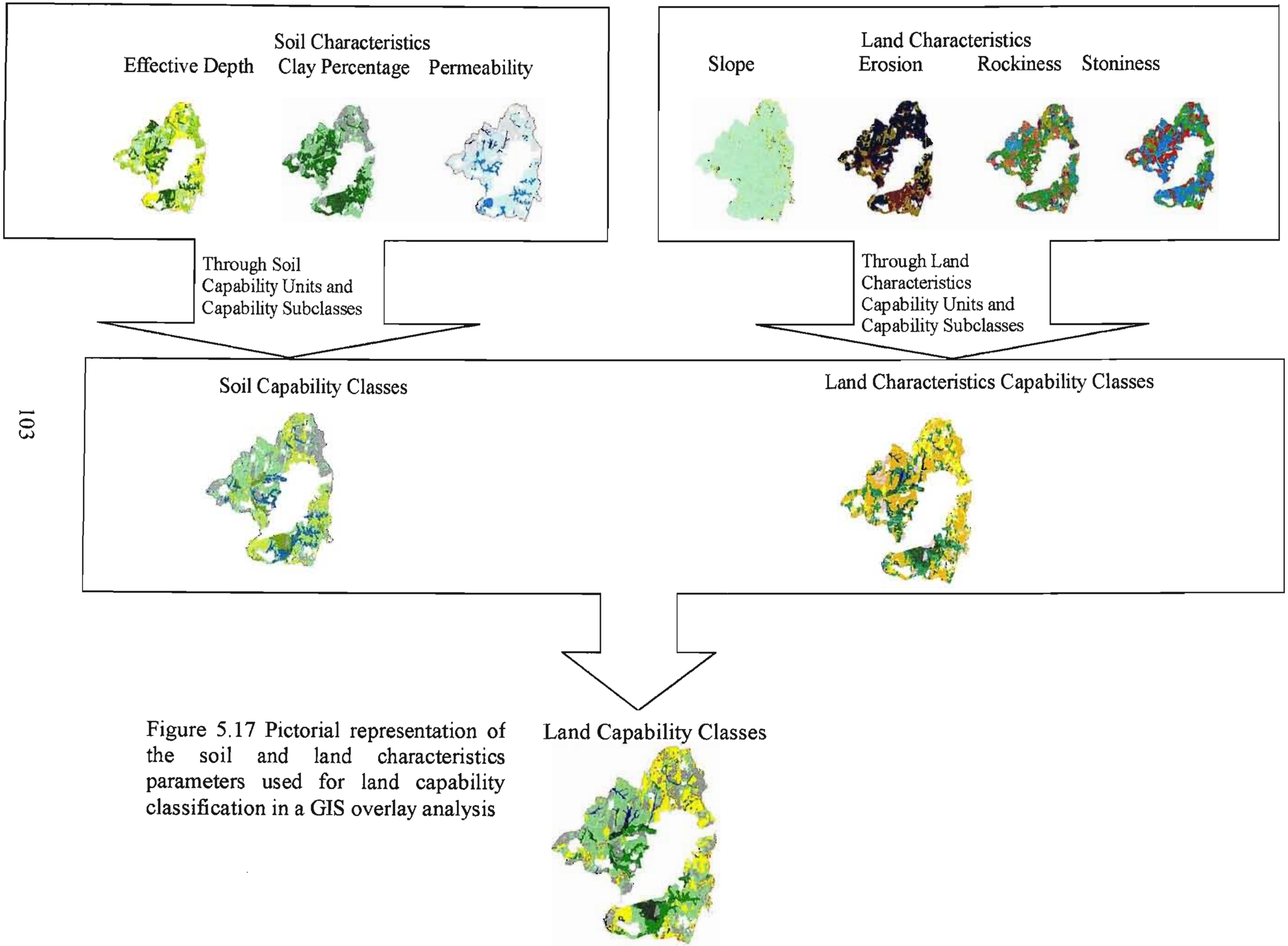

Figure 5.17 Pictorial representation of the soil and land characteristics parameters used for land capability classification in a GIS overlay analysis

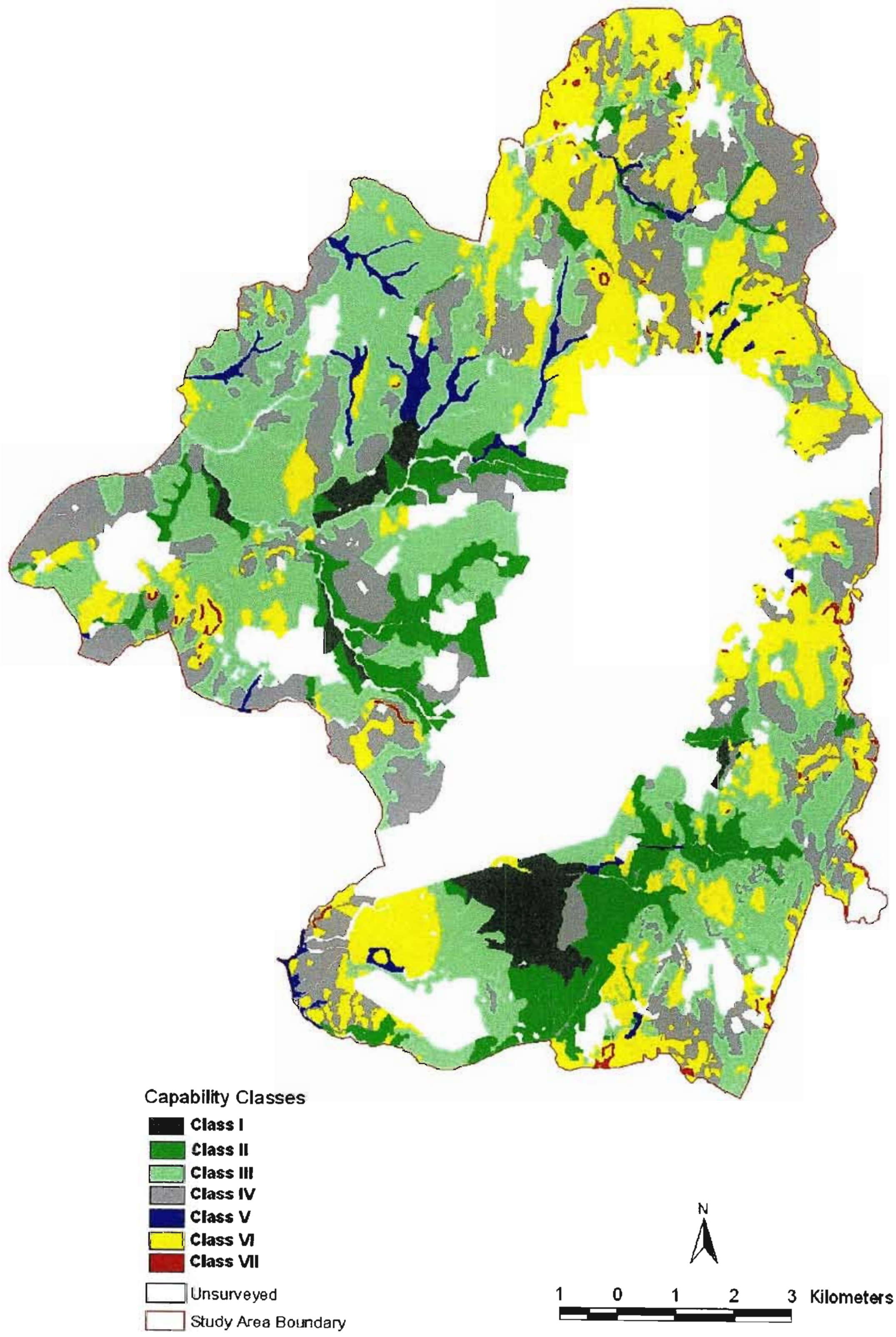

Figure 5.18 Map of Land Capability Classes

5.3.4 Climatic Capability Classes

Figure 5.19 shows pictorial representation of the climatic parameters used in the climatic capability classification and the resulting capability classes. The results of the climatic capability classes arrived at three classes, class III to V. The spatial distribution of these classes in the study area is presented in Figure 5.20.

Climatic capability class III has a mean monthly precipitation greater than one third of the monthly potential evapotranspiration during the growing season. Although the values for the ratio of MAP to PET is between 0.3 and 0.34 the mean and mean annual minimum temperatures for this class are between 16.9°C and 17°C and greater than 7°C respectively. The mean annual maximum temperature for this class range between 24°C and 25°C. The cumulative heat units in this capability class are larger than 1340 degree days for the growing season. This capability class extends from the center to south and south west of the study area.

For the climatic capability class IV although the average monthly precipitation of the growing season exceeds one third of potential evapotranispiration the values for the ratio of MAP to PET are less than 0.3.The mean annual temperature for this class is between 16°C and 16.9°C and the mean annual minimum temperature is between 6.5°C and 7C. The mean annual maximum temperature for this class range between 24°C and 25°C. The cumulative heat units for this capability class range between 1320 and 1340 degree days. Most of the lands in the western parts of the study area are classified as climatic capability class IV.

Although the average monthly precipitation for climatic capability class V is not different from the other classes both mean and mean annual minimum temperatures with the cumulative heat units are restrictive to limit the choices of the growing crops. The mean monthly temperature for this class V is less than 16°C and even the mean annual minimum temperatures are less than 6.5 °C. Mean annual maximum temperature for this class is between 23°C and 24 °C.

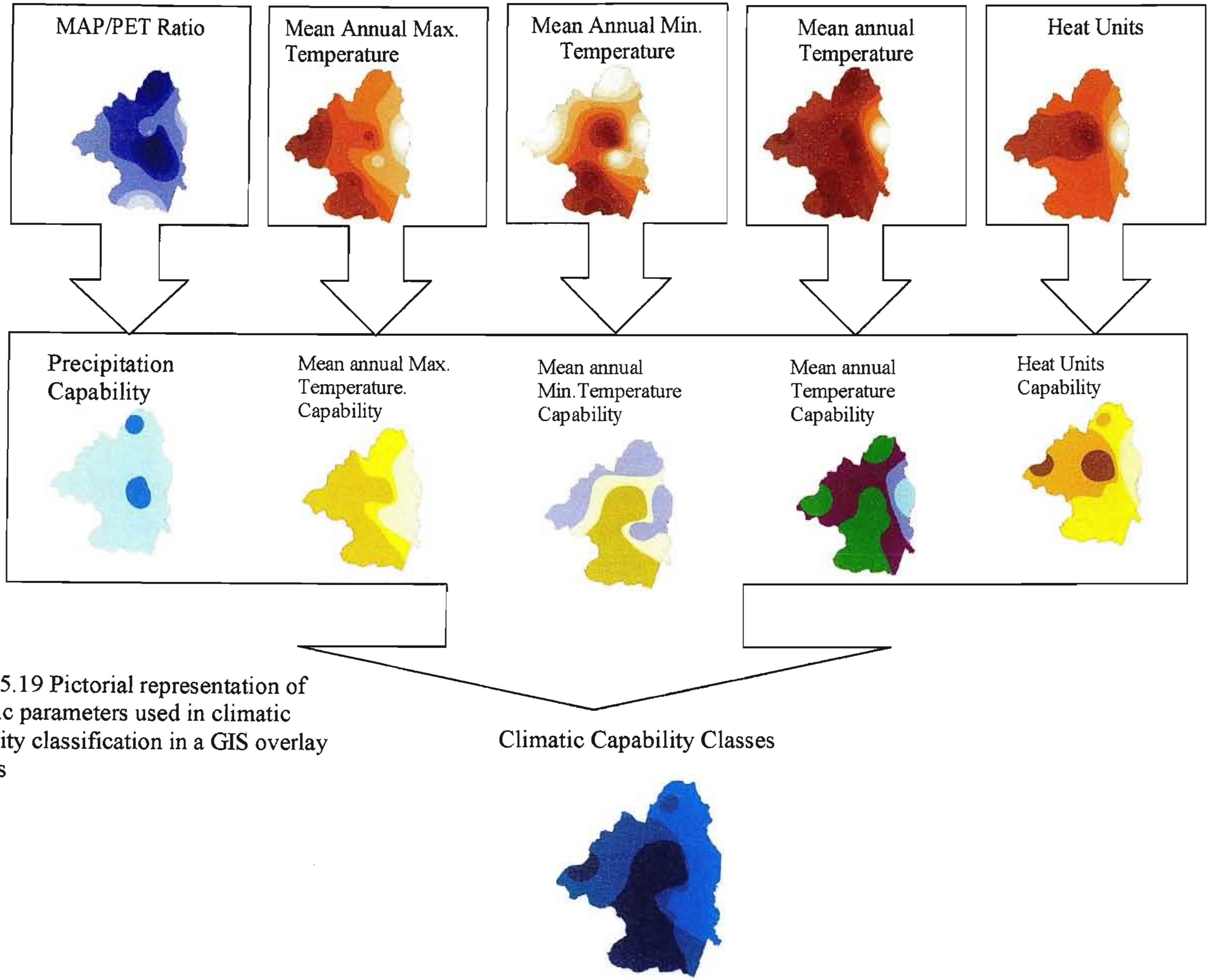

Figure 5.19 Pictorial representation of Climatic parameters used in climatic capability classification in a GIS overlay analysis

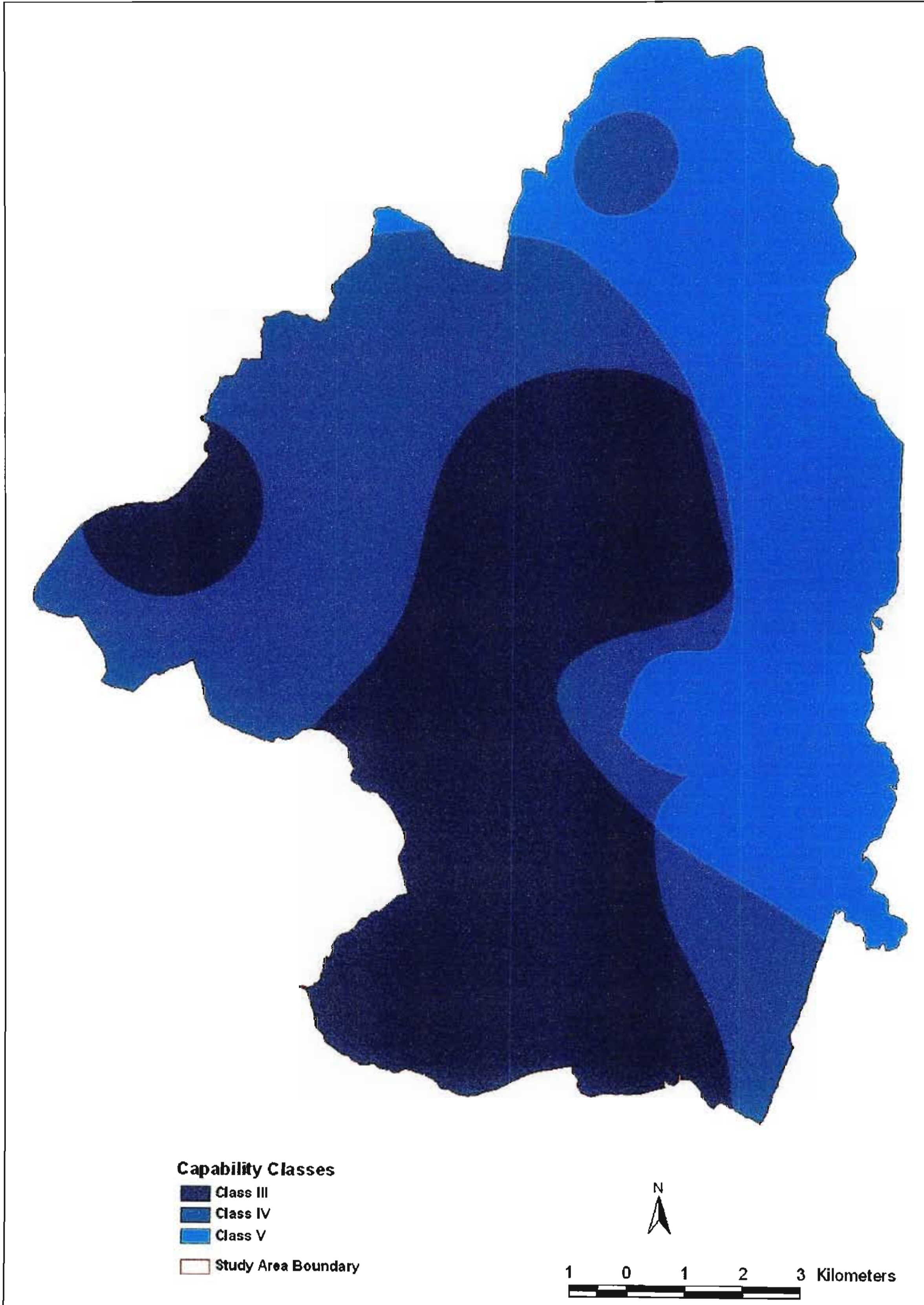

Figure 5.20 Map of Climatic Capability Classes

The amount of heat units that accumulate during the growing period is less than 1320 degree days, which are between 1277, and 1320-degree days. This climatic capability class is limited to the eastern parts of the study area extending in a north-south direction of the study area.

5.3.5 Final Land Capability Classes

In determining the final land capability classes, the role of climatic capability need to be considered either to up-grade or down-grade the capability class of the land in question (Scotney *et al*, 1991). Although three climatic capabilities were arrived at none of them had any serious limitation as to warrant up-grading or down-grading of any of the land capability classes. Therefore, determination of the final land capability classes in the study area was based on the soil and land capability classes. Thus, the climatic capability classes have no influence on the final land capability classes.

Figure 5.21 shows pictorial representation of the climatic and land capability classes used in the final land capability classification and the resulting final land capability classes and orders in the study area. The results of the classification revealed seven final land capability classes, class I to class VII. Figure 5.22 illustrates the geographical distribution and extent of each final land capability class in the study area. Class I and II lands are very limited and together account for 13.9 percent of the study area. Most of the land in the study area falls under class III and covers 36.9 percent of the area. Classes IV and VI account for 23.6 and 23 percent coverage respectively. A small portion of the study area (2 percent) is covered by class V, whereas class VII covers only 0.5 percent.

Land in class I have no limitations that restrict their use. These lands in the study area are suitable to a wide range of use and may be used safely for cultivated crops. The lands in class I are not subjected to any damaging flood. They are productive and suited to intensive cropping. In class II land some limitations of the soil and land characteristics are encountered to reduce the choices of the growing crops. Lands in class II, therefore, require moderate conservation practices. However, limitations in this class II land are few and the practices are easy to apply. Class III land has relatively severe limitations that

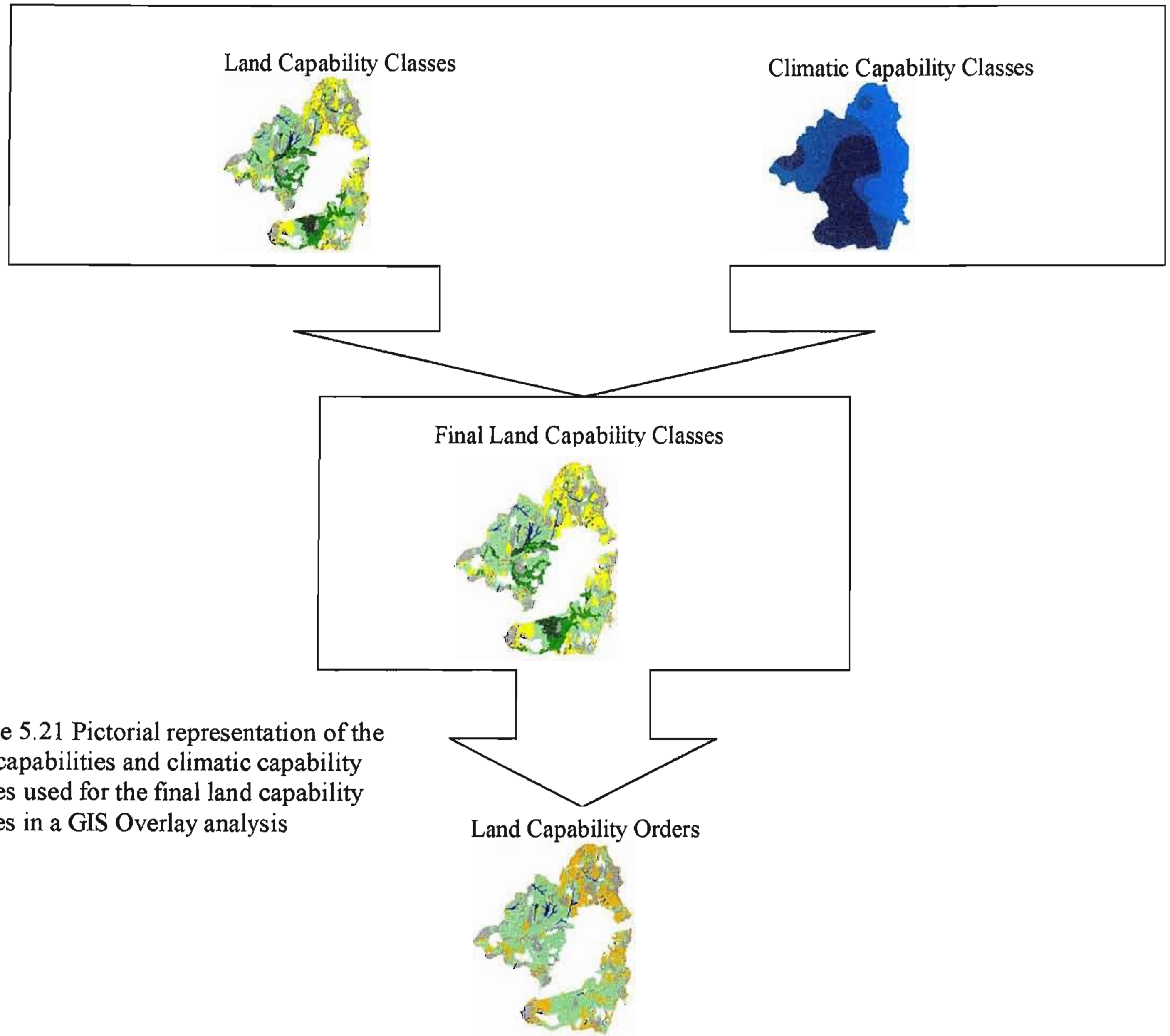

Figure 5.21 Pictorial representation of the land capabilities and climatic capability classes used for the final land capability classes in a GIS Overlay analysis

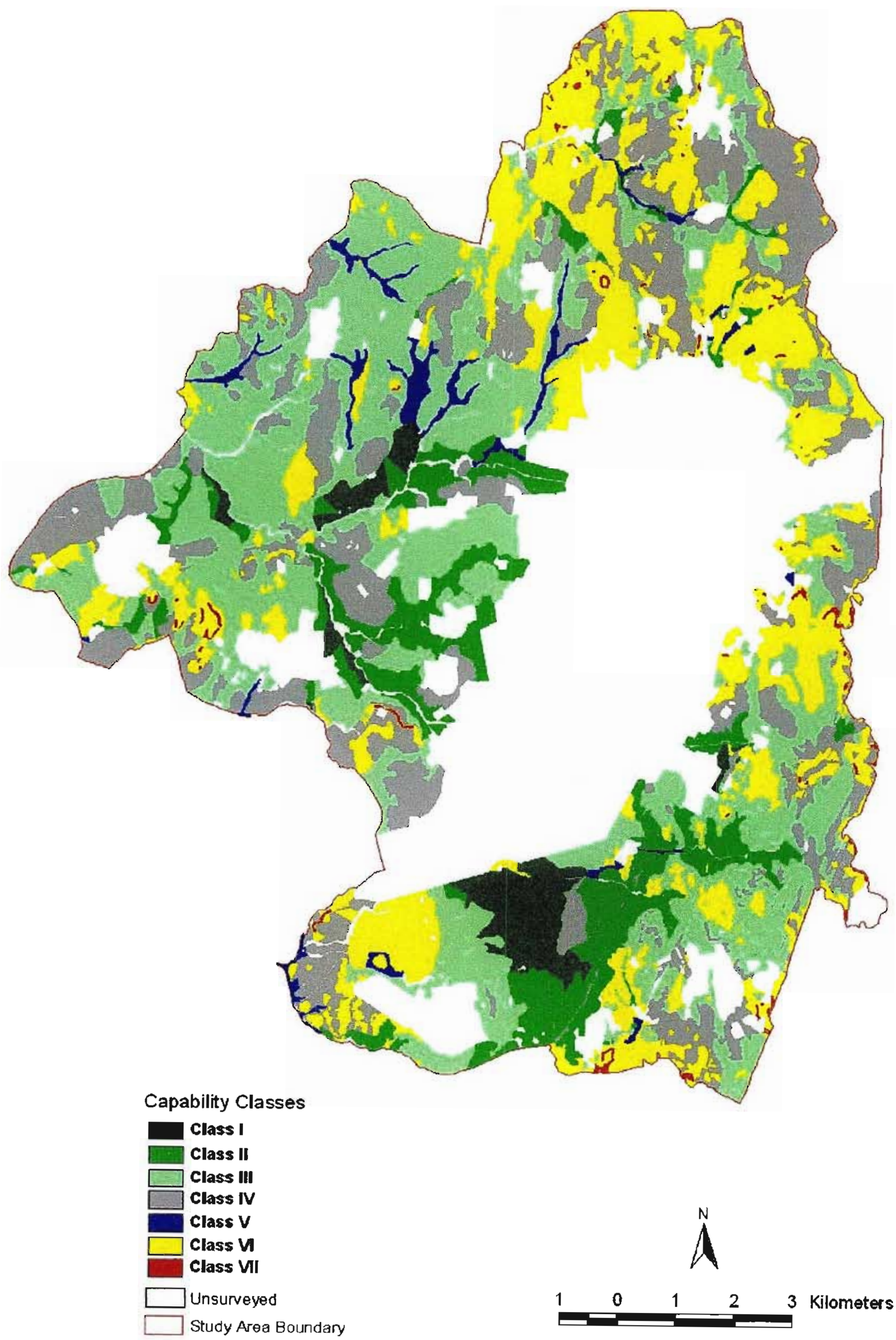

Figure 5.22 Map of Final Land Capability Classes

reduce the growing crops. Land in class III requires special conservation practices as compared to class II land. Therefore, lands in class III have more restrictions than those in class II when used for cultivated crops. The limitations in this class may result from the effects of one or more of the soil and land Characteristics. Class IV land has very severe limitations that restrict the choice of the growing crops. The restrictions in use of the land in class IV are greater than for those in class III. This class IV land requires very careful management and continuous cropping is very difficult. Therefore, land in this class IV requires rest and fallowing when used for crop cultivation. Hence, the harvest produced may be low in relation to inputs used.

Class V land in the study area has a limitation of wetness that restrict the land for any crop production. This land is frequently flooded during the rainy season and is permanently wet. As a result cultivation of the common crops is not feasible. However, such land in the study area can be safely used for pasture. Class VI land has very severe limitations of both soil and land characteristics. Limitations such as shallow soil effective depth, steep slope, severe sheet erosion and rockiness are very common. This land is generally unsuitable to cultivation and its use is largely limited to pasture or range and forestation. Therefore, this land requires special conservation measures. Apart to grazing this land is suitable for non-agricultural development projects. Class VII land is characterized by very shallow soil effective depth and steeper slopes. This land in the study area is even less useful for grazing. However, it is suitable for any conservation measures and non-agricultural development projects.

A detailed description of each of the final land capability class is provided in Appendix E. Table 5.1 shows the extent of the final land capability classes in hectares.

Table 5.1: Final Land capability classes and their extent in hectares.

Final Land Capability Class	Area (ha)	Percentage of the total area
I	407.85	3.6
II	1158.11	10.3
III	4149.43	36.9
IV	2652.08	23.6
V	221.53	2
VI	2594.87	23.1
VII	57.55	0.5
Total	11241.42	100

5.3.6 Land Capability Orders

In reality land capability classes are the highest categories in land capability classification. However, grouping these capability classes into capability orders can simplify and satisfy the needs of planners (Scotney *et al*, 1991). The land capability classes in the study area were grouped into four land capability orders. In deed, out of the seven land capability classes, only the first four classes (class I, II, III, and IV) are considered as arable land for crop cultivation (Klingbiel and Montgomery, 1961; Scotney, 1970; Ivy, 1977; Scotney *et al*, 1991; Guy and Smith, 2002).

However, given the objective of the study and the local conditions in the study area, the assessment arrived at four land capability orders at (high to moderate potential arable to non-arable lands). The geographical extent of each land capability order is presented in Figure 5.23.

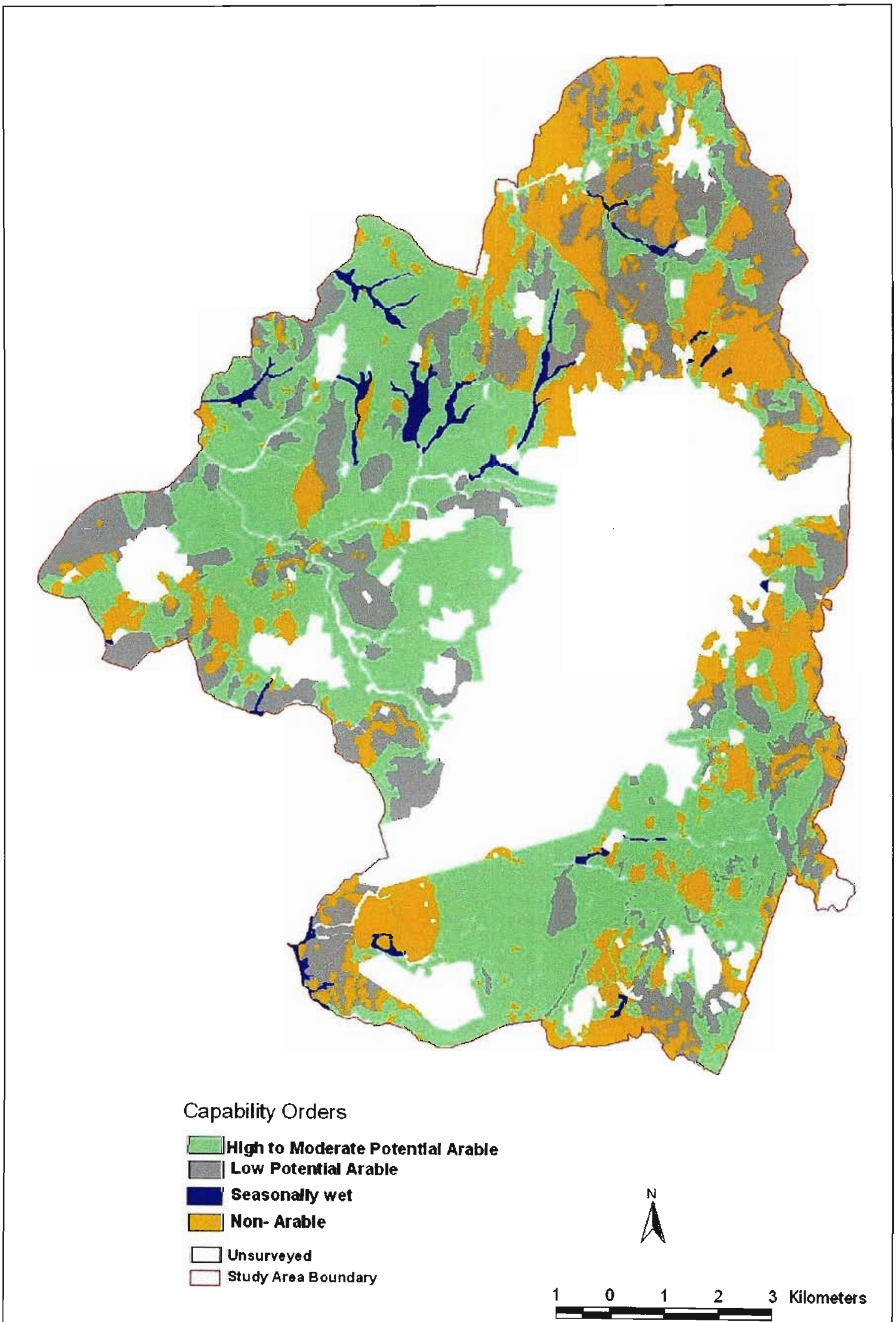

Figure 5.23 Map of Land Capability Orders

Out of the seven capability classes in the study area, the first three classes I, II and III are considered as arable land with "high to moderate" potential. This land capability order covers 5715.39 ha (50.8 percent) of the study area. This capability order is mainly found in the south and central parts of the study area. Land capability class IV, although arable with severe limitation, is classified as of "low potential". This capability order has an area of 2652 ha (23.6 percent) of the study area. This land is largely found in the northeastern, north, west and southwestern parts of the study area.

However, classes VI and VII are grouped as non-arable land. These two classes extend over 2652.42 ha (23.6 percent) and are widely distributed in north and east of the study area. Nonetheless, 221.53 ha (2 percent) of the land in the study area is classified as "seasonally wet land". The largest portion of this capability orders is located in the central part of the study area. Table 5.2 below indicates the area in hectare for the capability orders in the study area.

The high to moderate potential arable lands in the study area have a good agricultural potential when used for crop cultivation. These lands can be used safely for a wider range of crops with some conservation practices. Low potential arable lands are relatively marginal productive when used for crop cultivation. These lands require a careful management and higher input. Hence, the use of fallow is typical conservation measure in such low potential arable lands. In such low potential arable lands in the study area the choice of growing crops is very limited. Seasonally wetlands are restricted for crop cultivation as a result of the encountered permanent wetness limitations. These lands have a good potential for pasture and wetland habitat conservation. The non-arable lands are not suitable for any agricultural uses. Their use to agriculture is limited as a result of the permanent limitations of both soil and land characteristics. Hence, these lands are useful for non-agricultural development projects. Table 5.2 indicates the extent of the land capability orders in hectare in the study area.

Table 5.2: Land capability orders and their extent in hectares.

Capability orders	Land Capability class	Area (ha)	Percentage out of the total area
High to moderate potential Arable	I, II and III	5715.39	50.8
Low potential Arabl	IV	2652.08	23.6
Non-Arable	VI and VII	2652.42	23.6
Seasonally Wetland	V	221.53	2
Total	----	11421.42	100

5.4 Summary

Soils of the study area are widely related to the geological set-up and past erosion regimes. As a result the physical characteristics of soils show a wide range of variation where deep and moderately deep soils are confined to the stream basins and the flat lands respectively. Soils of the steeper slopes and the coarser textured soils in flat lands are well drained. However, in most of the flat lands adjacent to the stream basins the soils are poorly to moderately drained.

Soil characteristics such as soil effective depth, percentage clay and soil permeability are the most important factors that determine the soil capability classes in the study area. Soil effective depth is a prominent factor that determines the soil capability classes in the study area. Hence in most of the flat land where permeability and percent clay are suitable capability classes were down-graded as a result of shallower effective soil depth. Five soil capability classes were identified in the study area.

Land characteristics such as erosion hazard, slope, wetness, rockiness and stoniness are other important factors that determine the capability class of a land. Based on these factors seven land characteristics capability classes have been identified. Theses land characteristics capability classes were used in combination with the soil capability classes to produce the land capability classes.

Climatic capability assessment was based on the climatic variables such as precipitation, evapotranspiration, temperatures and heat units. The results of the assessment revealed three climatic capability classes, class I to III. These climatic capability classes were compared with the land capability classes to arrive at the final land capability classes. However, the comparison revealed none of the climatic capability class had a serious limitation to influence the final land capability classes. Hence, the final capability classes in the study area were identified based on both soil and land characteristics capability classes.

Four land capability orders arrived at ranging from "high to moderate potential" arable land to non-arable land. Grouping of these orders was based on the potential productivity of the classes in the final land capability classes of the study area. Classes I to III were designated as "high to moderate potential" arable land. Class IV lands in the study area were grouped as "low potential" arable land. Class V land was identified as "seasonal wetland". However, Classes VI and VII were placed as non-arable land capability order.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study emerges with findings that could help solve the current problems of misuse of land resources in the study area. In response to the current problem of land allocation for urbanization and other development projects the study was aimed at preparing a land capability map for the study area through proper assessment and survey of the land resources. The study was successful in achieving this

The review made on relevant methods and related work supported the foundation of the methodology applied in the land resources assessment for land capability classification in the study area. The USDA method for land capability classification developed by Klingebiel and Montgomery (1961) and the classification system used in Republic of South Africa as revised by Scotney, *et al* (1991) were adopted with some modifications to meet the local conditions in Eritrea and the objectives of the study. The methodological procedures, which initially recognize the identification of the existing, land resources and incorporate a thorough study of their status and recommend a detailed soil and land characteristics survey, facilitated the assessment of the land resources in the study area.

The soil survey employed in this study identified a total of five soil groups and eight soil subgroups in the study area. The profile description made by examining and describing the defined diagnostic horizons of the exposed soil profile provided the base information that was used as criteria to identify the capability class of the land in the study area. Assessment of the soil characteristics showed that the physical and chemical properties of soils in the study area are restrictive in the capability of the land. Effective soil depth is a major determining and limiting factor. In most of the flatlands where slope is suitable the capability of this land was down-graded as a result of the effective soil depth. Although, the clay to clay loam soils in the study area have a good agricultural potential in the south of the study area the excessively stored moisture of the clayey soils that have been identified as less productive, permeability has been found as serious problem in restricting the choice of crops grown in this area. Soil organic matter in all types of the soils in the study area is generally very low; only about 35 percent of the total area has sufficient organic matter as per the FAO (1990) organic matter rating.

The assessments of the characteristics of the land indicate that most of the sampled profiles have no problem of wetness throughout their effective depths. However, the problem of wetness in the study area is more restricted to areas of the heavy textured clay soils adjacent to the watercourses, which are permanently wet throughout the rainy season and yet are wet at a depth of 15 cm in the dry season. These areas have been identified as seasonal wetlands in the study area.

The impact of surface rockiness and stoniness is a serious problem in the north and southeast of the study area. This limitation is highly magnified particularly in areas of shallow soils where the rocky surface and abundant stone covers are serious problems that limit the use of the land in most of the east, northeast, west and southeast of the study area.

Erosion hazard and slope characteristics in the study area showed an interdependent effect on the capability class. In most of the intensively cultivated flat lands severe sheet erosion and rills are observed due to bad farming practices. The qualitative observable erosion status combined with the quantitative results of the potential erodibility based on soil texture and organic matter was more reliable in reflecting the erosion hazard status in the study area.

Although moisture stress occurs uniformly throughout the study area, temperature, particularly the mean monthly minimum, in the study area has shown a high degree of variation within the study area due to the effects of the cold winds in winter from the sea to the adjacent higher ground of the study area. The accumulated heat units (degree days) during the growing period in the study area showed a spatial variation that support a range of crops throughout the study area.

The IDW interpolation technique is suitable, but it has drawbacks showed more of generalization to the case of the slope classes and the effect of clustering to the spatial distribution for most of the climatic variable maps.

Although three climatic capability classes were identified and compared with the land capability classes none of these climatic capability classes were warrant to up-grade or down-grade the final land capability classes. The land capability classification has, therefore, determined seven final land capability classes. Of which class III land is 4149.43 ha (36.9 percent) of the study area followed by class IV and VI. These classes are 2652.08 ha (23.6 percent) and 2594.87 ha (23.1 percent) of the study area respectively. However, class I land in the study area is very limited.

Grouping of these classes has produced four land capability orders in the study area. Classes I, II and III are combined as "high potential" land capability order. Class IV lands are identified as "low potential" land capability order. However, class V land is designated as "seasonal wetland" capability order. The rest classes VI and VII are combined as non-arable land capability order. The "high potential" land capability order in the study area covers 50.8 percent of the total areas in the study area. Low potential and non-arable land both account for 47.2 percent in the study area. The remaining (2 percent) of the study area is identified as seasonally wetland.

6.2 Recommendations

As agriculture is the mainstay of the community in the study area, the following recommendations are suggested for securing a sustainable and healthy environment in the study area.

The impact of human settlement on the available land suitable for agriculture and its consequences on food security and environmental sustainability have become a serious problem in recent years (Dunphy, 2000). The sustainable uses of land resources need a considerable assessment of the physical limitations and appropriate decisions on the best way of using the land. Choosing the best way to use the land, based on the sustained capacity of the land, is a fundamental objective of land capability classification. This study assessed the physical limitations of the land to identify the potential sustained capacity of the land in the study area of Asmara city environs. The assessment revealed four land capability orders on which a sound and appropriate land use recommendation could be made.

In response to the above and in pursuit of the objective of the assessment and arrest the negative impact of urbanization in the study area, and improve on environmental sustainability, it is recommended that the identified high to moderately potential land (Classes I, II and III land) shown in (Figure 5. 22) should be protected from non-agricultural development projects and used for agricultural purposes.

Although urbanization is a competing with agricultural land use, and the prime arable land in the study area is limited as compared to the size of the community in the study area as described in chapter three, the land capability class IV (marginally productive land) should also be reserved for agricultural uses with careful management. Otherwise, to secure efficient use of land this land should only be released for non-agricultural development when urbanization in the study area extends over all non-arable land.

Land, which is classified, as class VII which is about 65 ha is not suitable for agricultural development and can be immediately designated for non-agricultural development activities. Although Class VI land which is about 2652 ha (23 percent) of the total area is currently used as grazing land, it can be designated for urbanization and other non agricultural development projects with a careful management after or in combination with class VII land.

Land which is classified as class V (seasonally wetland) need to be protected from any human interventions and with a proper management and reclamations it can be used for the growth of valuable grass and/or used for grazing in the dry season. However, these seasonal wetlands are currently highly degraded as a result of the attitudes of the community towards wetland. Otherwise when these wetlands are properly managed and protected they have a good potential as fodder sources and wet land habitat that must be conserved.

Although livestock production is one of the main sources of income for the community in the study area, grazing land is essentially needed. However, the continuous expansion of the city into the grazing lands will obviously put the livestock population in the area at risk. Therefore, the introduction of poultry and dairy farming can solve the problem of land use competition in this area. The expansions of Asmara into pre-urban areas will increasingly swallowing the arable land and result shortages of agricultural land. At this juncture prioritizing development activities that can benefit the rural community to enable generating income and employment opportunity could prevail a relief on the heavily competition of the limited arable land in the study area.

Agriculture in the study area is mainly of subsistence type. Therefore, advisory and support services should be provided to support farmers to shift to sustainable intensive commercial production. This will be required in improving the traditional farming systems and shifting from the cereal production to intensified cultivation of vegetables and other horticultural crops. These intensified farming systems allow year-round production and can be practiced on small plots, making efficient use of the limited land resource in the study area. Moreover, the proximity to urban and peri-urban areas allows farmers to benefit from the urban market.

Furthermore, allocating fertile land for non-agricultural use, Kushet village (Figure1.1) is a case in point, is a loss of arable land that could have been used for food production. It is advisable that planners and land developers recognize and be able to integrate urban agriculture with their general development plans and designing development plans for integrated urban and rural development. Agriculture close to urban areas provides fresh food to the urban and peri-urban populations creates a green environment in the area and generates income and employment to the community in the study area (UNDP, 1996).

As land capability classes does not depict how suitable a particular land for a particular crop is, land suitability assessment is essentially recommended based on the land capability classes. Therefore, further studies such as suitability assessment and socio-economic study are required to implement land use planning as the capability classification is only the starting point and provides base information for a detailed land use planning.

This study was aimed to classify the sustained capability of the land in the study area and has successfully achieved its objectives. The results of this study may be used as base information by decision makers and as a guide to planners and land developers in directing the land resource to various development projects in the study area. Therefore, the results of this classification can be used in two ways.

First, areas classified with good agricultural potential can be reserved for agricultural production to meet the future demand for food and improving the efficiency of farming of all possible land falling in capability classes I, II and III.

Second, in the field of survey for town planning, the results can be used as a guide during town expansion and allocation of any other non agricultural development projects to areas of non arable and/or less valuable or marginally productive land. In this case a policy of restriction or reservation of prime arable lands could be adopted and development would have to be directed to non-arable areas.

Furthermore, the methodological approaches followed in this study can be used for land capability assessment elsewhere in the country.

Limitations of the study

Information on the climatic variables of temperature and evapotranspiration from the selected meteorological stations in and around the study area were unavailable, hence these data were interpolated and estimated using the FAO Local Climate Estimator which is mainly based on linear altitude correlations. As a result these variables have shown a tendency of uniformity on both temperature and potential evaporation throughout the study area.

Therefore, for more reliable result on the slope and climatic variables, the results in this assessment require further refinement using more detailed data on temperature and evaporation from the respective metrological stations in and around the study area and particularly a better technique for modeling the slope classes and changing the climatic data to grid format so as to enable mapping at monthly level.

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Appendix A

Appendix A.1 Descriptions of the Major soil groups of the study area (WRB, 1998).

Vertisols

These soils are from Latin **vertere, to turn; connotative of turn over of surface soils** (FAO-UNESCO, 1990). They have a vertic A surface horizon within a depth ranging 35 to 50 cm. They have a greater than 30 percent of clay in all horizons to a depth of 80 cm and more. The surface horizon is vertic, i.e. it has strong swell and shrink with cracks, which open and close periodically (WRB, 1998). Thus, these vertic horizons are a clayey surface horizon, which is a result of shrinking and swelling, and has polished and grooved ped surface (slickenside), or wedge-shaped or parallelepiped structural aggregates.

These soil groups are characterized by dry and wet, and show coarse cracks of greater than 5 cm, which extend for about 70 cm down from the surface at average. They have a structure of prismatic, angular blocky to a blocky plate through out the study area with a colour of brown to dark brown. The subsurface horizon of these soils is white to grayish with a thickness of about 25 to 50 cm and greater than. In some places they are underlain by a brittle lime pan of white patches varying between 25 and 50 cm in thickness. These white patches are believed due to the presence of either powdery lime soft carbonate and/or most probably from the feldspar of the underlying granite as kaolinitic materials. They have an average pH value of about 7.5.

According to the WRB (1998) soil classification system the ***Eutric vertisols*** subgroup soils belong to the Vertisols of the study area. These soil subgroups have a vertic A horizon with a depth of 15 to 25 cm with a very dark grayish colour. The sub surface horizon of these soils is stratified colluvial basalt with poor drainage capacity. They have a medium base saturation thought the horizons with a pH value of 8 having a silt clay texture and angular to blocky structure.

Cambisols

This soil group is from Late Latin ***cambiare, to change; connotative of change in color, structure and consistence*** (FAO-UNESCO, 1990). They are characterized by an Ochric A surface horizon with a depth ranging from 15 to 20 cm, and light red to brownish in colour. In this surface horizon it has a strong chroma, redder hue and high clay content than the underlying horizon. The underlying horizon has a noncarbonated B-horizon with white patches. However, the subsurface B-horizons are dominantly with highly weathered rock materials developing into soils occupied by coarse, medium and fine gravels. The course sand and fine weathering stones are very common in their B-horizons. These sub surface horizon shows an alteration in relation to the underlying horizons where lacking the set of properties diagnostic for ***ferralic, argic, nitric*** or ***spodic horizon*** and the dark colours, organic matter content and structure of a ***histic, folic, mollic or umbric horizon***(WRB,1998).

The ***Eutric cambisols*** are the subgroups of the Cambisols, which are dry and strong brown in colour. These soils have no diagnostic sub surface horizon other than cambic, where the cambic B-horizon is the main future of these soils. They have a sandy to clay loam texture and granular to medium with weak rock fragments.

Leptosols

These soils group are From Greek, ***leptos, thin; connotative of weakly developed shallow soils*** (FAO-UNESCO, 1990). These soils attain an ochric A surface horizon where lightly darkened by organic matter, but have no diagnostic horizons other than a mollic, ochric, umbric, yermic or vertic horizon(WRB, 1998).These soils are limited in depth either by a continuous hard rock or with a weakly weathered rock materials within 25 cm from the soil surface. In some places of the study area they are overlying with a calcium carbonate within 25 cm depth. Such soils are equivalent to the ***Mispah form*** soils of South Africa, which are soils with orthic A surface horizon but lack any characteristics of the other diagnostic horizon (Mac Vicar, 1991). These soils comprise the sub group ***paralithic*** and

Eutirc leptosols where the former is consisting of a broken rock contact with fissures which allow roots to penetrate the underlying rock. These soils are often with weakly expressed weathering morphology and rock fragments, and in many places bed rock is exposed at the surface. They are underlain by continuous massive hard pan materials at a depth (Between 5 to 10 cm).This subsoil in the study area has a dark brown in colour. They have a sandy loam soil texture and a structure of angular blocky dominantly very weak rock fragments of abundant rounded grave. The sandy loam texture at a maximum depth of less than 25 cm with low base saturation, freely drained, stony and rocky where their water holding capacity is very poor (FAO-UNESCO, 1990).

Epileptic Regosols

This is from Greek, ***rhegos, blanket; connotative of a mantle of loose material overlying the hard core of the earth*** (FAO-UNESCO, 1990). These soils have an ochric a surface horizon within 20 to 35cm in depth. The sub surface horizons have yellow to brown colour with no defined structure. These soils are shallow apedal soils as per Soil Classification Working Group (1991) in South Africa. Dominantly they are underlain by a continuous hard rock (Between 25 to 50 cm). However in some areas they extend up to 70 cm in depth where the underlying materials are quartz, chlorite schist's Meta sediments at a weathering stage.

These soils in the study area are in general highly compacted and dry where cultivation is very difficult as a result of crusting. The surface has 20 to 40 percent stoniness cover with abundant gravels of quartz. However, these soils have silt clay textured with good drainage but very low or poor water holding capacity.

Calcaric Cambisols

These soils are characterized by accumulation of ***secondary carbonates*** at a depth "between 25 to 50 cm" (WRB, 1998). They have an ochric A surface horizon with a very light red to brownish in colour and a depth ranging from 15 to 25cm. The subsurface B horizon has a secondary carbonates having a depth (Between 20 to 35 cm) in thickness. The underlying material is a brittle secondary lime pans with low porosity soft carbonates, which can easily broken by a spade. It has a colour nearly white to grayish and the underlying material is weakly weathering probably dry and precipitated secondary lime.

Plinthic Cambisols

These soils have an ochric A surface horizon with a depth ranging from 15 to 20cm.It has a yellow to brown subsurface cambic B horizon having a thickness of 50 to 75 cm which is underlying by a soft plinthic B horizon with a thickness of 20 to 35cm.These soft plinthic are suggested to develop under a natural condition by fluctuating the water table. However, in areas adjacent to the Mai-Bella stream. These soils may be developed due to continuous irrigation. This horizon does not permanently harden on repeated drying and wetting. Underlying material is only highly gleyed in this area. These soils are relevant to the Glencoe form soils of South Africa system.

Luvisols

These soils are from Latin, ***Leure, to wash, "lessiver"; connotation of accumulation of clay*** (FAO-UNESCO, 1990). These soils have an ochric a surface horizon with a depth of 30 to 35 cm in thickness and they are light brown in colour. They contain an Argic B horizon according to the WRB which is similar to the pedocutanic B horizons of the South Africa system. They are underlain by saprolite weathering materials. The thickness of the subsurface horizon is at average a bout 35 cm having light brown in colour. These soils are of high base status and accumulation of clay content in their lower horizons. Their structures are highly deteriorated with high silt content. However, in steep slopes these soils are highly susceptible to erosion and accumulation of clay.

Fluvisols

These soils are from Latin ***fluvius, river, connotative of alluvial deposits*** (FAO-UNESCO, 1990). They have an ochric A surface horizon having a thickness of ranging between 35 to 70 cm from the surface. These soils have a ***fluvic*** soil material starting within 25cm from the soil surface and continuing to a depth of at least 50 cm from the soil surface; and no diagnostic horizons other than a ***his tic, mollic, ochric, tacyric, umbric, yermic, salic or sulphuric*** horizon (WRB1998). Therefore, these soils lack any diagnostic sub surface horizon rather than a deeply stratified alluvial colluvial parent materials. They have a thickness of about at average for about 120 cm. They are young soils with weak horizon separation. These soils have a silt loam texture with an effective depth greater than 100 cm. The recent sediments and wetness are typical characteristics of these soils in the study area. These soils are free of stoniness and rockiness, and are well drained with high natural fertility which makes them favorable for varies of field crops on stream banks of the study area.

Rock-Leptosols Complex

These soils are so closely mixed with the exposed bedrocks in the study area. Although they are dominantly covered with rocks, they are very shallow soils having a depth of 1to 25 cm in thickness from the surface soil. They are underlain by a continuous hard rock. These soils, the fact they are shallow in depth they were to be grouped to the Leptosols, however, hence they are mixed up physically with the rocks it has been found unnecessary or complicated to show them in a larger scale. Therefore, they can be presented as a complex soil map unit when they are so intimately mixed geographically, which is impractical, because of the scale being used to separate them (Mac Vicar, 1991).

Appendix A.2 Correlation of WRB soil groups of the study area to the RSA and USDA soil classification systems as per Mac Vicar, 1977.

World Soil Reference base (WRB)	Symbols	Republic of South Africa (RSA)	USDA
Vertisols with calcic and/or Eutric, haplic characteristics at various depth, and vertic cambisols	VR	Arcadia form, Lonehill soil family, calcareous in or immediately below A horizon	Vertisols- Pelloxererts(Typic,eutic); Pallusterts, Haplusterts (Typic, eutic); Chromoxererts(Typic); Chromusterts
Cambisols: with ochric, calcic and eutric characteristics	CM	Glenrosa form, keurloof soil family with calcareous B horizon	Inceptisols – Eutrochrepts
Organic Diagnostic material with vertic horizon through out (Soils of the Wetland)		Champagne form, Manchica soil family.	Most probably related to Histosol-Medihemists
Luvisols: Chromic horizon, gleyic luvisols ochric horizon	LV	Swartland form, Spneyton soil family	Alfisols- Haplustalfs (Typic, udic,ultic; Inceptisols- haplaquepts (typic, alric); Humaquwepts (typic).
Eplipthic Regosols	RG	Colvelly form, Bukkland soil Family (shallow apedal Soils)	Entisols- Lithic and Liptic Durochrepts(eutic-lithic) Ustipsamments and quartz Psamments Plinthic orthents,psamments

World soil Reference Base (WRB)	Symbols	Republic of South Africa	USDA
Leptosols- Lithic, Eutric and rock complex	LP	Mispah form, MyHill Soil family	Entisols- Lithic Torriorthents,xerorthents, Ustorthents. Entisols- Torrifluvents Ustifluvents.
Fluvisols gleyic	FL	Dundee form, Mtamvuna soil family.	As for Clovelly form, but having a lithic contact with hardened plinthite.
Calcareous cambisols (apedal with hard pan carbonates)	CL	Most probably to Askham form, Aroab soil family	Inceptsols-Eutrochrepts; (Ruptic, Lithic-Ruptic); Ustochrepts.
Cambisols – ochric and eutric with paraplinthic characteristics	CM	Glencoe form	Not specified
Not specified except in situ rock weathering shallow and young soils		Glenrosa form, Tsende soil family	Not specified
Rock-leptosol complex		Are more closely Related to complex soil map units	Complex soil map units

APPENDIX A. 3

SUMMARY OF SOIL PHYSICAL AND CHEMICAL PROPERTIES IN THE STUDY AREA

Sample No.	Soil Eff. depth (cms)	Texture Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Texture Class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg) Ca++	Mg++	K+	Na+	CEC meq/100g soil
1	110	35.3	7.6	29.6	37	ClLm	7.6	0.06	1.64	5.49	0.07	41	9.67	0.54	0.87	52.07
2	100	14.3	4.7	45.9	35	Cl	7.93	0.08	2	8.3	0.1	45.7	16	0.53	1.27	63.5
3	130	10.84	5.16	55.8	28	Cl	8.03	0.15	2	9.1	0.1	51.7	16	0.61	1.97	70.27
4	70	23.6	21.4	25.8	29	Lm	7.47	0.06	2	4.3	0.1	47.3	11.3	0.041	0.9	60
5	170	17.54	11.46	42.9	28	ClLm	7.88	0.11	2	27	0.1	60.3	18.3	0.67	1.9	81.08
6	55	33.95	12	26.45	37.6	ClLm	7.35	0.07	2.10	7.76	0.1	37.5	7.5	0.54	0.93	46.45
7	60	32.31	10.69	26.7	30.05	Lm	7.1	0.05	2.34	6.36	0.12	42.5	9.5	0.405	0.985	53.4
8	70	27.8	23.45	23.7	25.05	saclLm	7.2	0.08	2.13	3.36	0.075	64.5	13.5	0.34	1.025	79.35
9	90	17.9	8.1	46.0	28	Cl	7.77	0.08	1.72	4.31	0.07	58.33	11.33	0.48	1.20	71.37
10	60	10.87	5.13	56.8	27.2	Cl	7.3	0.07	1.83	3.69	0.08	49.5	10.5	0.505	1.025	61.5
11	160	21.06	10.06	39.92	28.96	ClLm	7.98	0.196	1.00	4.09	0.04	50.2	14.4	0.48	2.274	67.36
12	130	23.7	12.3	40.43	23.57	Cl	8.03	0.12	1.15	5.46	0.06	46.67	11	0.61	1.67	59.97
13	80	27.23	23.20	23.6	25.97	SaClLm	7.4	0.11	1.87	14.72	0.08	49	9.33	0.35	1.11	59.8
14	120	21.61	10.50	39.03	28.8	ClLm	8	0.08	1.07	8.24	0.05	43.33	12	0.49	1.41	57.23
15	55	36.15	9.80	26.45	37.6	Lm	7.35	0.07	2.10	7.76	0.10	37.50	7.5	0.54	0.93	46.45
16	60	33.05	10.20	26.70	30.05	Lm	7.1	0.05	2.34	6.36	0.12	42.50	9.5	0.41	0.99	53.40
17	100	11.70	7.30	45.90	35	Cl	7.93	0.08	2.00	8.30	0.10	45.70	16	0.53	1.27	63.50
18	100	10.80	8.20	45.90	35	Cl	7.93	0.08	2.00	8.30	0.10	45.70	16	0.53	1.27	63.50
19	90	36.10	11.00	41.60	21.4	Cl	8.13	0.13	3.51	4.50	0.08	49.00	13.00	0.71	0.67	63.38
20	90	18.13	6.30	37.17	38.4	ClLm	7.83	0.20	2.71	47.33	0.11	27.00	12.33	0.46	4.21	44.03
21	60	26.60	10.00	29.40	34	ClLm	7.5	0.04	2.08	3.20	0.10	45.00	8.00	0.28	0.76	54.00
22	10	51.50	11.10	14.10	23.3	SaLm	7.3	0.08	2.22	19.30	0.14	12.00	3.00	1.47	0.97	17.40
23	15	46.20	13.20	16.10	24.5	SaLm	7.3	0.07	2.50	4.06	0.14	34.00	12.00	0.31	1.09	47.40
24	20	45.80	10.40	19.80	24	SaLm	7.5	0.06	2.70	4.15	0.12	35.00	13.00	0.34	1.24	50.00
25	40	33.70	8.30	5.30	35.6	Lm	7.5	0.08	0.79	21.60	0.11	9.00	4.00	0.12	0.34	13.46
26	75	37.00	12.10	17.50	33.4	Lm	7.8	3.83	0.82	1.73	0.03	66.00	19.00	0.17	8.77	93.90

Appendix A.3 Cont.

Sample No.	Soil Eff. depth (cms)	Texture: Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg): Ca++	Mg++	K+	Na+	CEC meq/100g soil
27	70	27.60	8.30	32.00	32.1	ClLm	7.4	0.05	2.00	2.48	0.07	46.00	9.00	0.38	0.91	56.30
28	60	18.60	10.20	36.40	34.8	ClLm	6.9	0.05	2.64	10.10	0.18	36.00	9.00	0.52	0.99	46.50
29	70	20.00	10.00	35.00	35	ClLm	7.3	0.07	2.20	6.08	0.04	38.00	8.00	0.32	0.68	47.00
30	60	16.13	9.00	43.70	31.17	Cl	8.47	4.68	1.49	0.13	42.00	13.00	1.09	10.21	0.56	24.86
31	60	32.50	12.40	7.60	47.5	Lm	6.95	0.08	2.14	3.73	0.09	10.00	3.00	0.23	0.12	13.35
32	60	30.50	21.30	8.10	40.1	Lm	5.43	0.63	3.41	7.58	0.20	23.00	6.00	0.13	0.36	29.49
33	55	19.30	11.30	19.40	50	StLm	6.3	0.05	1.78	3.12	0.09	10.00	2.00	0.10	0.21	12.31
34	55	32.50	10.60	13.90	43	Lm	6.91	0.08	2.31	5.50	0.15	12.00	3.00	0.12	0.50	15.63
35	40	33.00	13.10	11.30	42.6	Lm	7.6	0.08	0.76	20.20	0.11	10.00	4.00	0.13	0.33	14.46
36	60	32.70	19.30	21.00	23	SaClLm	7.2	0.08	0.65	19.00	0.10	9.00	5.60	0.12	0.42	15.36
37	70	38.55	16.70	23.70	25.05	SaClLm	7.2	0.08	2.13	3.36	0.08	64.50	13.50	0.34	1.03	79.35
38	55	25.45	10.50	26.45	37.6	Lm	7.35	0.07	2.10	7.76	0.10	37.50	7.50	0.54	0.93	46.45
39	70	35.00	10.00	25.80	29	Lm	7.47	0.06	2.00	4.30	0.10	47.30	11.30	0.04	0.90	60.00
40	130	33.68	12.32	40.43	23.56	Cl	8.03	0.12	1.15	5.46	0.06	46.67	11.00	0.61	1.67	59.97
41	80	39.43	11.00	23.60	25.96	SaClLm	7.4	0.11	1.87	14.72	0.08	49.00	9.33	0.35	1.11	59.80
42	130	34.8	11.20	40.43	23.57	Cl	8.03	0.12	1.15	5.46	0.06	46.67	11	0.61	1.67	59.97
43	130	23.80	9.60	47.10	19.50	Cl	7.88	0.14	2.80	32.90	0.10	55.00	12.00	1.30	0.69	68.99
44	65	22.7	12.30	28.50	36.35	ClLm	7.97	0.45	3.34	9.645	0.12	44.65	12.15	0.57	5.56	63.15
45	60	20.80	10.20	30.00	39.00	ClLm	7.40	0.05	0.20	2.48	0.07	46.00	9.00	0.38	0.91	56.30
46	30	42.5	14.20	17.00	25.30	SaLm	7.50	0.04	2.03	2.61	0.06	49.00	10.00	0.29	0.98	60.30
47	120	17.90	8.10	45.10	28.90	Cl	8.03	0.11	1.43	7.39	0.11	43.00	13.00	0.55	0.41	56.99
48	140	18	6.80	47.90	27.30	Cl	7.80	0.10	1.56	7.60	0.09	48.00	11.00	0.49	1.52	62.00
49	55	19.10	6.50	34.80	35.00	ClLm	7.30	0.05	2.57	12.10	0.11	35.00	9.00	0.75	0.88	45.63
50	90	18.1	7.90	46.50	27.50	Cl	7.80	0.13	2.75	4.60	0.07	43.00	12.00	0.71	0.44	56.15
51	100	13.00	6.90	51.00	28.30	Cl	7.10	0.08	2.20	4.70	0.09	47.00	11.00	0.57	1.33	59.90
52	60	12.7	5.20	48.70	33.40	Cl	7.80	0.06	1.93	3.54	0.06	47.00	16.00	0.41	1.34	64.80
53	80	13.60	11.20	47.90	27.30	Cl	7.60	0.11	1.41	5.70	0.07	48.00	17.00	0.40	1.52	66.92
54	15	29.80	23.00	14.70	27.60	SaLm	7.45	0.01	0.65	4.90	0.07	4.50	1.45	0.03	0.20	20.97
55	80	4.76	1.20	48.70	45.34	StCl	8.30	0.11	7.80	1.86	0.07	40.00	19.00	0.34	4.50	63.84

Appendix A.3 Cont.

Sample No.	Soil Eff. depth (cms)	Texture Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg) Ca++	Mg++	K+	Na+	CEC meq/100g soil
56	125	27.80	9.20	42.40	19.60	Cl	8.12	0.78	1.30	8.90	0.09	37.00	8.00	1.27	1.56	47.83
57	90	14.8	10.00	48.30	26.90	Cl	7.85	0.09	1.75	5.20	0.07	59.50	10.00	0.50	1.27	71.00
58	110	9.70	7.60	56.80	25..9	Cl	7.50	0.05	1.38	2.74	0.07	48.00	10.00	0.38	1.04	59.40
59	80	15.6	10.30	27.54	46.56	Lm	8.70	0.14	0.14	2.00	0.11	27.90	18.70	2.20	0.11	48.91
60	20	29.00	22.60	19.70	27.50	SaLm	7.45	0.11	0.65	5.60	0.07	4.60	1.35	0.04	0.21	6.20
61	20	31.39	24.00	20.50	24.50	SaLm	7.50	0.09	0.72	5.00	0.07	4.80	1.25	0.03	0.25	5.33
62	55	19.40	11.20	19.40	50.00	StLm	6.30	0.05	1.78	3.12	0.09	10.00	2.00	0.10	0.21	12.31
63	55	33.2	9.90	13.90	43.00	Lm	6.91	0.08	2.31	5.50	0.15	12.00	3.00	0.12	0.50	15.63
64	90	19.5	10.00	45.80	24.70	Cl	7.57	0.09	1.29	8.97	0.08	43.00	12.00	0.71	0.45	56.16
65	90	26.2	12.60	17.20	44.00	Lm	7.02	0.07	2.32	8.80	0.09	25.00	5.00	0.22	0.22	30.44
66	60	12.6	9.20	17.50	40.50	Lm	7.50	0.18	2.25	10.00	0.10	31.00	6.00	0.36	0.45	38.30
67	80	32.6	12.40	17.90	37.30	Lm	8.02	0.29	2.22	11.25	0.19	38.00	7.00	0.50	0.70	46.20
68	80	9.8	10.00	28.90	52.30	StLm	8.30	0.40	1.99	1.89	0.10	30.00	29.00	0.35	5.20	64.55
69	15	56.7	23.00	18.70	24.60	SaLm	7.50	0.08	1.93	10.70	0.08	47.00	8.00	0.23	1.07	56.30
70	15	59.6	20.00	15.70	24.70	SaLm	7.30	0.08	2.26	18.90	0.14	1.30	3.00	1.48	0.96	18.11
71	30	48.3	15.00	20.20	31.50	Lm	7.80	0.43	0.96	7.52	0.10	7.80	2.80	0.45	1.50	12.00
72	25	3.05	6.65	35.00	54.30	StClLm	8.00	0.10	0.98	5.60	0.08	28.00	17.00	0.20	1.11	46.30
73	20	30.6	23.00	17.40	28.90	SaLm	7.40	0.07	1.33	10.60	0.11	45.00	12.00	1.45	1.60	60.05
74	60	29.1	20.00	17.50	33.40	Lm	7.80	3.83	0.82	1.73	0.03	66.00	19.00	0.17	8.77	93.90
75	80	21.1	10.00	38.00	28.90	ClLm	8.00	0.22	1.66	4.11	0.07	33.00	10.00	0.39	3.49	46.90
76	100	24.4	11.20	33.40	30.80	ClLm	8.30	0.11	1.20	32.10	0.07	37.50	8.00	0.95	1.76	48.30
77	120	20.7	5.60	47.40	26.30	Cl	8.40	0.16	1.83	9.37	0.08	26.00	10.00	0.63	3.62	40.30
78	35	8.4	5.60	32.20	53.80	StClLm	8.10	0.54	1.56	2.92	0.01	28.00	8.00	0.84	3.22	40.06
79	30	25	18.30	21.40	35.30	Lm	7.70	0.14	2.15	3.18	0.10	20.00	9.00	0.31	1.20	30.51
80	130	15.3	9.70	39.40	35.10	ClLm	7.10	0.51	2.02	7.64	0.10	20.00	7.00	0.19	1.44	28.63
81	100	17.5	23.20	17.30	39.00	Lm	7.50	0.07	1.40	3.90	0.08	20.00	7.00	0.14	0.31	27.45
82	50	16.2	22.00	23.40	39.40	Lm	7.80	0.05	0.90	3.60	0.01	30.00	12.00	0.35	0.56	42.91
83	200	4.9	9.30	21.90	63.90	StClLm	7.60	1.28	8.30	1.93	0.01	30.00	29.00	0.42	5.40	64.82
84	120	15.3	3.80	50.00	30.90	Cl	7.90	0.09	1.66	23.50	0.10	28.00	12.00	0.24	3.51	43.80

Appendix A.3 Cont.

Sample No.	Soil Eff. depth (cms)	Texture Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg) Ca++	Mg++	K+	Na+	CEC meq/100g soil
85	70	14.13	10.30	37.17	38.40	ClLm	7.83	0.20	2.71	47.33	0.11	27.00	12.33	0.46	4.21	44.03
86	25	41.2	15.00	19.80	24.00	SaLm	7.50	0.06	2.64	4.25	0.12	35.00	13.00	0.34	1.24	49.60
87	35	36.6	17.00	14.30	33.10	SaLm	7.70	0.15	1.40	2.10	3.45	24.00	8.00	0.31	1.20	33.51
88	40	17.6	23.00	21.40	38.00	Lm	7.70	0.14	2.15	3.18	0.09	20.00	9.00	0.31	1.20	30.51
89	120	13.2	4.80	50.10	31.90	Cl	8.00	0.93	1.26	1.40	0.12	29.00	16.00	0.35	7.87	53.22
90	70	25.1	18.20	21.40	35.30	Lm	7.70	0.14	2.15	3.18	0.10	20.00	9.00	0.31	1.20	30.50
91	90	12.1	11.00	39.30	32.60	ClLm	8.00	0.56	1.62	7.60	0.09	38.00	17.50	0.27	4.20	59.97
92	50	12.35	9.60	34.45	43.60	ClLm	6.70	0.07	2.92	12.45	0.14	25.00	5.50	0.27	2.25	33.00
93	60	17	11.00	39.10	32.90	ClLm	7.10	0.51	2.02	7.64	0.10	20.00	7.00	0.19	1.14	28.33
94	90	20	18.00	23.60	38.40	Lm	7.30	0.06	1.39	5.09	0.09	21.00	6.00	0.14	0.31	27.45
95	140	21.2	12.00	33.73	33.05	ClLm	7.98	0.18	1.28	6.01	0.05	25.00	6.75	0.22	2.24	34.20
96	100	20.6	9.10	45.60	24.70	Cl	7.30	0.04	1.33	3.59	0.07	43.00	6.00	0.35	0.85	50.20
97	80	36.1	15.30	33.97	24.63	ClLm	7.70	0.24	1.04	16.39	0.05	28.67	8.33	0.20	2.61	39.83
98	55	11.6	19.00	26.00	43.40	Lm	7.50	0.09	1.49	4.62	0.08	26.00	4.00	0.14	1.55	31.70
99	155	21.1	17.10	33.40	28.40	ClLm	8.00	0.16	1.98	1.27	0.12	48.00	18.00	0.19	0.55	66.74
100	60	18.2	10.30	37.40	34.10	ClLm	7.10	0.51	2.02	7.64	0.09	22.00	5.00	0.16	1.42	28.58
101	60	16.6	21.00	25.20	37.20	Lm	7.70	0.14	2.15	3.18	0.07	23.00	6.00	0.31	1.20	30.51
102	40	12.5	19.00	25.70	42.80	Lm	7.70	0.14	2.15	3.16	0.07	23.00	6.00	0.30	1.20	30.10
103	40	15.5	16.00	25.70	42.80	Lm	8.70	0.35	0.82	2.44	0.01	41.00	10.00	0.14	3.07	54.20
104	70	17.2	12.30	30.00	40.10	ClLm	7.50	0.01	2.17	39.50	0.09	24.00	5.00	0.30	2.56	31.86
105	70	22.7	13.00	38.70	25.60	ClLm	6.60	0.05	1.86	3.56	0.07	22.00	7.00	0.14	1.55	31.70
106	40	17.45	10.05	31.20	41.30	ClLm	7.20	0.51	2.00	6.76	0.09	19.00	8.00	0.17	1.44	28.61
107	50	13.5	18.00	25.70	42.80	Lm	8.70	0.35	0.82	2.44	0.01	41.00	10.00	0.14	3.06	54.20
108	60	18.7	24.00	23.30	35.00	Lm	7.00	0.13	2.00	2.18	0.08	23.00	6.00	0.32	1.10	30.42
109	90	16.1	12.60	28.60	42.70	ClLm	6.70	0.03	1.56	6.32	0.08	21.00	8.00	0.16	1.13	30.30
110	90	19.9	14.00	38.70	25.60	ClLm	7.80	0.14	2.17	39.50	0.10	24.00	5.00	0.30	2.52	45.70
111	150	7.1	12.00	28.49	52.34	StLm	8.00	0.17	2.15	1.93	0.19	48.00	11.00	0.04	5.40	64.82
112	55	35.5	14.00	23.00	20.50	SaClLm	6.60	0.07	1.75	0.08	0.08	33.00	6.00	0.12	2.74	41.86
113	80	17.9	21.00	25.70	35.40	Lm	7.70	0.51	0.14	3.18	0.11	21.00	8.00	0.31	1.20	30.51

Appendix A.3 Cont.

ample No.	Soil Eff. depth (cms)	Texture Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg) Ca++	Mg++	K+	Na+	CEC meq/100g soil
114	60	19.5	20.00	25.00	35.50	Lm	8.10	0.54	1.56	2.29	0.12	30.00	6.00	0.84	3.21	40.25
115	80	20.9	24.00	22.40	36.70	Lm	6.40	0.04	2.50	14.20	0.11	28.00	13.00	0.24	0.86	42.10
116	150	7.3	9.70	38.90	44.10	StClLm	8.80	0.40	2.17	39.50	0.12	46.00	9.00	0.05	4.50	59.55
117	35	10.5	19.50	12.20	53.20	StLm	7.70	0.14	2.15	3.02	0.13	22.00	7.00	0.32	1.20	30.50
118	60	17	10.00	30.00	43.00	ClLm	7.13	0.03	1.36	3.85	0.13	11.00	3.00	0.14	0.15	14.29
119	30	13.5	27.00	15.70	32.80	Lm	7.26	0.04	1.30	26.10	0.06	22.00	7.00	4.00	0.32	26.64
120	30	41.5	17.00	10.00	31.50	SaLm	7.80	0.06	1.00	27.30	0.04	16.00	6.00	0.35	0.59	22.94
121	40	18.9	22.00	22.40	36.70	Lm	6.40	0.04	2.50	14.20	0.11	26.00	12.00	0.24	0.86	42.10
122	60	32.6	13.00	29.60	24.80	ClLm	6.76	0.02	2.09	43.55	0.09	10.62	1.87	0.19	0.04	12.64
123	80	18.6	25.00	23.60	31.10	Lm	7.01	0.04	2.49	74.05	0.09	10.75	1.75	0.22	0.05	12.75
124	75	48.4	10.00	19.50	22.10	SaLm	6.50	0.01	4.30	56.12	0.08	8.75	1.87	0.19	0.03	10.97
125	70	14.5	21.00	21.90	42.60	Lm	7.30	0.08	0.87	1.28	0.09	10.00	8.50	0.12	0.05	18.67
126	70	22	23.00	12.00	43.00	Lm	6.55	0.03	0.83	0.65	0.07	4.00	18.75	0.35	0.05	19.15
127	70	40.7	12.00	21.70	25.60	SaClLm	7.80	0.61	1.13	0.78	43.55	8.60	14.56	0:17	0.05	14.81
128	70	47.8	9.60	14.80	27.90	SaLm	7.60	1.29	1.37	0.09	26.10	22.00	4.00	0.32	0.32	26.62
129	65	13	21.00	23.00	43.00	Lm	6.80	0.15	1.05	12.50	0.09	27.00	13.00	0.16	0.34	40.50
130	85	15.5	10.00	39.40	35.10	ClLm	7.10	0.51	2.02	7.56	0.73	20.00	7.00	0.19	1.44	28.63
131	90	17.5	11.00	31.10	41.40	ClLm	7.38	0.42	1.27	12.50	0.12	28.00	16.00	0.12	0.18	44.30
132	80	14.9	9.60	37.10	40.40	ClLm	7.74	0.08	1.58	33.20	0.06	39.00	11.00	0.44	0.91	51.30
133	100	13	8.60	31.60	46.80	ClLm	7.30	0.20	1.76	2.56	0.12	21.88	9.00	0.17	0.05	31.02
134	100	18.1	10.70	36.70	34.40	ClLm	8.40	0.07	1.60	33.20	0.06	22.00	7.00	0.44	0.91	51.31
135	60	25.6	18.00	23.30	33.10	Lm	7.01	0.04	1.75	74.06	0.09	8.00	2.75	0.22	0.22	11.11
136	35	25.6	17.90	18.00	39.00	Lm	7.95	0.97	1.02	23.89	0.07	21.00	8.00	0.12	0.18	29.30
137	30	17.8	10.20	37.60	34.40	ClLm	8.20	0.09	1.60	33.20	0.06	24.00	15.00	0.45	0.90	40.35
138	35	46.7	10.00	12.50	31.00	SaLm	7.55	0.67	1.33	21.58	0.08	22.36	11.00	0.50	0.13	33.89
139	40	43.2	14.20	14.80	27.90	SaLm	7.60	1.30	1.40	21.67	0.08	20.36	8.70	0.35	0.16	29.51
140	55	29.4	23.00	16.10	32.60	Lm	7.65	0.74	1.99	24.00	0.07	20.37	9.70	0.17	0.32	30.70
141	80	17	21.10	15.30	46.60	Lm	7.46	1.20	1.27	19.80	0.11	23.00	8.90	0.26	..08	32.34
142	40	18.2	9.00	37.00	35.80	ClLm	7.30	0.51	2.02	7.63	0.09	20.00	7.00	0.19	1.44	28.64

Appendix A.3 Cont.

ample No.	Soil Eff. depth (cms)	Texture Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg) Ca++	Mg++	K+	Na+	CEC meq/100g soil
143	85	18.8	12.00	36.60	32.60	ClLm	7.50	0.14	2.17	39.30	0.10	24.00	5.00	0.30	2.59	31.90
144	50	24	11.30	34.70	30.30	ClLm	7.45	0.21	0.89	4.88	0.05	25.00	7.00	0.32	1.75	33.32
145	55	25.4	9.60	34.70	30.30	ClLm	7.70	0.15	1.36	3.50	0.09	25.00	4.50	0.13	1.45	31.08
146	35	17.3	8.70	36.00	38.00	ClLm	7.10	0.52	1.97	8.90	0.12	23.00	8.00	0.18	1.56	32.74
147	45	38.1	13.00	29.60	28.60	ClLm	6.90	0.02	0.71	7.80	0.13	24.50	7.90	0.15	1.36	32.95
148	55	18.7	10.30	34.30	36.70	ClLm	7.80	0.08	1.60	33.20	0.06	31.00	8.00	0.44	0.91	40.31
149	20	27.3	8.20	29.40	35.10	ClLm	6.80	0.19	1.24	21.90	0.09	23.00	12.00	0.45	0.35	35.80
150	45	37.9	7.80	29.70	24.60	SaClLm	6.20	0.06	0.61	16.00	0.06	24.00	8.00	0.02	0.15	32.17
151	40	24	11.00	28.50	36.50	ClLm	7.80	0.42	1.95	17.00	0.12	26.00	9.00	0.28	0.20	35.48
152	50	19.4	19.00	19.90	41.70	Lm	7.90	0.70	1.80	21.06	0.08	21.00	7.00	0.20	0.14	28.34
153	55	54.9	9.20	12.30	23.70	SaLm	7.40	0.70	1.58	29.00	0.15	35.00	15.00	0.64	0.16	50.80
154	60	13	14.00	23.50	50.50	StLm	7.60	0.34	1.23	25.00	0.65	26.00	15.70	0.16	0.25	42.11
155	35	45.4	13.00	19.60	22.00	SaLm	6.50	0.01	4.30	56.12	0.18	23.00	8.50	0.21	0.04	31.75
156	80	3.7	15.60	25.90	54.80	StLm	6.50	1.03	1.51	23.45	0.12	20.00	9.70	0.35	0.06	30.11
157	80	5.3	11.2	25.20	58.50	StLm	6.00	1.90	2.70	19.80	0.18	16.00	8.70	0.58	0.06	25.16
158	80	4.3	2.70	26.00	67.00	StLm	6.90	0.09	1.72	0.40	0.12	3.75	2.70	0.35	0.06	6.68
159	100	7.6	14.90	23.10	54.40	StLm	7.56	0.97	1.81	32.70	0.12	23.50	11.00	0.16	0.25	31.91
160	100	8.5	7.30	33.00	51.20	StClLm	8.20	1.30	2.00	31.00	0.09	37.00	17.00	0.17	0.24	54.41
161	80	16	21.00	20.00	43.00	Lm	7.00	0.09	1.13	29.70	0.09	32.00	15.10	0.16	0.10	37.36
162	90	31	10.90	29.50	28.60	ClLm	6.80	0.02	0.70	67.54	0.06	5.00	3.60	0.17	0.05	8.82
163	70	17	21.00	12.00	60.00	StLm	6.80	0.06	1.19	0.48	0.05	13.00	3.70	0.10	0.08	16.88
164	70	19.3	24.30	23.30	33.10	Lm	7.00	0.04	3.70	8.80	0.09	17.00	8.00	0.22	0.22	25.44
165	75	32	12.80	37.30	17.90	ClLm	8.00	0.29	2.20	112.50	0.19	30.00	8.00	0.50	0.70	39.12
166	50	55	15.30	13.10	16.70	SaLm	7.30	0.50	2.10	33.00	0.09	21.70	7.80	0.23	0.11	25.79
167	50	55.2	16.70	11.10	17.40	SaLm	7.80	0.80	1.46	36.00	0.80	21.75	13.20	0.19	0.10	25.14
168	60	30.2	13.00	39.30	17.40	ClLm	7.30	0.06	1.39	5.09	0.12	20.00	7.00	0.14	0.31	27.45
169	110	3.2	7.80	33.70	53.30	StLm	6.30	0.60	3.50	63.00	0.09	17.00	7.75	0.35	0.06	25.16
170	90	22.2	27.00	18.20	30.90	Lm	7.50	0.67	0.60	3.00	0.13	7.20	3.73	0.19	0.03	11.88
171	115	7.1	17.80	26.80	48.30	Lm	7.05	0.14	1.06	2.40	0.13	10.00	3.25	0.21	0.04	13.49

Appendix A.3 Cont.

Sample No.	Soil Eff. depth (cms)	Texture Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class	pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg) Ca++	Mg++	K+	Na+	CEC meq/100g soil
172	45	43.9	12.00	12.50	31.60	SaLm	7.80	0.04	0.70	2.48	0.09	5.00	4.83	0.02	0.03	9.88
173	90	6.7	9.60	35.40	48.30	StLm	7.10	0.07	2.26	5.68	0.09	17.63	7.00	0.35	0.01	24.99
174	120	14.83	19.80	22.8	42.57	Lm	7.07	0.10	2.58	7.59	0.11	23.33	5	0.2	1.36	29.9
175	100	4.9	15.60	34.40	55.10	StClLm	6.63	0.24	1.94	1.98	0.08	17.00	3.63	0.19	0.03	20.85
176	80	3.1	3.90	26.33	67.00	StLm	6.90	0.09	1.72	0.40	0.13	13.00	5.00	0.15	0.06	18.21
177	60	61.2	11.90	9.70	17.30	LmSa	7.70	0.95	1.82	25.00	0.06	10.00	8.00	0.07	0.56	18.63
178	35	67.5	14.60	5.70	12.20	LmSa	7.90	0.95	1.65	36.00	0.05	9.00	5.80	0.07	0.13	15.00
179	20	60.3	9.80	12.00	18.00	SaLm	7.30	0.90	2.50	2.56	0.09	13.00	7.10	0.12	0.18	20.40
180	100	7.5	3.50	19.00	70.00	SaLm	7.25	0.03	0.77	0.42	0.12	19.00	7.60	0.08	1.20	27.80
181	15	68.7	13.40	4.40	13.50	LmSa	7.90	0.50	1.23	4.20	0.12	35.00	13.00	0.34	1.20	49.50
182	80	4.8	11.70	25.20	58.20	StLm	6.00	2.00	2.66	5.40	0.12	12.00	4.00	0.58	0.06	16.64
183	65	18.7	26.80	12.00	43.00	Lm	6.50	0.03	0.83	0.65	0.15	21.00	7.60	0.87	1.05	29.52
184	60	17.7	20.30	20.00	42.00	Lm	6.60	0.03	1.06	0.29	0.13	19.00	8.40	0.80	1.01	29.20
185	35	49.7	9.30	9.80	31.20	SaLm	8.80	0.38	1.67	24.00	0.04	11.00	9.00	0.12	0.10	20.22
186	40	25.7	19.30	12.00	43.00	Lm	6.90	0.06	1.19	0.48	0.06	9.00	5.70	1.60	0.54	16.84
187	60	3.6	13.20	24.40	58.80	StLm	5.40	2.50	3.43	28.00	0.09	14.00	5.50	0.40	0.06	19.96
188	35	55.7	15.30	19.40	9.60	SaLm	7.80	0.04	0.80	22.80	0.08	12.00	6.00	0.31	0.54	18.85
189	30	64.4	13.20	7.60	14.80	LmSa	7.74	0.27	1.34	5.06	0.07	21.00	6.00	0.10	0.01	27.11
190	40	62	15.60	7.60	14.80	LmSa	7.80	0.25	1.34	4.25	0.06	22.00	4.50	0.10	0.06	26.66
191	50	11	17.00	12.00	60.00	StLm	6.90	0.03	1.09	0.26	0.06	19.00	6.50	0.06	1.05	26.61
192	45	7.5	3.60	33.70	53.30	StClLm	6.30	0.60	3.50	5.43	0.09	17.63	7.00	0.35	0.06	25.04
193	45	68.9	9.20	7.60	13.30	LmSa	8.00	0.29	1.90	1.70	0.05	13.00	5.30	0.08	0.10	18.48
194	35	68.1	9.90	7.10	14.90	LmSa	7.90	0.32	1.19	1.96	0.06	12.00	5.10	0.10	0.08	17.28
195	110	12.1	7.20	25.90	54.80	StLm	6.50	1.00	1.51	3.74	0.07	19.00	4.75	0.35	0.06	24.15
196	110	24.7	10.30	36.80	28.20	ClLm	7.80	0.08	1.60	31.90	0.06	30.90	8.10	0.44	0.91	40.24
197	70	9.2	11.30	34.40	55.10	StClLm	6.60	0.24	1.94	1.90	0.09	17.00	3.63	0.19	0.03	20.85
198	70	7.4	8.90	35.40	48.30	StClLm	7.10	0.07	2.26	5.68	0.08	16.00	8.63	0.35	0.01	24.99
199	110	6.6	15.00	33.30	55.10	StClLm	6.50	0.27	1.89	1.60	0.09	16.30	3.50	0.17	0.02	19.52
200	75	37.5	15.20	21.70	25.60	SaClLm	7.80	0.60	1.13	5.96	0.07	21.70	5.97	0.35	0.04	27.53

Appendix A.3 Cont.

Sample No.	Soil Eff. depth (cms)	Texture					pH	EC mS/cm	OM (%)	P ppm	N (%)	Exchangeable cations (Cmol/Kg)				CEC meq/100g soil
		Sand (%)	VfSand (%)	Clay (%)	Silt (%)	Textural class						Ca++	Mg++	K+	Na+	
201	75	32.6	13.00	29.60	24.80	SaClLm	8.70	0.05	1.36	4.70	0.08	20.00	7.50	0.19	0.11	27.80
202	45	71.5	7.60	7.60	13.30	LmSa	8.00	0.29	1.86	1.78	0.74	15.60	7.60	0.08	0.10	23.38
203	45	67.8	9.80	7.60	14.80	LmSa	7.70	0.27	1.34	5.67	0.08	18.00	6.80	0.09	0.10	25.80
204	45	70.6	14.30	4.40	10.70	LmSa	7.50	0.50	1.38	5.06	0.07	17.00	7.50	0.67	0.10	25.27
205	45	68.5	13.20	7.50	10.80	LmSa	7.90	0.29	1.40	5.90	0.09	16.50	11.00	0.09	0.06	27.64
206	50	22	23.00	12.00	43.00	Lm	6.50	0.03	0.80	4.70	0.08	17.00	5.70	0.40	0.06	23.16
207	35	70.4	17.30	4.50	7.90	LmSa	7.60	0.42	1.95	5.30	0.08	17.00	7.00	0.26	0.20	24.46
208	35	65.5	16.20	7.50	10.80	LmSa	7.90	0.29	1.40	5.06	0.08	17.00	5.60	0.09	0.06	22.75
209	80	12.2	24.50	23.80	39.50	Lm	7.80	0.27	1.23	7.64	0.09	20.00	9.00	0.15	0.43	29.58
210	120	9.8	6.50	35.40	48.30	StClLm	7.10	0.07	2.26	5.68	0.08	15.00	9.63	0.35	0.01	24.99
211	80	20	8.70	28.60	42.70	ClLm	6.70	0.03	0.31	3.66	0.02	22.00	5.00	0.07	1.13	28.20
212	35	25.7	9.50	29.40	35.40	ClLm	6.80	0.19	1.24	6.50	0.10	21.00	11.00	0.06	1.23	32.29
213	60	19.9	7.60	31.10	41.40	ClLm	7.30	0.42	1.27	3.56	0.09	9.00	5.00	0.12	0.18	14.30
214	60	14.8	6.80	31.60	46.60	ClLm	6.30	2.00	1.76	2.40	0.12	10.00	3.50	0.21	0.04	13.73
215	45	43.6	23.20	23.30	33.10	Lm	7.00	0.04	0.80	74.00	0.13	9.95	2.00	0.18	0.05	12.80
216	100	6.1	13.20	25.90	54.80	StLm	6.50	1.00	1.51	5.57	0.09	10.75	3.00	0.35	0.03	14.08
217	70	25.7	6.70	36.40	31.20	ClLm	7.10	0.09	2.54	3.59	0.10	58.00	11.00	0.50	0.99	70.50
218	70	26.2	9.70	32.00	32.10	ClLm	7.40	0.05	2.00	2.48	0.07	46.00	9.00	0.38	0.91	56.30
219	155	11.8	7.60	28.30	52.30	StClLm	9.50	0.20	1.99	5.79	0.09	24.00	5.00	0.16	0.47	29.62
220	55	21	25.00	18.60	35.30	Lm	7.50	0.09	1.59	2.41	0.09	40.00	7.00	0.34	0.99	48.30
221	25	45	12.70	17.00	25.30	SaLm	7.30	0.04	2.03	2.61	0.06	49.00	10.00	0.29	0.98	60.30
222	25	69.1	4.50	9.30	17.10	LmSa	7.80	0.05	1.89	2.82	0.11	54.00	17.00	0.22	0.93	71.00
223	25	43.6	13.10	18.70	24.60	SaLm	7.50	0.08	1.93	10.70	0.08	47.00	8.00	0.23	1.07	56.30
224	25	24	6.50	40.10	29.40	Cl	8.10	0.06	0.77	2.69	0.05	40.00	16.00	0.42	1.50	57.90
225	35	56.3	13.60	11.00	19.10	SaLm	7.90	0.10	0.08	1.73	0.01	10.00	2.00	0.11	1.01	13.10

Appendix B

Appendix B **Descriptions of the symbols of the parameters and limitations used in land capability classification for the Study Area**

B.1 Soil characteristics

Table1: Description of the limits for effective depth criteria

Symbol	Effective Depth (cm) from the soil surface	Description
D1	≥ 100	Very deep
D2	80 - < 100	Deep
D3	50 - < 80	Moderately deep
D4	25 - < 50	Shallow soils
D5	<25	Very shallow soils

Table2: Description of texture class criteria

Symbol	%Age clay	Texture class description
T1	> 35	Clay
T2	30 - ≤ 35	Clay loam
T3	15 - < 30	Loam to sandy loam
T4	0 - < 15	Sandy soil

Table3: Description of the permeability classes' criteria

Symbol/class		Description
2	Severely restricted	Land with strong structure, weathered rock, >35 clay
3	Restricted	These land surfaces have rocky and/or strong structure, grey colours with mottles and greater than 35 clay percent.
4	Slightly restricted	These lands are with clay percent of greater than 10, but have frequent mottles during the rain season.
5	Good	In these lands, although the percent clay is greater than 10 there is no otherwise slight mottles and grey colour. They have sand clay loam and fine sandy loam texture classes
6	rapid	Theses are areas of where clay percent of the soil is between 5 and 10 with fine and course texture having a sandy loam texture class.

B.2 Land characteristics

Table1: Description of wetness criteria

Symbols	Description
W1	Good and well drained soils. These soils are free of any signs of wetness within 80cm of the surface through out their effective depth.
W2	In these soils there is no evidence or signs of wetness within the top 50cm of the surface. However, slightly mottling is observed bellow the specified depth.
W3	Such places in the study area are temporarily wet during the rain season, where the surface is frequently wet for considerable periods, particularly when rain is frequent, they remain wet and cause problem for the crops during the growth period. Crops are selective; hence, mottling is to occur between 20 to50cm of the surface.
W4	These are lands, which are permanently wet through out the rain season. Although they are deep and more clayey because of wetness they are abandoned from cultivation. Hence the land is saturated within 15 cm of the surface. These qualify them wetland of the study area.

Table2: Description of the rockiness criteria

Symbol	%Age cover	Description
R1	0 - < 2	The surface is free from rockiness i.e. no rockiness limitations
R2	2 - < 10	Rockiness is less sufficient to cause significance limitation with tillage
R3	10 - < 20	Land has sufficient limitation to interfere in tillage but is possible for raw crops.
R4	20 - < 40	Rockiness is severe to make all type of tillage practical
R5	≥40	In these land rockiness is very severe for growing any crops, but may be used for grazing and a forestation programmes

Table3: Description of stoniness criteria

Symbol	%Age	Description
S1	0 - <15	The area has free to rare stoniness cover
S2	15 - < 40	Stoniness is frequent
S3	≥ 40	Stoniness is abundant

Table4: Description of erosion hazard criteria

Symbols	Description
E1	These soil types have no apparent or slight sheet erosion.
E2	In this area erosion is moderate with moderately loss of the topsoil mainly by sheet erosion. However, visible rills, which are non-obstacle for tillage, are taking place to develop.
E3	Loss of the topsoil by high and severe sheet erosion and rills. Rills are terraced to develop to permanent gullies, some times remain with no crop during cultivation. Otherwise, can only be levelled by machinery.

Table5: Description of the slope limits for the steepness, slope classes of the surface criteria.

Symbol (slope class)	Slope in Degree	%Age slope	Description
I	0 -1	0 - < 2	Flat to almost flat (level)
II	1 - < 3	2 - < 5	Gently sloping
III	3 - < 5	5 -< 8	Moderately sloping
IV	5 - < 7	8 - < 15	Strongly sloping
VI	7 - < 17	15 - < 30	Moderately steep
VII	≥ 17	>30	Strongly steep

Appendix C

Appendix C.1 Determining soil erodibility class

As discussed in sub section of erosion assessment K-value is estimated from the available soil properties information with some pre stated parameters .The following equation and tables are used to determine the soil erodibility class for various soil group in the study as they are provided for Soil Erodibility assessment.

Equation4.1. (Smithers and Schulze, 1995). Estimation of erodibility class from the K-value
Where:

$$K= 0.01317(0.00021(12\text{-}Om\ \%)\ M^{1.14} + 3.25(Ss-2) + 2.5(Ps-3))$$

Where: Om% is the percent of organic matter for the respective soil type

M is obtained from the equation M= (SS %*(SS% +Sa))

Where: SS% is percent silt plus percent of very fine sand

Sa = percent of existing sand

S_s = Soil structure class

P_s = Soil permeability class

Table1: Soil structure class information (Wischmeier *et al,* 1971)

Soil structure	Structure class (S_s)
Very fine granular	1
Fine granular	2
Medium or Coarse granular	3
Blocky, platy or massive	4

Table2: Permeability information for the major soil texture classes (Renard *et al.*, 1991)

Texture class	Permeability class (P_s)
Clay, Silty Clay	6
Silty Clay Loam, sandy Clay	5
Sandy Clay Loam, Clay Loam	4
Loam, Silty Loam[1]	3
Loamy Sand, Sandy Loam	2
Sand	1

[1]NOTE: Although the silt texture class is missing because of Inadequate information, it would usually be class3.

Table3: Soil Erodibility Factors (K_{nom}) for various erodibility classes

Soil erodibility class	K_{nom}
Very high	> 0.70
High	0.50 - 0.70
Moderate	0.25 - 0.50
Low	0.13 - 0.25
Very low	< 0.13

Appendix C.2 Soil Erodibility Potential in the Study Area

Table 4 Soil Erodability Classes in the Study Area

Sample No.	Soil Texture Class	Organic Matter (%)	Silt (%)	very fine Sand (%)	Sand (%)	Soil Structure Class	Soil Permeability Class	K-Value	Soil Erodability Class
1	ClLm	1.64	37	7.6	35.3	3.25	2.50	0.40	Moderate
2	Cl	2	35	4.7	14.3	6.5	7.50	0.36	Moderate
3	Cl	2	28	5.16	10.84	6.5	7.5	0.30	Moderate
4	Lm	2	29	21.4	23.6	3.25	-2.50	0.21	Moderate
5	ClLm	2	28	11.46	17.54	3.25	2.50	0.26	Moderate
6	ClLm	2.10	37.6	12	33.95	3.25	2.5	0.44	Moderate
7	Lm	2.34	30.05	10.69	32.31	0	0	0.24	Low
8	SaClLm	2.13	25.05	23.45	27.8	3.25	5	0.43	Moderate
9	Cl	1.72	28	8.1	17.9	6.5	7.5	0.34	Moderate
10	Cl	1.83	27.2	5.13	10.87	6.5	7.5	0.29	Moderate
11	ClLm	1.00	28.96	10.06	21.06	3.25	2.5	0.29	Moderate
12	Cl	1.15	23.57	12.3	23.7	6.5	7.5	0.37	Moderate
13	SaClLm	1.87	25.97	23.20	27.23	3.25	2.5	0.41	Moderate
14	ClLm	1.07	28.8	10.50	21.61	3.25	2.5	0.29	Moderate
15	Lm	2.10	37.6	9.80	36.15	0	0	0.35	Moderate
16	Lm	2.34	30.05	10.20	33.05	0	0	0.24	Low
17	Cl	2.00	35	7.30	11.70	6.5	7.5	0.37	Moderate
18	Cl	2.00	35	8.20	10.80	6.5	7.5	0.38	Moderate
19	Cl	3.51	21.4	11.00	36.10	6.5	7.5	0.34	Moderate
20	ClLm	2.71	38.4	6.30	18.13	3.25	2.5	0.30	Moderate
21	ClLm	2.08	34	10.00	26.60	3.25	2.5	0.34	Moderate
22	SaLm	2.22	23.3	11.10	51.50	3.25	-2.5	0.25	Moderate
23	SaLm	2.50	24.5	13.20	46.20	3.25	-2.5	0.27	Moderate
24	SaLm	2.70	24	10.40	45.80	3.25	-2.5	0.23	Low
25	Lm	0.79	35.6	8.30	33.70	0	0	0.33	Moderate
26	Lm	0.82	33.4	12.10	37.00	0	0	0.37	Moderate
27	ClLm	2.00	32.1	8.30	27.60	3.25	2.5	0.31	Moderate
28	ClLm	2.64	34.8	10.20	18.60	3.25	2.5	0.30	Moderate
29	ClLm	2.20	35	10.00	20.00	3.25	2.5	0.32	Moderate
30	Cl	1.49	31.17	9.00	16.13	6.5	7.5	0.38	Low
31	Lm	2.14	47.5	12.40	32.50	0	0	0.50	Moderate
32	Lm	3.41	40.1	21.30	30.50	0	0	0.45	Moderate
33	StLm	1.78	50	11.30	19.30	0	0	0.46	Moderate
34	Lm	2.31	43	10.60	32.50	0	0	0.40	Moderate
35	Lm	0.76	42.6	13.10	33.00	0	0	0.51	High
36	SaClLm	0.65	23	19.30	32.70	3.25	2.5	0.38	Moderate
37	SaClLm	2.13	25.05	16.70	38.55	3.25	2.5	0.36	Moderate
38	Lm	2.10	37.6	10.50	25.45	0	0	0.30	Moderate
39	Lm	2.00	29	10.00	35.00	0	0	0.24	Low
40	Cl	1.15	23.56	12.32	33.68	6.5	7.5	0.41	Moderate
41	SaClLm	1.87	25.96	11.00	39.43	3.25	2.5	0.32	Moderate
42	Cl	1.15	23.57	11.20	34.8	6.5	7.5	0.40	Moderate
43	Cl	2.80	19.50	9.60	23.80	6.5	7.5	0.29	Moderate
44	ClLm	3.34	36.35	12.30	22.7	3.25	2.5	0.34	Moderate
45	ClLm	0.20	39.00	10.20	20.80	3.25	2.5	0.43	Moderate
46	SaLm	2.03	25.30	14.20	42.5	3.25	-2.5	0.29	Moderate
47	Cl	1.43	28.90	8.10	17.90	6.5	7.5	0.36	Moderate
48	Cl	1.56	27.30	6.80	18	6.5	7.5	0.33	Moderate
49	ClLm	2.57	35.00	6.50	19.10	3.25	2.5	0.27	Moderate

Table 4. Cont.

Sample No.	Soil Texture Class	Organic Matter (%)	Silt (%)	very fine Sand (%)	Sand (%)	Soil Structure Class	Soil Permeability Class	K-Value	Soil Erodability Class
50	Cl	2.75	27.50	7.90	18.1	6.5	7.5	0.32	Moderate
51	Cl	2.20	28.30	6.90	13.00	6.5	7.5	0.31	Moderate
52	Cl	1.93	33.40	5.20	12.7	6.5	7.5	0.34	Moderate
53	Cl	1.41	27.30	11.20	13.60	6.5	7.5	0.35	Moderate
54	SaLm	0.65	27.60	23.00	29.80	3.25	-2.5	0.42	Moderate
55	StCl	7.80	45.34	1.20	4.76	3.25	7.5	0.22	Low
56	Cl	1.30	19.60	9.20	27.80	6.5	7.5	0.32	Moderate
57	Cl	1.75	26.90	10.00	14.8	6.5	7.5	0.34	Moderate
58	Cl	1.38	25.90	7.60	9.70	6.5	7.5	0.30	Moderate
59	Lm	0.14	46.56	10.30	15.6	0	0	0.43	Moderate
60	SaLm	0.65	27.50	22.60	29.00	3.25	-2.5	0.41	Moderate
61	SaLm	0.72	24.50	24.00	31.39	3.25	-2.5	0.39	Moderate
62	StLm	1.78	50.00	11.20	19.40	0	0	0.46	Moderate
63	Lm	2.31	43.00	9.90	33.2	0	0	0.40	Moderate
64	Lm	1.29	24.70	10.00	19.5	6.5	7.5	0.16	Low
65	Lm	2.32	44.00	12.60	26.2	0	0	0.41	Moderate
66	Lm	2.25	40.50	9.20	12.6	0	0	0.26	Moderate
67	Lm	2.22	37.30	12.40	32.6	0	0	0.35	Moderate
68	StLm	1.99	52.30	10.00	9.8	0	0	0.40	Moderate
69	SaLm	1.93	24.60	23.00	56.7	3.25	-2.5	0.47	Moderate
70	SaLm	2.26	24.70	20.00	59.6	3.25	-2.5	0.42	Moderate
71	Lm	0.96	31.50	15.00	48.3	0	0	0.44	Moderate
72	StClLm	0.98	54.30	6.65	3.05	3.25	5	0.49	Moderate
73	SaLm	1.33	28.90	23.00	30.6	3.25	-2.5	0.42	Moderate
74	Lm	0.82	33.40	20.00	29.1	0	0	0.44	Moderate
75	ClLm	1.66	28.90	10.00	21.1	3.25	2.5	0.27	Moderate
76	ClLm	1.20	30.80	11.20	24.4	3.25	2.5	0.33	Moderate
77	Cl	1.83	26.30	5.60	20.7	6.5	7.5	0.32	Moderate
78	StClLm	1.56	53.80	5.60	8.4	3.25	5	0.48	Moderate
79	Lm	2.15	35.30	18.30	25	0	0	0.37	Moderate
80	ClLm	2.02	35.10	9.70	15.3	3.25	2.5	0.30	Moderate
81	Lm	1.40	39.00	23.20	17.5	0	0	0.48	Moderate
82	Lm	0.90	39.40	22.00	16.2	0	0	0.48	Moderate
83	StClLm	8.30	63.90	9.30	4.9	3.25	5	0.31	Moderate
84	Cl	1.66	30.90	3.80	15.3	6.5	7.5	0.33	Moderate
85	ClLm	2.71	38.40	10.30	14.13	3.25	2.5	0.32	Moderate
86	SaLm	2.64	24.00	15.00	41.2	3.25	-2.5	0.26	Moderate
87	SaLm	1.40	33.10	17.00	36.6	3.25	-2.5	0.42	Moderate
88	Lm	2.15	38.00	23.00	17.6	0	0	0.43	Moderate
89	Cl	1.26	31.90	4.80	13.2	6.5	7.5	0.34	Moderate
90	Lm	2.15	35.30	18.20	25.1	0	0	0.37	Moderate
91	ClLm	1.62	32.60	11.00	12.1	3.25	2.5	0.28	Moderate
92	ClLm	2.92	43.60	9.60	12.35	3.25	2.5	0.35	Moderate
93	ClLm	2.02	32.90	11.00	17	3.25	2.5	0.30	Moderate
94	Lm	1.39	38.40	18.00	20	0	0	0.41	Moderate
95	ClLm	1.28	33.05	12.00	21.2	3.25	2.5	0.35	Moderate
96	Cl	1.33	24.70	9.10	20.6	6.5	7.5	0.34	Moderate
97	ClLm	1.04	24.63	15.30	36.1	3.25	2.5	0.36	Moderate
98	Lm	1.49	43.40	19.00	11.6	0	0	0.44	Moderate
99	ClLm	1.98	28.40	17.10	21.1	3.25	2.5	0.33	Moderate

Table 4. Cont.

Sample No.	Soil Texture Class	Organic Matter (%)	Silt (%)	very fine Sand (%)	Sand (%)	Soil Structure Class	Soil Permeability Class	K-Value	Soil Erodability Class
100	ClLm	2.02	34.10	10.30	18.2	3.25	2.5	0.31	Moderate
101	Lm	2.15	37.20	21.00	16.6	0	0	0.38	Moderate
102	Lm	2.15	42.80	19.00	12.5	0	0	0.41	Moderate
103	Lm	0.82	42.80	16.00	15.5	0	0	0.44	Moderate
104	ClLm	2.17	40.10	12.30	17.20	3.25	2.5	0.39	Moderate
105	ClLm	1.86	25.60	13.00	22.7	3.25	2.5	0.27	Moderate
106	ClLm	2.00	41.30	10.05	17.45	3.25	2.5	0.38	Moderate
107	Lm	0.82	42.80	18.00	13.5	0	0	0.45	Moderate
108	Lm	2.00	35.00	24.00	18.7	0	0	0.41	Moderate
109	ClLm	1.56	42.70	12.60	16.1	3.25	2.5	0.44	Moderate
110	ClLm	2.17	25.60	14.00	19.9	3.25	2.5	0.27	Moderate
111	StLm	2.15	52.34	12.00	7.1	0	0	0.41	Moderate
112	SaClLm	1.75	20.50	14.00	35.5	3.25	2.5	0.28	Moderate
113	Lm	0.14	35.40	21.00	17.9	0	0	0.44	Moderate
114	Lm	1.56	35.50	20.00	19.5	0	0	0.39	Moderate
115	Lm	2.50	36.70	24.00	20.9	0	0	0.43	Moderate
116	StClLm	2.17	44.10	9.70	7.3	3.25	5	0.39	Moderate
117	StLm	2.15	53.20	19.50	10.5	0	0	0.56	High
118	ClLm	1.36	43.00	10.00	17	3.25	2.5	0.42	Moderate
119	Lm	1.30	32.80	27.00	13.5	0	0	0.42	Moderate
120	SaLm	1.00	31.50	17.00	41.5	3.25	-2.5	0.44	Moderate
121	Lm	2.50	36.70	22.00	18.9	0	0	0.39	Moderate
122	ClLm	2.09	24.80	13.00	32.6	3.25	2.5	0.30	Moderate
123	Lm	2.49	31.10	25.00	18.6	0	0	0.35	Moderate
124	SaLm	4.30	22.10	10.00	48.4	3.25	-2.5	0.19	Low
125	Lm	0.87	42.60	21.00	14.5	0	0	0.50	Moderate
126	Lm	0.83	43.00	23.00	22	0	0	0.60	High
127	SaClLm	1.13	25.60	12.00	40.7	3.25	2.5	0.35	Moderate
128	SaLm	1.37	27.90	9.60	47.8	3.25	-2.5	0.30	Moderate
129	Lm	1.05	43.00	21.00	13	0	0	0.49	Moderate
130	ClLm	2.02	35.10	10.00	15.5	3.25	2.5	0.30	Moderate
131	ClLm	1.27	41.40	11.00	17.5	3.25	2.5	0.42	Moderate
132	ClLm	1.58	40.40	9.60	14.9	3.25	2.5	0.37	Moderate
133	ClLm	1.76	46.80	8.60	13	3.25	2.5	0.42	Moderate
134	ClLm	1.60	34.40	10.70	18.1	3.25	2.5	0.33	Moderate
135	Lm	1.75	33.10	18.00	25.6	0	0	0.35	Moderate
136	Lm	1.02	39.00	17.90	25.6	0	0	0.47	Moderate
137	ClLm	1.60	34.40	10.20	17.8	3.25	2.5	0.32	Moderate
138	SaLm	1.33	31.00	10.00	46.7	3.25	-2.5	0.34	Moderate
139	SaLm	1.40	27.90	14.20	43.2	3.25	-2.5	0.34	Moderate
140	Lm	1.99	32.60	23.00	29.4	0	0	0.43	Moderate
141	Lm	1.27	46.60	21.10	17	0	0	0.50	Moderate
142	ClLm	2.02	35.80	9.00	18.2	3.25	2.5	0.31	Moderate
143	ClLm	2.17	32.60	12.00	18.8	3.25	2.5	0.31	Moderate
144	ClLm	0.89	30.30	11.30	24	3.25	2.5	0.33	Moderate
145	ClLm	1.36	30.30	9.60	25.4	3.25	2.5	0.31	Moderate
146	ClLm	1.97	38.00	8.70	17.3	3.25	2.5	0.33	Moderate
147	ClLm	0.71	28.60	13.00	38.1	3.25	2.5	0.40	Moderate
148	ClLm	1.60	36.70	10.30	18.7	3.25	2.5	0.35	Moderate
149	ClLm	1.24	35.10	8.20	27.3	3.25	2.5	0.36	Moderate

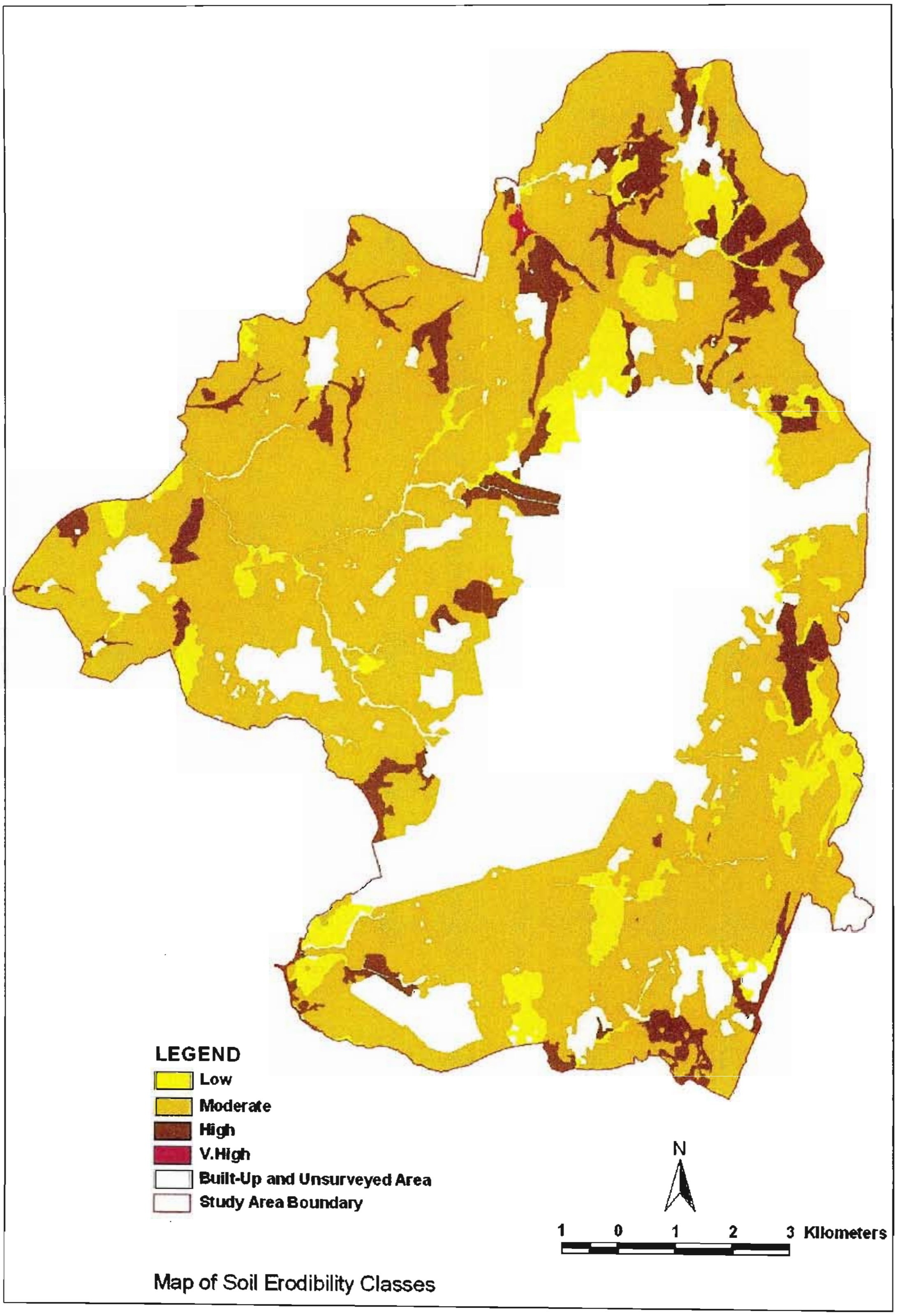
Table 4. Cont.

Sample No.	Soil Texture Class	Organic Matter (%)	Silt (%)	very fine Sand (%)	Sand (%)	Soil Structure Class	Soil Permeability Class	K-Value	Soil Erodability Class
150	SaClLm	0.61	24.60	7.80	37.9	3.25	2.5	0.29	Moderate
151	ClLm	1.95	36.50	11.00	24	3.25	2.5	0.37	Moderate
152	Lm	1.80	41.70	19.00	19.4	0	0	0.45	Moderate
153	SaLm	1.58	23.70	9.20	54.9	3.25	-2.5	0.26	Moderate
154	StLm	1.23	50.50	14.00	13	0	0	0.49	Moderate
155	SaLm	4.30	22.00	13.00	45.4	3.25	-2.5	0.19	Low
156	StLm	1.51	54.80	15.60	3.7	0	0	0.50	Moderate
157	StLm	2.70	58.50	11.2	5.3	0	0	0.45	Moderate
158	StLm	1.72	67.00	2.70	4.3	0	0	0.49	Moderate
159	StLm	1.81	54.40	14.90	7.6	0	0	0.50	Moderate
160	StClLm	2.00	51.20	7.30	8.5	3.25	5	0.45	Moderate
161	Lm	1.13	43.00	21.00	16	0	0	0.51	High
162	ClLm	0.70	28.60	10.90	31	3.25	2.5	0.34	Moderate
163	StLm	1.19	60.00	21.00	17	3.25	5	0.94	V.high
164	Lm	3.70	33.10	24.30	19.3	0	0	0.33	Moderate
165	ClLm	2.20	17.90	12.80	32	3.25	2.5	0.23	Low
166	SaLm	2.10	16.70	15.30	55	3.25	-2.5	0.24	Low
167	SaLm	1.46	17.40	16.70	55.2	3.25	-2.5	0.28	Low
168	ClLm	1.39	17.40	13.00	30.2	3.25	2.5	0.23	Low
169	StLm	3.50	53.30	7.80	3.2	3.25	5	0.40	Moderate
170	Lm	0.60	30.90	27.00	22.2	0	0	0.48	Moderate
171	Lm	1.06	48.30	17.80	7.1	0	0	0.48	Moderate
172	SaLm	0.70	31.60	12.00	43.9	3.25	-2.5	0.39	Moderate
173	StLm	2.26	48.30	9.60	6.7	0	0	0.32	Moderate
174	Lm	2.58	42.57	19.80	14.83	0	0	0.41	Moderate
175	StClLm	1.94	55.10	15.60	4.9	3.25	5	0.60	High
176	StLm	1.72	67.00	3.90	3.1	0	0	0.49	Moderate
177	LmSa	1.82	17.30	11.90	61.2	3.25	-2.5	0.23	Low
178	LmSa	1.65	12.20	14.60	67.5	3.25	-2.5	0.23	Low
179	SaLm	2.50	18.00	9.80	60.3	3.25	-2.5	0.20	Low
180	SaLm	0.77	70.00	3.50	7.5	3.25	-2.5	0.63	High
181	LmSa	1.23	13.50	13.40	68.7	3.25	-2.5	0.24	Low
182	StLm	2.66	58.20	11.70	4.8	0	0	0.45	Moderate
183	Lm	0.83	43.00	26.80	18.7	0	0	0.65	High
184	Lm	1.06	42.00	20.30	17.7	0	0	0.50	Moderate
185	SaLm	1.67	31.20	9.30	49.7	3.25	-2.5	0.34	Moderate
186	Lm	1.19	43.00	19.30	25.7	0	0	0.55	High
187	StLm	3.43	58.80	13.20	3.6	0	0	0.43	Moderate
188	SaLm	0.80	9.60	15.30	55.7	3.25	-2.5	0.19	Low
189	LmSa	1.34	14.80	13.20	64.4	3.25	-2.5	0.24	Low
190	LmSa	1.34	14.80	15.60	62	3.25	-2.5	0.26	Moderate
191	StLm	1.09	60.00	17.00	11	0	0	0.70	High
192	StClLm	3.50	53.30	3.60	7.5	3.25	5	0.38	Moderate
193	LmSa	1.90	13.30	9.20	68.9	3.25	-2.5	0.18	Low
194	LmSa	1.19	14.90	9.90	68.1	3.25	-2.5	0.21	Low
195	StLm	1.51	54.80	7.20	12.1	0	0	0.43	Moderate
196	ClLm	1.60	28.20	10.30	24.7	3.25	2.5	0.28	Moderate
297	StClLm	1.94	55.10	11.30	9.2	3.25	5	0.57	High
198	StClLm	2.26	48.30	8.90	7.4	3.25	5	0.42	Moderate
199	StClLm	1.89	55.10	15.00	6.6	3.25	5	0.61	High

Table 4. Cont.

Sample No.	Soil Texture Class	Organic Matter (%)	Silt (%)	very fine Sand (%)	Sand (%)	Soil Structure Class	Soil Permeability Class	K-Value	Soil Erodability Class
200	SaClLm	1.13	25.60	15.20	37.5	3.25	2.5	0.37	Modrate
201	SaClLm	1.36	24.80	13.00	32.6	3.25	2.5	0.31	Modrate
202	LmSa	1.86	13.30	7.60	71.5	3.25	-2.5	0.17	Low
203	LmSa	1.34	14.80	9.80	67.8	3.25	-2.5	0.21	Low
204	LmSa	1.38	10.70	14.30	70.6	3.25	-2.5	0.22	Low
205	LmSa	1.40	10.80	13.20	68.5	3.25	-2.5	0.20	Low
206	Lm	0.80	43.00	23.00	22	0	0	0.61	High
207	LmSa	1.95	7.90	17.30	70.4	3.25	-2.5	0.21	Low
208	LmSa	1.40	10.80	16.20	65.5	3.25	-2.5	0.23	Low
209	Lm	1.23	39.50	24.50	12.2	0	0	0.48	Moderate
210	StClLm	2.26	48.30	6.50	9.8	3.25	5	0.41	Moderate
211	ClLm	0.31	42.70	8.70	20	3.25	2.5	0.45	Moderate
212	ClLm	1.24	35.40	9.50	25.7	3.25	2.5	0.37	Moderate
213	ClLm	1.27	41.40	7.60	19.9	3.25	2.5	0.39	Moderate
214	ClLm	1.76	46.60	6.80	14.8	3.25	2.5	0.40	Moderate
215	Lm	0.80	33.10	23.20	43.6	0	0	0.58	Moderate
216	StLm	1.51	54.80	13.20	6.1	0	0	0.48	Moderate
217	ClLm	2.54	31.20	6.70	25.7	3.25	2.5	0.26	Moderate
218	ClLm	2.00	32.10	9.70	26.2	3.25	2.5	0.32	Moderate
219	StClLm	1.99	52.30	7.60	11.8	3.25	5	0.49	Moderate
220	Lm	1.59	35.30	25.00	21	0	0	0.46	Moderate
221	SaLm	2.03	25.30	12.70	45	3.25	-2.5	0.28	Moderate
222	LmSa	1.89	17.10	4.50	69.1	3.25	-2.5	0.17	Low
223	SaLm	1.93	24.60	13.10	43.6	3.25	-2.5	0.27	Moderate
224	Cl	0.77	29.40	6.50	24	6.5	7.5	0.38	Moderate
225	SaLm	0.08	19.10	13.60	56.3	3.25	-2.5	0.30	Moderate

Appendix C.3 Map of Soil Erodibility Classes in the Study Area



Appendix D

Appendix D.1 Climatic characteristics

Table1: Criteria for climatic capability classes

Ratio of MAP to annual APAN	**Capability class(C)**
0.3- 0.37	C7, C8
0.38 -0.44	C5, C6
0.45 – 0.49	C3, C4
0.5 – 1.0	C1, C2, C3, C4, C6
Mean annual minimum Temperature (°c)	**Class**
>7	C3
6.5 - 7	C4
<6.5	C5
Heat Units of the Growing Season (Degree Days)	
>1340	C3
1320 - 1340	C4
<1320	C5
Mean Ann. temperature	**Class**
> 20	C1, C7, C8
18 - 20	C2, C5, C6, C7, C8
16 - 18	C3, C5, C6, C7
12 - 16	C4, C5, C6
< 12	C7

Appendix D.2 Description of Climatic Capability Classes

code	limitation rating	description
C3	Moderate	This class is with slightly restricted growing season as compared to the other places of the study area. Precipitation in this class exceeds 1/3 of PET for most of the growing season. The average monthly and monthly mean minimum temperatures are between 16.5°c and 17°c. Heat units for this class are larger than 1340 degree days for the growing season. Therefore, this class is relatively good for moderate range of adopted crops.
C4	Moderate to severe	In this class both moisture stress and low temperature are moderately restrictive in the growing season. Average monthly rainfall exceeds 1/3 of the monthly PET. Average monthly and monthly mean minimum of temperatures are about 16°c and heat units are more restrictive than defined in class 3 which range between 1320 -1340, therefore, further limit the choice of crops grown.
C5	severe	Moderate to severe restriction of growing season due to low temperature and moisture stress. Mean monthly temperatures and monthly mean minimum temperatures are less than 16°c and 6°crespectively through out the year with heat units between 1277 and 1320 degree days. Hence the area is highly susceptible to frost. Therefore, this area is relatively suitable for very limited crops.

Appendix E

Land capability classes description

Class I – Land in this class has no or slight limitations. Soils in this class have no significant limitations in use for wide range of crops. They are very deep, well to imperfect drained with good stand to uphold moisture and are easily worked. The surfaces in this class land are free from any rockiness and stoniness limitations. Despite the fact that, these soils are fairly supplied with nutrients as a result of intensive cultivation they are highly responsive to inputs of fertilizer. Slopes in this class land are flat to almost flat where erosion hazard is none to slight. This class land is therefore, highly productive and suited for a wide range of crops in the study area that have a high potential for intensive crop production.

Class II- Land in this class II has very few permanent limitations. Soils in this capability class have moderate limitations that restrict the range of crops grown. In general soils of this class land are moderately deep less than the ideal effective depth with good moisture holding capacity. However, in some places of the study are although soil effective depth are very deep, the excessive clayey nature of the soil texture is very critical to crops creating problem for plant growth during the rain season where permeability is restricted for most of the crops. Limitations such as rockiness and stoniness are not sufficient to cause significant problem with tillage. Otherwise, the limitations are moderate and soils can be managed and cropped with little difficult. Slopes in this class range from almost flat to gently sloping where erosion hazard is recorded as moderate sheet erosion with very few signs of rills. This class land is therefore under good management they are moderately to high productive for a fairly wide range of crops.

Class III- The permanent Limitations in this capability class III land are severe that restrict the choices of crops. Soils are moderately to shallow effective depth with relatively low moisture holding capacity although they are well drained soils. In this class land slow permeability of the sub soil is typically observed. Slopes in this class land are moderately slopping where erosion are with severe sheet erosion and frequent signs of rills. In some places of the study area this class land has sufficient limitations of rockiness and stoniness to influence tillage. The limitations are more severe that the soils in class II have moderate slopping where erosion is with severe sheet erosion and frequent signs of rills. In some places of the study area this class land has sufficient limitations of rockiness and stoniness to influence tillage. The limitations are more severe that the soils in class II land. However, this class land with good management they are moderately productive for a fair range of crops.

Class IV- This class IV land has very severe limitations. Soils are with severe limitations that restrict the range of growing crops. Hence, soils effective depth is shallow to support a range of crops. Although soils in this class IV are well drained they have a very poor moisture holding capacity. Slopes are generally characterized by gentle to steep sloping. Erosion hazard in this capability class IV land is very severe where severe sheet erosion and rills that developing to gullies are prominent features that creating tillage problems. Furthermore, Rockiness and stoniness are serious and severe limitations in this class land. In general this class land has poor soil for cultivation. Cultivated crops are very few and are highly selected as a result of the combined effect of both soil and land characteristic limitations. Hence, regularly cropping is only possible in save use when fallowing for several years is applied. As a result this land is low to fair productive for a very few range of crops. Thus, this land is marginal productive for agriculture in the study area.

Class V- Land in this class V is unsuitable for crop cultivation as a result of severely restricted permeability. Despite soils in this class are moderate to deep their use for field crops is constrained as a result of excessive wetness, where land is permanently wet through out the rain season. Although their slopes are flat to almost flat, these lands are part of the watercourse during the rain season. Hence, wetness is a severe limitation of this land capability class in the study area. However, this land has a good potential productivity for pasture and is used for grazing during the dry season.

Class VI- Soils in this class VI capability land are very shallow to support crops. However, soils provide some sustained grazing for farm animals of the study area. Otherwise, limitations such as rockiness and stoniness are so severe that makes improvement of grazing difficult. Slopes in this class vary from strong sloping to moderately steep. As a result of the shallow soils and nature of the surface slope erosion hazard is severe were several rills are typical land characteristic of this class in the study area. Nonetheless this class land is being used for grazing purposes.

Class VII- Land in Class VII has very severe permanent limitations of use that render it unfavorable for cultivation. Both soils and land characteristic have no capability for arable cultivation or permanent grazing. Permanent limitations such as rockiness, stoniness, effective depth and excessively steep slopes are the main characteristic of this class land. Hence, this class land in the study area comprises areas of rocky and bare soils of the small domes and hills. Therefore this class VII land is used neither for cultivation nor for grazing. However, it can be only safely used for tree plantation for conservation measures. Otherwise, it is useful in the study area for various construction development project purposes.