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**UNIFORM PRODUCTIVITY AREAS
AND
LAND DEGRADATION RISK
IN ETHIOPIA**

**by
Awegechew Teshome**

**A Thesis submitted to the
Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for
Master's degree.**

**Geography Department
Carleton University
Ottawa, Ontario
May 8, 1990.**

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and

"Land Degradation Risks in Ethiopia"

submitted by Awegechew Teshome

in partial fulfilment of the requirements for
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Thesis Supervisor

Chair, Department of Geography

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ABSTRACT

The Canadian Analysis of Drought in Africa (CANDAF) software package has been downsized to CANDAF-Ethiopia. CANDAF defines Uniform Productivity Areas (UPAs) based on analysis of regional climatic records. Ethiopia has been divided into 13 UPAs, with the boundaries determined from climatic records being modified by consideration of topographic and soil factors. The long-term average monthly soil moisture balance of each UPA has been simulated using rainfall records, calculated potential evapotranspiration and soil moisture storage capacity.

The productivity of about 44% of Ethiopia is limited by severe moisture deficiency. The moisture simulation results and the minimum growing period for Ethiopian crops (generally >90 days) were employed to assess each UPA's suitability for seasonal and perennial crops and the nature of land degradation risks. The establishment of crop calendars and a system of mid-season crop production estimation is recommended to assist in improving food production while reducing the risks of land degradation.

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I would like to thank Jim Dyer, who allowed me to make use of CANDAF as the basis of this thesis. Jim has been working with me enthusiastically in developing the CANDAF-Ethiopian package from the continental software files. His valuable comments, suggestions and encouragement, throughout the process of writing the text, provided motivation and is highly appreciated. Jim and his colleagues at Agriculture Canada (Soil and Climate section) have been very helpful in assisting me to gain some computer skills and allowing me to use their facilities.

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CHAPTER ONE

Sustainable Productivity and The Need For Areally Specific Analysis.

1.0. INTRODUCTION

Ethiopia is a country where per capita food production has dropped consistently in the past decade [Earthscan (1985); FAO (1986)]. This disturbing trend has been given many different explanations. Whatever the causes, this trend must be reversed or millions of human lives will be further threatened by its undesirable effects. In this document, an analytical procedure is proposed to investigate regional production potential and the risks of land degradation processes affecting food production in Ethiopia.

Can Ethiopia feed itself? If it can, why has it failed to do so? Is the state of the environment part of the problem? From the resource and environmental point of view alone, these questions are complicated to answer, because no one is fully knowledgeable of the status, distribution and inherent characteristics of Ethiopia's environmental resources. However, to solve the problems associated with food production, the environmental resources have to be taken into consideration. By remaining ignorant of the inherent characteristics of the resources, the task of making land use and food production systems productive and sustainable will continue to be difficult.

Further questions arise about the country's land use practices, particularly newly introduced practices aimed at achieving food self

sufficiency. Are they competing with or complementing each other? Are they the right type to sustain productivity, or are they incompatible with the inherent characteristics of the resource base and a major cause of land degradation? To what extent are the external forces, such as demographic changes, forcing the land use practices to stress the resource base and expose it to degradational processes which may be irreversible?

Unlike some north African countries, such as Niger, Mali, Somalia and Chad, which are single ecosystem dominated countries (Lewis and Berry, 1988 and Shahin, 1989), Ethiopia has a wide diversity of ecosystems. All of Ethiopia is within the tropics, although due to altitude, some of the Ethiopian highlands experience temperate-like climatic conditions. With the exception of a few mountain areas which were glaciated during parts of the Pleistocene, the soil parent materials are old and consequently, many of its soils are old and are not rich in soluble materials. In areas which have been tectonically active, some of the best quality soils of the region have developed on volcanically-derived parent materials.

The country is the source of many rivers, including the Blue Nile, Shebelle, Genalle, Atbara, Omo and others. Despite this, surplus rainfall is generated only from a small part of the country. For much of the country, rainfall variability is the biggest problem in agriculture, as well as for most other human activities that depend on water resources. Historically, Ethiopia's climate has followed the pattern of a sequence of years with above average rainfall followed by a series of years with below average rainfall (Wood, 1977 and Nicholson, 1981).

Ethiopia has a long history of existence as an independent nation, dating from about 3000 B.C. Agrarian life and urbanization along the

highlands started from this time. Today the country is one of the world's least developed nations, with a GNP of \$140 U.S per capita (UN, 1987). Most of the Ethiopian farmers are subsistence peasants. These subsistence farmers produce food, primarily to feed themselves and their family, without using any major capital input. The subsistence farmers use their labor, land, and livestock, but lack the purchased inputs of fertilizers, pest control chemicals, mechanization and irrigation. In many cases, these latter inputs could raise yield levels significantly. Simply because the traditional farmers do not have the means of increasing yield levels, raising total production cannot be done without increasing the land area under cultivation, and hence expanding farmland into fragile ecosystems. Any increment of food production achieved by farming more land necessitates an increased demand for livestock numbers, as a source of energy to farm the expanding crop land. This low input/low yield form of agriculture has been considered as the main cause of land degradation (FAO, 1986). The fact that Ethiopia has the largest livestock population in the African continent (FAO, 1986), is disturbing. What is most amazing about the Ethiopian subsistence farmers is that, without purchased inputs, they produce almost all crops needed to feed the population and, in addition, to earn some foreign exchange for the government.

With the extensive environmental diversity in the country, a wide range of crops is grown for subsistence and commercial purposes. An examination of the range of crops found throughout Ethiopia indicates that many of them are not indigenous. However, the country is known also to be one of the sources of native genetic material of the world's cereal crops (Vavilov, 1951 and Dasman, 1984). Cereals which have a bad

reputation in causing environmental degradation, particularly in arid and marginal lands (Lewis and Berry, 1988), are grown extensively in Ethiopia.

A major fundamental cause of land degradation problems is rooted in the inherent characteristics of the resource base which are often ignored, or at least mis-stated. It is a contention of the writer that Ethiopians would not have been the victim of the amplified land degradation problems, if the inherent environmental constraints of the country had been taken into account in planning recent food production systems. This belief is the basis of the linkage being assumed here between sustainable food production and environmental resource protection. This does not mean that land degradation problems are caused only by the inherent characteristics of the resource base and the traditional farming systems used. Other factors, such as land use management issues, poverty, government investment priorities, political instabilities and effectiveness of international aid programmes have contributed to Ethiopia's land degradation problems.

The above short introduction gives us the picture of contemporary Ethiopia, which was transformed politically from a semi-feudal society to socialism almost 16 years ago.

In this paper a holistic approach is pursued to explore the capabilities of the resource base [plant-soil-climate] in sustaining the country's natural and agricultural ecosystems. To this effect, CANDAF-Ethiopia was developed from a computerized climate analysis system called CANDAF (Canadian Analysis of Drought in Africa). This computer software package for weather-based African drought analysis was developed by Agriculture Canada for CIDA (Dyer and Cianferro, 1988). The package has

the potential to evaluate weather-based production potential under both current and historical climatic conditions. The Ethiopian portion from CANDAF is therefore adopted to aid the process of investigating the risk of land degradation in that country. CANDAF-Ethiopia operates on an area basis rather than on a site-by-site basis. The UPA concept has been employed to subdivide the country using an ecosystem approach. UPAs (Uniform productivity Areas), according to Bain, Mack, and Prevost (1986), are land units which are similar in factors which dominantly affect agricultural productivity. These may include soil conditions, climatic conditions, vegetation characteristics, landforms, topographic features and land use practices discernible by the area's spectral uniformity when compared to adjacent areas. The susceptibility of the resource base to the processes of land degradation has been investigated by examining each distinct eco-region separately. The contribution of land use practices in each UPA to the process of land degradation has also been examined.

1.1. OBJECTIVES

- 1.1.1. To establish CANDAF-Ethiopia and the Ethiopian UPAs from the continental package and other related pedological and topographic information,
- 1.1.2. To investigate the susceptibility of the Ethiopian resource base to the processes of land degradation,
- 1.1.3. To evaluate the current agricultural systems of the country from the perspective of land degradation risks,
- 1.1.4. To investigate the potential for expansion of the major agricultural systems beyond their current limits.

Sustainable productivity, to meet the food, shelter and fiber demand of the growing human population of Ethiopia, is a high priority. Sustainable grazing/browsing production is also equally important to sustain Ethiopia's large livestock population and to protect the country's resource base from degradative processes following overgrazing and trampling.

Food production systems which are ineffective and non-compatible to the resource base of a particular region can lead to land degradation because of

- 1) Failure to produce the required food to feed the human and livestock population,
- 2) A lack of ground cover resulting from low biomass production,
- 3) Bare soil exposure due to poor crop growth and crop failures, and soil erosion,
- 4) Lack of basic essentials for crop growth which include: soil moisture, temperature, soil structure and texture, and soil nutrients.

The sustainable yields of food production systems are dependent on the quality of the resource base, and conversely, on the other hand, the sustainable productivity of the resource base is influenced by the appropriateness of the land use systems that are practised. This is a feed back relationship, and hence, land use patterns that are incompatible with the resource base lead to the acceleration of land degradation followed by insufficient biomass production and food production short-falls.

Soil and climate factors are the primary parameters of investigation

used to evaluate the sustainable productivity of the Ethiopian UPAs. The major agroecosystems of each UPA are described to assess their compatibility with the resource base. The description of the agroecosystems includes both the cropping and grazing activities. Length of growing season and typical planting date, water and temperature requirements, and, locations and months of successful growth of the common perennial and annual crops have been identified. The major soil types supporting the annual and perennial crops are also included in terms of their water retention capacity and effective root depth. At the end of the descriptive process, the most appropriate soil water storage and crop water coefficients are used to examine the success of each agroecosystem in producing reliable biomass production in the UPA through a computerized water balance procedure.

CHAPTER TWO

BACKGROUND INFORMATION ON ETHIOPIA

2.1. LOCATION, TOPOGRAPHY and AREA.

Ethiopia, in the horn of Africa, south and west of the Red Sea, extends from latitude 3°N to 18°N and from longitude 33°E to 48°E. It encompasses an area of 1,223,600 km².

It is bordered to the east and south east by Djibouti and Somalia, in the south by Kenya and in the west by Sudan. To the north-east, Ethiopia has almost 1000 kms of coast line along the Red Sea. The Dahlak Islands, in the Red Sea, are also part of Ethiopia. Fig 2.1 shows the political map of Ethiopia.

Ethiopia consists, topographically, of highlands surrounded by extensive lowlands. The Great Rift Valley of East Africa divides the Ethiopian highlands into eastern and western sections. The Rift Valley has a width ranging from 40 to 60 km and contains ten lowland lakes. The western highlands, with an average elevation of 2500m, include most of the western half of the country from the Red Sea coast in the north to the Kenyan border in the southwest. These highlands are characterized by steep gorges and abrupt escarpments that make communication difficult. The northern parts of these highlands are dominated by the Semien Mountains, which rise to more than 4620m. The eastern highlands are characterized by lower elevations and are less broken by valleys and gorges. These highlands descend gently eastward towards the Indian Ocean.

The bisected highlands are surrounded by extensive lowlands: the

Red Sea coastal plains and the Danakil lowlands in the north and northeast; the Sudanese deserts in the west; the Somali and Ogaden deserts in the east and southeast; and the Kenyan lowlands in the south.

The lowest point of Ethiopia is -150m at Dallol, in the Danakil lowlands. The total area below sea level is approximately 6,400 km², less than 1% of Ethiopia. Approximately 482,000 km² (41%) of Ethiopia is between sea level and 1000 meters in elevation, 672,000 km² (56%) is between 1,000 meters and 3000 meters, and 31,000 km² (3%) is above 3,000 meters (Donahue, 1969). The highest point of Ethiopia, Ras Dashen, has an altitude of over 4620.

Ethiopia contains a wide diversity of life and landscapes, many of them exhibiting spectacular ruggedness and scenic beauty.

2.2. CLIMATIC RESOURCES.

Ethiopia enjoys both tropical and temperate climatic conditions, due to its range of altitudes. Both the temperature and rainfall conditions pose problems to the country's biomass production. In order to optimize the use of these essential resources in biomass production, it is very important to understand the physical mechanisms involved.

Temperature in Ethiopia is highly influenced by altitude. Ethiopia has two different temperature lapse rates (FAO, 1984). Most of Ethiopia has a lapse rate of -0.59 °C/100m rise, but the south-eastern lowlands and the Ogaden region have a lapse rate of -0.27 °C/100m rise.

At the extreme, Dallol (elevation 150m/b/s/l) in the Danakil depression has a mean daily temperature of 34.5 °C, while the temperature

Figure 2.1

ADMINISTRATIVE DIVISIONS OF ETHIOPIA

at the highest peak in Ethiopia (Ras Dashen) is sufficiently low that light snowfall can be experienced at almost any time of the year. Dallol (Pedgley, D.E., 1967) is one of the hottest locations of the world, with an annual mean maximum temperature of 41°C, annual minimum of 28°C and mean annual temperature of 34.5°C. Over a 58 month period (1960 to 1965), with some missing months, every month had at least one day in excess of 38°C, while some days the thermometer never went below 30°C. The extreme temperatures recorded were 21°C and 49°C (Pedgley, 1967).

According to Griffiths, (1972), Ethiopia gets rainfall by three mechanisms:

- 1) The Inter Tropical Convergence Zone (I.T.C.Z), via the trade winds, brings summer rain from the south east to most parts of Ethiopia. This summer rain starts in mid-June and continues until mid-September. The seasonal movement of this zone brings different amounts of rainfall and different lengths of rainy seasons to the southern and northern parts of the country.
- 2) The monsoons from the Indian Ocean also bring rainfall mainly to the south and south eastern lowlands of Ethiopia, which have a bimodal rainfall distribution with rainfall periods from March to May and September to October. Depending on location, the monsoons and the trade winds may strengthen or check each other. The areas where they converge, such as some parts of northeastern highlands of central Ethiopia, receive more precipitation than the surrounding areas.
- 3) The Ethiopian highlands, receive orographic rainfall, as a consequence of the cooling, condensation and production of rainfall

when winds are forced to rise. As a result, the windward sides of the mountains, such as eastern Gondar, receive more precipitation than the leeward sides of western Tigray.

These three different mechanisms are responsible for the formation of four distinct annual rainy seasons, of which two have similar causes. The four different rainy seasons are:

1. The big rains in the summer, during which over 85% of the food crops are produced. These rains are called "Kirmet" in Amharic. The single cause of Kirmet rains is the monsoonal air flow pattern, which affects the different parts of the country to different extents and at different times of the year: in the high rainfall areas of southwestern Ethiopia Kirmet occurs from spring until autumn; in the northern, northwestern, central north-eastern, and eastern highlands, the big annual Kirmet rains occur from June to mid-September; the Red Sea coastal plains receive only a small amount of precipitation from this seasonal rain; and Kirmet does not occur at all in the Ogaden plains and the south and southeastern lowlands of Ethiopia. The Kirmet rain ceases in the north around the end of August with the retreat of the I.T.C.Z., which gradually moves southward until the end of October, leaving most of the country under the influence of the easterly trade winds.
2. The rains in the spring, known as "Belg" in Amharic, occur as a result of the existence of moist, unstable easterlies. The Belg rains normally occur in the eastern, south and southeastern lowlands. Some windward sides of eastern, central and north-

eastern highlands receive small amounts of Belg rains. In southwestern Ethiopia, the Belg rains gradually evolve into the monsoonal rains of the summer. The Belg rains may bring rainfall to the coastal plains immediately following the winter rains. These rains do not normally occur in northern, and northwestern Ethiopia.

3. The rains in autumn known as "Tseday" in Amharic, also have their origin in moist, unstable easterlies. In the wetter parts of southwestern Ethiopia, Tseday rains gradually evolve from the monsoonal summer rains. In the eastern highlands, they come immediately after the summer rains. In the coastal plains, the Tseday rains merge into the following winter rains. In the central and northeastern highlands, Tseday rains are very sparse and unreliable. Tseday rains do not normally occur in the north and northwestern Ethiopia.
4. The winter rains are limited to the Red Sea coastal plains of Ethiopia. The cause of their occurrence is the convergence of the dry winds from the Sahara and Arabia with moisture-bearing wind systems from the Red Sea.

These four rainy seasons do not produce four distinct annual growing seasons anywhere in the country, but provide a growing season of varying duration. If an area is influenced by two or more rain generating mechanisms, the appropriate rainy seasons either merge into one another to extend the growing season, produce two rainy seasons, or the rain during part of the period may not be enough to compensate for potential

evapotranspiration and to support biomass growth.

Short-falls in precipitation have become a common experience to the Ethiopians. This can be attributed to several factors :

- 1) Because of its location south of the Sahara and in proximity to the Arabian deserts, the winds from the north pass dominantly over dry continental areas and are dry. As a consequence, extensive areas of the country receive no rainfall when winds blow from these directions.
- 2) The presence of the large island of Madagascar also contributes to the aridity of eastern and south-eastern Ethiopia, by blocking the monsoon winds from the Indian Ocean. Madagascar is one of the reasons why east Africa is more arid than west Africa (Nieuwolt, 1977).
- 3) The large landmass of the Arabian peninsula, across the Red Sea and the Gulf of Aden, also blocks some moisture-bearing winds from reaching the horn of Africa.

The direction of moisture-bearing seasonal air masses and elevations determine the amount of rainfall received in Ethiopia. Areas which are in the path of moisture-bearing winds, like southwestern Ethiopia, get more rainfall. Areas with high altitudes, excluding some leeward slopes, also receive more rainfall than most lowlands. The southwestern lowlands (the Baro and Akobo River plains), situated close to the all year round moist areas of the country, lie in the path of the summer rain bearing winds and get more rainfall than the eastern and southeastern lowlands. Rainfall variability increases as rainfall amount decreases and when rain-bearing winds pass from highland to lowland areas.

This introductory discussion of the climates of Ethiopia indicates that, in general, the lowlands suffer from low precipitation and high temperatures, while the highlands have moderate precipitation and may be affected by frost hazards. Despite the temperate characteristics of a large part of the country, Ethiopia does not have any season sufficiently cold to preclude plant growth and hence cropping is possible throughout the year so long as adequate moisture is available. As in many other regions of Africa, water supply governs the Ethiopian agro-ecosystems.

2.3. SOIL RESOURCES.

Ethiopian soils are extremely variable due to the variable physiography, diverse climatic patterns, and other differences in the five soil forming factors (i.e. time, climate, parent material, topography and biological factors, after FAO, 1984a).

Ethiopia is located across a series of major fault lines associated with low magnitude geologic movements (Last, 1987). These movements have brought magma from the deepest layers to the surface during many past volcanic eruptions. Last (1962) has distinguished three dominant types of parent rocks as of importance in influencing the properties of the soils of Ethiopia:

1. Granites of the crystalline basement are the parent materials for some soils of the west and southwestern highlands. These have the tendency of forming sandy soils.
2. Volcanic rocks are wide spread in central Ethiopia. The soils developed from volcanic basalts tend to form fertile loams, generally red, but sometimes black.

3. Limestone and sand-stone are common in the eastern lowlands. Shallow, poor sandy soils are common in this area.

Systematic study of Ethiopian soils is a recent endeavour. Murphy (1968) distinguished the Ethiopian soils by their color and chemical properties, without classifying them according to any of the recognized soil classification systems. Donahue (1968) regrouped the work of D'Hoore, 1964, who had designated the Ethiopian soils into 18 units, according to the 7th Approximation (1960). According to Donahue, most of the Ethiopian soils can be classified into 4 orders :

1. Aridisols comprise 50% of Ethiopia and occur mostly in the eastern and to a lesser extent in the southern, part of the country.
2. Entisols occupy 25% of Ethiopia, mostly in the mountainous west. They are predominantly rocky.
3. Ultisols occur in the southwest and total 6% of Ethiopia.
4. Vertisols comprise 19% of the country and occur mostly at intermediate elevations in the western half of Ethiopia.

The FAO - UNESCO (1977) world soil map, Africa section, identified 13 soil associations within the Ethiopian territory and estimated their areal coverage (Table 2.1).

Westphal (1975) translated the FAO-UNESCO soil associations of Ethiopia into USDA Soil Taxonomy terms. According to his translations, the following seven orders and thirteen suborders of soils are found in Ethiopia.

- A. Entisols are soils which lack distinct pedogenic horizons.

Suborders

1. Fluvents occur in several parts of the country on recent fresh

water deposits of rivers. Their medium to fine texture gives them good water holding capacity. They are good agricultural soils, particularly when they contain weatherable minerals.

2. Psamments are sandy soils with low water holding capacity. They are common in the northern provinces of Tigray and Eritrea. They are susceptible to wind erosion.
3. Orthents occur largely in east and south-east Ethiopia. They are formed on recent erosion surfaces and, as a result, are very shallow with solid rock appearing close to their surfaces.

- B. Inceptisols are soil orders where further soil development processes have taken place than in Entisols, and the beginnings of B-horizon development are evident. Ethiopian Inceptisols have fine texture, contain some weatherable minerals and have a relatively high cation exchange capacity. In warm seasons they contain plant-available water for more than three consecutive months.

Suborders

1. Andepts occur in the southern Rift valley, around Lake Chamo and Lake Abaya. They have generally formed in volcanic ash deposits and contain allophane.
2. Tropepts include weakly-developed soils that are more or less freely drained. Their color ranges from brownish to reddish. These soils are found in the central and eastern highlands of Ethiopia.

Table 2.1. The major soils of Ethiopia and the extent of Ethiopian territory which they occupy (FAO-UNESCO Classification, Africa section, 1978).

MAJOR SOIL GROUP	EXTENSION (in 1000 ha.)	Percentage of COVERAGE	SOIL TAXONOMY EQUIVALENT
1. Regosols	26959	22.12	Entisols
2. Cambisols	24934	20.50	Inceptisols
3. Nitisols	17597	14.44	Alfisols
4. Yermosols	16530	13.56	Aridisols
5. Xerosols	12915	10.60	Aridisols
6. Lithosols	8426	6.91	Entisols
7. Vertisols	5496	4.51	Vertisols
8. Arenosols	3478	2.85	Entisols
9. Fluvisols	1932	1.58	Entisols
10. Acrisols	1260	1.03	Ultisols
11. Ferralisols	859	0.70	Oxisols
12. Andosols	844	0.69	Inceptisols
13. Solonchaks	319	0.26	Aridisols
14. Salt flats	316	0.25	
TOTAL	= 121,865,000 ha.	100.00%	

- C. Aridisols are found in the arid regions of Ethiopia. have one or more pedogenic horizons, but lack a surface horizon significantly darkened by humus.

Suborders

1. Argids occur only in western Eritrea along the Sudanese border. These soils have an argillic horizon.
2. Orthids do not have an argillic B horizon. They cover extensive areas north, south and east Ethiopia. Depending on their location, these soils can be saline, alkaline or gypsic.

- D. Vertisols are heavy-textured soils with high amount of montmorillonitic clay. The soils in this order have high bulk density, slow permeability, and crack when they are dry. Due to their high clay contents, Vertisols have a very high cation exchange capacity, which is fairly uniform with soil depth. They exhibit self-mulching that results in the formation of gilgai micro-relief.

Suborders

1. Uderts have a soil moisture regime in which the soil neither remains dry for as long as 90 cumulative days nor for as long as 60 consecutive days in the 90 days when the soil temperature at 50cm is above 50C. There are two groups of Uderts in Ethiopia :
 - a. Pelluderts,- their moist color ranges from gray to black. They are found in the valleys around the capital city.

b. Chromuderts are more strongly colored and are found in southwest Ethiopia.

2. Usterts, have a drier soil moisture regime, and are seldom found outside southwest Ethiopia.

E. Alfisols are soils which have an argillic B-horizon as a result of translocations of silicate clays. They retain a high base saturation and are generally fertile.

Suborders

1. Udalfs are found in the warm humid areas of southwest Ethiopia. They are brownish or reddish in color.
2. Ustalf are only located in small areas, mainly in southwest Ethiopia.

F. Ultisols resemble Alfisols in having an argillic B-horizon, but they are more leached and generally poorer in plant nutrients.

Suborders

1. Udufts are found in scattered areas in southwestern Ethiopia. The Udufts are more or less freely drained, humus-poor Ultisols found in humid climates with a well distributed rainfall. The upper horizon is light colored, whereas the color of the argillic horizon ranges from yellowish brown to reddish.

G. Oxisols are extremely weathered soils, dominated by kaolinite, free oxides and quartz minerals. Their texture is sandy loam or finer.

Suborders

Orthox is the only suborder occurring in Ethiopia. The Oxisols are concentrated in high rainfall areas of southern Ethiopia.

2.4. HYDROLOGICAL RESOURCES.

The high rainfall and the rugged topography of Ethiopia have resulted in numerous rivers and lakes. The major rivers of Ethiopia are the Blue Nile, Takaze, Atbara, Baro, Akobo, Omo, Awash, Genale, and Wabi Shebelle. The drainage systems of these major rivers are totally influenced by the topographic nature of the country and river discharges are very much correlated with the amount of precipitation received. Most of the western highlands are drained westwards via the Mereb, Takaze and Abay (the Blue Nile) to the Nile system. The Abay/Blue Nile originates from Lake Tana, the largest highland lake. The southwestern high rainfall area of Ethiopia drains into the White Nile system by the Akobo, Gilo and Baro rivers. The Omo River drains the southern part of the Rift Valley southwards into the closed basin of Lake Turkana bordering Kenya. The southeastern highlands drain into the Indian Ocean through Somalia by the headwaters of the Wabe, Shebelle and Juba river systems. Discharges from the central Rift Valley escarpments enter a series of closed basins. In the northern Rift Valley, the Awash crosses the Afar plains and terminates in Lake Abbe near the Djibouti border. Discharges from the extreme north and northeastern parts of Ethiopia are short and intermittent and enter into the Red Sea via the Barka and other small rivers.

According to FAO (1984), 0.6% (683,000 ha) of the country is covered by water bodies, including the 12 major lakes of Ethiopia. Lake Tana and

Lake Ashenge, the only two highland lakes, are situated in the central highlands. The remaining ten are in closed basins along the central and southern portions of the Great Rift Valley.

2.5. VEGETATION and WILDLIFE RESOURCES.

The diversity and distribution of Ethiopian vegetation are influenced by the diverse soil types, altitude, rainfall and temperature conditions of the country. The floral and faunal resources of Ethiopia are not well studied, which makes the process of understanding the ecological role of these natural resources more difficult. FAO-UNESCO (1977) and F/O (1984) have provided vegetation classifications for Ethiopia.

2.5.1. FAO-UNESCO (1977) Classification.

FAO-UNESCO (1977), in its effort to classify the soils of Africa, has categorized Ethiopian vegetation into five major vegetation communities:

1. Tropical wet evergreen forest, which includes all the tropical montane rainforests of Ethiopia.
2. Savanna
 - a. highland dry savanna
 - b. open rain-green thorn tree savanna
 - c. lowland dry savanna
 - d. thornbush savanna
3. Mediterranean machia and forest, which includes all plant species with hard leaves developed to reduce water loss.

4. **Semi-desert vegetation**
 - a. thorn trees and succulents
 - b. tropical and subtropical semi-desert low vegetation
5. **Desert vegetation, which includes all plant species growing in desert areas.**

This vegetation classification, which is designed to follow the FAO-UNESCO (1977) soil classification in Ethiopia, distinguishes these broad vegetation regions on the physiognomy and structure of the vegetation and not on the floristic species composition.

2.5.2. FAO (1984) Classification.

The FAO (1984) classification followed a different approach by initially determining whether climatic or edaphic factors predominated in determining the vegetative community. Hence, according to FAO (1984), Ethiopian vegetation communities are first categorized as either climatic climax vegetation, or edaphic climax vegetation, and these classes are further subdivided. This is more useful classification for the present purpose and will be considered in more detail.

2.5.2.1. Climatic climax vegetation.

Climatic climax vegetation covers 73.8% of the country. Six main vegetation communities, for which climate plays a leading role, have been differentiated.

- a). Afroalpine vegetation.

The Afroalpine vegetation community, composed of tussock grasslands, scrubs, lichens, mosses and algae, occurs above 4000m. The annual precipitation varies from 800-1500mm, and often falls as snow or sleet, which melts almost immediately. The growing period lasts for 9-12 months. The zone is characterized by large diurnal temperature fluctuations, as a result of great insolation during the day time and considerable heat loss by long wave radiation during the night. The soils on which the Afroalpine vegetation grows are shallow and eroded. Some moraines, from glacial periods, are present. The various floral species have adaptive mechanisms to withstand the environmental problems posed by soliflucation, frost hazards, rapid temperature changes and xeromorphic conditions.

b). Subafroalpine vegetation.

The Subafroalpine community occurs between 3300-4000m. The same environmental constraints exist as in the Afroalpine region, but at a lower intensity. These less severe climatic and edaphic conditions require less adaptation by this community. Woodlands are the dominant vegetation growing in the subafroalpine region, although some grasslands also exist, due to the influence of edaphic parameters.

c). Forest communities.

The forest communities, which include coniferous, deciduous, evergreen and broad leaved species, cover a large altitudinal range. In most cases, the conifers grow in the dry highlands, the deciduous trees grow in areas with pronounced dry seasons, and the evergreen and broad-leaved forests grow in parts of the country that are humid

all year round. The growing period for Ethiopia's deciduous forests lasts from 1-12 months. Moisture availability is the prime factor that determines the distribution of the deciduous and coniferous forests. The deciduous species have tolerance to the wide range of soils in the region, making the soil less dominant in influencing their growth and distribution. In most of the humid areas the deciduous forests occur from 450 to 3500m, and are intermixed with the coniferous forests. The extent of the coniferous forests is limited to between 2300 and 3300m. Due to good environmental conditions, the trees have grown to extraordinary size and height. In the humid areas, the closed canopies of the forest prevent most of the sunlight from reaching the ground. Here, epiphytic herbs and ferns are found in the canopies of the huge trees and benefit from the incoming radiation. Creepers have developed into giant lianas to enable them to reach the forest canopy and the sunlight. In areas where the humidity is very low, the plants have adapted to xeromorphic conditions. Plants flourishing in areas of excess moisture and high humidity are hydromorphic.

d). Woodland savanna vegetation.

The woodland savanna vegetation is characterized by grasses, bushes, shrubs and trees at different levels of dominance. They grow in mixtures where the boundary of the different grassland communities often changes due to climatic influences (dry and wet seasons) and human activities such as fire, deforestation and overgrazing. The community occupies an altitudinal range from 250 to 2300m. The mean annual rainfall ranges from 200 to 1400mm. The growing period lasts

from zero to ten months. The soils are diverse but all are influenced by aridity. Most of the open grassland areas are dominated by Vertisols. The woodland savanna vegetations have developed different adaptation mechanisms to ensure their survival in this sensitive environment. Xeromorphic plants, which can withstand problems of aridity, grow at lower elevations.

Vegetation of the more arid woodland savanna areas tends to have deciduous characteristics. Plants with deciduous characteristics shed their leaves during the dry season to reduce water loss, and increase their photosynthetic activities during the wet season by growing more photosynthetically active green materials. Some plant species have also evolved mechanisms to limit the intensity of browsing and grazing by herbivores.

e). Steppe vegetation.

The steppe vegetation communities are characterized by, scattered woody plants, less than 4m tall, with various species of shrubs, scrubs, and tufts of grass in the wide intervening spaces. Trees are not common in this community. The altitudinal range of the steppe vegetation is 100 and 1400m and the mean annual rainfall is 100 to 550mm. The growing period lasts from zero to less than six months. The dominant soils are Yermosols, Xerosols, and Solonchaks. These soils have problems of alkalinity, salinity and gypsic conditions. To withstand these environmental problems, the steppe plants have relatively short life spans. Their leaves are small, usually thorny, and are resin or gum bearing. Geophytes and annuals are common features of the steppe communities.

g). Semi-desert vegetation.

The semi-desert vegetative community grows in patches. Plant heights are less than one meter. There are wide spaces between the patches of scrubs on which scanty and hardy grass species grow. Trees are normally absent, except along the fringes of major river courses. The vegetation communities are restricted to the coastal region, and to the Ogaden, Afar and southern plains of Ethiopian territory. The semi-desert vegetation occupies altitudes from about -150m to 500m and receives a mean annual rainfall of 50 to 300mm. The growing period is at most one month. Solonchaks, Xerosols and Yermosols are the most common soil types of the region. To withstand the excessive aridity and high temperatures of the region the plants are dwarf and xeromorphic with sclerenchymatic or pubescent leaves. The leaves are armed with thorns and alkaloid contents to resist browsing. Root systems are well developed and create a dense network down to a considerable depth to enable the plants to utilize the subsoil moisture.

2.5.2.2. Edaphic climax vegetation.

The Edaphic Climax Vegetation includes all the vegetation communities whose existence is influenced primarily by the chemical and physical properties of the soils on which they are growing. As a result, their distribution is uneven. Edaphic Climax Vegetation covers 26% of the country, over a wide range of the elevations. Edaphic climax communities are found along edges of rivers, lakes, seas, swamps and marshes. In addition, they grow on the Vertisols, which in most cases support an open

grassland type of vegetation. In all cases, soil properties take precedence over climatic factors in influencing the character of this vegetation community.

2.5.3. Flora and Fauna.

A list of common vegetation communities of both climatic and edaphic climax vegetation, in Ethiopia is provided in Table 2.2. Within these diverse, adapted and widely distributed vegetation communities, a wide range of wildlife species live. According to the International Union for the Conservation of Nature and Natural Resources (I.U.C.N., 1978), Ethiopia has 103 mammal and 824 avifaunal species along with varieties of reptiles and amphibians. 7 species of mammals and 23 species of birds are endemic to Ethiopia. Due to this outstanding species diversity and ecological representativeness, Ethiopia and the surrounding regions that include Africa south of the Sahara, Madagascar, and part of the Middle east, were named as the Ethiopian zoogeographical region, one of the 5 zoogeographical regions of our world (Darlington, 1957).

Ten national parks, two wildlife sanctuaries and fourteen wildlife reserves have been established in order to protect the wildlife resources and the habitat in which they are living. Two of the national parks are listed as world heritage sites, for their endemic plant and animal species along with their spectacular scenic beauty. The total area of 2.5 million hectares set aside as conservation areas is very small when compared with the almost 1.25 million square kilometer land surface area of Ethiopia. Ethiopia has wildlife resources which require protection and the environmental constraints of which need to be understood.

Table 2.2

Major climatic and edaphic vegetation communities

- 1. Climatic Vegetation Communities**
 - 1.1. Afroalpine Vegetation Communities**
 - 1.2. Subafroalpine Vegetation Communities**
 - 1.3. Forest Communities**
 - 1.3.1. Juniperus forest**
 - 1.3.2. Arundinaria forest**
 - 1.3.3. Podocarpus forest**
 - 1.3.4. Aningeria forest**
 - 1.3.5. Olea forest**
 - 1.3.6. Baphia forest**
 - 1.4. Woodland Savanna**
 - 1.4.1. Juniperus woodland**
 - 1.4.2. Acacia woodland**
 - 1.4.3. Mixed deciduous woodland**
 - 1.5. Steppe Vegetation Community**
 - 1.6. Semidesert Vegetation Community**
- 2. Edaphic Vegetation Communities**
 - 2.1. Wetlands**
 - 2.1.1. Papyrus-typha swamp**
 - 2.1.2. Echinochloa & Tamarix manifera marsh**
 - 2.2. Riverine Forests**
 - 2.3. Grasslands**
 - 2.3.1. Hyparrheria rufa grassland**
 - 2.3.2. Hyparrheria filipendula grassland**
 - 2.3.3. Sorghum purpureo-sericeum grassland**
 - 2.3.4. Cenchrus ciliaris grassland**
 - 2.3.5. Chrysopogon aucheri-dactyloctenium scindicum grassland**
 - 2.3.6. Aristida grassland**
 - 2.4. Halophytic Vegetation Community**

(Modified from FAO 1984)

2.6. AGRICULTURAL SYSTEMS.

Ethiopian land use practices have evolved over thousands of years in response to the need for sustainable and sufficient food supply and the opportunity and constraints provided by the relief, slope, elevation, climate and soil fertility of Ethiopia. For most of this time, growing crops and raising livestock have been in harmony with the resource base. However, this harmonious relationship is not being maintained and the pressure threatens the food production systems. All farming systems that are typical of the tropics are practised somewhere in Ethiopia (FAO, 1984). As with the natural vegetation regions, the agricultural practices of Ethiopia are diverse and the environmental constraints of all systems must be understood if future conflicts between food production and conservation of the resource base are to be managed successfully.

The following four land use systems (Westphal, 1975), provide a suitable basis for discussing Ethiopia's agricultural systems:

1. the seed farming complex
2. the ensat planting complex
3. the pastoral complex, and
4. shifting cultivation.

Approximately 23% of the total land area of Ethiopia has been brought under cultivation and 51% of Ethiopia is now under the full utilization of pastoral activities (FAO, 1984). Livestock makes a contribution to the livelihood of about 85% of the Ethiopian population (Atlas of Ethiopia, 1988).

2.6.1. The Seed farming complex.

The seed farming complex involves mainly cereals, pulses and oil crops, all of which reproduce by seed. Tuber crops, fruit crops and green vegetables are nearly absent in this system. The crops are planted by broadcasting the seeds onto land ploughed using a "Marsha", a metal implement that breaks the soils without turning it over. The broadcast seeds are ploughed in again using the "Marsha", pulled by a pair of oxen. The unturned soil, the grass roots and crop residues protect the soil against erosion. Cattle are kept primarily for ploughing and to produce ploughing team replacements. Rotation of legumes with cereal crops, which assists in maintaining the fertility of the soil, is widely practised. Livestock are kept throughout the year on natural pasture and stubble. Dung is used as a source of fuel, and hence the fertility of the soil is only preserved by the plants growing on the farmland at the time of fallowing, provided they are not excessively grazed. Fallowing in the seed farming complex is indicated as a period when farmland is not cultivated to grow cereals, pulses or oil crops, but livestock are allowed to feed upon the naturally growing plants. Rotation of pastoral and cultivation activities is practised, as a result of which, there is a severe competition that dictates the balance between cultivated land and pasture land. Terracing and drainage activities, to protect the soil and water resources from erosional processes, are part of the traditional farming practices. Irrigation is not widely practised, except along small rivers and streams, mainly due to topographic problems. This farming system is widely practised in the central and northern highlands of Ethiopia.

2.6.2. The Ensat planting complex.

The ensat planting complex is practised in the altitudinal range of 1600 and 3000m, in humid southwestern Ethiopia where the rainfall is reliable and the mean annual temperature is 16 to 20°C. Ensat (Ensat edule) is a herbaceous plant related to the fruit banana, for which reason people call it "false banana". The roots of ensat are consumed as food. In this farming complex, ensat is intercropped with a variety of crops. Tuber crops are dominant and, unlike in the seed farming complex, cereals are of secondary importance to the farmers practising this system. The variety of crops grown assures year round food production. As a result, areas practising this system support denser human and livestock populations. Livestock dung is very important to continued ensat cultivation and to other tuber crops. The continual and extensive use of manure makes this system superior to the seed farming complex in maintaining the fertility of the soils.

2.6.3. The Pastoral complex.

The pastoral areas are located mostly in the lower and drier parts of the country. These pastoral ecosystems support large herds of cattle, sheep, and goats, although the driest pastoral ecosystems are utilized predominantly by camel herds. Under the pastoral complex, livestock is reared as a means of subsistence and the system is adapted for survival and not for surplus quality food production. Grazing systems vary among the Ethiopian pastoralists; most are nomadic or semi-nomadic. Some pastoralists occupy lands that are favorable for cultivation, but they

maintain their pastoral traditions of raising livestock without any external land use interferences. In most cases where cultivation is feasible, the traditional pastoral ecosystems have been transformed to intensive cultivation to grow both commercial and food crops.

2.6.4. Shifting cultivation.

Shifting cultivation is practised by the indigenous tribes along the major river banks and humid areas of remote and inaccessible parts of the country. Shifting cultivation involves the clearing of forest and the growing of crops until the land is abandoned to forest regrowth, because the fertility of the soils has decreased. New areas are then cleared and the human settlements move as required. Most of the areas where shifting cultivation is practised are infested by trypanosomiasis, which prevents the raising of livestock

2.7. Socio-Economic and Political Systems.

In the census of 1984, Ethiopia's population was estimated to be 42,169,203, out of which 21 million were males and 21.2 million females. The annual population growth rate was 2.9%. 86% of the total population was living in the rural areas and 14% lived in urban centers having 2000 or more inhabitants. The urban population is growing at an annual rate of about 6.6%, of which 4% represents net immigration from the rural areas. By the turn of the century the population size is expected to be close to 54 million with the urban population constituting 29% and the rural population 71% (C.S.A., 1986). The national population density is 25 persons/km², but varies widely from region to region. The Shewa

region, in which the capital city is located, has a density of 274 persons/km², whereas, the remote region of Bale has a population density of only 6.5 persons/km². According to Last (1987), 10% of the Ethiopian population lives below 1000m, 20% between 1000-1800m, and 70% above 1800m.

The highlands, due to their favorable climatic conditions, are the home of settled agriculture where millions of farmers produce a variety of food crops. Nearly all the major settlements of the country are also in the highlands. The exceptions are two ports (Assab and Mitsiwa), two border ports (Moyale and Teseney), a river port (Gambella), and the Ethio-Djibouti railway-created cities of Dire Dawa and Nazareth. Regions above 2000m are free of malaria, and malaria is one of the factors limiting the occupation of the lowlands, that would otherwise be suitable for agricultural activities. Eradication of malaria and other improvements of health services have allowed some regional capitals to be moved to lower elevations.

Ethiopia is the only African country that has never been colonized. But, this has not made the country immune to colonial-related problems. Since its neighbors were colonized, Ethiopia has been exposed to various kinds of border conflicts with the surrounding countries. Some of the civil wars also trace their origin to colonialism. Throughout its long existence as an independent nation, Ethiopia has gone through many difficulties due to ethnic and religious conflicts.

Ethiopia was ruled by monarchs over thousands of years. The semi-feudal system was overthrown in 1974 and replaced by a socialist government. The new government has adopted and adapted Marxism-Leninism as its guiding principle for ruling Ethiopia. Economic activities are

centralized and the country is a single Marxist party state. All means of production, factories, urban areas and extra houses, and, rural and farmlands, are proclaimed to be state properties.

Ethiopia is an agricultural country that produces both food crops and livestock products. Agriculture, the most important sector of the economy, employs about 85% of the labor force, contributes 50% of the GDP and accounts for 90% of the country's exports. Coffee accounts for 60% of the exported agricultural products, while oilseeds, cotton, skin and hides contribute the remaining portion (Cohen,1988).

Before the revolution, most of the Ethiopian land was under the control of the aristocracy, the church and feudal lords. While the feudal relationships varied in different areas of Ethiopia, few had secure rights to specific plots of land to support themselves and their families. These socio-economic relationships were exploitive and encouraged the peasants to stress the land resources. The peasant-feudal relationship was abolished by the revolution which guaranteed free access to land for any one interested in agricultural activities. The current government's land use policies are to incorporate the millions of peasant families into Peasant Associations (PAs) and/or Producer Cooperatives (PCs). Subsistence farmers who are not willing to organize themselves in service cooperatives and in collectives do not get any support from the government. The peasant sector cultivates 90% of the Ethiopian farmland and accounts for 95% of the agricultural output, including most food crops and virtually all livestock. Peasants are required to sell a certain portion of their agricultural products to the government before selling the remainder on the free market. The government purchases at lower

prices than in the free markets and uses the produce to meet the food demands of the large urban centers (i.e. Addis Ababa, Asmara, and Dire Dawa). Failing to meet the government quota can mean risking loss of their land holdings.

The State farms and Service cooperatives, developed as part of the new political systems, are absolutely dependent on government supports. The state farms, which produce a number of crops and most of the cotton and sugar cane, consume 85% of agricultural inputs, but run at a loss without reaching their target production. The cooperatives get substantial assistance from the government. They still perform badly, although better than the state farms.

The revolution that has guaranteed free access to farmlands, has not attempted to control the ever increasing livestock population. Every peasant is entitled to cultivate at least two hectares of land, but can raise any number and species of livestock, which pasture on common grazing land. What is happening is the tragedy of the commons (Hardin, 1968), with the common grazing land experiencing overgrazing and acceleration of land degradation. A key strategy to control land degradation is to reduce livestock numbers, because they commonly exceed the carrying capacity of the available land (FAO, 1986).

Ethiopia is currently characterised by political instability (Talal et al., 1986). This instability is aggravated by a sessionist war in the north. Political instabilities stress people, which, in turn, puts pressure on the resource base, leading to processes of severe land degradation that may be irreversible (Blaikie, 1985). As a result of internal conflict, excessive resources, both labor and capital, are spent

for security purposes. These resources would be much better used if applied to rehabilitate and protect the resource base and to boost food production.

CHAPTER THREE
LAND DEGRADATION
and
PROCESSES OF LAND DEGRADATION

3.1. GENERAL

There are several definitions of land degradation, all of which have the central idea of emphasizing the deterioration of land resources. According to Coote et al. (1982), land degradation is the process or processes of deterioration of soil edaphic qualities relative to their natural or most productive previous state. Deterioration of soil edaphic qualities can result from any causative factor or combination of factors which damage the physical, chemical, or biological status of the land. Torrance (personal communication, 1989) visualizes land degradation as an unintentional output of the agricultural systems which reduces the productive capacity of the agricultural system itself and goes completely counter to the idea of sustainable agriculture.

According to Blaikie et al.(1987), land degradation is a reduction in the capability of land to satisfy a particular use. If the land is transformed from one system of production, such as hunting and gathering to agriculture, or agriculture to urban use, they argue that the land is not degraded, rather its quality is used as a physical basis for building a new capability for production. By these standards, even deforestation is not considered as a land degradation process, provided the economic basis of the land is upgraded by the activity. This approach ignores the changes in hydrology, the microclimate, and the soil system associated with deforestation. However, if the economic productivity is not

sustained in the process of transforming one land system into another type of production system, the transforming process is degradation.

According to Chisholm and Dumsday (1987), any use of land promotes land degradation. The impact of this use is, in turn, a function of the economic, social, political and environmental elements. From this point of view, land degradation is the product of human decisions to benefit the perpetuation of the human race by practising some form of land use on environmental resources.

Humans need food, fiber and shelter to maintain life. Plants are the primary sources of food, fibre, shelter, and feed for livestock. In turn plants depend on solar energy, temperature, moisture and soil. It is obligatory for human beings to ensure that the resource bases on which crops depend are safeguarded from the undesirable effects of degradational processes. Many land use practices can easily degrade land capability and lead to environmental problems. Land degradation at a specific site is not necessarily caused at that site. Many effects are off-site, as for example the deposition of transported soil particles in low lying areas. Other problems associated with land degradation include: loss of sustainable production, declining water quality, loss of genetic diversity and intensification of land use conflicts. The most shocking effects of land degradation in the Third World are felt when people and livestock perish because of the loss, by the supporting systems, of the ability to produce adequate food.

The inherent characteristics of the resource base and the formation processes play a decisive role in the process of land degradation. Land uses which are incompatible with the resource base can enhance

degradational processes to an irreversible degree. The intensification of land use activities (with or without inputs) has recognizable impacts on the biotic and abiotic resources of a land. Generally, any land use activity where soil destruction exceeds the rate of soil formation will degrade the resource base and will not be sustainable. It is argued here, however, that soil resources can sustainably support some level of biomass production, if the proper land use practices are applied.

Land degradation includes many processes including: wind erosion, water erosion, salinization, acidification, flooding and vegetation decline. Although links have been observed between some of these processes, most of them work independently. These processes of land degradation are basically the same throughout the world (Lewis and Berry, 1988). Because of relative differences in environmental and land use elements, variations in the severity of the processes occur in different ecosystems. Land degradation may be naturally caused, but human-induced land degradation is most common.

3.2. NATURALLY-CAUSED LAND DEGRADATION PROCESSES.

Leaching, soil erosion, soil compaction, and deleterious changes in plant species and cover, hydrological regimes, soil and water chemistry that take place naturally, in the absence of human activities, can be grouped as naturally-caused land degradation processes. These processes and changes can be enhanced by human activities. The natural factors accentuating land degradation are climate, topography, soil properties and vegetation cover.

3.2.1. Climate

In general, the degradational effects of climate should be evaluated in terms of the erosivity and velocity of wind, intensity and erosivity of rainfall and running water, its influences on alkalization and salinization, and precipitation and evaporation balances. Climatic variabilities, both in space and time, have great influence on the severity of degradational processes. The main climatic variables involved are rainfall, wind, water balance, frost action and temperature.

The kinetic energy of rainfall which is closely associated with rainfall intensity, is very important in detaching the soil particles and carrying them away through the process of water erosion. The erosive efficiency of rainfall is also influenced by the erodability of the soil and land use practices.

Land degradation by wind is influenced by wind velocity and erosivity and surface factors such as topography, soil moisture content, soil texture, and land use practices and vegetation cover.

Water balance, as one of climatic variables, has a series of inter-related processes to cause land degradation. The imbalance between the inflow and outflow of water is the principal cause of land degradation taking place in an area. Inflow involves the input of water at the surface and to the deeper levels of the soil. Rainfall, runoff, condensation and irrigation are sources of inflow at the soil surface. Lateral circulation, and rising water table are the sources of inflow for the deeper horizons. Evapotranspiration and percolation to the deeper layers or the lateral movement of water out of the soil profile are the

ways of accomplishing the process of outflow. Tremendous inflow, depending on the type of soil, can cause land degradation due to waterlogging. Excessive outflow may result in serious water erosion and leaching of soluble nutrients beyond the reach of plants roots. High evapotranspiration, without reliable soil moisture recharge, can deplete the available soil moisture and expose the soil to the degradative effects of desiccation.

The degradative processes associated with frost action are a feature of high altitudes in the tropical highlands. The frost action, causing alternate freezing and thawing of the top soil, can result in either improving the soil structure or degrading it. Yield reduction can be observed when frost occurs during the growing period of seasonal crops.

The influence of temperature is dominantly through its interaction with the other climatic variables. Temperature plays an important role in soil water and soil chemical balance, by being a major determinant of evaporation and evapotranspiration processes. Soil salinization is one of the effects of climate created by excessive temperatures and prolonged aridity. High temperatures also enhance the combustibility of accumulated fuels, such as dead vegetation. If fires are started by human activities or natural forces, such as lightning and volcanoes, severe land degradation may result, due to loss of organic matter, and create unfavourable environmental conditions for the soil fauna. The loss of ground cover by burning exposes the soil to severe runoff hazard at the time of rain.

3.2.2. Topography.

Topography has a key role in exposing the soil to various types of degradation. The steepness, length and direction of the slope can all be of importance. The moisture and temperature variabilities, created by topography, influence the potential severity of various degradational processes, especially through their influence on vegetation cover. When human use is made of rugged landscapes, incompatibility of land use practices to the topographic pattern can easily make the resource base susceptible to irreversible degradation.

3.2.3. Soil Properties.

The chemical and physical properties of soil can influence the nature and severity of degradation processes. The porosity and permeability of a soil, which are major determinants of infiltration and runoff during rainfall events, are influenced by soil composition, texture and structure.

Soil texture, structure and its permeability are the most important physical aspects influencing soil erodability (Morgan, 1980). The potential for wind erosion is related to soil texture (sand or silty) and to the climatic conditions, because only dry, non-cohesive soil can be moved by wind. The potential for a soil to develop salinity or alkalinity, and waterlogging are related to the soil's chemical properties, and its climatic and topographic setting. Prolonged influences of sea water or marine or lagoon deposits, recent rising of ground water saturated with soluble salts, deposition of wind blown

material from the sea, bare soils rich in soluble salts, and persistence of aridity in areas rich in sodic parent materials are the main natural causes of salinization and alkalization (Brady, 1984). Mineralogy, organic matter content and cation exchange capacity contribute to the fertility status of a soil. Soils, developed in mild climates, are more resistant to erosion and more responsive to improved technologies than are low fertility soils developed on highly-weathered landscapes under severe climatic conditions (Lal, 1987). Young parent materials, high fertility, temperate-like conditions and responsiveness to improved technologies can mask the impacts of soil degradation in agricultural system. This is particularly true for many North American soils (Lal and Greenland, 1979).

3.2.4. Vegetation.

Under natural conditions, the top layer of the soil profile is where rapid modifications of soil properties mainly occur. It is also the most valuable soil and the layer most exposed to external impacts. Vegetation (including litter fall), protects the soil surface from wind and water erosion, and as the ultimate source of organic matter, improves the physical nature of a soil. Organic matter provides microbial habitat and energy for its own decomposition, which initiates nutrient recycling.

3.3. HUMAN INDUCED LAND DEGRADATION.

According to the United Nation Environment Programme (UNEP, 1977, 1982), soil degradation is the diminution of the soil's current or potential capacity to produce food, feed and fiber crops as a result of one or more degradative processes that affect the quality and

productivity of a soil in supporting biomass growth. Processes include waterlogging, erosion, laterization, compaction and crusting, leaching, salinization and alkalization, organic matter loss, and nutrient imbalance. These degradative processes may be categorized as physical, biological and chemical.

The physical land degradation processes are mainly mechanical actions which influence the structural quality of the soil surface. Compaction and crusting, which reduce the permeability of the soil to water and inhibit seedling emergence and root growth, are examples. Excessive runoff can occur easily, following the reduction of infiltration and permeability. Plants growing on physically-degraded soils face problems of nutrient, water and air uptake. The biological degradation processes are primarily associated with the loss of organic matter and vegetation cover. Soil is protected by vegetation from undesirable atmospheric influences and the organic matter from vegetation improves the physical and chemical properties of the soil. Loss of live and dead vegetation from the soil surface causes serious biological degradation and loss of fertility. Chemical degradation changes the physical nature, decreases the fertility status and decreases the ability of the soil to support life. It is not possible to separate the three forms of land degradation, because they rarely occur separately and a change of one factor commonly initiates broader changes.

Generally, the human induced degradative processes represent an acceleration of natural chemical, physical and biological processes to a point where the deleterious aspects exceed the resilience limits of the resource base. Human-induced degradative processes are a direct result

of land use activities conducted to supply the basic human needs of food, shelter and fiber. Crop cultivation, grazing, mining and urbanization or increased rural settlements are the major land use activities that place pressures on the soil resources. Lack of understanding of the carrying capacity of the resource base increases the risk of exposing the resources to irreversible degradation. As human and livestock populations increase, the risk of degradation increases. The major degradation processes enhanced by human activities will be discussed.

3.3.1. Waterlogging

Excess water from waterlogging eliminates aeration and creates an anaerobic medium. Anaerobic conditions destroy or inhibit the microorganisms responsible for the decomposition of organic matter. Mineralization and humification of plant materials are slowed down and excess accumulation of organic matter may occur. Topographic, pedogenic, climatic and anthropogenic factors are the main causes. Poor internal drainage, or imbalance between inflow and outflow, can create waterlogged conditions. Soils with very clayey texture are more prone to waterlogging than sandy soils due to their lower porosity and permeability. Also, the presence of swelling clay minerals, which absorb water, swell and decrease permeability when excess amounts of water are available, facilitates the occurrence of waterlogging. Impermeable layers, compact parent materials or hardened layers also retard water flow and can lead to waterlogging.

Areas that receive excessive precipitation in relation to evaporation and evapotranspiration can suffer from severe soil degradation due to waterlogging. Soil degradation can also occur in areas where

rainfall is much less than potential evapotranspiration, if frequent storms and excessive rainfall occur in a short period of time. Areas experiencing periodic droughts or intense cold, which limit normal plant growth, can easily be prone to waterlogging problems due to high rates of runoff occurring on poor quality plant cover. Runoff water from the nearby upland areas enhances the formation of waterlogging in low lying areas.

Human activity in areas susceptible to waterlogging can aggravate the situation and may be the principal cause in some areas. Irrigation, when not combined with properly designed drainage networks, or when excessive amounts of water are applied, raises the water table. This improper irrigation in many places has resulted in deterioration of the soil structure, and transformation of fertile soils into waterlogged swamps. In some arid regions, irrigation and waterlogging are accompanied by salinization.

3.3.2.Erosion

Overgrazing, deforestation and intensive row cropping are the causes of severe erosion. Cultivating and deforesting lands with high slopes increases the rates of soil erosion by water. Growing plants with small canopy cover and low levels of litter production, thus reducing mulch, exposes soils to the effects of erosive rainfall and runoff. The soil removed from these lands, in many cases, reduces the productive capability of areas where it is deposited. Overgrazing is caused by increasing livestock numbers beyond the carrying capacity of the land. The result is destruction of vegetative cover and severe trampling which destroys the

structure and resistance of the soil. The concentration of livestock around watering points concentrates these effects.

Cultivation loosens the soil surface and decreases (or eliminates) the surface cover. These actions decrease the resistance to both wind and water erosion. The top few centimeters, which are the most fertile, are lost. The consequences of erosion are most severe on subsistence farmlands which receive little or no nutrient amendments to replenish the lost fertility. The loss of the surface soil also increases drought stress and runoff because of decreased infiltration and reduced water holding capacity.

3.3.3. Laterization

Laterite layers are hard crusts, rich in aluminum and iron, that hinder normal farming operations, restrict root growth and reduce productivity (Lal, 1987). There are both natural and human factors for the formations of laterites. Tropical rainforests and wooded savanna are the natural vegetation regions where laterized soils predominate, for example, 15% of the sub-Saharan African soils are laterized or prone to laterization (Lal, 1988). The natural factors result in the formation of soft iron or aluminum-rich layers near the soil surface, when it is protected by natural vegetation cover. The transformation of the forests to savanna, by burning and excessive cultivation, starts the degradative processes of laterization. The exposure of these soft layers by erosion, and their subsequent desiccation hardens them, through iron-aluminum cementations, into extensive rock-like sheets or hard pavements in a few years.

3.3.4. Compaction and Crusting

Compaction, as a degradation process, is damage to soil structure caused by intensive cultivation. Soil conditions conducive to compaction include a low soil organic matter content, predominance of clays with little or no swell-shrink capacity, high contents of silt and fine sand, low biomass content, absence of freezing and thawing, and excessive desiccation by extremely hot and dry conditions. Lack of soil fauna activity also exposes soils with the above conditions to a high degree of compaction problems (Josens, 1983). Compaction results in a reduced number and size of pores that make it difficult for water and air to enter the soil or for plant roots to grow. The physical degradation process of compaction leads to reduced infiltration, increased runoff, accelerated soil erosion and severe decline in crop yield. As a result of compaction, it has been shown that infiltration rates can decline by as much as 80% over a 3 to 4 year period, and yield reduction can be as much as 50% for some sensitive crops such as maize and rice (Lal, 1988).

Crusting is the formation of a thin, sealed surface and causes the loss of most rainfall as runoff. Crusting and the subsequent runoff reduce water available for crop growth and retard seedling emergence and stand establishment.

3.3.5. Leaching and Soil Acidification

The driving agent of leaching is water. The absence of vegetation cover speeds up the leaching process in areas where there is excess water. As water percolates through the soil profile, it creates changes in the

morphological and physico-chemical aspects of the soil. Due to the downward movements of water, porosity and permeability are reduced, and root penetration and root depths are affected. Soil acidification is a natural and continual process resulting in the leaching of Ca, Mg, and K ions from the root zone and replacing them by the H and Al ions. Consequently, the upper horizons of the leached soils are acidified. However, according to Coote et al (1982), accelerated acidification is brought about by three principal processes:

- 1). Addition of sulfur, in the elemental form or as sulfides or sulfur dioxide, which oxidizes to sulfate giving an acid reaction,
- 2). Applying nitrogen fertilizer, either as urea or in the form of ammonia or ammonium,
- 3). Oxidation of sulfides to sulfates when marine sediments are drained, a common problem in coastal plains and estuaries.

Accelerated acidification decreases the availability of macro-nutrients and may increase the solubility of some micro-elements to toxic levels. As a result, crop growth is reduced.

Aluminum solubility increases and aluminum becomes toxic when the soil P^H is low. As a result of aluminum toxicity (Sanchez, 1976), root development is restricted, and the roots become thicker and stubby and show dead spots. Studies by Foy (1964), indicate that aluminum tends to accumulate in the roots and impedes the uptake and translocation of calcium and phosphorus to the tops. High levels of soluble aluminum are toxic to such crops as maize, beans and other legumes. Unless the aluminum concentration is reduced, severe yield declines occur due to toxicity. On the other hand, cowpeas and cassava are relatively tolerant

to high aluminum concentration (Lal, 1988). Human activities that speed up leaching and result in acidification, include modification of the roughness of the soil surface, changing the type of plant cover (deforestation and removal of crops) and other activities that diminish plant transpiration.

Leaching has different influences on different types of soils primarily due to climatic variations. Soils developed in areas of heavy rainfall exhibit more serious leaching than do the arid land soils. The heavy rainfall in equatorial areas, for example, facilitates continuous high percolation of water into the soil profile, which makes the soil acid and desaturated. Because of this situation, leaching is a common process in the Oxisols and Ultisols. Destroying the vegetation cover of these soils aggravates leaching and acidification.

3.3.6. Salinization and Alkalinization

In arid and semi-arid regions, soil salinization and related processes are serious problems threatening land productivity. Irrigated lands are particularly threatened by concentrations of salts. Based on the UNESCO/FAO (1977) soil map of the world, 70 million hectares of Africa had salt affected soils. The affected area is greater today. The enrichment of soils with soluble salts (chlorides, sulphates and carbonates) of sodium, magnesium or calcium causes salinization. Salinization originates when water is lost by evaporation and transpiration leaving behind the soluble minerals. If the water table is heavily laden with soluble salts, it also contributes to the process of salinization whenever its elevation increases due to seepage. The high

concentrations of soluble salts raise the osmotic pressure of the soil solution, consequently, plants will have problems obtaining the soil water for the process of photosynthesis and transpiration.

Cultivation and removal of perennial indigenous plants can change the balance between soil water and ground water and start the build up of soluble salts on the soil surface. Percolating water dissolves soluble salts and when the salt-laden ground water enters an outlet zone, evaporation and capillary action cause the salts to be deposited, at the soil surface and in the profile, to produce salinization. Similarly, excess irrigation water can raise water table levels or move laterally through the subsoil to bring dissolved salts to the surface (FAO, 1981). The salt content increases with surface evaporation until crop damage results and undesirable salt tolerant plants invade the area. Salt crust can easily be formed as a result of further evaporation and loss of vegetation cover.

The presence of a high proportion of Na ions causes alkalization. The seriousness of alkalization depends on the amount of Na ions available in the soil, but soils with high proportions of adsorbed Na are compact and their structural stability is very poor. Solonetzic soils have a columnar structure in the B horizon which is formed when clays are dispersed by Na ions, are translocated and accumulate in deeper horizons. The boundary between the leached and the illuviated zones is distinct. Low permeability of the illuvial horizons facilitates the establishment of hydromorphic conditions.

The presence of salinization and alkalization modifies the soil morphology and the vegetation. Salts weaken biological activities, which

in turn reduces the amount of organic matter produced. The consequence of this is greatly decreased ability of the soils to sustain biomass production.

3.3.7. Soil Organic Matter Loss.

The biological activity of most soil fauna entirely depends on the energy availability from the soils. Soil organic matter is the primary source of this energy. Reduction of soil organic matter results in reduced soil faunal population, diversity and activity. Excessive biomass removal, burning, indiscriminate and excessive application of pesticides, and intensive cultivation are some of the deleterious practices affecting the organic matter content. Excessive removal of live and dead plants to be used as fuel and construction materials decrease organic matter input. Intensive cultivation enhances oxidation, by which large amounts of organic matter can be lost.

Soils which have their organic matter content reduced to low levels undergo a rapid deterioration in soil structure and productivity. They are easily crusted and compacted, and have a high susceptibility to erosion, because of low infiltration rates and severe runoff hazards.

3.3.8. Nutrient Imbalance.

Most of the African soils of the humid regions are derived from geologically matured, deeply weathered parent material and retain few soluble plant nutrient reserves. This gives them too little resistance to drastic human intervention. The limited inherent fertility in the root zone is exhausted by harvesting of crops and by erosion hazards, such as runoff and seepage flows. In sub-Saharan Africa, maize and sorghum with

yields as low as 1 ton/ha remove as much as 30-40 kg/ha of nitrogen, 2-10 kg/ha of phosphorus, 5-30 kg/ha of potassium, and 5-10 kg/ha each of calcium and magnesium (Lal, 1988). Most African farmers do not have the means of buying fertilizers and must use crop residues as feed for their livestock and fuel for cooking. These necessities reduce the nutrient return to the farmland to sustain the productivity of the soils. Intensive exploitation of their nutrients without inputs/replacements seriously degrades the soil.

Extensive human-induced degradation is caused by poorly-planned food production schemes that do not give allowance to soil and climate variabilities. This is a common experience of some development plans designed on the belief that the climates are stable and humidity is constant. When shortfalls appear due to unfavorable conditions, they are compensated by cultivating more fragile lands. Although shortfalls should be expected in some years, failure to plan for these years may lead to environmental disaster.

Because of human-induced degradation, crop yields are affected, and labor and capital inputs are lost without satisfactory returns. Other things being equal, the outcome of work on degraded land is less than that on the same land without serious degradation. Productivity on degraded land continues to decline unless measures are taken to restore the capability of the resource base. All these arguments illustrate how human-induced land degradation occurs when land is poorly managed. Some aspects of human-induced degradation can be more severe in areas of low technology and/or low levels of environmental awareness.

However, the effects of human interference do not always have to be

harmful. It is mainly through human intervention to restore and improve the capability of a soil, that a new productive agro-ecosystem for reliable food production can be established.

3.4. LAND DEGRADATION PROCESSES FROM THE ETHIOPIAN PERSPECTIVE.

There are serious deficiencies in information on the extent and rate of land degradation in Ethiopia, so a complete inventory of the different forms of land degradation in Ethiopia will not be undertaken. However, there are sufficient indicators from which to deduce the probable presence of major land degradation problems. Some of these indicators are:-

1. A tropical African country where 60% of its land surface has slopes > 20% degrees, and is dominated by undulating and rugged highlands of steep slopes (Timberlake, 1985).
2. The recurrence of drought and famine.
3. An agricultural country where over 90% of the total population is subsistence farmers and where crop cultivation has occurred for thousands of years.
5. The largest livestock population on the African continent.
6. Less than 4% of the land surface is covered by closed-canopy forests, and only 5% of the country has the potential for future expansion of agricultural activities (FAO, 1984).
7. Except for the volcanically-derived soils, most of the Ethiopian soils are poor in terms of fertility, subject to erosion, and need lots of inputs and management skills to make them productive. The national soil loss is estimated to be one thousand million tonnes per annum (FAO, 1986).

8. The restricted range of endemic species of mammals (8 spp) and birds (24 spp) indicates the occurrence of massive habitat destruction in the country.
9. The presence of 656 urban centers with 2000 people or more, which create demand for fuelwood and construction materials from the remaining meager forest resources.
10. Having in excess of 42 million people makes the country the third most populous African country. Ethiopia stands second, next to Nigeria, for human population in the black African countries.

In this section, the nature of Ethiopia's soils (with emphasis on their susceptibility to degradation), the evidence of biological degradation and the risks of degradation associated with land use practices employed will be reviewed. Table 3.1 shows the characteristics of the main soils association in Ethiopia.

3.4.1. Parent Materials.

Except for some peaks, Ethiopia was not glaciated to any significant extent during the pleistocene period and hence missed what is essentially a rejuvenating opportunity in terms of soil development and nutrient availability.

The distribution and types of the major parent materials of the Ethiopian soils are shown below. (Geographic area is designated by UPAs, which are defined and delineated in chapter 5. See Figure 5.2). The list and descriptions of the parent materials were modified after FAO (1984a).

1. Western Ethiopia including Keffa (UPA¹) and part of UPAs 2, 7, 6 & 5 is dominated by volcanic and felsic parent materials. Some soils

- of UPAs 1, 2 and 3 have granites as their parent rock materials.
2. Predominantly volcanic parent materials are distributed in central Ethiopia, mainly in UPA6 (Shewa) and the highlands of UPA4 (Eastern highlands).
 3. The escarpments of northern Ethiopia (UPA9, UPA8, and the northern tip of UPA6) have exclusively volcanic parent materials.
 4. The northern highlands of UPA4, UPA1, and the northern part of UPA7 have variable parent materials. Volcanic lavas and fine grained igneous rocks are predominant.
 5. Evaporites, limestones and sandstones are the common parent materials of the Ogaden region (UPA11), UPA13 and UPA12.
 6. The southern part of UPA3 has deeply weathered parent materials of gneisses and granites.
 7. Fluvial and lacustrine deposits are the dominant parent materials in the southern Rift Valley and southwestern lowlands of UPA2 (Gambella).
 8. Some soils of UPA10 (Afar) have been developed dominantly from alluvial and colluvial parent materials. Saline and sodic phases increase towards Dallol (UPA13) and Djibouti.

The list indicates that many of Ethiopia's soils are old, developed on land surfaces that have been in existence for many millions of years. They are underlain by deep layers of weathered rock, and soil forming processes have gone on for so long that many soluble elements and minerals have been largely removed from the system.

Table 3.1

Major characteristics of the Ethiopian soils

Main Soil Association	Soil Development	Limiting Factors
Solonchaks, Solonets (Saline soils)	- mixed accumulation of salts, sodium or both	- toxic levels of salts, sodium or both
Yermosols, Xerosols & Shifting Sands (Desert soils)	- weak, generally limited to accumulations of lime, gypsum or salts	- moisture deficit due to drought, coarse textured
Arenosols & Regosols (Sandy soils)	- weak development in coarse textured materials - strong development in Podzols	- moisture stress - low water retention capacity - low nutrient content
Ferralsols, Acrisols & Dystric Nitisols (Acid soils of tropical lowlands)	- highly weathered deep soils - high levels of Fe & Al oxides - clay accumulation in Acrisols & Nitisols - low nutrient retention capacity	- soil acidity - Al toxicity - erosion hazards for Acrisols - phosphate fixation
Eutric Nitisols & Andosols (Soils of tropical highlands)	- develop on basic rocks or volcanic material	- phosphate fixation
Vertisols & Vertic groups of other soils (Dark clay soils)	- deep cracking, clays	- hardness when dry - sticky when wet - temporary waterlogging
Lithosols & Lithic subgroups (Shallow soils)	- weak soil development	- shallowness & steep relief
Gleysols & Fluvisols (Poorly drained soils)	- high ground water influence - accretion of fresh sediments in Fluvisols - accumulation of Pyrites in brackish water deposits	- waterlogging - flooding & acidity in Sulfidic soils

(Modified from FAO-UNESCO 1977)

3.4.2. Soils degradation risk in Ethiopian arid and semi-arid lands.

The principal degradation risks in the arid and semi-arid lands of Ethiopia are erosion (both by water and wind), presence of petrocalcic horizons and salinization. Yermosols, Solonchaks, Xerosols and some Regosols (Aridisols and Entisols by Soil Taxonomy) are the dominant soil associations present in the arid and semi-arid parts of Ethiopia. Almost all the lands of Ogaden (UPA11), Afar (UPA10), Dallol (UPA13) and Barentu (UPA12) are arid lands. Most of the remaining Ethiopian UPAs have a certain portion of land that is semi-arid.

The amount, type and annual distribution of rainfall, the percentage of vegetative cover, slope and soil properties are the major natural factors influencing soil erodability in the arid and semi arid regions. As the total rainfall decreases, the vegetative cover declines and the protection from wind and rain diminishes. Because of the low total rainfall, the severity of erosion is minimal in most years. At times when rainfall is higher than normal, the amount of vegetation is critical, as a protective agent for the soil against water erosion. Overgrazing, frequent clearing of perennial plants and their replacement by annuals and/or intensive cultivation can lead to catastrophic erosion by both water and wind.

The major portion of the arid and semi-arid areas of Ethiopia is covered by sandy soils. Due to their coarse texture, they can absorb most of the rain that falls on them without experiencing erosion by water. The ease of percolation of water through the soil profile can make the depth

at which water is stored beyond the reach of plant roots. Because of low clay contents, these soils are poorly aggregated and when this is compounded with low organic matter contents (a situation aggravated by intensive cultivation), they are easily degraded by excessive tillage and overgrazing. When the soil structures are damaged, susceptibility to wind erosion is increased.

Shortage of moisture and high temperatures allow the accumulation of soluble salts on the soil surface. Because of the salt concentration in the soils, plant growth is affected badly, with the exception of some adaptable and salt-loving vegetation communities. Arid land soils can be exposed to human-induced salinization in areas where improperly-managed irrigation is practised and where drainage of the irrigation water is inadequate.

3.4.3. Soil degradation risk in the Ethiopian humid regions.

The main soil orders of the humid areas of Ethiopia, mainly in Keffa (UPA1) and Nyala (UPA3), are the Oxisols and the Ultisols. Ultisols and Oxisols have undergone intense weathering and most soluble minerals have been removed from them. They tend to have problems of acidity, low nutrient retention capacity and aluminum toxicity. Their high oxide mineral content also gives them a high capacity to fix phosphates in forms unavailable to plants. To make use of these soils for sustained production, a constant application of phosphate fertilizers, is needed. The major degradation risks are acidity, crusting, phosphate fixation and leaching.

Nutrients critical for the support of plant and animal life are

largely contained in the living vegetation. The removal of the vegetation, therefore, lowers the potential for future plant growth. Ultisols and Oxisols have undergone intense weathering and most soluble minerals have been removed from them. Consequently, these soil orders have low capability to store nutrients. Nutrients critical for the support of plant and animal life are largely locked in the living vegetation. The removal of the vegetation, therefore, lowers the potential for growth. The area where these soils develop receives plenty of rainfall and leaching is a serious problem. The productivity of soils of the humid areas depends on the protection of the vegetation supported by them and clearing such land can lead to irreversible degradational processes. The good physical characteristics of these soils make them fairly resistant to erosion, but when they are deprived of their vegetation cover, serious degradation of their physical characteristics can occur. Soil crusting, one of the physical degradation processes, can occur immediately after the soils are exposed to the erosive effects of the rainfall. Soil crusting inhibits the emergence and reduces water infiltration into the soil which results in runoff and soil erosion.

The green vegetation growing on these soils conceals their low inherent fertility as well as their limited ability to sustain reliable biomass harvesting over a long period of time. These acid soils need long fallow periods if they are to retain their productivity, due to their low contents of weatherable minerals, low moisture retention capacity and low inherent fertility. Not fallowing them for the desired period of time exposes these soils to irreversible degradation problems.

3.4.4. Soil degradation risks in the Ethiopian Highlands.

The single most important soil degradation risk in the Ethiopian highlands is soil erosion by water. Highland soils are widely distributed in the UPAs of Eastern highlands (UPA4), Shewa (UPA6), Asmera (UPA8), Abay (UPA7), Tigray (UPA9) and some in Keffa (UPA1) and Nyala (UPA3).

The high weatherability of the parent materials of the highland soils of Andosols and Alfisols makes them rich in the soil nutrients essential for plant growth. The highlands receive enough rainfall for crop production unfortunately, the terrain is rugged and steeply sloping, and rainfall intensity may be high. The erosiveness of intense rainfall, compounded by the steepness of the topography, can cause severe land degradation as it detaches soil particles and deposits them in the lowlands. The lowland soils are adversely affected by the deposition of the eroded materials. In particular, some good alluvial soils may be buried by sediments of poor quality, such as sand or coarser material brought down from the eroded hillsides.

Due to the high susceptibility to erosion of the Ethiopian highland soils, there is significant erosion in about 50% (270,000 km²) of the highlands, including about 150,000 km² on which serious erosion has left relatively shallow soils (ADAB, 1985). Recent research in UPA5 (Abay) where the Blue Nile originates, indicates an average annual soil loss of some 20 tonnes per hectare (FAO, 1986).

3.4.5. Soil degradation risks in poorly drained soils and

Vertisols.

Poorly drained soils can be found on gently sloping and lowlying regions of the country where rainfall is high or drainage is poor. The alluvial soils, lacustrine soils, soils of inland depressions, peaty soils, soils of narrow valleys and other soils situated in low lying areas and valleys are poorly drained. The most common land degradation problem for these soils is waterlogging which may result from rising water tables, floods, lateral seepage and poor irrigation practices. Floods, persistent weed invasion, low nutrient contents and disease hazards are some of the problems associated with these poorly drained soils.

The Vertisols are not usually poorly drained because of low lying position, but they can become waterlogged, however, due to their high clay contents and domination by expanding clay minerals. The major constraints of the Vertisols are that they are sticky when wet, and hard when dry, creating tillage problems, especially for the subsistence farmers. During dry periods plants growing on Vertisols wither quickly, because of the rapid drying out and cracking. Vertisols can be productive if these constraints are overcome. To reduce the risk of degradation on Vertisols, infiltrating water is conserved during the dry season and draining of surplus water is required in the rainy season. The largest portion of the Ethiopian Vertisols are in southwestern Ethiopia in the Gambella UPA (UPA2).

3.5. HUMAN FACTORS WHICH INCREASE LAND DEGRADATION RISKS.

3.5.1. Biological degradation and deforestation.

Forests are the primary sources of fuel wood and forest products are used as sources of construction materials and for some industrial activities. Forests in Ethiopia are also regarded as a potential area for the expansion of both crop and grazing lands. Around 1900, 45% of Ethiopia was covered by closed canopy forests. Only 25 years ago, 16% of the country was still under forest cover, but now less than 4% of Ethiopia is forested. Virtually all of the northern regions have no remaining forests (ADAB, 1985 and Harrison, 1987).

In the Ethiopian highlands, due to their cool to cold climate, more fuel for heating and cooking is needed than in most African countries. In this environment, an Ethiopian family needs at least 6 cubic meters of fire wood per year (MMEWRS, 1981). In 1981, it was estimated that the total fuel wood and charcoal demand in solid wood equivalent was 20-30 million cubic meters and the consumption of charcoal was about 150,000 tonnes for the country as a whole. On an annual basis the country uses 200,000 hectares of forests to meet the fuel and charcoal demand of its people (ADAB, 1985).

Not all Ethiopians have equal access to reliable sources of fire wood. In those parts of the country, especially northern Ethiopia, where little or no wood is available, the people use cattle dung and/or agricultural wastes as sources of fuel. The practice of using agricultural wastes and cattle dung as sources of fuel has a detrimental effect on soil productivity as it reduces the amount of nutrients and

organic matter returned to the soil.

The presence of plant cover reduces the probability of salinization that may threaten the productivity of soils in low-lying sites. Secondary salinization can occur with the removal of the perennial vegetation cover because the reduced crop transpiration changes the hydrological balance of the area. The reduction in evapotranspiration results in increased vertical and/or lateral drainage in hill slopes and the leaching of salt to ground waters causing the water table to rise and become more saline. Clearing vegetation on poorly drained soils can contribute to waterlogged conditions, with or without the influence of soluble salts. The effects of clearing are especially serious in high rainfall areas covered by rainforests where high intensity storms are common. Due to land clearing, the surface and subsurface soil permeabilities are reduced, runoff increases and soil erosion by water is accelerated. By clearing vegetation, one is replacing the native perennial types of vegetation that are well adapted to the effects of drought, wind and fire, by less adaptable, exotic and annual plant species. The replacement species commonly produce less litter for surface soil protection or the surface may be protected at certain seasons.

Forests have many roles in keeping soils productive. Plants protect sandy, poorly-structured and infertile soils against wind erosion. In general, forests improve the microclimate of a land in terms of temperature, wind and moisture conditions. When trees are removed, wind speed near the surface is increased and can more easily blow away the finer soil particles that were once protected. Another result of forest

clearing is that temperature ranges are increased by allowing more energy to reach the ground during the day and by increasing the terrestrial radiation losses during the night. The changes in the microclimate of the soils create unfavorable conditions for soil micro-organisms that are important in the process of decomposition and nutrient cycling. Some soil nutrients in some ecosystems are largely stored in the living biomass, thus the removal of the vegetation takes away critical nutrients that are important for the productivity of the soil resources of the area. All these undesirable effects of deforestation have taken place in Ethiopia as its forest resources have dwindled, from covering almost 50%, to less than 4% of its area.

3.5.2. Crop cultivation.

Almost all of the Ethiopian crops are grown by rainfed agricultural activities. Rainfed cultivation involves frequent tillage and exposure of the land to desiccating winds. At the beginning of the rainy season the well tilled and dessicated farm land is easily washed away by rainfall. When the crops become established their canopies protect the soil against erosion. At the end of the rainy season, the crops are harvested and animals are released into it for stubble grazing. The overgrazed and trampled farmland can also be eroded, again by untimely and unpredictable erosive rainfall that may come before the planting season.

Rainfed farm land can be abandoned when rainfall is persistently inadequate to grow crops. A more common trend in arid areas of Ethiopia has been the clearing of land for rainfed cropping with resultant severe

land degradation due to sand drifting and soil erosion by winds. Under these marginal conditions for rainfed agriculture, soil exhaustion is generally rapid and erosion is a severe problem. The landuse practices which minimize degradation are needed.

Some areas of Ethiopia have been cultivated for thousands of years. These old farm lands in many cases have been overcultivated and have lost most of their organic matter. As the need for food increased, farm lands have increased areally onto steep slopes and ecologically-sensitive ecosystems. Soils poor in organic matter are highly susceptible to structural damage when they are cultivated. The structural damage is accentuated because of practices, particularly in the Ethiopian highlands, of using crop residues as fuel. Soils with little organic matter are more susceptible to erosion by wind and water, to moisture loss and to soil compaction and the formation of plough pans. In seasonally wet environments, compacted soils and plough pans restrict root growth and impede drainage which results in waterlogging.

The various types of subsistence crop cultivation activities require variable lengths of fallow periods to restore soil fertility, control weeds and to reduce labor requirement. The length of fallow required depends upon several factors, including soil fertility and climatic conditions and is constrained by the availability of land and population density. In modern Ethiopia population pressures make it impossible to rest agricultural lands (both farm and grazing lands) to allow them to regain their fertility. The continuous usage leads to reduced productivity because of loss of soil fertility. The productivity loss is compensated by increasing the land area that is cultivated.

Most Ethiopian farmers practise subsistence agriculture and do not produce surplus. The subsistence farming practices are labor intensive and the crops are varied and hardy but low yielding. The subsistence farmers do not use fertilizers to maintain the fertility of the soils and the productivity of the system, to a large extent, depends upon the return of organic matter to the soil to maintain the physical structure stability of the soil and to supply nutrients.

Traditionally farmers have grown legumes with non-legume crops and rotated crops of different canopy and root habits to exploit the soil resources and moisture conditions at varying levels. These are wise practices. Some of these intercropping practices have been considered to be "primitive" because they are difficult to mechanize and consequently, farmers have been encouraged to grow cash crops under monocropping conditions to generate income for themselves and foreign exchange for the government. As a consequence, commercial crops, such as coffee, are expanding onto the easily farmed land at the expense of food crops and the food required by the subsistence farmers has to be grown on more marginal lands which are more subject to soil degradation and produce less.

Cereal crops, such as teff, peas, beans, wheat, barely, sorghum, corn and others, are widely grown in the country. In Ethiopia, more land degradation is associated with cereals than with either tuber crops or fruit trees. To grow cereals, the farmers break the land before planting, and leave it exposed without vegetation cover for most of the year both after harvest and immediately after planting. This practice increases the ability of wind and water to erode the soil resources on which the cereals

are cultivated.

The Ethiopian land tenure system does not grant farmers full ownership of their holdings. Consequently, farmers are reluctant to make investments or take timely conservation measures, such as building terraces and making drainage ditches, to protect the land and to increase the capability of their holdings. This attitude has contributed to the degradation of the Ethiopian farm lands through a desire for short term gains without consideration for the long term.

3.5.3. Sedentarization.

Due to unreliability of moisture supply to carry out agricultural activities, the arid and semi-arid areas of Ethiopia (mostly lowlands) are the home of a multitude of grazing and browsing animals. At present, 51% of Ethiopia is rangeland (FAO, 1986) and it is estimated that the country has 27.2 million cattle, 24 million sheep, 18 million goats, 7 million equines and 1 million camels (Atlas of Ethiopia, 1988). The livelihood of the inhabitants of the dry lowlands is very much influenced by the location of water and grazing for these animals, and to some extent by the location of areas on which to grow rainfed crops. Livestock herding is conducted using one of the nomadic, semi-nomadic or settled approaches, although it is usually part of a mixed farming system. All three approaches contain a high degree of risk and require adaptations to environmental uncertainties, in particular, periodic droughts which reduce herd sizes and kill the rainfed agricultural crops. Traditionally, the nomadic and semi-nomadic approaches have dominated :- in the arid and semi-arid regions, with movement being seasonal, flexible and

regionalized, in order to make the most effective use of the resources of water and grazing in these inhospitable environments.

From a resource management point of view, nomadism is a very efficient way of utilizing the scattered and dispersed resources of the Ethiopian arid lands. However, there are other views of nomadism. Nomadism makes it difficult for local and central governments to provide health and education services. Traditional movements do not recognize political boundaries and the nomads do not stay for long periods in any district which creates problems in building the feeling of national, political identity and accepting the responsibility of citizenship. Conflicts among nomadic groups over grazing and watering points, may draw neighboring countries into war.

The government response to the problems associated with nomadic movement has been to start settling them down. As a result of sedentarization, provision of health, education and agricultural services and tax collection is easier, and political delegation can be exercised with less difficulty. Efforts have been made to provide veterinary services and reliable water sources within the reach of the settled pastoralist. Unfortunately, these measures have turned out to be the biggest causes of environmental degradation of the pastoral ecosystem. Part of the problem is that the country does not have any law that restricts the number of livestock each person may own. This becomes a serious problem when the provision of reliable water sources attracts large numbers of pastoralists with their livestock to the well locations. While the water supply is abundant and year round, the grazing resources are left at the mercy of atmospheric influences. When the environment is

favorable, grazing is abundant but when there is drought serious problems of overgrazing arises. Improving the water supply without increasing the grazing potential of the land accelerates the over utilization of the meager forage. The provision of the improved water supply has commonly lead to overgrazing and an acceleration of land degradation.

The degrading effects of overgrazing include both the loss of vegetative cover and a change in the species composition which increases the proportion of unpalatable woody species that provide poor surface protection. The changes in the type and amount of vegetative cover are accompanied by an increased number of dust storms, sand drifting and extension of bare areas.

The process of sedentarizing nomads is accompanied by a tendency for them to change from pastoral to crop growing activities. In years with good rains, high yields deceived people, who were unfamiliar with cropping, into introducing some concentrated and intensive production systems in these areas. In the periodic dry periods that inevitably came, these areas were incapable of sustaining crop production. The consequence was irreversible land degradation, including the expansion of deserts. With crop failure, further problems arise when people collect firewood from the few stands of trees that exist and take it to the nearest urban centers to get food in exchange. The localized use of the pastoral lands as sources of firewood for the sedentarized population and for income in time of drought enhances the formation of unproductive bare lands.

3.5.4. Irrigation.

Most of the Ethiopian lowlands and river valleys have the potential

for irrigation. Ethiopia has 2-3 million hectare of irrigable lands, of which only 100,000 ha. or 3% has been developed. Excluding the ground water potential, a total of 101 billion m³ of water is estimated to be produced by the ten major Ethiopian rivers. Only 3% of this huge water resource is consumed in the country and the remaining 97% flows to the neighboring arid countries (Atlas of Ethiopia, 1988).

Most of the large scale irrigation works are on the state farms in the Awash valley, where 70% of the nation's irrigable lands are situated (Atlas of Ethiopia, 1988). The areas where the irrigation activities are performed were originally pastoral ecosystems. While production benefits are obtained, the world wide undesirable effects of irrigation are not exclusive of Ethiopia. Consequently, salinization, silting of water reservoirs, lessening of deposition in downstream areas, waterlogging, spread of water-related diseases and weeds, and water pollution from pesticides or fertilizer use, are all occurring due to the practice of irrigation.

3.5.5. Urbanization.

In 1984, there were 656 or more urban centers in the country with a population of close 5 million or 11.29% of the Ethiopian population. The urban population is growing at an annual rate of about 6.6% of which 4% represents net immigration from the rural areas (CSA, 1986).

There is substantial evidence to prove that urbanization plays a significant role in the process of land degradation in Ethiopia. Most of the Ethiopian urban centers are established on good agricultural lands and their expansion occurs at the expense of the agricultural lands, simply

because flat and relatively well drained lands are desirable for construction purposes. Excessive amounts of wood resources have been destroyed to meet their construction and fuel demands.

As the urban centers expand, they demand more food supplies, but by engulfing good crop land, they push the food producing activities into more ecologically sensitive ecosystems. They also require heavy investment in transportation systems and other improvements to benefit from the products of the more distant newly-established production zones.

Urban growth has drained many young men from the rural areas, has destabilized the rural work force and put pressure on the remaining rural population to grow more food. Paradoxically, the increased demand is occurring when the ability of the rural labour force to meet the country's food and export demands has decreased dramatically.

Like other urban centers of the world, those in Ethiopia are centers of unrest that force the government to initiate and implement some inappropriate land use policies in the rural farming communities in order to satisfy the urban dwellers. Until recently, farmers were not paid fair prices for their harvests, because crop prices were controlled by the government, and farmers were not allowed to take their produce to the free market unless they had fulfilled their mandatory grain quota to the government. These trends of favoring the urban areas encourage the farmers not to invest many resources in maintaining the productivity of the soils on which the agricultural crops are grown. This leads to environmental degradation. When it becomes severe, rural people migrate to towns and cities, further aggravating the resource base pressures by increasing urban demand and reducing the capabilities of the rural areas.

CHAPTER FOUR

METHODS and PROCEDURES

4.1. CANDAF

Drought is the weather restraint that causes the most severe crop failures in Africa. The Canadian Analysis of Drought in Africa (CANDAF) system is a software package developed to analyze drought conditions in Africa using monthly rainfall records combined with information on soil water storage and crop water demand (Dyer, 1988). The operational use of CANDAF to analyze current African drought was therefore totally dependent on real-time rainfall records. The current monitoring application of CANDAF also relies heavily of historical weather and climate data to normalize current year estimates. Because CANDAF contains extensive climate reference files, long term planning was recommended as a secondary application of CANDAF (Dyer, 1989). For this study CANDAF was adapted to evaluate the role of climate in land degradation in Ethiopia.

Comparison of current years with the available historical record can be carried out in CANDAF to obtain information on the deviation of the current years from the mean or expected values. Climatic deviations of the eighties from normal conditions have been derived in various applications on a demonstration basis from the continental version (Dyer 1988a) and for Zambia (Dyer, 1989).

Thresholds representing specific probability values, to index drought impacts according to their deviation from the mean and their

degree of unusualness, were derived from the 40 year monthly rainfall data provided in the continental version of CANDAF from archives developed by Nicholson (1984). In addition to normalizing, current estimates were assigned probabilities of recurrence in future years based on comparison to the threshold values for each selected probability. This was a risk analysis process of linking operational decision making to long term land use policy. The historical risk analysis feature was retained in CANDAF-Ethiopia for both future planning and real time application of the software package.

The most important function in CANDAF for this application to Ethiopia was the soil moisture balance computed at the end of each month (option 3 of the main menu for the real time process - see Dyer and Cianferro , 1988). Rainfall records were combined with the normally expected evapotranspiration potential (PE) and soil moisture storage from the previous month to simulate the soil water balance for each month. Monthly PE and rainfall normals were obtained from FAO (1984). Coefficients for consumptive water use by plants under well-watered conditions and for soil water storage capacities must be provided for the 12 month simulation period in the soil moisture model. These coefficients allow the soil moisture simulations to reflect soil texture and depth and plant root growth patterns. Soil water balance provides a more accurate assessment of crop water use and crop growth rates than could come from straight rainfall accumulation. Crop water use is equated to actual evapotranspiration.

The soil moisture simulation model in CANDAF is described in detail elsewhere (Dyer, 1988, Dyer and Cianferro, 1988) so will only be discussed

briefly here. The main objectives of the model are to give realistic estimates of moisture reserves left in the soil profile at the end of each month and the actual amount of moisture lost through evapotranspiration. This actual moisture loss will be below PE for any situation where water supply (either rain or irrigation) does not meet or exceed PE. The CANDAF soil moisture model achieves this difference between actual and potential evapotranspiration by simplifying the daily-based moisture extraction equation defined by Baier and Robertson (1966) to a monthly time step and for one layer of soil instead of six layers. Iterative calculations determine the mean monthly actual evapotranspiration rates. The general response of the model is for the actual to potential evapotranspiration ratio to decrease to zero as soil moisture reserves are depleted and to increase or decrease in response to plant tissue density. The rooting depth is taken into account by thickening the soil layer as roots penetrate deeper soils. The simulation is always for 12 months, with the simulations reflecting antecedent periods by using the last simulated soil moisture value as an initial content value.

4.2. CANDAF-ETHIOPIA: DEVELOPMENT

CANDAF has been downsized from continental to national scale to investigate the degradation risk taking place in the different parts of Ethiopia as a result of climatic, soil and land use influences. To this effect, historical and normal climate records at all Ethiopian meteorological sites were extracted from the original continental files.

The downsizing steps to establish CANDAF-Ethiopia were:

- a) Digitize the Ethiopian political boundaries as Lat-Long coordinates

(both the national and provincial boundaries)

- b) Locate and classify the FAO meteorological stations within the Ethiopian boundary based on the annual precipitation they receive in millimeters. Some stations from the neighboring countries have also been included as part of the study.
- c) Isolate all climatic and other data not available from CANDAF files that could help describe the Ethiopian territory.
- d) Create new Uniform Productivity Area (UPA) boundaries for Ethiopia (discussed in section 4).

Based on step c) 130 meteorological stations have been identified under country code-11 (the CANDAF code for Ethiopia). The range of aridity throughout the country was characterized and the 130 meteorological stations were categorized into four groups, according to annual rainfall levels (see Fig 6.1).

CANDAF has previously been downsized for real time application in Zambia (Dyer,1989). CANDAF-Zambia was employed in a similar way to the continental version to relate current situations and past experience, to help predict crop yields from mid-season conditions and drought-related crop failures following periods of low rainfall. The steps in real-time operation included

1. Normalizing the current rainfall data as a percent of past rainfall records,
2. Projecting to the end of the growing season using the available rainfall data from the current year and normal rainfall for the remaining months of the growing season,
3. Simulating crop water use from soil moisture estimates, normal

evapotranspiration potential and both current and normal rainfall.

Although the version of CANDAF downsized for Ethiopia, has this same potential real-time application, the main objective in developing CANDAF-Ethiopia was to identify the regional climate factors that affect on-going land degradation processes. Therefore, in step three only normal rainfall data was used.

4.3. CANDAF-ETHIOPIA: APPLICATION.

The growing condition requirements of the major crop types of the country from some selected areas were evaluated, based on simulated actual evapotranspiration and soil moisture using crop development characteristics of the selected areas.

The major land use practices have been assessed throughout the country with respect to climate-based variations in soil moisture. High risk of land degradation is directly linked to the incompatibility of the resource base with the type and intensity of land use. This assessment was partially conducted through a national rainfall analysis. But to identify the compatible land use practices according to the humidity levels of each area, the amount of stored soil moisture to support reliable biomass growth with tolerable moisture stress was required.

In the application of CANDAF to Ethiopia, a shortlist was created of FAO climate stations within each of the newly defined Uniform Productivity Areas (UPAs) which were specific to natural ecological boundaries within Ethiopia's boundaries. Upon establishing each UPA shortlist, a monthly barchart of PE and rainfall totals was created for

the UPA. These barcharts give a visual interpretation of the nature of growing seasons and the diversity of climate-based growing conditions found in Ethiopia.

CANDAF-Ethiopia was employed to assess the potential productivity and carrying capacities of the country's agricultural systems. Accumulated rainfall, soil moisture at the end of the month, and crop water use during the growing season, are the three basic variables used to depict the impacts of drought on both farm and grazing lands. The soil moisture model was used to define the effective growing season for both perennial (forage) and annual field crops.

The CANDAF-based analysis of the climatic resources can draw on six climatic-based simulation indices. The indices are referenced by codes from zero to five in the CANDAF menu as indicated below :

- 0 - rainfall accumulation
- 1 - soil moisture storage in mm
- 2 - soil moisture expressed as percent of capacity
- 3 - crop water use/actual evapotranspiration
accumulation
- 4 - flood water volume/excess moisture
- 5 - potential evapotranspiration

Indices 1 to 4 all involve the soil moisture simulation model. When soil moisture simulations are executed with the shortlist option in effect in CANDAF, a soil moisture output table is generated for the 12 month simulation period. The table includes the months (identified by number), the soil moisture storage capacities (FLD CAP), the crop water use coefficients and the average soil moisture simulation from the shortlist.

Soil moisture and FLD CAP are both in mm. Also the table gives the integrated value which is the average or total for the defined period, depending on the chosen index, and the spatial standard deviation. The crop water use (index 3) and the soil moisture output table are the main bases for the land use interpretations which were generated from this analysis.

Since the main land use question examined here was pastoralism compared to seasonal field crops, two soil moisture output tables were generated for each UPA : one for annuals and one for perennials.

The mapping option of CANDAF-Ethiopia was employed to identify and map areas that were particularly prone to persistent drought. Mapping increased the overall understanding of regional rainfall sensitivity. A map was used to demonstrate spatial variability of annual rainfall in the country. To apply the CANDAF mapping function, the African continental outline had to be replaced by a digital outline for Ethiopia. For convenience to possible future use of this analysis by government officials, internal political boundaries are also shown. An understanding of the fragility of areas, which can enable the recommendation of compatible land uses to reduce the risk of land degradation, requires isolating information from each area. A function was included in CANDAF to create a shortlist of climate stations which share a common property (Dyer and Mack, 1986). The criteria for such a property can be index values which fall below a selected threshold, where any of the six indices described above can be used, on all sites located within a defined area.

4.4. DESIGNATING ETHIOPIAN UPAs.

The diverse resource base of Ethiopia makes evaluation of her vegetative productivity a complex task. The types of land use practices which provide optimum production in the various areas of Ethiopia require that each unique area be considered individually. The UPA concept, which evaluates the biomass production of an area, was originally initiated and implemented by Agriculture Canada to simplify identification of the capabilities, limitations, and productivity of Canadian agricultural lands (Bain et al., 1985 and Mack et al., 1986). Based on this same concept, identification of Ethiopian UPAs will enable us to evaluate the potential productivity of the country's agricultural lands. This area-by-area approach should also be a useful basis on which to catalogue land degradation processes, rates of land degradation, and the risk of accelerating these degradational processes in the future.

When CANDAF was applied to Africa on the continental scale, 89 Uniform Productivity Areas (UPAs) were demarcated, based on climatic information and a variety of geographical and ecological considerations (Dyer and Mack, 1986). Eight of these continental UPAs include Ethiopian territory.

In adapting CANDAF for application to a country that has as diverse a land base as Ethiopia, a more intense appraisal is required and more factors may need to be considered. In this application to Ethiopia, topographic and soils information is employed to refine the positioning of UPA boundaries, as identified by available climatic information, and to divide some of the climatically-identified UPAs which differ according

to these new parameters.

The main reason behind choosing these factors in demarcating the UPA boundaries is their influence in one way or the other on biomass production and the processes of land degradation. Climate has enormous influence on biomass production; conversely, climatic agents such as wind, rain and temperature contribute to the process of land degradation. Topography has strong influence on the range of climates and also plays an extensive role in the processes of land degradation through slope, drainage and elevation. Soils are the natural media which support terrestrial plant growth. The variable fertility status and physical properties of different soils have major influences on the quality and quantity of biomass produced. These same chemical and physical properties also influence the rate of degradational processes caused by the external factors of climate, topography, and biological and human activities.

The availability of information has determined the relative importance that has been placed on soils, topography, and climate in delineating the Ethiopian UPAs. The climatic information extracted from CANDAF, specifically the spatial distribution of the 130 meteorological stations within Ethiopia, enabled climate to play the leading role in UPA boundary demarcation. The initial drawing of boundaries based on climate is accomplished by an interpolation between climatic stations which are irregularly located. The mountainous nature of the country and the easy access to topographic information, made topography the second parameter for UPA boundary demarcation. The soils, which are the victim of land degradation processes, were used third in the process of boundary demarcation. This is due both to the deficiencies in information on

Ethiopian soils, and to their extensive associational occurrence with climatic and topographic conditions.

Dyer and Mack (1986) demarcated their 89 continental UPAs based on largely climatic observations and the locations of the 1000 climate stations available. Although geographic information was used in the original UPA definitions, two important differences exist between this study and the continental analysis. First, the original UPAs were based on very coarse resolution (1: 5,000,000) and, second, Dyer and Mack (1986) relied heavily on NOAA satellite imagery as an empirical indicator of biomass.

In the first step of the current analysis, the 8 UPAs that intersected Ethiopia were reviewed and some were subdivided. The main reason for subdividing the continental UPAs was to distinguish, as separate entities, areas that the continental analysis had grouped but which were not geographically contiguous when examined on a finer scale, and to break up UPAs that were particularly elongated. Subdividing was done only where it left each UPA with enough climate stations to characterize its climate. The result is that Ethiopia has been divided into 13 UPAs in CANDAF. In the first instance, these new UPAs are still defined almost entirely on the basis of interpolation of climatic parameters measured at the 130 stations in Ethiopia, supplemented by four nearby stations in neighboring countries, without considering that such features as sudden changes in elevation or specific elevation contours may actually best represent the location at which the areal differences actually occur. Refinement of boundaries has been accomplished by adding considerations of topography and soil characteristics.

In the second step, the topographic map of Ethiopia was overlaid on the UPA map to facilitate adjustment of the boundaries based on topographic information. In other areas where major rivers or valleys show distinct soil associations and different climatic conditions, valleys and rivers have been used as UPA boundaries in these areas. In some cases, topographic considerations led to major adjustments in the location of UPA boundaries. In areas where elevational changes are dramatic, contours have been employed.

The section of the FAO-UNESCO soil map of Africa (1977) covering Ethiopia was overlaid on the Ethiopian UPAs and topographic maps, in the third step, to further refine the boundaries of the 13 UPAs. The soil characteristics used for differentiation at the order level tend to be the result of the long term integration of the effects of the soil forming factors of climate, vegetation and parent material. In redefining the boundaries based on soil considerations, attempts were made to keep large contiguous areas dominated by a single soil order or soil association in the same UPA, unless the climate data indicated that this was inappropriate. Although they did not have a leading role in defining the UPAs, soils had a significant contribution in setting the final UPA boundary lines. Regardless, in several cases, areas dominated by uniform soil associations have been divided among two or more UPAs as a result of the influence of topography. Table 4.1 shows the new Ethiopian UPA numbers and names and the corresponding continental UPA numbers.

Each UPA can be described in terms of climate, topography, soils, demographic factors, vegetation, crop and land use practices. In theory, each UPA should have a limited range for each characteristic and the UPA

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description gives, more or less, a picture of each of UPA, in line with the notion of interdependent ecosystems. Descriptions of each UPA will be presented in the next chapter. These descriptions are based on the interpretation of the FAO-UNESCO soil map of Africa-Ethiopia section (1977), the atlas of Ethiopia (1988), the climate of Africa (Griffiths, 1972), review of the work of Dyer and Mack (1986) on the original continental basis of definition, various FAO documents which contain information about the agricultural systems and resource base of Ethiopia, and personal experience.

Table 4.1

Continental and National UPA's

Continental UPAs Intersecting Ethiopia	New Ethiopian UPAs	Remarks
50	Asmera(8), Tigray(9), Abay(7), Shewa(6)	subdivision due to moisture, topographic and vegetation cover variations
45	Keffa(1), Nyala(3), Eastern Highlands(4)	moisture variations, and differences in elevations, crop types and farming systems
37	Gambella(2)	
42	Barentu(12), Abay(7)	differences in soil types, variations in humidity, and differences in wind and leeward positions
46	Lower Rift Valley(5)	
51	Ogaden(11), Afar(10)	presence of a highland UPA in between UPA 10 and UPA 11, flourishing agro-industrial establishments in UPA 10, and dominance of pastoralism in UPA 11
13	Dallol(13)	
49	Afar(10), Dallol(13)	elevational differences (UPA 13 - 0-500 m asl; UPA 10 - 500-1000 m asl), presence of the Awash River, which contributes to the development of enormous irrigation activities strictly in UPA 10

CHAPTER FIVE

ETHIOPIAN UNIFORM PRODUCTIVITY AREAS

The country has been divided into 13 UPAs, on the bases discussed in chapter four. Each of the 13 UPAs is considered to be a distinct ecosystem with a unique range of characteristics. At the same time as considering each UPA to be distinctive in its characteristics there are common features among the UPAs and linkages which make them interdependent in the process of biomass production. Overall, the aggregate of UPAs, interacting with one another, form the total ecosystem that lies within the political boundary of Ethiopia. In the following description each UPA will be identified by a number and by a verbal descriptor.

5.1. UNIFORM PRODUCTIVITY AREA 1 - KEFFA

Location: The Keffa UPA is located in the highlands of south western Ethiopia. The elevation ranges from 1000m to 3500m. Approximate area is 165,898 km².

Climate: Gore, the town with the highest annual rainfall (up to 2500mm/yr) in the country is situated in this UPA. Precipitation is recorded every month with $P > E$ for 7 to 9 months. The summer monsoons bring most of the rain. The occurrence of heavy rainfall can be attributed to: the windward facing slopes (to the southeast) which enable

Figure 5.1 Continental UPAs intersecting Ethiopia

Legend

1. Keffa	8. Asmera
2. Gambella	9. Tigray
3. Nyala	10. Afar
4. Eastern Highland	11. Ogaden
5. Lower Rift Valley	12. Barentu
6. Shewa	13. Dallol
7. Abay	

Figure 5.2 Ethiopian Uniform Productivity Areas

the zone to benefit heavily from monsoons; the high elevations; and the persistence of unstable air masses over the area for up to ten months.

The Atlas of Ethiopia (1988) classifies the climates of the Keffa UPA as:

- 1) A grassland type of climate which prevails in areas adjacent to the Gambella UPA. It includes the lowland regions (up to 1750m) with dry months in the winter. The mean annual rainfall is between 680 and 2000mm and the mean temperature of the coldest month is above 18°C.
- 2) A tropical rainforest climate with a mean annual rainfall between 1200 and 2800mm. The temperature of the coldest month is above 18°C. This tropical rainforest climate prevails in the same elevational range as the grassland climate type.
- 3) A warm temperate climate without a dry season. The temperature of the coldest month is less than 18°C. Areas experiencing this warm temperate climate get adequate rainfall throughout the year. The abundant and reliable soil moisture supports forest growth throughout the season. Most of the country's remaining closed canopy forest is located in this climatic area.

The moisture-based sub-regions of this UPA are classified as prehumid, humid, and moist humid (Atlas of Ethiopia 1988), and only very limited areas have substantial moisture deficits. Most of the UPA has either less than 100mm or between 100 and 300mm moisture deficiency. Most localities with mean annual moisture deficit of less than 100mm have a mean annual water surplus of greater than 900mm. In other localities the mean annual water surplus is between 300mm and 700, depending on the

density of vegetation cover. The moisture surplus from the uplands of UPA1 pass through the lowlands to form the Baro, Gilo, Akobo, and Omo rivers which enter UPA2 and southern Sudan.

Soils: The soils have developed on either volcanic or felsic parent materials. The common soils are: Chromic Vertisols - fine textured soils on level to gently undulating terrain with slopes ranging from 0 to 8%; Eutric and Humic Cambisols - fine textured soils on steeply dissected mountains with slopes over 30%; Eutric N'tosols - fine and medium textured soils on 8 to 30% slopes; Plinthic Ferralisols - fine textured soils on undulating areas with slopes between 0 and 8%; and fine textured Orthic Acrisols situated on level to undulating terrain of the UPA.

Vegetation: The dominant vegetation is broad leaf forest, that includes Baphia, Olea, Arundinaria and Aningeria. Tall grasses intermingled with trees are located in the lowlands adjacent to the Gambella UPA. The origin of Coffee Arabica is believed to be within this area, where it still grows wild in the natural forests.

Land Use: The most important agricultural systems in the Keffa UPA are the enset planting complex, shifting cultivation, and the pastoral complex, although the seed farming complex is practised in settlement areas and in the regions bordering the Abay and Shewa UPAs. UPA1 is best known for growing tuber crops: [Enset (false banana), yam, potato, and other root crops]. Intercropping of different crops, and even crops with trees is widely practised. Due to the availability of surplus moisture

throughout the year, food production from the various intercrop farming systems continues all year round. Livestock is a major component of the land use activities of the area. Some localities of the Keffa UPA support the largest population densities in the country, with a density of 300 persons per square kilometer. Large numbers of people from the drought stricken provinces of Tigray and Wello have been settled in parts of this moisture-rich UPA.

The risk of land degradation due to water erosion is high to very high, especially in areas where the human population is dense and farming activities use moderate and intensive cultivation. Areas outside human settlement zones are still covered by high forest, grasslands and bushlands.

5.2. UNIFORM PRODUCTIVITY AREA- 2 GAMBELLA

Location: Gambella UPA is located in the lowland areas of southern and south-western Ethiopia along the border of Kenya and Sudan. Most of the land is between an elevational range of 500 and 1000m, although isolated areas along the Maji escarpment reach 2000m. Approximate area is 59,723 km².

Climate: The Gambella UPA receives rain, associated with the inter-tropical convergence zone, from spring to autumn. The mean annual rainfall is between 600 and 2000mm and the mean temperature of the coldest month is above 18°C. The southwestern lowlands closer to the humid Keffa UPA, get more precipitation than the south and the southeastern

counterparts.

The moisture-based sub-regions are classified as moist subhumid, dry subhumid, and arid (Atlas of Ethiopia, 1988). The mean annual moisture deficit ranges from 300mm to more than 900mm while the mean annual water surplus ranges from less than 100mm to 400mm.

The Baro, Akobo, and Gilo rivers arising in Keffa, UPA pass through this region on their way to join the Nile, while the river Omo enters Lake Turkana, which is part of the closed basin system of the Rift Valley. The western part of the Gambella UPA has swampy and marshy areas flooded with excess river discharges from the humid highlands.

Soils: The dominant soils are: Haplic Yermosols - mostly medium and fine textured soils developed on steeply dissected mountainous areas with dominant slopes over 30%, they are commonly sodic; Chromic and Pellic Vertisols - fine textured soils on level to gently undulating topography with dominant slopes varying from 0 to 8%, they are often flooded seasonally; Eutric Nitosols - stony medium textured soils on slopes over 30%; Humic Cambisols - fine textured soils developed on steep mountains with slopes over 30%.

Vegetation: Tall grasses (Hyparrhena, Cenchrus, Chrysopogon and Dactyloctenium) with intermingled trees, are the dominant vegetation. Coniferous forests are restricted to the escarpment above 1800m. The woodlands are deciduous trees which change their storey and canopy cover seasonally with the seasonal changes of moisture abundance. The swamps and marshes are covered by Nile cabbage, while a variety of riverine

forest species grow along the major river banks.

Land Use: The non-tse-tse infested areas are used by pastoralists. Slash and burn or shifting cultivation is practised by the indigenous inhabitants to grow crops, as a supplement to their diet obtained by hunting and gathering. The highland inhabitants living close to the humid zones grow a variety of crops, including coffee. Latest studies indicate that UPA2 is one of the selected areas to grow cotton. Settlement programmes have also been conducted around Gambella. However, the most important natural resource of the UPA is wildlife. Big mammals such as the elephants, giraffes, buffaloes, hartebeests, elands and others are abundant. In this zone, the country has large conservation areas which are comparable to the east African national parks, size, diversity and abundance of wildlife species.

Fire is the major environmental threat of this UPA. Fires are used to poach wildlife products and to clear land for agricultural activities. The degradation risk in the Maji escarpment due to erosion is moderate to high. The lowland is threatened by slight degradational processes as a result of water logging (on the Vertisols) and salinization on the arid land soils.

5.3. UNIFORM PRODUCTIVITY AREA- 3 NYALA

Location: Nyala UPA is located in southeastern Ethiopia. The elevation ranges from 1000m to 4310m. Approximate area is 105,069 km². Mount Batu the second highest mountain of Ethiopia, is located in this UPA. Mount

Batu is part of the Bale Mountains National Parks, where two endemic mammals, the mountain nyala and siemen fox with their protected habitats are safeguarded from extinction.

Climate: The highlands, above 2000m, receive their precipitation from the summer monsoons, while the lowlands depend totally on precipitation generated during spring and fall by easterly winds. The spring and fall rains are highly unreliable, so the areas depending on these rains are susceptible to drought and famine hazards.

The large altitudinal differences, 1000m and nearly 4400m, produce 4 climatic sub-divisions:

- 1) Hot semi-arid climates with mean annual temperatures between 18°C and 27°C, and mean annual rainfall between 400 and 800mm. These areas experience high variability and unpredictability of rainfall.
- 2) Tropical climates, which experience dry months in the winter, occur up to an altitudes of 1750m. The mean temperature of the coldest month is above 18°C and the mean annual rainfall is between 700 and 2000mm.
- 3) Warm temperate climates prevail from 1750m to 3200m. The rainfall varies considerably both in amount and seasonal distribution. The mean temperature of the coldest month is below 18°C, and for more than four months this climate type has mean temperatures just above 10°C.
- 4) Cool highland climate occurs above 3500m. The mean temperature of the warmest month is 10°C or less. Annual rainfall is between 800 and 2000mm.

The moisture sub-regions are arid, dry subhumid, moist subhumid, and humid. The mean annual moisture deficits are 500-700mm in arid areas, 100-500mm in dry and moist subhumids areas, and less than 100mm in humid areas. The mean annual water surplus is less than 100mm in arid areas, from 300-500 mm in moist humid regions, and 700mm for the humid regions. The highland discharges cause the formations of several rivers that traverse the bordering dry lands of the Ogaden UPA. The Weyb, Welmel and Genale rivers merge to form the River Juba which passes through Somalia, while the River Dawa disappears in the arid soils of the Ethio-Somali border region.

Soil: Plinthic Ferralsols - fine textured soils on steep terrain with slopes over 30%; Xerosols (Haplic and Humic) - fine textured soils on slopes ranging between 0 and 8%; Haplic Yermosols - medium textured soils on lands having slopes over 30%, and coarse textured Calcic Regosols on level to gently undulating terrain with slopes ranging from 0 to 8%, are the common soils of the UPA.

Vegetation: A sequence of vegetation communities occurs influenced dominantly by altitude and climatic conditions. The sequence, by descending altitude, is afroalpine, subafroalpine, coniferous forest, broad leaf forest, and, woodland and savannah.

Land Use: Except for shifting cultivation, all the identified farming systems of Ethiopia are practised in UPA3. Pastoralism is dominant in the lowlands, while the highlands are known for their wheat and barley

production. The enset growing complex is widespread along the escarpment of the Rift Valley and on the highlands of UPA3 having enough humidity. In areas where the enset planting complex is dominant, the density of the human population reaches close to 300 persons/km².

Water erosion is the prime cause of land degradation in the highlands. Lowlands are losing their qualities due to aridity and overgrazing.

5.4. UNIFORM PRODUCTIVITY AREA - 4 EASTERN HIGHLANDS

Location: The Eastern Highlands UPA, in eastern Ethiopia, has more or less rectangular shape. It is bounded on 3 sides by the hot semi-arid climatic conditions of western Ogaden (UPA11) and the northern part of the Rift Valley (UPA10 -Afar). The southern side is bordered by the humid zone UPA, Nyala. The highest point is at 3100m and the lowest point, at 500m, is along the boundary to UPA10. The boundary contour line with the Ogaden UPA is at 1000m. Approximate area is 71,889 km².

Climate: The UPA receives variable amounts of precipitation in the spring, summer and autumn. Areas above 1700m, have a warm temperate type of climate in which the mean temperature of the coldest month is below 18°C and the mean annual rainfall is above 1000mm. A tropical type of climate exists below 1700m where the mean annual rainfall is between 600 and 2000mm, and the coldest month is above 18°C. A hot semi-arid climate with mean annual temperature between 18 and 27°C, and the mean annual rainfall between 400 and 800mm, is also present. The moisture subregions

are classified as moist subhumid, dry subhumid and semi-arid (Atlas of Ethiopia, 1988). The respective mean annual moisture deficits are humid areas (100-300mm), moist subhumid (300-500mm), dry subhumid (500-700mm), and the semi-arid areas (700-900mm). The mean annual water surplus for the humid areas ranges from 100 to 300mm and for the remaining areas is less than 100mm. The high elevations of this UPA allow it to receive better precipitation than the surrounding lowlands. The water surplus of the eastern highlands UPA is the source of the Wabe, Fafen, Galeti, and Wabe Shebelle rivers that cross and benefit the adjacent Ogaden UPA and the neighboring country of Somalia.

Soils: The dominant soils are: Haplic Yermosols - medium and fine textured soils on steep lands of slopes above 30%; Xerosols (Calcic and Haplic) - medium and fine textured soils on level to gently undulating lands with slopes ranging between 0 and 8%; Cambisols (Eutric, Dystric and Calcic) - medium and fine textured soils on steeply dissected terrain with slopes over 30%; Calcaric Regosols - medium and fine textured soils on slopes greater than 30%; Eutric Nitosols - fine textured soils on steeply dissected terrain with slopes over 30%; and the fine textured Chromic Vertisols on relatively gentle slopes ranging between 0 and 8%.

Vegetation: Grasslands grow in the lowland areas bordering the Afar and Ogaden UPAs. Acacia, deciduous, and wooded grassland vegetation dominate in the moist and subhumid regions. Juniperus and Podocarpus are the principal tree species of the highland areas.

Land Use: Pastoralism and the seed farming complex are the dominant types of farming systems in the whole UPA. The enset planting complex is not common, unless it is practised with coffee plantation and other cash crops, like "chat". Shifting cultivation is not well known to the inhabitants of the whole UPA. A range of crops are grown by the subsistence farmers. Sorghum, wheat, teff, and maize are the common crops of the area. Sorghum varieties known to be drought resistant are cultivated by the subsistence farmers. Vast areas of the UPA are intensively cultivated, which has resulted in shallow and stoney soils.

The primary cause of land degradation is considered to be water erosion. Wind erosion is accelerating in the lowlands, mainly due to loss of vegetation cover and aridity.

5.5. UNIFORM PRODUCTIVITY AREA- 5 LOWER RIFT VALLEY.

Location: The Lower Rift Valley UPA is located totally within the Rift Valley system. The altitude ranges from 500m to 2000m. The 2000m elevations are along the Rift Valley escarpments on both sides of the UPA. Approximate area is 60,829 km². The Lower Rift Valley UPA extends to Lake Turkana and the Ethio-Kenyan border. Eight lakes are situated within this UPA. The lakes which vary both in size and depth, are habitat for a variety of aquatic species and the breeding ground for both indigenous and European migrant bird species.

Climate: Most of the Lower Rift Valley does not receive summer rain,

rather it receives the "big" rains in spring and "small" rains in autumn. A few locations within the southern part of the Rift Valley system receive some summer rainfall associated with the neighbouring more humid Keffa and Nyala UPAs. The Rift Valley escarpments strongly influence the climates, which are generally drier toward the southern end of the valley. The moisture-based sub-regions are arid, semi-arid, and dry subhumid. The arid areas are located along the Ethio-Kenyan border, while the semi-arid areas are distributed as pockets across the bottom of the Rift Valley close to the lakes, and the dry subhumid areas are adjacent to the humid zones of the Keffa and Nyala UPAs. The mean annual moisture deficiencies correlate with the moisture region and are greater than 900mm in the aridlands, 500-900mm in the semi-arid regions, and 300-500mm in the dry subhumid areas. The mean annual water surplus for the arid and semi-arid areas is less than 100mm, and for the dry subhumid areas is between 100 and 300mm.

Soils: The main soils are: Haplic Yermosols - medium textured soils on steep mountains of slopes greater than 30%; Orthic Acrisols - medium textured soils on rolling and hilly topography of slopes ranging between 8 and 30%; Haplic Xerosols - medium textured soils on lands having slopes less than 8%; Chromic Vertisols - medium textured soils on lands having slopes between 0 and 8%; Calcaric Fluvisols - medium textured soils on gently undulating terrain with slopes between 0 and 8%; and medium textured Ochric Andosols on rolling to hilly areas (8 - 30%) and on steep mountains with slopes over 30%.

Vegetation: Grassland (Aristida, Cenchrus), woodland and savanna (composed of acacia and other mixed vegetation), and wetland and swamps are the major plant communities on the lowlands of this UPA. Juniperus and Podocarpus trees cover vast areas of the escarpment, whereas the foot of the escarpment supports mixed deciduous tree species.

Land Use: Pastoralism is the dominant land use activity. The escarpments are intensively cultivated. Cultivation is moderate on the bottom of the Rift Valley and the foot of the escarpments. Maize, teff, sorghum, wheat, beans, coffee, and enset are grown. The population density on the escarpments is one of the highest in the country ranging from 100 to 300 persons/km².

The escarpments that are densely settled and intensively cultivated are threatened by a high rate of water erosion. Enormous areas of the UPA are exposed rock or sand surface. Wind erosion is moderate to high in areas where the vegetation cover is scarce. The UPA is best known as a source of charcoal for the urban areas including Addis Ababa, which directly contributes to desertification of some areas within the region. The arid lands are exposed to salinization and sodication degradational processes, due to lack of enough precipitation and continuous overgrazing.

5.6. UNIFORM PRODUCTIVITY AREA-6 SHEWA

Location: Shewa UPA is located in the heartland of Ethiopia. The altitude ranges from 1000m to 4000m. Approximate area is 105,069 km². It

has the most significant urbanization, industrialization and agricultural activities of the country. Due to its richness in climatic and soil resources, UPA6 is the most important and reliable grain producing zone of Ethiopia.

Climate: The major rains originate with the summer monsoons, however, much of the northeastern highlands portion of UPA6 receives a bimodal rainfall pattern. Easterly winds provide a secondary rainfall sometime in the February to May period, as they ascend over the highlands. For example, Debre Sina, an old historic town located on the eastern highlands, receives precipitation virtually every month. This additional rain, called short rains ("belg"), comes in the spring and supports up to 15% of the country's grain production.

The Shewa UPA has three major climatic classifications : tropical; warm temperate; and cool highland (Atlas of Ethiopia, 1988).

- 1) The tropical climate prevails between 1000m and 1750m, with a mean annual rainfall between 600 and 2000mm, and a mean temperature of the coldest month above 18°C. The winter months are dry. Grasses, and tall grasses, intermingled with trees, constitute the vegetation of this tropical climate region.
- 2) The warm temperate climate prevails from an elevation of 1750m to 3200m with a mean temperature of the coldest month below 18°C, and a mean temperature above 10°C for more than four months. Winter rainfall occurs. Areas of heavy rainfall are covered predominantly by forests, and areas of moderate rainfall support primarily grass species.

- 3) The cool highland climate occurs in isolated highland areas above 3500m. The mean temperature of the coldest month is 10°C or less. The annual rainfall is between 800 and 2000mm, the winter months are dry.

The moisture sub-regions classify as humid, moist subhumid, and dry subhumid. The mean annual moisture deficits are dry subhumid (500-700mm), moist subhumid (300-500mm), and humid (100-300mm). The mean annual water surplus is 700-900mm for the humid region, 300-700mm for the moist subhumid, and 100-300mm for the dry subhumid. The Shewa UPA is the source of the Awash River which flows eastward to the Afar UPA, and it is also one of the main water sources for the major tributaries flowing westwards to the Blue Nile system.

Soils: The parent rock materials are uniform and predominantly volcanics. Topography is the main differentiating soil forming factor. Most of the soils are fine textured, and occur on a range of topography and slope values. The major soils include: Vertisols (Chromic and Pellic) - fine textured soils on gently undulating lands with slopes of 0 - 8%; fine textured calcaric Fluvisols on level to gently undulating lands with slopes ranging between 0 and 8%; Eutric Nitosols - fine textured soils on hilly land with slopes of 8 - 30%; Eutric Cambisols - fine textured soils on steeply dissected terrain with slopes greater than 30%; Cambic Arenosols - coarse textured soils on steeply dissected terrain with slopes above 30%; and some Cambisols - medium-textured soils on undulating slopes up to 8%.

Vegetation: Afroalpine and sub-Afroalpine, coniferous and broad leaf forests are the major vegetation communities. Larger areas of coniferous forests are found in this UPA than in any other part of the country.

Land Use: Except for shifting cultivation, all the types of farming systems generally used in Ethiopia are practised in UPA6. The seed farming complex is the most popular, as it includes crops to feed people and to get cash from export enterprises. All types of cereals, pulses, and oil seeds needed by the country are produced. As almost all of the farming activities are on a subsistence basis, there is an absolute and heavy dependence on livestock to perform farm tillage activities. The livestock are not only the source of energy to farm the land, they are also sources of food and foreign exchange. The enset planting complex is restricted to the areas of UPA6 bordering the all year round moist UPA1.

The capital city, Addis Ababa, and numerous other urban centers are located in this UPA. The human pressure on the resource base to meet its need for food, fuel and shelter has threatened the ecosystem. Land degradation, in the rural areas has resulted from the growing numbers of humans and livestock. The fallowing period on most farmlands has been shortened.

Water erosion is the biggest cause of land degradation. Land degradation by water erosion has accelerated recently because of high rates of deforestation, driven by a need for more fuel wood and for putting more land into agricultural production. These pressures from the growing number of both livestock and human population have threatened the

productive capacity of the UPA, which is the major grain producing zone of the country.

5.7. UNIFORM PRODUCTIVITY AREA 7- ABAY

Location: Abay UPA is located in the northwestern Ethiopia adjacent to the Sudanese border. The elevation ranges from 500m to over 4650m. Ras Dashen, the highest mountain in Ethiopia, is situated in this UPA. Approximate area is 107,834 km².

The rugged topography is inhabited by the Walia ibex and Siemen fox, endemic Ethiopian mammals. Because of their outstanding and spectacular natural features of the endemic species, the high mountainous areas (the Seimen mountains) of the Abay UPA were awarded world heritage status by UNESCO and IUCN (International Union For Conservation of Nature and Natural Resources) in 1980.

Climate: The highlands of the Abay UPA are on the windward side of the summer monsoon winds. The climates of UPA7 can be classified into four categories (Atlas of Ethiopia, 1988):

- 1) A grassland type of climate with mean temperature of the coldest month above 18°C, and the mean annual rainfall between 680 and 2000mm. This climate occurs below 1700m. Tall grass, and grasses intermingled with trees are the main vegetation features.
- 2) A tropical rainforest climate with the mean temperature of the coldest month above 18°C, and the mean annual rainfall between 1200mm and 2800mm.

- 3) A warm temperate climate with the mean temperature of the coldest month below 18°C. The annual rainfall is high, but its distribution and amount vary with location. This climatic type prevails between 2300 and 3200m.
- 4) A cool highland climate, restricted to the highest point of the Seimen mountains, with the mean temperature of the warmest month 10°C or less and the annual rainfall between 800 and 2000mm. This area experiences dry months in the winter. Light snow falls are a rare occurrence.

The moisture sub-regions of the Abbay UPA are dry humid, moist humid, and humid. The lowlands have large moisture deficits (700-900mm), the highlands have deficits of 100-300mm, and the areas in between these two extremes have mean annual moisture deficits of 300-500mm. The annual water surplus is from < 100mm-300mm in the lowlands, 700-900mm in the highlands and between 300-700mm in the intermediate altitudes. UPA7 is the source of the Blue Nile river ("Abay"), on which millions of people in the Sudan and Egypt depend for their survival. Lake Tana, the biggest highland lake of the country and the source of Blue Nile/Abay, is located in this UPA.

Soils: The parent material is exclusively volcanic. The rainfall is comparatively high and most of the highland soils are stony and shallow, due to both natural and man made erosion. Structural movement and hundreds of years of intensive farming activities influence the soil erosion patterns. The dominant soils are: Eutric Regosols - fine textured soils on steeply dissected mountains with slopes over 30%; Eutric Nitosols

- fine textured soils situated in broken terrain with slopes ranging from 15 - 30%; Chromic Vertisols - fine textured soils on undulating land with slopes varying between 0 and 8%; Cambisols (Hemic, Eutric and Dystric) - fine textured soils on steeply dissected terrain of slopes close to 30%; Eutric Fluvisols - fine textured soils on level to gently undulating lands with slopes between 0 and 8%; Cambic Arenosols - coarse textured soils on steeply dissected mountains with slopes between 15-30%; and fine textured Orthic Acrisols on rolling lands with slopes between 8 and 15%.

Vegetation: The extreme highlands are covered by afroalpine forests. Coniferous forest of Podocarpus and Juniperus species grow in areas below the afroalpine zone. Broad leaf forests mixed with grasses are dominant at lower elevation where there is enough moisture and favorable temperature. The lowlands close to the Sudanese border are predominantly open grasslands.

Land Use: The primary land use activity of the UPA is subsistence agriculture, with almost no stands of forest in the intensively cultivated farm lands. It is also common to observe cultivated lands interspersed with different types of vegetation. Seed farming complex, shifting cultivation and pastoral complex are the major farming systems in the UPA. A range of crops is grown from the lowlands up to the top of highest mountain of the country. Teff, sorghum, maize, wheat, barley, and potato are grown on subsistence land holdings.

The tremendous amount of river discharges from the adjacent uplands provides the lowlands of UPA7 with irrigation potential to allow crop

production throughout the year. These lowlands have enough precipitation, good soils and sufficient growing period to support crop cultivation. However, mainly due to the cultural orientation of the inhabitants, pastoralism is the dominant land use practice. The lowlands accommodate a variety of wildlife species, because of which, Fawda (1982) has recommended them for wildlife development and utilization activities.

The major causes of land degradation in UPA5 are high erosivity rainfall, and intensive cultivation on steep slopes. Most of the landscape is rugged with steep slopes, where it is impossible to carry out extensive cultivation without causing severe soil erosion. Almost all the steeply sloped lands have, unfortunately, been put under cultivation to meet the food demands of the growing population. The consequence of farming these steep slopes is to lose the topsoil and leave behind exposed bedrock. The monsoon winds are loaded with heavy moisture, stay for about four months over these windward highlands and produce a rainfall of high erosivity. The concentration of the high rainfall in a short period results in the highest rainfall erosivity in the country (FAO, 1984). The high erosivity causes millions of tonnes of topsoil to be carried away by the Blue Nile and its tributaries to the neighboring desert countries. Both intensity and duration of rainfall are factors in the process of land degradation.

5.8. UNIFORM PRODUCTIVITY AREA 8 - ASMERA

Location: The Asmera UPA is located in the northern tip of the country. The elevation ranges from 500 to 2000m. Approximate area is 51,428 km².

Climate: The Asmera UPA has three distinct climatic types

(Atlas of Ethiopia, 1988):

- 1) A hot arid climate occurs in its western and eastern areas, bordering the Barentu and Dallol UPAs, and UPA3, respectively. The mean annual temperature is between 27°C and 30°C, while the mean annual rainfall is less than 450mm. Winds are strong, cloud cover is scanty, temperature is high, and relative humidity is low. Most of this area is barren, while some has sparse vegetation.
- 2) A hot semi-arid climate prevails between the highlands to the south and the hot arid area (1). The mean annual temperature is between 18°C and 27°C, and the mean annual rainfall ranges between 400 and 820mm. The rainfall is highly variable from year to year. Steppe-type vegetation, with high resistance to the harsh climatic conditions, dominates.
- 3) The cool semi-arid climate is confined to the southern highlands of the UPA, with altitudes above 1600m. The annual temperature varies between 12°C and 18°C, and the mean annual rainfall is between 400 and 620mm. Steppe vegetation, adapted to low temperature and moisture conditions dominates.

In this arid to semi-arid region, the mean annual moisture deficit ranges from 700 to 900mm in its southern highlands to > 900mm over most of the area. The mean annual moisture surplus over the whole UPA is less than 100mm.

The Asmera UPA is one of the drought-prone zones of Ethiopia, suffering from low moisture, high temperature and large rainfall

variability. The major sources of moisture are the winter rains, caused by the interplay of the Saharan and the Arabian winds, both of which arrive from continental areas and have little moisture. The southern highlands receive some monsoon precipitation due to their elevation, but even these receive little and unreliable rainfall.

Soils: Most of the soils are stoney and shallow with a depth of less than 50cm. The dominant soils are: Regosols (Eutric and Dystric) - medium textured soils situated on steeply dissected terrain with slopes over 30%; Cambisols (Eutric, Dystric and Humic) - medium and fine textured soils on steep terrain of over 30%; Orthic Acrisols - fine textured soils on level to rolling lands of slopes between 8 and 15%; Cambic Arenosols - coarse textured soils on rolling and steeply dissected lands with slopes ranging between 8 - 30%; Haplic Xerosols - medium and fine textured soils developed on level to gently undulating, and rolling to hilly terrains with slopes varying from about 8 - 30%; and fine textured Eutric Nitosols on undulating and rolling terrains with slopes under 15%.

Vegetation: The distribution and types of vegetation in the UPA are heavily influenced by the climatic resources. Woodland and savanna vegetation, such as Juniperus and Acacia, grow where there is enough rainfall. Areas with scanty precipitation are covered by grass and steppe-type vegetation.

Most of the land is exposed rock or sand surface. The highlands are intensively cultivated and the adjacent lowlands are moderately cultivated. Some inaccessible areas are covered by bush or shrub plant

communities.

Land Use: The UPA was the gate way of the early settlers of Ethiopia (Atlas of Ethiopia, 1988). From ancient times, it has been exposed to intensive land use activities to support the early kingdoms of ancient Abyssinia (Pankhurst, 1961). Considerable land degradation is currently occurring in the UPA, in the form of water and wind erosion, and has been attributed to intensive human activities (Henricksen et al, 1985). The degradation of the vegetative resources has contributed to the present status and future risks of land degradation on the stoney and shallow soils of this area.

5.9. UNIFORM PRODUCTIVITY AREA 9 - TIGRAY

Location: The Tigray UPA, part of the northern highlands, has rugged topography on which intensive cultivation has been practised since time immemorial. The elevation ranges between 500 and 3900m. Approximate area is 53,087 km².

Climate: The monsoon rains are the major influence on climate, but the highlands of the Tigray UPA are situated to the leeward side of the main Ethiopian highlands and, as a consequence, this UPA receives insufficient rainfall to support plant growth. However, in the southern portion of this UPA, some highland areas, facing the easterlies, receive some rainfall from this source.

This UPA has three climatic subregions (Atlas of Ethiopia, 1988):

- 1) A hot arid climate with strong wind, high temperature, low relative humidity and almost no cloud cover occurs below 1000m and adjacent to the coastal zone. The mean annual rainfall is less than 450mm. Barren land and sparse vegetation dominate in this portion.
- 2) A hot semi-arid climate occurs in the elevation ranges between 1000 and 1500m. The mean annual temperature is 18°C to 27°C and the mean annual rainfall is 410 to 820mm, with high variability from year to year.
- 3) A grassland climate occurs between 1800 and 3200m. The mean temperature of the coldest month is above 18°C and rainfall is greater than 700mm. The prevailing climatic conditions are quite different from the previous climatic types. The temperature of the coldest month is less than 18°C, and the rainfall distribution and amount vary from area to area.

The moisture sub-regions of the Tigray UPA are dry sub-humid, semi-arid and arid. The mean annual moisture deficit of the three subregions are > 900mm, 500-700mm and 300-500mm, respectively. The mean annual water surplus for most of the UPA is under 100mm, but the highlands, with their higher rainfall may have a mean annual surplus of up to 300mm.

Soils: The dominant soils are: Cambisols (Eutric, Calcic and Dystric) - medium and fine textured soils on steeply dissected mountains with slopes over 30%; Calcic Xerosols - medium textured soils on gently undulating terrain with slopes between 0 and 8%; Orthic Acrisols - fine textured soils occur on rolling land with slopes varying between 8 and 30%; Eutric Regosols and Eutric Nitosols - fine textured soils, situated respectively

on gently undulating land, and on steep slopes; and Cambic Arenosols are coarse textured soils on steeply dissected terrain with slopes greater than 30%.

Vegetation: The dominant vegetation is mixed deciduous woodland and savanna, composed of grasses and acacia trees. Podocarpus and Juniperus trees grow in the highland areas. Vast areas of the UPA are exposed rock or sand surface.

Land Use: The primary farming system of the UPA produces a range of pulse and cereal crops. Livestock are predominantly kept as draft animals for cultivation. Most of the highlands are susceptible to drought hazards due to their rainshadow position. Unfortunately, a high to very high water erosion problem exists when excessive rain falls on the steeply sloping lands of the rainshadow localities that are devoid of vegetation. Extensive land degradation has occurred as a result of hundreds of years of intensive cultivation and uncontrolled exploitation of the vegetation resources for grazing and general expansion of agriculture. With accelerated erosion, the topsoil has been removed leaving behind shallow and stoney soils with less than 50cm depth. In recent years, some drought victims have been evacuated from this area and settled where moisture reliability and soil fertility are believed to be better.

5.10. UNIFORM PRODUCTIVITY AREA 10 - AFAR

Location: The Afar UPA is located totally within the northern half of the

Rift Valley system of east-central Ethiopia. UPA10 is lowland, bounded by highlands to the northwest and southeast. The elevation ranges from sea level to 1000m. The approximate area is 49,769 km². This area is commonly known as the Afar Triangle, after the pastoralist Afar people who inhabit the area.

Climate: The Afar UPA lies in a rainshadow. The adjacent highlands of the Shewa UPA (to the northwest) receive rainfall in spring and summer, while the summer rains benefit the Eastern Highlands UPA (to the southeast). The rain falls in the highlands and the dry winds descend into this triangle to make it a rainshadow. However, when the trade winds are excessively loaded with moisture, some precipitation falls and supports biomass production for the pastoralists.

Areas in the north, close to the Dallol UPA, experience hot arid climatic conditions with excessively hot temperatures, low relative humidity, clear sky, and strong wind. The mean annual temperature is 27°C to 30°C. Portions of the UPA bordering the Shewa and Eastern highlands UPAs are semiarid, with more precipitation and lower temperature. The variability and unpredictability of precipitation causes fluctuation in the productivity throughout the area. The overall mean annual moisture deficit and water surplus of this UPA are more than 900mm and less than 100mm, respectively.

The unique hydrological feature of this UPA is the Awash basin, which receives water from numerous rivers and streams draining from the neighboring highlands. The Awash is the only major river of Ethiopia which flows completely within the country's political boundary. It has

14 tributaries and enters Lake Abbe close to the Ethio-Djibouti border, after travelling 1200km. Irrigation water from the Awaci has facilitated the establishment of large agro-industrial activities which process, for export and domestic consumption, the agricultural products grown by irrigation.

Soils: The dominant soils are: Regosols (Eutric and Calcaric) - medium and fine textured soils on steep terrain with slopes over 30%; Chromic Vertisols, Calcic Xerosols, Calcaric Fluvisols, and Haplic Yermosols - all medium textured soils on level to gently undulating lands with slopes ranging from 0 - 8%; and coarse textured Lithosols on level to gently undulating plains with slopes ranging from 0 to 8%.

Vegetation: Halophytic vegetation grows on Yermosols and Xerosols, while the Vertisols and Fluvisols are covered by riverine forests and water-loving vegetation. Grasslands, steppe and mixed vegetation communities grow on the other soil associations.

Land Use: A large portion of the zone adjacent to the Dallol UPA and Djibouti is exposed rock or sand surface. Areas bordering the humid highlands are covered by various types of vegetation communities. Isolated lowland areas are covered by swamps and marshes.

The principal land use activity is pastoralism. Traditionally the Afar people are pastoralists who move about the area seeking good grazing and water for their livestock. Dryland farming by subsistence farmers is extensive along the semi-arid areas close to the humid highlands. The

abundant and easily-harnessed water resources of the Awash basin have enabled the country to develop major hydro power plants and to support 70% of Ethiopia's irrigation farming activities. The UPA is reported to have 175,000 hectares of potentially irrigable land (Atlas of Ethiopia, 1988). The UPA produces a variety of lowland crops, vegetables, fruits and 64% of the country's cotton.

Wildlife species, specifically gazelles, antelopes, hartebeests and equids are effective utilizers of this climatically-constrained environment. Wild ass, one of the eight endemic mammals of Ethiopia, inhabits the extreme dry and rocky parts. They are threatened by habitat destruction associated with irrigation development.

The primary causes of land degradation are associated with high temperatures, irrigation activities and overstocking around pastoralist settlement areas. The soil degradation risk due to wind erosion is high in areas where vegetation cover is non-existent. Salinization and sodication are problems in areas with high temperature and low precipitation.

5.11. UNIFORM PRODUCTIVITY AREA 11 - OGADEN

Location: The Ogaden UPA covers much of the eastern and south eastern lowlands of Ethiopia, extending to Somalia and Kenya. The topography is flat and elevation ranges from almost zero to 1000m. Approximate area is 257,142 km².

Climate: The Ogaden UPA is an extremely arid area, suffering from low,

erratic and unreliable rainfall. Heavy rains in spring, and light rains in autumn are the sole sources of precipitation. The absence of the summer rains renders this UPA very susceptible to drought and famine calamities.

The moisture sub-regimes are arid and semiarid, the temperature regime is hot. The mean annual moisture deficit in the arid region is greater than 900mm, and in the semiarid region is between 700 and 900mm. The overall mean annual water surplus throughout is less than 100mm (Atlas of Ethiopia 1988). In the hot arid climatic zone, the land has only sparse vegetation cover. The mean annual temperature is between 27°C and 30°C. and the mean annual rainfall is less than 450mm. Other climatic constraints include: low relative humidity, little cloud cover, strong winds and high temperature, which in most cases, make potential evaporation 20 times more than rainfall. The hot semiarid climatic zone is located between the arid desert and the subhumid climate of the Eastern highlands UPA. The temperature is between 18°C and 27°C. The rainfall is variable, but is sufficient to support adequate vegetation for numerous wildlife species and domestic livestock to survive.

The two major river basins in this UPA are the Genale and Wabi Shebele, both of which originate from the Eastern Highlands and Nyala UPAs, and flow across the Ogaden UPA to Somalia. The Genale reaches the Indian Ocean, whereas the Wabi Shebele after about 2000km, "sinks" into the sands.

Soils: Regosols (Eutric and Calcaric) - fine textured soils on level to rolling terrains with slopes ranging from 0 - 15%; Yermosols (Haplic,

Calcic and Gypsic) - coarse and medium textured soils on level to rolling plains of slopes between 0 and 15%; Calcaric Fluvisols - fine textured soils on terrain with slopes between 15 and 30%; and the medium textured Haplic Xerosols on level to gently undulating lands with slopes between 0 and 8%, are the dominant soils of the UPA. As a consequence of high aridity, most of the soils have high accumulation of salts on their surfaces.

Vegetation: The dominant vegetation community is open grassland composed of grass species such as Cenchrus ciliaris, Aristida, Chrysopogon and Dactyloctenium. Areas close to the subhumid zones support woodland and savanna vegetation. The major rivers crossing this vast dryland look much like green strips from the air, due to the broad leaf forests growing on each side of the river banks and extending outward for 3 to 5 kilometers.

Land Uses: The land use activities and land cover condition of the UPA are severely affected by the climatic constraints of low precipitation and high temperature (FAO, 1984). The UPA has much unutilizable land. The dominant land use activity is pastoralism. Cultivation of crops only occurs along the major rivers. A diversified and adaptable wildlife population roams freely in this harsh environment. Gazelles and medium to large size antelopes have different adaptive mechanisms to overcome the water deficit and high temperature stress.

The sloping areas, adjacent to the humid zones from which the major rivers originate (Eastern Highlands and Nyala), are susceptible to moderate water erosion. The lowlands are losing their productive

qualities through the processes of salinization, sodication, and wind erosion. The risk of chemical degradation (i.e. salinization and sodication) is rated as moderate. The wind erosion risk is high to very high, due to little vegetation cover to serve as windbreaks.

5.12. UNIFORM PRODUCTIVITY AREA 12 - BARENTU

Location: The Barentu UPA is located in northwestern Ethiopia along the Sudanese border. The altitude ranges from 500m to about 1400m. Approximate area is 35,944 km². UPA12 is the receiving area for river discharges from the Asmera and Tigray UPAs. The Barka river originates from the highlands of Asmera and traverses Barentu northwards to its final destination in the Red sea. The Takeze river originates in Tigray and combines with other tributaries from UPA2 to form the Atbara river, which flows into the Nile system in the Sudan.

Climate: The rainfall in the Barentu UPA comes with the summer monsoon, but these rain-bearing winds do not bring enough moisture to balance the high rate of evapotranspiration caused by the high temperatures. Consequently, the UPA is an arid region, with a mean annual moisture deficit of greater than 900mm, and a mean annual water surplus of less than 100mm (Atlas of Ethiopia, 1988).

Soils: The Barentu UPA is dominated by three major arid-region soils: Luvic Xerosols - medium textured soils on level to gently undulating plains with slopes between 0 and 8%; Gypsic Yermosols - medium textured

soils on terrain with slopes ranging from 0 to 8%; Eutric Regosols - medium textured soils on steeply dissected lands with slopes close to 30%; and some fine textured Chromic Vertisols on gently undulating land, close to the Sudanese border, with slopes between 0 and 8%.

Vegetation: The dominant vegetative community is open grassland, mainly composed of grass species, such as Aristida and Sorghum purpureo-cericum. In the semi-arid part adjacent to the Asmera UPA, woodland and savanna dominated by Acacia species occur.

Land Use: Nomadism is the predominant land use in the area, although, rainfed agriculture is carried out where the rainfall is sufficient to support the hardier crops, such as sorghum. The land is occasionally cultivated and risk of land degradation is primarily attributed to salinization and sodication. Overgrazing presents a high risk of degradation in pastoral areas.

5.13. UNIFORM PRODUCTIVITY AREA 13 - Dallol

Location: The Dallol UPA is located along the Red sea coast of Ethiopia. The elevation ranges from -150m to 600m. Dallol, the lowest point in Ethiopia is situated in this UPA. Approximate area is 76,313 km².

Climate: Dallol, according to Griffiths (1972), is considered to be one of the hottest locations in the world, with an annual mean maximum temperature of 41°C, annual mean minimum 28°C and a mean value above 35°C.

The mean annual rainfall of 50 to 300 mm occurs in autumn, winter and spring. The growing period is at most one month (FAO 1984), and this occurs erratically when the total precipitation exceeds the potential evapotranspiration of the area. A number of seasonal and intermittent rivers flow into this zone from the Asmera UPA. In most cases, these intermittent rivers do not reach the Red Sea, unless there is heavy rainfall both in the neighboring UPAs and in Dallol UPA itself.

Soils: The major soils are : Orthic Solonchak - medium textured soils on level to gently undulating lands with slopes between 0 and 8%; Eutric and Chromic Regosols - medium and fine textured soils on level to gently undulating terrain having slopes between 0 and 8%; and some medium textured Dystric Andosols on steeply dissected terrain along the Asmera UPA with slopes ranging between 15 and 30%. Eutric Regosols and Vitric Andosols are capable of supporting plant growth. A large portion of the UPA is dominated by unconsolidated deposits of sand dunes, colluvial and alluvial fans and beach sands, which are all Xerosols without vegetation cover. Solonchaks, Lithosols, and Xerosols, all of which have undergone very little soil development, also are present. The high temperature and low rainfall encourage accumulation of salts on the soil surface and demand that plants be drought tolerant and salt tolerant.

Vegetation: Most of the UPA is devoid of vegetation. The most successful plant species in this water deficit zone are steppe, halophytic, and semidesert vegetation, such as Aristida and Acacia species. The shrub and tree species have thorns and alkaloid which protect them against heavy

browsing impact. Generally the plants provide poor ground cover, but they typically have deep root systems to exploit subsoil moisture located at depth.

Land Use: The main land use activities in this hot and moisture deficient UPA are salt mining from the salt flats, and limited pastoralism around settlement areas. Vast areas of the UPA are unusable. The primary causes of degradational processes are the natural agents of wind, moisture deficiency, and high temperatures. Accumulation of salts and wind erosion are the two most threatening land degradation processes.

CHAPTER SIX

RESULTS and DISCUSSION

Results

6.0. Introduction

Maps, barographs and moisture indices are employed to carry out the climate analysis of Ethiopia. Barographs for each UPA depict the distribution of P and PE on a monthly basis while the soil moisture tables translate rainfall into plant available moisture reserves. The maps show the humidity levels of the different parts of the country as represented by the FAO meteorological stations. Figure 6.1. shows the regions of Ethiopia where rainfall is below 400mm, 400 to 800mm, 800 to 1200mm, and above 1200mm. The UPA barographs for monthly normal values of P and PE represent the area average of all meteorological stations in each UPA. Thus, it must be cautioned that local conditions can vary around these values in all UPAs. The area standard deviations, given in the simulation tables for water use accumulation, help identify this variance. In conjunction with P and PE, moisture index (P/PE) was calculated to assess the length of growing period in each UPA. A value above 0.5 is required for the month to be considered part of the growing season. Tables 6.2a, 2b, 2c, 2d, 2e, 2f and 2g show the P/PE indices for all UPAs.

Soil moisture content simulation output tables for both perennials and annuals are presented for each UPA. These allow evaluation of the climatic potential for the growth and reproduction of crops in the various UPAs. The basic idea behind conducting simulation is to estimate the monthly available soil moisture.

Figure 6.1 Humidity classes of Ethiopia

These tables also contain the consumptive use factors and moisture storage capacities used in the simulations (Dyer, 1988a).

Soil moisture is strongly influenced by soil and crop parameters. Soil texture controls the storage of available soil water and the retention of water by soil. In line with this, the average soil texture and depth for each UPA has been determined to estimate a representative field capacity (FLD CAP) in each UPA. For example, the two northern UPAs (Asmera and Tigray) have medium-textured soils on sloping land with 50cm depth and 70mm moisture storage capacity (FLD CAP). The Gambella UPA has deep fine-textured Vertisols on gentle plains, with a field capacity of 130mm. The crop coefficients are, on the other hand, dimensionless factors which simply reflect plant and root density.

Roots exert suction on soil to absorb soil water. As the soil water is depleted, the soil develops increasing resistance against the suction exerted by plants. Retention of water by soils is related to soil texture, and finer textured soils with smaller pores can retain water more strongly, but also retain more water with any given suction than coarse textured soils. From a soil moisture point of view, UPAs dominated by sandy soils are more susceptible to droughts than UPAs with clayey or clay loam soils, because sandy soils store less water than clay loam and release moisture more easily.

The assumption in the simulation table is that field capacity (which is a function of texture and root depth of the representative soils in each UPA), is the maximum level to which soil can be recharged by monthly precipitation infiltrating the soil. The moisture requirements of annuals and perennials is shown as "CROP" in the simulation tables. The moisture

requirement of the perennials (1.00) are constant throughout the year, whereas for annuals, these parameters are seasonally variable according to their development stage and the amount of photosynthetically active materials they contain. The first row of the simulation table identifies the months by number (eg. January - 1 etc.).

The soil and crop parameters have to be determined as explained above from subjective interpretation of soil and agronomic information. The simulation and biomass accumulation periods must also be identified for each UPA to start the simulation. The simulation output provides estimated available soil moisture for all 12 months of the simulation period for each UPA. However, in order to obtain a reliable monthly soil moisture for both seasonal and perennial crops, a great deal of flexibility is required in handling the accumulation and simulation periods and estimating the soil and crop parameters. The starting month of the simulation periods for annuals and perennials is variable among UPAs depending on the rainfall regime. Biomass accumulation for perennials is done for 12 months, because they need moisture and must provide livestock feed year round. The seasonal crops have shorter life spans within a year and hence the biomass accumulation period is based on their seasonal moisture requirement. For example, a seasonal crop with a four month growing period only needs an accumulation for the four months to investigate the adequacy of moisture availability and use for its growth and reproduction. Two accumulations are shown in bimodal UPAs to select better the growing period with less risk of crop failure and associated land degradation processes in the light of the difference in biomass production. The shorter accumulation period is shown in brackets,

for example, the simulations for seasonal crops in UPAs 4 and 5.

In all perennial, bimodal and monocropping activities, the simulation procedure is the same. Accumulation period (Accum) ends at the last month of simulation and, for seed planting complex, takes in the rainy season. Initial Soil Moisture (SMIN), the amount of soil moisture at the start of the simulation process was selected iteratively to match the final simulated soil moisture estimate. After running the simulation for the desired period of months, the soil moisture balance (S.M) for each month, the area average accumulation and the standard deviation of moisture consumed by plants are shown at the bottom of each simulation table. Comparison of the soil moisture to the respective field capacity $[S.M/FLD\ CAP \times 100]$ has been used to investigate whether the monthly available soil moisture is below a certain threshold percentage such as below 50% or 30% of the monthly field capacity. To clarify the tables, the Keffa data (Tables 6.3a & 6.3b) will be used as an example. In this table: P and PE are presented by month, on the barograph; for perennials, the soil moisture simulation is carried out from November to October (11-10), the field capacity remains constant at 120 mm of water and reflects the moisture holding capacity and the plant rooting depth. The crop moisture requirements are assumed uniform at 1.00, which means that the moisture requirement of the crop is 100% throughout the year (i.e. does not change seasonally). S.M. indicates on monthly basis the available soil moisture balance in millimeter at the end of that month. SIMULATION 3 is one of the six climatic based simulation indices of CANDAF, which indicates the simulation process of crop water use/actual evapotranspiration in each UPA for perennial and seasonal crops. START

indicates the month in which accumulation was started, in this case 11 represents November and ends in October (10) from 11 to 10. SMIN (soil moisture initial) indicates the amount of soil moisture in millimeters at the end of the simulation month. The same interpretation holds true for seasonal crops, except that their moisture requirements and field capacity change seasonally and the accumulation period is shorter.

6.1. Soil Moisture Computations for Perennials,

General Assumptions

Perennials are plants that require at least a year to finish their life cycle of flowering and production of seeds. The assumption in the soil moisture simulations for perennials is that they use a relatively constant amount of soil moisture throughout the year for their growth and reproduction and they establish a fixed distribution of roots. Perennials could be food, cash crops, and browsable or grazable plant materials. Provided suitable species exist and produce some sustainable harvest throughout the year, without exposing the soil to land degradation, any of these uses of perennials is of benefit to the country. Therefore, the simulation process considers all plants, such as grasses, shrubs, trees and herbaceous plants, having at least a year long life span as perennials. More emphasis has been given to perennial plants that could be used as sources of feed for livestock and wildlife species. Table 6.2 shows the representative perennials for the Ethiopian UPAs.

6.2. Soil Moisture Computations for Annuals,

General Assumptions

Annuals take in a group of plants with a life span lasting less than a year or for one season within a year. Annuals pass through a series of basic development stages including seed germination, canopy development, flowering and grain production. The rate of moisture consumption by annuals is heavily dependent on the amount of green material they support as canopy cover. The abundance of green matter from annual crops changes rapidly over their life span. Consequently, the moisture requirement of the seed germination stage is lower than for flowering and seed production, due to the greater abundance of photosynthetic materials during the latter stages. This calls for a close examination of soil moisture availability at critical periods in order to reduce risk of crop failure.

Numerous grass species, herbs and most food crops are classed as annuals, because of their seasonal life span. The time needed to prepare the land before the onset of rainfall, for ease of seed germination, and a dry harvest season are common requirements of all the annual food crops. Germination cannot easily be achieved unless there is enough soil moisture in the prepared land, and harvesting process can easily be hampered if the rainy season extends beyond crop growth requirements. Annuals can also be susceptible to crop failure due to inadequate moisture when they flower and fruit. The agronomic requirements of annuals is more complex and difficult to deal with than the perennials whose requirement is specific, i.e. adequacy of moisture. This complexity of agronomic requirements is evident in examining the growing conditions of the annuals in each UPA. Table 6.2 shows the representative annuals for the Ethiopian UPAs.

Table 6.2
Major seasonal and perennial crops of Ethiopia

Annuals/Seasonals		
	Amharic Name	English Name
Cereals		
	Dagussa	African/Finger millet
	Gabs	Barley
	Bokollo	Maize
	Adja	Dats
	Bultuk	Pearl millet
	Mashella	Sorghum
	Teff	Teff
	Sende	Wheat (bread)
	Sende	Wheat (durum)
Pulses		
	Shembera	Chickpea
	Atar	Field pea
	Adongare	Haricot bean
	Bakela	Horse bean
	Messer	Lentils
Oilseeds		
	Gulu	Castor oil
	Lose	Groundnut
	Talba	Linseed
	Nug	Niger seed
	Gomman zar	Rape seed
	Suf	Safflower
	Salit	Sesame
- various species of grazable & browsable seasonal range plants		
Perennials		
Cash Crop		
	Chat	-
	Bunna	Coffee
	Gesho	-
	Enset	"False banana"
- various species of grazable & browsable perennial range plants		
- no English equivalent		

6.3. KEFFA UPA 1

6.3.1. Precipitation and Potential Evapotranspiration -Keffa

(Figure 6.3)

Keffa UPA has one long growing season, extending for nine months from March to November. Over these months, the precipitation exceeds the potential evapotranspiration, with monthly excesses from May through October. Precipitation occurs in all months with the lowest rainfall (25mm each) being recorded in December and January. The year round precipitation availability allows year round biomass growth and makes this UPA among the most humid regions of Ethiopia.

6.3.2. Soil Moisture Simulations For Perennials - Keffa

(Table 6.3a)

The available soil moisture is always above 10% of field capacity and in only four months does the percentage of available soil moisture conditions indicate that the UPA is not suitable for land use activities based on perennial plant growth and production. Eight months (April 44.2%, May 88%, June 98%, July 99%, August 99.2%, September 98.3%, October 85% and November 41% of the field capacity) have surplus available soil moisture which has resulted in the UPA being quite diverse in its plant species composition. Perennial crops for food, feed and cash can be grown year round. Perennial-based land use activities, however, have to be at the appropriate intensity to minimize the risk of exposure to land degradation when available soil moisture is low. Care is required, at the time of working on the land and during harvesting activities, not

to expose the soil to severe water erosion.

6.3.3. Soil Moisture Simulations For Annuals - Keffa

(Table 6.3b)

Available soil moisture is abundant from April through October. The remaining five months also have sufficient available soil moisture to provide low risk of moisture stress. Too much precipitation and excess soil moisture in most seasons hamper land preparation efforts and harvesting activities. Consequently, most of the UPA is unsuitable for effective growth and production of seasonal crops. However, with careful planning, some isolated areas of the UPA could be suitable for growing seasonal food crops. Moisture abundance may encourage people to carry out extensive annual cropping which may result in severe land degradation due to severe runoff, leaching, crusting and acidification hazards.

CLIMATE DESCRIPTION FOR KEFFA ; UPA 1

[illegible]**SOIL MOISTURE SIMULATIONS (in mm) FOR:**

MONTH	11	12	1	2	3	4	5	6	7	8	9	10
FLD CAP	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	50.	22.	14.	14.	26.	53.	106.	118.	119.	119.	118.	103.

ANNUALS

MONTH	11	12	1	2	3	4	5	6	7	8	9	10
FLD CAP	50.	50.	50.	50.	50.	50.	100.	120.	120.	120.	120.	100.
CROP	.50	.50	.50	.50	.50	.50	1.00	1.10	1.20	1.20	1.20	1.00
S.M.	18.	10.	7.	9.	15.	46.	92.	119.	119.	119.	118.	112.

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6.4 Gambella UPA 2

6.4.1. Precipitation and Potential Evapotranspiration -

Gambella (Figure 6.4)

Some rain occurs in every month. Rainfall is greater than the monthly potential evapotranspiration from May to October, but excesses are most apparent in July, August and September. The UPA has one growing season lasting for six months, from May to October, in which the total precipitation is well above potential evapotranspiration. The abrupt decline of precipitation in November reduces the risk of crop damage by rain at the time of harvest. December and January have only 5mm precipitation each.

6.4.2. Soil Moisture Simulations For Perennials - Gambella

(Table 6.4a)

Gambella is a unique Uniform Productivity Area where soil moisture stress and soil moisture availability have equal annual duration. From November to the end of April, the UPA faces a serious soil moisture stress affecting the normal growth and production of perennial plants. The perennial plants have a dormant phase during the dry season. The remaining six months, May through October, have abundant available soil moisture on which perennial plant growth and production can be supported without facing moisture stress. To reduce the risk of waterlogging and erosion by water, the perennial-based land use activities have to be minimized in the months when available soil moisture is high.

6.4.3. Soil Moisture Simulations For Annuals - Gambella

(Table 6.4b)

For six months, from May through October, the UPA has abundant available soil moisture, allowing dependable seasonal crop production. In the remaining six months the available soil moisture percentage of field capacity ranges from zero in December and January to 5.5% in April. The processes of crop harvest and land preparation are facilitated by the four months of moisture deficit and the two months with no available soil moisture (December and January). The UPA has the good potential of supporting crops, such as maize and sorghum, with long growing seasons, but little potential for small grains, such as teff, which require shorter growing periods.

CLIMATE DESCRIPTION FOR GAMBELLA ; UPA 2

MONTHLY PRECIPITATION (P) AND POTENTIAL EVAPOTRANSPIRATION (E) (in mm)

		25	50	75	100	125	150	175	200	225	250
1	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	P										
2	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPP										
3	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPPPPPP										
M	4	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPP										
O	5	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP										
N	6	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP										
T	7	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PP										
H	8	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PP										
S	9	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PP										
10	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PP										
11	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPPPPPP										
12	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	P										

Table 6.4a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	11	12	1	2	3	4	5	6	7	8	9	10
FLD CAP	130.	130.	130.	130.	130.	130.	130.	130.	130.	130.	130.	130.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	13.	2.	2.	5.	7.	16.	60.	82.	130.	130.	124.	68.

SIMULATION 3 START 11 ACCUM. 11-10 SMIN 68
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
895.197 79.262

Table 6.4b

ANNUALS

MONTH	11	12	1	2	3	4	5	6	7	8	9	10
FLD CAP	55.	55.	55.	55.	55.	55.	65.	85.	110.	130.	130.	110.
CROP	.50	.50	.50	.50	.50	.50	.60	.80	1.10	1.20	1.20	1.10
S.M.	1.	0.	0.	1.	1.	3.	52.	72.	126.	130.	124.	78.

SIMULATION 3 START 11 ACCUM. 5-10 SMIN 78
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
700.639 56.636

6.5. NYALA UPA 3

6.5.1. Precipitation and Potential Evapotranspiration - Nyala

(Figure 6.5)

The Nyala UPA has two distinct growing seasons, from March to mid-June and from July to October. For the March to mid-June growing period, rainfall exceeds PE for April and May, and is greater than half of the potential evapotranspiration in March and June. If this first period is used for cropping, quick harvest has to be achieved in June to allow the second cropping activity to commence in July. The second growing period of four months, from mid-June to November, has precipitation greater than monthly evapotranspiration in all months. The total length of growing season for the UPA is, therefore, eight months, which implies the two periods can be treated as a single growing period for certain crops.

6.5.2. Soil Moisture Simulations For Perennials - Nyala

(Table 6.5a)

No month has available soil moisture below 10%, although, for five months, the available soil moisture is at or below 40% of the field capacity. In the remaining seven months April through October the available soil moisture is reliable and can support sustainable perennial-based land use activities.

6.5.3. Soil Moisture Simulations For Annuals - Nyala

(Table 6.5b)

The UPA has bimodal patterns of available soil moisture. The two

humid seasons cannot, however, be used to support two cropping activities due to the risk of crop damage during harvest by the merging of the two rainy seasons in June. For this reason the most reliable cropping pattern is to use the seven months with adequate soil moisture to grow big grains, such as sorghum and maize, which require long growing periods. Monthly available soil moisture accumulation is never close to field capacity in any month, but is adequate and reliable from April to October. This facilitates the satisfactory growth of seasonal crops that do not like too much moisture and are relatively uniform in their habits of moisture utilization.

25 50 75 100 125 150 175 200 225 250

Table 6.5a

PERENNIALS

SIMULATION 3 START 12 ACCUM. 12-11 SMIN 40
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
809.559 196.168

Table 6.5b

SINULATION 3 START 12 ACCUM. 4-11 SMIN 40
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
686.104 165.190

6.6 EASTERN HIGHLANDS UPA 4

6.6.1. Precipitation and Potential Evapotranspiration

-Eastern Highlands (Figure 6.6)

No months are without rainfall, and the UPA has a slight tendency to bimodal rainfall distribution. March to June, and from mid-June to October define the periods. From March to mid-June, there are three months in which monthly precipitation is greater than half the monthly potential evapotranspiration. These short rains can facilitate processes of land preparation, and in some isolated localities can support quick maturing crop varieties which can be harvested before the onset of the heavy rains in late-June and early-July. The second growing season, starts with the onset of the long rainy season and has a full three months with precipitation greater than the respective monthly evapotranspiration. This is the best growing period, and the harvesting activities can be accomplished in the months of October, November and December with little fear of crop damage due to heavy rain.

6.6.2. Soil Moisture Simulations For Perennials

-Eastern Highlands (Table 6.6a)

There is no month with zero soil moisture. There are five months, May through September, with reliable available soil moisture to support sustainable perennial-based land use activities with minimum risk of soil degradation due to lack of plant cover. But within the following period from October to May the land is susceptible to erosion resulting from vegetation removal, overgrazing and trampling, when the growth and

production of perennial plants is slow due to reduced soil moisture availability.

6.6.3. Soil Moisture Simulations For Annuals

-Eastern Highlands (Table 6.6b)

The UPA has a tendency towards bimodality in its available soil moisture patterns. The available soil moisture in April (23%), May (44.4%), and June (48.2%) is less than 50% of the respective monthly field capacity of the soils. Crops that are drought tolerant and quick maturing, for harvesting before the onset of the long rainy season, can make use of this available soil moisture. If food crops cannot be harvested by June, crops which have alternative values for grazing or protecting the soil should be grown during this period and the food crops planted for the long rainy season. The April-June growing period is undependable. The second growing period, extending from July to October, is more reliable. Land preparation can be conducted in June when the soil is loose enough for tillage, flowering and grain production proceed with little fear of moisture stress in August and September, and harvesting can be done in the dry months of October and November. Some selected areas, if aided by up to date agronomic information and if closely monitored, can produce annual crops during both growing periods.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

		25	50	75	100	125	150	175	200	225	250
1	EEEEEEEEEEEEEEEEEEEE										
-	PPPPP										
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-	PPPPPPPPP										
3	EEEEEEEEEEEEEEEEEEEE										
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M	4	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPP										
O	5	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPP										
N	6	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPP										
T	7	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPP										
H	8	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPP										
S	9	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPP										
10	EEEEEEEEEEEEEEEEEEEE										
-	PPPPPPPPPPPP										
11	EEEEEEEEEEEEEEEEEEEE										
-	PPPPP										
12	EEEEEEEEEEEEEEEEEEEE										
-	PP										

Table 6.6a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	90.	90.	90.	90.	90.	90.	90.	90.	90.	90.	90.	90.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	21.	9.	4.	7.	13.	21.	35.	43.	41.	60.	74.	62.

SIMULATION 3 START 10 ACCUM. 10-9 SMIN 62
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
698.308 146.681

Table 6.6b

ANNUALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	35.	35.	35.	35.	40.	60.	85.	90.	85.	90.	90.	85.
CROP	.50	.50	.50	.50	.50	.60	.80	1.10	1.00	1.10	1.20	1.10
S.M.	5.	4.	0.	1.	0.	9.	20.	40.	41.	59.	75.	63.

SIMULATION 3 START 10 ACCUM. (3)7-10 SMIN 63
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
(388.079) 552.619 105.037 (52.952)

6.7. LOWER RIFT VALLEY-UPA 5

6.7.1. Precipitation and Potential Evapotranspiration

-Lower Rift Valley (Figure 6.7)

No month has precipitation greater than the full potential evapotranspiration of the area, although every month receives some rainfall. Precipitation and potential evapotranspiration are equal in the month of July. In general, the growing season can extend up to seven months. From Figure 6.7, a weak bimodality can be seen to define two rainfall periods, from March to mid-June, and from late June to October. In each of these two periods quick maturing annuals could be grown with satisfactory output.

6.7.2. Soil Moisture Simulations For Perennials

-Lower Rift Valley (Table 6.7a)

There are only three months (July to September) when the percentage of the available soil moisture is greater than 40% of the field capacity. For five months the available soil moisture is below the minimum requirement to carry out perennial-based land use activities. Within these five months (November through March), the perennial crops face moisture stress that can easily expose them to land deradation hazards due to overgrazing and excessive vegetation removal.

6.7.3. Soil Moisture Simulations For Annuals

-Lower Rift Valley (Table 6.7b)

The highest percentage of monthly available soil moisture in July

(53%) is less than 60% of the field capacity. This is a strong indication for the marginality of the accumulation of available soil moisture. There are two periods, from March to June and from July to November, of slightly increased soil moisture storage. In general terms, however, the first soil moisture storage period is not reliable for growing seasonal food crops, as the monthly available soil moisture is less than 40% of the field capacity. The second growing season has enough moisture to prepare the land and plant in June, with harvest occurring in the relatively dry season of late October and November.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

		25	50	75	100	125	150	175	200	225	250
1	EEEEEEEEEEEEEEEEEEEE										
-	PPPPP										
2	EEEEEEEEEEEEEEEEEEEE										
-	PPPPPPPP										
3	EEEEEEEEEEEEEEEEEEEE										
-	PPPPPPPPPPPPPPPP										
M	4	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPP										
O	5	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPP										
N	6	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPP										
T	7	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPP										
H	8	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPP										
S	9	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPP										
10	EEEEEEEEEEEEEEEEEEEE										
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11	EEEEEEEEEEEEEEEEEEEE										
-	PPPPPPPP										
12	EEEEEEEEEEEEEEEEEEEE										
-	PP										

Table 6.7a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	12	1	2	3	4	5	6	7	8	9	10	11
FLD CAP	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	9.	6.	11.	14.	37.	39.	27.	50.	49.	45.	34.	15.

SIMULATION 3 START 12 ACCUM. 12-11 SMIN 15
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
666.623 151.520

Table 6.7b

ANNUALS

MONTH	12	1	2	3	4	5	6	7	8	9	10	11
FLD CAP	35.	35.	35.	50.	80.	90.	85.	85.	90.	100.	80.	50.
CROP	.50	.50	.50	.70	1.00	1.00	.90	1.10	1.10	1.20	1.00	.80
S.M.	4.	0.	1.	6.	30.	36.	26.	49.	46.	44.	33.	19.

SIMULATION 3 START 12 ACCUM. (7)3-10 SMIN 19
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
(315.050) 543.682 126.302 (95.477)

6.8. SHEWA UPA 6

6.8.1. Precipitation and Potential Evapotranspiration

- Shewa (Figure 6.8)

There are no months without rainfall. The lowest rainfall (10mm) is recorded in December. Precipitation is greater than potential evapotranspiration from June to September, with excess rainfall particularly large in July and August. The growing season in which precipitation is adequate for plant growth extends for seven months, from April to October. Two cropping seasons may be possible in some selected areas, provided the rain in June does not affect the harvesting of crops grown from February to May. The rainfall in all months increases the susceptibility of areas without adequate vegetation cover to erosion hazards by water, especially in July-August when the risk is high. The harvest of crops grown in the long rainy season should not usually have problems with destructive rain in October, November and December, as heavy rain is uncommon in these three months.

6.8.2. Soil Moisture Simulations For Perennials - Shewa

(Table 6.8a)

There is no month with zero plant available soil moisture. The UPA suffers serious moisture stress for seven months, October to April, when the available soil moisture is well below 20% of field capacity. To avoid land degradation associated with biomass removal, intense grazing and other land use activities, which are heavily dependent on vegetation utilization and land disturbance have to be reduced to levels in line with

the available soil moisture during these moisture-stressed months. The land use activities can be increased when available soil moisture is higher from May to September. From June through September the available soil moisture is sufficient to support growth with less exposure to degradation risk.

6.8.3. Soil Moisture Simulations For Annuals - Shewa

(Table 6.8b)

There are no months without available soil moisture. The lowest available soil moisture, 22.5% of the field capacity, occurs in December and January. The year-round vegetative cover in the UPA, makes the UPA suitable for seasonal plant growth with low risk of moisture stress. Annual food crops can be grown from May to September when the available soil moisture is well above 55% of the field capacity of the soils. The excess soil moisture in September (117% of field capacity) can restrict harvesting in that month. The dramatic decline of soil moisture in October facilitates a delayed harvest, but it may encourage bare ground encroachment if the land is immediately exposed to intensive grazing, due to the increasing susceptibility of the vegetation to dryness. The probable risk periods of land degradation are, therefore, between October and March when available soil moisture is low, and in August and September when runoff is high due to soil moisture beyond the field capacity of the soils.

25 50 75 100 125 150 175 200 225 250

Table 6.8a

PERENNIALS

SIMULATION 3 START 10 ACCUM. 10-9 SMIN 81
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
709.139 132.906

Table 6.8b

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SIMULATION      3      START 10 ACCUM.    6-9  SMIN 94
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
              396.660              43.777

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6.9. ABAY UPA 7

6.9.1. Precipitation and Potential Evapotranspiration

- Abay (Figure 6.9)

There are no months without rainfall. The lowest rainfall is 5mm, in December and January. Precipitation is much higher than potential evapotranspiration from June through September. The growing period for this UPA is close to six months, from May to October. The low amount of rainfall in November, December and January facilitates the efforts of annual crop harvests. The rains from February to May, may facilitate land preparation and allow the planting of crops as soon as the long rainy season starts.

6.9.2. Soil Moisture Simulations For Perennials - Abay

(Table 6.9a)

No month is without some soil moisture available for plant growth. From June through October the available soil moisture is well above 50% of the field capacity and is sufficient to support growth without exposing the resource base to severe degradation. However, the UPA is highly susceptible to degradative processes from November to April when the available soil moisture is, in most cases, well below 20% of the field capacity. High degradation risk, deriving from poor land use practices during the dry season, arises at the onset of the rainy season when heavy rains fall on unprotected soil surfaces. The risk of land degradation is associated with intense grazing, excess biomass removal and land breaking

during moisture stressed months.

6.9.3. Soil Moisture Simulations For Annuals - Abay

(Table 6.9b)

The months with and without available soil moisture are equal in number. The UPA has no available soil moisture for six consecutive months (from November to April). The excessive evapotranspiration potential within the period evaporates the precipitation before it can infiltrate the soil profile. This situation makes the vegetative cover and the soils very fragile to land use activities such as grazing, farming and vegetation removal. The period from May to October is an ideal season for annual crop production because of the abundant supply of available soil moisture. However, during this period extra care has to be taken to avoid land degradation due to runoff and water erosion. Land preparation ought to be conducted in May, while October should be used for harvesting. Delaying harvest into the months of zero available soil moisture may induce and accelerate land degradation processes associated with dryness.

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SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	11	12	1	2	3	4	5	6	7	8	9	10
FLD CAP	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.N.	8.	8.	2.	3.	3.	5.	26.	85.	100.	100.	96.	36.

SIMULATION 3 START 11 ACCUM. 11-10 SMIN 36
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
669.674 53.505

ANNUALS

MONTH	11	12	1	2	3	4	5	6	7	8	9	10
FLD CAP	40.	40.	40.	40.	40.	40.	50.	80.	100.	100.	100.	100.
CROP	.50	.50	.50	.50	.50	.50	.60	.80	1.00	1.10	1.20	.90
S.M.	0.	0.	0.	0.	0.	0.	20.	78.	100.	100.	96.	39.

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SIMULATION      3      START 11 ACCUM.      6-10 SMIN 39
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
                538.486                56.528

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6.10. ASMERA UPA 8

6.10.1. Precipitation and Potential Evapotranspiration

-Asmera (Figure 6.10)

The UPA receives some rains in each month. With the exception of July and August, when precipitation is greater than potential evapotranspiration, the Asmera UPA suffers from rainfall deficiencies. From February to June monthly rainfall is less than half of the monthly evapotranspiration, and crop production is not possible. The rains from February to May allow preparation of the land for effective utilization of the precipitation of the two months rainy season. The UPA has only one reliable growing season, of less than four months, from mid-June to mid-September. In this UPA, the long rainy season starts and ends abruptly, which leads to a high susceptibility to erosion hazards by water.

6.10.2. Soil Moisture Simulations For Perennials - Asmera

(Table 6.10a)

Soil moisture is available for plant growth throughout the year. However, only in July and August is the soil moisture above 50% of the field capacity. In the remaining ten months, the UPA is under heavy moisture stress. In these ten months of moisture stress (moisture is always under 20% of the field capacity), the perennials do survive, but do not produce abundant plant material for animal feed and do not protect the soil against environmental hazards such as intense heat and erosive rainfall. This biomass shortfall is especially acute in overpopulated, overstocked and over-utilized areas.

6.10.3. Soil Moisture Simulations For Annuals - Asmera

(Table 6.10b)

There are no months without available soil moisture. However, for at least eight months the available soil moisture is one third of the field capacity. This prolonged period of severe moisture stress affects the growth and reproduction of annuals. The only reliable season when seasonal crops can be grown without facing moisture stress is from July to mid-September. The available soil moisture declines abruptly in September and presents a risk that crops can be caught by moisture stress during their final grain production stage. To reduce the risk of grain production failure in September, it is desirable to make use of the available soil moisture in May and June to prepare the seed bed and to plant crops. This allows use of the abundant soil moisture during July and August for growth and grain production. Non-food-crop annuals can be supported for at least eight months and protect the soil and water resources of the UPA against erosion, if they are not exploited beyond their carrying capacity by livestock. The unreliable rains from February to May should not mislead farmers into growing crops in this period. These rains do not recharge the available soil moisture above 37% of field capacity and attempting to make use of this soil moisture for growing crops and for intensive grazing will most likely result in crop failure, severe degradation problems and reduction in the length of growing period associated with the long rainy season. Based on the monthly availability of soil moisture, the reliable growing period for the UPA is less than three months.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

Table 6.10a

PERENNIALS

SIMULATION 3 START 10 ACCUM. 10-9 SMIN 5
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
490.719 252.106

Table 6.10b

SIMULATION 3 START 10 ACCUM. 7-9 SMIN 10
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
247.315 63.788

6.11 TIGRAY UPA 9

6.11.1. Precipitation and Potential Evapotranspiration

-Tigray (Figure 6.11)

Every month normally receives some amount of rainfall with there being a weak bimodality in the annual rainfall distribution. The precipitation from February to May does not exceed half of the potential evapotranspiration in any month, but may be adequate to loosen the soil, and facilitate land preparation for timely planting at the onset of the long rainy season. The precipitation during July and August is almost twice the potential evapotranspiration. The overall growing season starts in mid-June and continues into September, with the total period being less than four months. The dramatic decline of rainfall in October allows the annual crops to be harvested efficiently.

6.11.2. Soil Moisture Simulations For Perennials - Tigray

(Table 6.11a)

Two months, October and May, have zero soil moisture available for plant growth. In July and August, the available soil moisture is recharged to 100% of field capacity. However, during September this abundant soil moisture declines dramatically for five months, which severely affects the sustainability of perennial-based land use activities. These periods of severe moisture stress make Tigray UPA susceptible to severe land degradation processes that can be started by vegetation disturbances due to overgrazing.

6.11.3. Soil Moisture Simulations For Annuals - Tigray

(Table 6.11b)

There are four months, November to February, with no storage of available soil moisture. From March through October the available soil moisture is sufficient to grow annuals. Food crop annuals can be satisfactorily grown from June to September, provided land preparation does not reduce the growing season. The success of this growing period is dependent on the months preceding July being used to prepare the land for successful seed establishment and on October remaining relatively dry for harvesting. Using the period from March to June to grow food crops may lead to harvest destruction by the onset of the long rainy season. It also reduces the length of the best growing season from July to September and increases the risk of degradation associated with the land preparation, after June harvest, required for the reliable growing season starting in July. Grazing, tillage, felling trees and excessive utilization of vegetation from October to March may exacerbate degradational processes in the UPA.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

		25	50	75	100	125	150	175	200	225	250
	1	EEEEEEEEEEEEEEEEEEEE									
	-	P									
	2	EEEEEEEEEEEEEEEEEEEE									
	-	PP									
	3	EEEEEEEEEEEEEEEEEEEE									
	-	PPPPPPPPPP									
M	4	EEEEEEEEEEEEEEEEEEEE									
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T	7	EEEEEEEEEEEEEEEEEEEE									
	-	PP									
H	8	EEEEEEEEEEEEEEEEEEEE									
	-	PP									
S	9	EEEEEEEEEEEEEEEEEEEE									
	-	PPPPPPPPPPPPPP									
	10	EEEEEEEEEEEEEEEEEEEE									
	-	PPP									
	11	EEEEEEEEEEEEEEEEEEEE									
	-	PP									
	12	EEEEEEEEEEEEEEEEEEEE									
	-	P									

Table 6.11a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	0.	3.	3.	2.	2.	13.	5.	0.	8.	70.	70.	23.

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SIMULATION      3      START 10 ACCUM. 10-9 SMIN 23
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
              481.433              79.314

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Table 6.11b

ANNUALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	30.	30.	30.	30.	30.	30.	30.	30.	40.	70.	70.	60.
CROP	.50	.50	.50	.50	.50	.50	.50	.50	.90	1.20	1.20	.90
S.M.	9.	0.	0.	0.	0.	12.	12.	12.	17.	70.	70.	32.

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SIMULATION      3      START 10 ACCUM.    7-9  SMIN 32
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
                292.764                25.851

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6.12. AFAR UPA 10

6.12.1. Precipitation and Potential Evapotranspiration

- Afar (Figure 6.12)

Rainfall occurs in every month, with July and August being the peak rainy season. During the remaining ten months, potential evapotranspiration is much greater than precipitation. There is a bimodal rainfall pattern which produces two rainy periods, January to May and June to October. The precipitation from January to May does not exceed half of the potential evapotranspiration, and the only reliable growing season is from July to September, when the precipitation in each month is at least greater than half of the potential evapotranspiration. Crop harvesting can be carried out without fear of rain damage in the subsequent months of October and November.

6.12.2. Soil moisture Simulations For Perennials - Afar

(Table 6.12a)

Except for the months of July and August, when available soil moisture is relatively high, there is severe moisture stress with soil water contents well under 10% of the field capacity. The extended moisture stress period of the UPA indicates the inability of the ecosystem to support year round perennial-based land use activities. The intensity of activities conducted in the months of July and August have to be brought down to a low level, in line with the potential of soil moisture to avoid irreversible land degradation processes.

6.12.3. Soil Moisture Simulations For Annuals - Afar

(Table 6.12b)

With only one month (August) having reasonable available soil moisture (57% of field capacity) and two months with no available soil moisture (November and December), food production in this UPA is very precarious. The soil moisture status, from September through July is much below 50% of field capacity, and cannot support plant growth for much of this period. With no available soil moisture in November and December, the UPA is highly prone to serious land degradation, primarily caused by lack of adequate vegetative cover. The overall poor soil moisture status makes the UPA unsuitable for annuals, especially seasonal food crops.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

	25	50	75	100	125	150	175	200	225	250
1	EEEEEEEEEEEEEEEEEEEE									
-	PPPP									
2	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPP									
3	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPP									
M 4	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPP									
O 5	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPP									
N 6	EEEEEEEEEEEEEEEEEEEE									
-	PPPPP									
T 7	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPP									
H 8	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPPPP									
S 9	EEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPP									
10	EEEEEEEEEEEEEEEEEEEE									
-	PPP									
11	EEEEEEEEEEEEEEEEEEEE									
-	PPP									
12	EEEEEEEEEEEEEEEEEEEE									
-	PP									

Table 6.12a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	2.	4.	3.	6.	9.	7.	8.	3.	3.	31.	50.	14.

SIMULATION 3 START 10 ACCUM. 10-9 SMIN 14
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
417.446 104.928

ANNUALS

Table 6.12b

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	40.	40.	40.	40.	40.	40.	40.	50.	80.	100.	100.	90.
CROP	.50	.50	.50	.50	.50	.50	.50	.60	.90	1.10	1.20	.90
S.M.	9.	0.	0.	1.	2.	1.	1.	9.	9.	27.	57.	15.

SIMULATION 3 START 10 ACCUM. 7-9 SMIN 15
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
237.547 55.467

6.13. OGADEN UPA 11

6.13.1. Precipitation and Potential Evapotranspiration

- Ogaden (Figure 6.13)

The UPA has four months with no rain. The remaining eight months all have deficits, in which the monthly potential evapotranspiration greatly exceeds the respective monthly precipitation. There is a distinctly bimodal rainfall pattern, with the two periods separated by two months with no rain. During the March to May period of rains, monthly precipitation is greater than half of monthly potential evapotranspiration for two months. In the second rainfall period, from September to November, only in October is precipitation greater than half of the potential evapotranspiration.

6.13.2. Soil Moisture Simulations For Perennials - Ogaden

(Table 6.13a)

The soil moisture availability does not qualify this UPA, in general, to be utilized for perennial based land use activities, because of the high risk of land degradation following even minimal pastoralism in combination with these uses.

6.13.3. Soil Moisture Simulations For Annuals - Ogaden

(Table 6.13b)

None of the monthly available soil moisture values exceed 50% of field capacity, which indicates the precarious situation of the UPA.

There is always the risk of exposing seasonal crop growth to moisture stress. Drought tolerant crops can be grown from March to May when the available soil moisture is close to 40% of field capacity. However, non-food indigenous plants can be grown for highly controlled grazing, to protect the soils from degradational effects and as a means of encouraging the regeneration of additional useful indigenous seasonal plants.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

		25	50	75	100	125	150	175	200	225	250
1	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-											
2	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	P										
3	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPPP										
M	4	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPPPPPPPP										
O	5	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PPPPPPPPPPPPPPPPPPPP										
N	6	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PP										
T	7	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-											
H	8	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-											
S	9	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE									
-	PPPP										
10	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPPPPPPPPPPPPPPPPP										
11	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPPPPPPP										
12	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-											

Table 6.13a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	12	1	2	3	4	5	6	7	8	9	10	11
FLD CAP	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	0.	0.	9.	9.	20.	10.	5.	2.	1.	9.	8.	5.

SIMULATION 3 START 12 ACCUM. 12-11 SMIN 5
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
260.084 45.100

Table 6.13b

ANNUALS

MONTH	12	1	2	3	4	5	6	7	8	9	10	11
FLD CAP	20.	20.	20.	20.	50.	50.	45.	25.	20.	50.	50.	25.
CROP	.50	.50	.50	.50	1.10	1.20	.90	.50	.90	1.10	1.20	.90
S.M.	2.	1.	9.	9.	20.	23.	9.	1.	9.	9.	17.	12.

SIMULATION 3 START 12 ACCUM. 4-11(6) SMIN 12
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
(165.762) 284.512 39.985 (30.431)

6.14. BARENTU UPA 12

6.14.1. Precipitation and Potential Evapotranspiration

-Barentu (Figure 6.14)

No precipitation at all is received from the month of November until the end of April, a total of six months. Only during August is precipitation greater than potential evapotranspiration, although in the months of July and September, precipitation is well above half of the respective monthly potential evapotranspiration. The UPA receives some rain in May, June and October, but potential evapotranspiration is excessively higher than the respective precipitation during these months. The UPA has a growing period of less than four months, extending from mid-June to the end of September. The abrupt start of the rains in the growing season makes the sun-baked soils highly susceptible to erosion hazards by the intense and voluminous rainfall.

6.14.2. Soil Moisture Simulations For Perennials - Barentu

(Table 6.14a)

For six months the UPA does not have adequate available soil moisture to support any kind of biomass growth. It is only in July and August that available soil moisture is sufficiently abundant to support biomass growth. The disappearance of the available soil moisture for plant growth for six consecutive months, and the prevalence of serious moisture stress for three months, makes perennial-based land use activities highly unreliable and makes the resource base highly

susceptible to very serious land degradation hazards.

6.14.3. Soil Moisture Simulations For Annuals - Barentu

(Table 6.14b)

There is some available soil moisture during every month, but only July and August have enough soil moisture to support seasonal growth. The abrupt build up and decline of the soil moisture in July and August may result in severe degradation from runoff occurring on unprotected land. In the remaining ten months (from September to June) potential biomass production is meager, since the available soil moisture is less than 30% of the respective field capacity of the soil. The UPA is most suitable for highly mobile and less intensive grazing activities. During the ten moisture-stressed months, there is a high need of conducting periodic checking to ensure sustainability and reduce the risk of degradation as a result of overgrazing and trampling. The only reliable growing season available for annual food crops is, the short period from July to mid-September.

**MONTHLY PRECIPITATION (P) AND POTENTIAL
EVAPOTRANSPIRATION (E) (in mm)**

		25	50	75	100	125	150	175	200	225	250
1	EE										
-											
2	EE										
-											
3	EE										
-											
M	4	EE									
-											
O	5	EE									
-		PPPP									
N	6	EE									
-		PPPPPPPPPP									
T	7	EE									
-		PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP									
H	8	EE									
-		PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP									
S	9	EE									
-		PPPPPPPPPPPPPPPPPP									
10	EE										
-		P									
11	EE										
-											
12	EE										
-											

Table 6.14a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	0.	0.	0.	0.	0.	0.	1.	6.	0.	33.	47.	10.

SIMULATION 3 START 10 ACCUM. 10-9 SMIN 10
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
315.615 88.233

Table 6.14b

ANNUALS

MONTH	10	11	12	1	2	3	4	5	6	7	8	9
FLD CAP	30.	30.	30.	30.	30.	30.	30.	30.	50.	70.	70.	60.
CROP	.50	.50	.50	.50	.50	.50	.50	.50	.90	1.10	1.20	.90
S.M.	9.	2.	2.	2.	2.	1.	9.	9.	9.	36.	56.	17.

SIMULATION 3 START 10 ACCUM. 7-9 SMIN 17
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
265.098 35.975

6.15 DALLOL UPA 13

6.15.1. Precipitation and Potential Evapotranspiration

- Dallol (Figure 6.15)

Zero rain is expected in the months of July and September, while 5mm of rain is recorded in each of May, July and August. During these months potential evaporation soars to nearly 250mm. The UPA receives from 10-35mm of rainfall per month from October to April, but total annual rainfall is only 165mm. This UPA has no reliable growing season, due to lack of a single period when the precipitation is at least half of potential evapotranspiration.

6.15.2. Soil Moisture Simulations For Perennials - Dallol

(Table 6.15a)

No soil moisture is available for ten months. The available soil moisture in January and February is not satisfactory (i.e. less than 4% of the field capacity) to support biomass growth. Consequently, any perennial biomass growth in this excessively moisture stressed UPA is quite unlikely. The standard deviation is zero, because the UPA has only one meteorological station.

6.15.3. Soil Moisture Simulations For Annuals - Dallol

(Table 6.15b)

The area is the only UPA without available soil moisture for seasonal growth. Almost six months are without rain and the remaining six

months of the year do not receive rainfall greater than half of the monthly potential evapotranspiration. Other environmental factors reduce the soil moisture. The excessively high temperature causes significant moisture loss before the precipitation can infiltrate the soil profile, and in some parts the dominance of sands and rocks enhances the deep percolation of water beyond the reach of the plant roots. These limitations make most of the UPA unsuitable for cultivated seasonal food crops.

CLIMATE DESCRIPTION FOR DALLOL ; UPA 13

MONTHLY PRECIPITATION (P) AND POTENTIAL EVAPOTRANSPIRATION (E) (in mm)

		25	50	75	100	125	150	175	200	225	250
1	EEEEEEEEEEEEEEEEEEEE										
-	PPPPPP										
2	EEEEEEEEEEEEEEEEEEEE										
-	PPPPPP										
3	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPP										
M 4	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PP										
O 5	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	P										
N 6	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-											
T 7	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	P										
H 8	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	P										
S 9	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-											
10	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPP										
11	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPP										
12	EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE										
-	PPPPPP										

Table 6.15a

SOIL MOISTURE SIMULATIONS (in mm) FOR:

PERENNIALS

MONTH	4	5	6	7	8	9	10	11	12	1	2	3
FLD CAP	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.
CROP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S.M.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	0.

SIMULATION 3 START 4 ACCUM. 4-3 SMIN 0
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
113.987 .000

Table 6.15b

ANNUALS

MONTH	4	5	6	7	8	9	10	11	12	1	2	3
FLD CAP	20.	20.	20.	20.	20.	20.	20.	20.	50.	50.	50.	40.
CROP	.50	.50	.50	.50	.50	.50	.50	.50	.90	1.10	1.20	.90
S.M.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

SIMULATION 3 START 4 ACCUM. 12-3 SMIN 0
SHORTLIST AREA AVERAGE AND STANDARD DEVIATION
63.780 .000

6.16. DISCUSSION

The following discussion is based on a comparative assessment of the climate resources of the 13 UPAs defined in this study. Soil constraints, particularly those that interact with climate, are also considered in this assessment. In addition to ranking the UPAs into high and low production potential areas, the specific production capabilities and systems, and the associated land degradation risks are identified. The descriptive climate parameters which are most useful in assessing the region are the degree of bimodality in seasonal rainfall distributions, the contrast in levels of precipitation between rainy and dry seasons, soil moisture thresholds and post-rainy season carry-over and the monthly relationship between evapotranspiration potential and rainfall. The discussion also considers the opportunities and risks associated with expanding population and food production.

6.16.1 Length of Growing Period (LGP).

Penman (1948) defines Length of Growing Period (LGP) as the period in days when moisture supply from precipitation exceeds half of the potential evapotranspiration (0.5 PE). According to Doorenbos and Kassam (1979), 0.5 PE is chosen as a threshold value for moisture availability because important physiological changes are induced in many crops below 0.5 PE. These changes in plant physiology can be strongly associated with the start of land degradation processes. On the other hand, when P exceeds 0.5 PET, germination is reported to proceed in most crops, which gives yield assurance and protection of soils from degradative processes by

providing vegetative cover.

On this basis, the two main types of growing period (GP) recognized by FAO (1984) are the normal growing period and the intermediate growing period. In the normal growing period, P exceeds PE , the soil profile accumulates moisture reserves and plant growth proceeds without restriction from moisture stress. In the intermediate growing period, P remains between 0.5 and 1.0 PE and no soil moisture reserves accumulate under these circumstances. The length of growing periods as defined by Penman (1948) were assessed for the Ethiopian UPAs based on the moisture index (P/PE) described by Walton (1971). Figures 6.2a to 6.2g show these indices for all UPAs for each month (note the variable scale). Except where excess moisture affects the production of some crops, yield increases as LGP increases (Henricksen and Durkin, 1985). This indicates that areas with short LGP have low yield capability and poor potential for sustainable crop cultivation.

There are six UPAs (Asmera, Afar, Tigray, Barentu, Ogaden and Dallol) with LGP ranging from none (Dallol) to three months (Asmera and Tigray). These six UPAs can be called low potential areas. In the remaining seven UPAs, the LGP varies from six months in Gambella and Abay, seven months in Shewa, eight months in Eastern Highlands and Lower Rift Valley, to nine months in the Nyala and Keffa UPAs. Each UPA, as indicated in Tables 6.16a & 6.16b have variable length of both intermediate and normal growing periods. These are the high potential areas of Ethiopia.

Most crops in Ethiopia, with the exception of pulses and very low yielding varieties of teff and wheat, require a growing season of at least 90 days (Henricksen and Durkin, 1985).

Figure 6.2a

I-P/PE, Ogaden UPA

Figure 0.20

I-P/PE for Asmera UPA

I-P/PE for Barentu UPA

Figure 6.2c

I=P/PE, Gambella UPA

I=P/PE, Eastern Highlands UPA

Figure 6.2d

I=P/PE for Abay UPA

I=P/PE for Shewa UPA

Figure 6.2e

I=P/PE for Dallol UPA

I=P/PE for Tigray UPA

Figure 0.41

I=P/PE for Afar UPA

I=P/PE for Keffa UPA

Figure 6.2g

I-P/PE, Nyala UPA

I-P/PE, Lower Rift Valley UPA

Based on this threshold, the six UPAs with short LGP are all highly unsuitable for crop cultivation due to their high susceptibility to dry spells ($P/PE < 0.5$) and to moisture stress occurring in the middle of the crop growth period. Crop failures resulting from moisture stress affect the livelihood of the farmer and expose the resource base (primarily the soils) to serious degradation risk. Food crops are not the only species affected by a short growing season. The productivity of numerous types of range plants which support millions of livestock, are also severely damaged by a short growing period, through inadequate moisture availability to complete their growth and reproduction. Consequently, during moisture stress periods livestock can overgraze the meager vegetation resources and cause severe land degradation. Most of the lands with short LGPs endure high temperatures and can suffer from salinization.

In most cases, rainfall in areas of short LGP starts and ends abruptly. The moisture indices and the PE barographs for the Asmera and Tigray UPAs show this fact clearly. For example in the Tigray UPA, the moisture index for June is 0.43, by July, it shoots up to 2.00 and remains high (2.24) in August, but decreases dramatically to 0.57 in September. This highly seasonal rainfall pattern has many disadvantages. In particular, it causes serious runoff and soil erosion when heavy rains fall onto the relatively dry and unprotected soils in broken and undulating lands. The sudden drop in precipitation in September (Asmera, Tigray and Afar UPAs) risks exposing late maturing crops to dry spells before they can produce grain. Abrupt increases and decreases in precipitation are also observed in the Abay UPA, but because the LGP is longer, Abay does not suffer from the same risk of moisture stress toward

the end of the growing period. Precipitation in Abay UPA has a high intensity over a short period ($P/PET=3.00$ for July and August) which increases runoff and accelerates erosion. In the UPAs of Tigray, Asmera and some parts of Abay, the soils are medium textured, dominated by stoniness and shallowness, with limited water retention capacities, and situated on sloped lands. These constraints enhance the runoff from these uplands and burial by eroded material increases the constraints of lowland soils, especially when coarse textured materials are deposited on low lying productive soils.

To increase the applicability of the definition of LGP by Penman (1948), FAO (1978) adds to the LGP the period during which plants can transpire stored available soil moisture. The addition of consideration of stored soil moisture to Penman's definition of LGP, is important to the investigation of the capability of the Ethiopian UPAs to support annual and perennial crops.

6.16.2. Perennial Crop Suitability.

The soil moisture computation tables for perennial crops identify the UPAs which have months without available soil moisture and months with severe moisture stress. UPAs having periods without available soil moisture are Ogaden(2), Tigray(2), Barentu(2) and Dallol (10). The UPAs with more than six moisture stressed months include Dallol (12), Ogaden(11), Afar(10), Tigray(10), Asmera(10), Barentu(10) and Lower Rift Valley(6.5). The Eastern Highlands, Gambella, Shewa and Abay UPAs, all have six moisture stressed months. Whereas, the UPAs of Keffa and Nyala have under four moisture-stressed months.

With the exception of some cash crops (such as coffee and fruit trees) and food crops (enset, cassava and yam), perennials in Ethiopia provide grazing and browsing to the country's livestock and wildlife. The productivity of perennials is strongly influenced by the availability of soil moisture. The carrying capacity of the grazing land declines, when moisture is unavailable, leaving these lands vulnerable to disturbances from grazing and browsing and other human activities such as fire and excessive vegetation removal.

The invasion of unpalatable plant species is an indication of overgrazing and range deterioration. Continued overgrazing leaves bare and trampled soils which are vulnerable to wind erosion and fire hazard during the dry season, and to severe water erosion upon the return of the unpredictable, erratic and aggressive tropical rainfall. The UPAs most subject to the hazards associated with pastoralism are those with not only low rainfall, but which also have distinct differences between wet and dry seasons. Those UPAs include Ogaden, Afar, Asmera, Barentu, Dallol, Tigray and Abay. The risk of degradation is aggravated by the increase of the livestock population when grazing land production is abundant and the lag time for reduction of livestock numbers when the productivity of grazing lands declines.

The reasons for most livestock being kept throughout the year, even when the available soil moisture is below 30% of the field capacity, are social, cultural and economic. In subsistence farming practices, the livestock are required to work the land. The pastoralists keep livestock as a means of survival. In both cases, livestock are treated as an accumulated security, to make future life more reliable and as insurance

3 OF/DE 3

MICRO

throughout the dry seasons. Domestic animals are the last assets to be sold off or eaten during drought and famine, but this does not occur before they have caused immense land degradation during these heavily moisture-stressed periods. Therefore, the UPAs having months with zero available soil moisture, or having many moisture-stressed months (<30% of the field capacity) face severe problems of overgrazing and trampling of the perennial communities unless livestock populations are carefully controlled during these critical moisture deficient months.

6.16.3. Annual Crop Suitability.

The abundance of moisture during most of the year makes the Keffa and Nyala UPAs unsuitable for seasonal cropping activities. Excess evapotranspiration and poor moisture availability disqualify the Dallol, Ogaden, Afar and Barentu UPAs from being used as reliable seasonal cropping sites. The LGP, in these four moisture deficient UPAs, ranges from zero to less than ninety days. The simulation and comparison Tables indicate that seven UPAs including Shewa, Abay, Tigray, Asmera, Eastern Highlands, Lower Rift Valley and Gambella, are suitable for seasonal cropping. The LGP for annuals in the suitable UPAs ranges from four months to six months. Their degree of suitability and the possible crops are assessed by the availability of soil moisture for a sufficient period to allow ploughing the land, seed establishment and grain production without exposing the crop to high risk of dry spells. The occurrence of a dry season after the stage of grain production has also been considered in the comparison process so as to avoid crop damage from excess moisture at the time of harvest. The LGP of annuals can be shortened by early

arriving rains (i.e. before the land is worked) and by dry spells occurring before they start producing grain. Unexpectedly long rainy periods, on the other hand, lengthen the LGP and cause harvesting problems with most small grains. Once the harvest is finished, the livestock are released into the farmlands to feed on the stubble. The grazing activities on the farmlands and the surrounding areas continue through the dry period until the next cropping season. In the case of the Abay UPA, one of the most suitable UPAs for annual cropping, this dry period lasts for six months. Within this six month period, the current situation is that dry land is overgrazed and trampled by the livestock, exposing the finer soil particles to wind erosion. To exacerbate the situation, a good portion of the crop residue is used as a firewood substitute, which means that the nutrients in it are not returned to the soil. To a lesser extent, the remaining UPAs suitable for growing seasonal crops suffer from similar problems.

6.16.4. Agricultural Practices and Degradation Risk.

Traditionally, Ethiopians living in some parts of the country make use of the bimodal distribution of rainfall to produce two grain crops. 85% - 90% of the crops are grown during the long rainy season ("Meher") and only 15% of the grain production is grown during the short rains ("Belg"), because of their limited length. The bimodal sequence most commonly experienced is for the short rains to come first, followed by a short dry season which allows crop harvest, and shortly thereafter comes the onset of the long rainy season. Unfortunately, this sequence is not reliable and in those years when there is total failure of the

Table 6.16a

Biomass accumulation comparison

UPA	Soil Moisture Accumulation For Perennial Cropping		Soil Moisture Accumulation For Annual/Seasonal Cropping	
	Area Average in mm	Rank	Area Average in mm	Rank
Keffa	873.815	1	671.639	3
Gambella	789.360	2	700.639	1
Nyala	782.991	3	686.104	2
Eastern Highlands	700.157	4	552.619	4
Lower Rift Valley	688.648	5	312.305	7
Shewa	679.699	6	396.660	6
Abay	618.122	7	538.486	5
Asmera	550.043	8	247.315	11
Tigry	531.574	9	292.764	8
Afar	472.523	10	237.547	12
Ogaden	406.892	11	284.512	9
Barentu	385.099	12	265.098	10
Dallol	253.524	13	63.780	13

Table 6.16b

Suitability comparison for perennial and annual cropping activities

UPA	Perennial Cropping		Seasonal Cropping		Moisture Index P/PE $\geq$ 0.5 PET (Number of Months)
	Reliable Months of Growth	Moisture Stressed Months	Reliable Months of Growth	Moisture Stressed Months	
Keffa	>8	<4	>7	<5	9
Gambella	6	6	6	6	6
Nyala	7.5	4.5	7	5	9
Eastern Highlands	6	6	6	6	8
Lower Rift Valley	5.5	6.5	<4	>8	8
Shewa	6	6	6	<6	7
Abay	6	6	<5	>6	6
Asmera	2	10	<4	>8	2
Tigray	2	10	<4	>8	3
Afar	2	10	<2	>10	2
Ogaden	1	11	<3	>9	3
Barentu	2	10	2	10	3
Dallol	-	12	-	12	-
- nil					

short rains yield reduction and severe land degradation occur. These resultant problems are most serious in areas of high population where the demand for food, forage and fuel is either beyond the production capability of the land or the supply is marginal.

The barographs and the simulation tables indicate that there are at least six UPAs with variable degrees of bimodality in their annual rainfall pattern (Afar, Ogaden, Nyala, Eastern Highlands, Asmera and Tigray UPAs). The Afar and Ogaden UPAs experience strong and distinct bimodalities. Unfortunately, in both UPAs, the precipitation in the short rains is less than 0.5 PE in every month. The low P/PE ratios explain why attempting to use them for bimodal (two crop) production results in both crop failure and severe land degradation. The Nyala UPA demonstrates bimodality, but the two rainfall periods have a high probability of merging together to form one long growing season. The short rains are not always followed by a long enough dry period to allow harvest. Early onset of the long rains also prevents the land used during the short rains from being tilled for the second cropping season. Tillage or land preparation, during the rainy period induces severe erosion. The best practice, to reduce land degradation risk and increase total yield in the Nyala UPA, is to use the two (often merging) rains to grow big grains, such as sorghum and maize, that require a longer LGP, or to devote totally the whole area to perennial cropping. However, given the demand for food, such land is likely to gravitate into more intensive use, rather than less intensive use.

The Eastern Highlands UPA has a strong tendency toward bimodality, with less merging of the two rains. It is more suitable to two crops of

quick maturing small grains than for the big grain crops, such as can be grown in the Nyala UPA. The Eastern Highland UPA is susceptible to land degradation risk both while working the land and at the time of crop harvest during the short dry period before the onset of the long rainy season.

The Asmera and Tigray UPAs have weakly bimodal rainfall distributions and, even though rainfall in the first period is limited, these UPAs are traditionally subject to efforts to produce two grain crops per year. The effort is unjustifiable, because, as FAO (1984) reports, the soils are stony, shallow, medium textured, and have poor moisture retention capacity and are drought-prone. They have been heavily and adversely influenced by structural movements and thousands of years of cultivation. The barographs (PE and P) and the simulation tables for both UPAs indicate that the short rains provide available moisture for little more than three months and often for much shorter periods. Given the minimum of 90 days required by most Ethiopian crops, yield expectations are very poor. Furthermore, the harvest period shortens the LGP in the long rainy season, since the second season land preparation is further pushed into July. Insufficient yield or no yield from the short rains and crop failure due to shortening of LGP in the main season is the beginning of the phenomena of drought, famine and social upheaval in northern Ethiopia. Because land preparation with the traditional ox-drawn plough is extremely difficult when the soil is very dry or excessively wet, understanding the occurrence of moist soil periods is crucial. In current practice, land preparation often begins immediately after each harvest, before the soils dry out, and starts again when the soil gets enough

moisture from the next rains. If the farmers in Tigray and Asmera UPAs used the first period of light rainfall for land preparation and took advantage of the full available LGP in the main rainy season, they could produce satisfactory yields with less risk of land degradation. The risk of famine can be clearly linked to the bimodal rainfall and evapotranspiration regimes in these UPAs. This argument is similar to the conclusion of Henricksen and Durkin (1985). Based on 30 years (1953-83) investigation of LGP, Henricksen and Durkin (1985) say that failure of short rains shortens the LGP of the main season and this has historically coincided with serious drought and famine years in northern Ethiopia, most particularly in the Asmera and Tigray UPAs. Unfortunately, the increasing demand for food and forage from the increasing human and livestock population mean that these fragile UPAs will continue to be subjected to bimodal production beyond their capability.

The high productivity areas, in some ways, appear to be more at risk than the inherently precarious UPAs. The high productivity areas, Keffa, Nyala, Gambella, Shewa, Eastern Highlands, Abay and Lower Rift Valley, are threatened by a population explosion from local growth and by the influx of other Ethiopians fleeing drought, famine and war. The Shewa UPA can be cited as an example of the risk of land degradation due to population explosion.

The Shewa UPA has the best seasonal cropping potential of any UPA (see section 6.8). It has also a satisfactory potential for associated perennial activities, including livestock production provided its intensity is kept within the carrying capacity of the UPA. Shewa is the center of major agro-industrial activities and encompasses many

flourishing urban centers, including the nation's capital city. Its population density is 274 persons/km² and its productive potential is currently stressed. If the population increase continues along the present trend, population density will increase and under the resulting pressure the UPA will face severe land degradation risk which would undermine its productive potential. The pressure would extend to the adjoining UPAs of Keffa, Lower Rift Valley and Afar, and increase degradation risk in these areas as well.

Keffa is the most fortunate UPA in its year round moisture availability, which enables it to support reliable year round perennial activities, including enset planting, intercropping and cash cropping (mainly coffee). Because of its year round biomass production, the UPA supports one of the most dense human populations (250-300 persons/km²) in the country. Migration of excess population from one high potential area (Shewa) to another high potential area (Keffa), increases the human pressure on the resource base of the second UPA, and land degradation risk would increase substantially especially because the skills needed in shifting cultivation, intercropping or enset planting (in Keffa) are not common knowledge to those people coming from the cereal growing Shewa UPA. Land degradation processes leading to runoff, crusting, leaching and acidity would commence as they clear the forests to grow crops. The inherent characteristics of the soils of the Keffa UPA, which are dominantly Oxisols and Ultisols, aggravate the level of risk. Changes in the microclimate related to decrease of the forest cover could also be problematic. If the expanding population from the Shewa UPA leads to migration into the more marginal zone of Afar, risks are also high.

Afar's rainfall is unreliable for both seasonal and perennial activities, unless it is supplemented by irrigation. The most compatible land uses in the UPA are, however, wildlife conservation and low intensity pastoralism, possibly on a free range basis. Attempting intensive rainfed cropping in this fragile ecosystem, would risk desert encroachment onto the areas used.

The remote and less inhabited Gambella UPA is the most promising area for expanding crop cultivation and for moving people from the low productivity and highly populated UPAs. Gambella, with its long LGP, is the best UPA to grow big grains, primarily maize and sorghum. However, there are certain constraints to be considered before Gambella is harnessed for additional food production. The dominant soil types include Vertisols, which are difficult to work due to their alternating drying and wetting. This calls for careful scheduling of field work to coincide with moist soil conditions. The short time with desirable soil moisture content may require the introduction of mechanization to assist in maintaining work schedules. A crop calendar to keep track of the environmental conditions would also help avoid untimely field work. The crop calendar can be developed from the moisture regimes described in the barcharts and soil moisture simulation tables developed here. Not assisting the farmers with mechanization means that crops cannot be planted and harvested on time and trafficability problems in the wet season can prevent weeding and other timely activities. Because of lack of drainage in the wetter soils, the surplus water may constrain more intensive crop production. Waterlogging is a risk.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1. CONCLUSION.

Ethiopia has been divided into 13 Uniform Productivity Areas (UPAs), based on climatic resources, topography and soils. Each UPA has a limited range of variability in each aspect. From rainfed biomass production point of view, 43.65% (523,683 km²) of the country has low production potential, because of severe moisture deficiency. Most of the remaining 56.35% (676,311km²) has medium to high potential, because of less risk of moisture stress.

In the low potential areas, the precipitation is erratic and unreliable, potential evapotranspiration is excessive and soil moisture reserves are not adequate to support biomass growth throughout the year. These climatically-constrained areas, in most cases, are also areas of unproductive soils. The soils tend to be shallow, stony, sandy and medium textured, have low moisture retention capacities, are drought-prone and have high concentrations of soluble salts. The plant communities supported have little diversity. The unproductive soils are vulnerable to a wide range of degradation processes, with the main land degradation risks being associated with excessive aridity. The common types of land degradation in these moisture-deficient low potential areas are salinization, sodication, wind erosion and water erosion by runoff. Thousands of years of cultivation and uncontrolled exploitation of vegetation resources for grazing and fuel (especially in the highlands of

UPAs 8 and 9) compound the inherent environmental limitations. The two main land use practices, crop cultivation (seed farming complex) and pastoralism, are susceptible to variable degrees of environmental problems associated with the soil and climatic constraints of each area. This susceptibility is evident by the frequent occurrence of drought and famine in the low potential UPAs, particularly in Tigray and Asmera.

There is sufficient evidence to conclude that intensive crop cultivation (i.e. by seed farming complex), for most of the low potential UPAs, has more undesirable effects than benefits. The limitations of the soil are combined with climatic constraints which make the LGP marginal for many crops. The LGP of less than 90 days, in many of the drier UPAs, is below the threshold required by most Ethiopian crops. The best option is to abandon the seed planting complex (intensive cultivation) in most of the low potential UPAs. The intensive cultivation should be replaced by forestry and wildlife conservation activities. Where seed planting complex continues, more broadcast seeding and mixing of species is needed to maintain ground cover and minimize the breaking of soil by tillage.

There is room for pastoralism in these areas. It is less susceptible to the environmental constraints, provided it is practised appropriately by keeping the number of animals in line with the carrying capacity of the area. Pastoralism is most compatible with those UPAs with moderate rainfall distributed throughout the year, but with strict culling, these UPAs with distinct dry seasons could support well managed livestock herds.

In the natural state, the soil and climatically-constrained low potential areas of Ethiopia support a variety of hardy indigenous

vegetation communities which serve as a source of food and habitat for wildlife species which have coping mechanisms to withstand the harsh environmental elements. As part of their adaptations, wildlife species are small sized, and are nocturnal, diurnal or crepuscular in their activities to reduce water requirements. Movement is the key strategy in their exploitation of the widely distributed vegetation resources. By moving around, they avoid overgrazing and trampling the vegetation and other associated land degradation processes. They are grazers, browsers and mixed feeders, which helps them to avoid over-exploiting rangelands and saves specific vegetation species from being wasted due to lack of specialized feeder. They are part of the natural balance. These attributes suggest that the wildlife resources of the low potential areas could be managed as part of the food production system of the country. Game ranching, a concept being considered elsewhere in Africa, could be a workable strategy for Ethiopia.

The livestock, although not indigenous to Ethiopia/Africa, through time have adapted to a productive existence in these precarious areas. Although not as efficient as the wildlife, when allowed to wander freely and exploit rangelands within its recovery limits, domestic livestock also represent a sustainable food production option. Integration of wildlife and livestock has a high potential for sustainably increasing food production, if the domestic stock are not allowed to concentrate in a particular area.

The high potential areas are more threatened by degradation than the inherently precarious parts of the country, because these areas are experiencing excessive pressures from increasing livestock and human

populations. The rainfed biomass production is not immune to climatic vagaries. The land degradation risks of the high potential areas are primarily associated with overgrazing, deforestation, runoff and water erosion, waterlogging, crusting, acidity and leaching. Many of these degradation risks are induced by water. Paradoxically, vast areas within these zones suffer from severe moisture stress for a number of months annually. The high potential zones can be victimized by the effects of climate and soil constraints combined with human actions. This calls for the adoption of land use practices which will minimize land degradation. Careful monitoring and planning of new or imported land use systems is called for.

There are some common attributes which make both the high and low potential areas susceptible to land degradation problems.

- 1) Low moisture availability during the dry season ("Bega") which hampers the sustainability of all kinds of biomass production and can lead to lack of ground cover during critical periods. The risks are most apparent in UPAs which exhibit sharp contrast between their rainy and dry seasons.
- 2) Livestock presence throughout the year, including the dry season ("Bega") when plant growth and reproduction are at a low level.
- 3) The most critical problem is the impact of season contrasts in grain prices and food supply. Grain is abundant and cheap during harvest time and immediately after harvest. The price of grain increases during the dry season ("Bega") and becomes most expensive during the long rainy season. If the rains, in the long rainy season, are not judged to be adequate, then the traditional wisdom recognizes

there will be grain scarcity. In the extreme, crop failure may occur and the drought leads to famine. In the latter case, farmers eat their seed grain and sell their livestock in order to buy grain (possibly grown by themselves) at high prices from traders or from anyone who had the money to buy and hoard grain at the time of harvest.

This series of events has been more common in the low potential UPAs than in the less climatically-constrained parts of the country. Their frequent recurrence is strongly linked to the presence of ongoing severe land degradation due to poor land use practices and they stimulate desperate measures which lead to land degradation.

The traditional food production systems have considerable potential for improved biomass production without land degradation. This has been witnessed by many people who visited the country, including Westphal (1975), Murphy (1958) and Harrison (1987). The Konso farmers from UPA1 (Keffa), for example, are famous for their intercropping and terracing activities. According to Harrison (1987), the Konso regularly cultivate 49 different shrubs and trees, and Harrison (1987) claims to have counted 24 different species of crops, including maize, barley, and millet, in a single Konso field of 0.2 hectares. Farmers from the central highlands (Shewa UPA) are practising agroforestry by allowing the naturally sprouting Acacia albida tree to grow. This tree serves as a source of mulch and fodder, and by fixing nitrogen it maintains soil fertility. From 1977 to 1984, highland Ethiopian farmers planted 500 million tree seedlings and constructed 700,000 km of terraces (Earthscan, 1985). The involvement of the grassroots and other untapped traditional wisdoms of

food production and resource conservation provide hope for development of compatible modern technology to help Ethiopia become self sufficient in food and to become environmentally conscious in using its resource base.

Probably the most promising area for modern technology to help farmers is by establishing crop calendars to advise them when to carry out the different stages of food production including the field operations of land preparation, planting, weeding and harvesting and how to manage both crops and livestock. The temporal distributions PE, rain and soil moisture, such as the monthly information described earlier, would be the basis of the calendars. This information would help farmers make the best use of the natural resources and would also forewarn if problems were apparent. Given the climatic diversity seen across Ethiopia, specific calendars would be needed in each UPA.

7.2. RECOMMENDATIONS.

The following recommendations, mostly deriving from this work but also looking beyond, are made.

- 1) Reduce severely the intensity of the seed farming complex (i.e. crop cultivation) as a major land use practice in the low potential areas [especially in the Asmera (8) and Tigray (9) UPAs] and substitute it by large scale wildlife and forestry activities, and by low scale, but, highly mobile pastoralism.
- 2) Reduce the dependency on bimodal rain distributions to grow two crops annually. It is more appropriate, especially in those low potential areas, to use the short rains to increase soil moisture availability and for cultivation without reducing the LGP in the

- long rainy season. The use of the short rains to grow non-harvestable crops will help to protect the soil and water resources.
- 3) Develop water harvesting techniques to be used as source of water to help establish seeds waiting for late rains and/or to help moisture stressed crops to produce grain. The water harvesting techniques should be simple to maintain and labor intensive and animal powered. Water harvesting by means of terracing, soil bunding, contour tillage, etc. not only increases crop yields, but provides the best safeguard against water erosion on sloped land.
 - 4) Develop and implement efficient farming tools such as the one developed by ILCA (International Livestock Center for Africa), to reduce the heavy dependency on livestock. ILCA (1984) has developed a tillage tool that enables a farmer to farm his land using one ox instead of a pair of oxen. This would contribute enormously to the reduction of livestock numbers used in cultivating farmlands.
 - 5) In the highlands where livestock are integrated with crop cultivation, keep the livestock in pens for stall-feeding instead of releasing them into grazing and farmlands. Using dung from the stall-fed animals to manure backyard gardens and nearby farmlands can eliminate overgrazing and turf destruction by trampling.
 - 6) Develop techniques for investigating the availability and reliability of soil moisture during the dry season ("Bega") to limit the intensity of grazing and farming activities and keep them within the capabilities and limitations of the available soil moisture.
 - 7) Based on the sharp decrease in available soil moisture in those UPAs with high contrast between rainy and dry seasons, cultural and

attitudinal changes toward harvesting livestock before consuming grain reserves during the dry season should be attempted. This reversal in attitude concerning personal wealth would not only reduce the susceptibility of the resource base to land degradation, but could also help stabilize grain prices. Cooperatives can be formed to deal with culling, processing, preserving and marketing of the livestock products. Simple but hygienic abattoirs and other shelters can be used to process "biltong" and to preserve the product for some time before it reaches the consumers. "Biltong", the preparation of meat through sun drying, rather than by cooking or freezing, represents a low cost and effective way of storing livestock products. It should be explored and, if necessary, researched further.

- 8) Establish mid-season production estimation systems to advise farmers on harvesting and marketing potentials for their crops. The same system would serve as a drought early warning mechanism, allowing drought assistance and famine relief programs to be implemented on a timely basis. This could help to minimize land degradation pressures associated with displaced people and starving livestock.
- 9) Help farmers to establish safe storage facilities to store their grain. This would save the peasants from seasonal, unfair prices. The sharp contrast between rainy period and dry season prices for small grains demonstrates clearly how little control dryland farmers have over grain prices.
- 10) Identify degraded lands and employ compatible, labor intensive rehabilitation techniques to improve these areas for food

production. If possible to : reforest and allow nature to take its own course on lands with slopes greater than 35%, to terrace lands with slopes greater than 20%, and to treat gullies according to the local preferences. Great care should be taken to safeguard technocratic and hierarchial approach, every thing has to be community based with the full participation of the community.

- 11) Integrate crop cultivation, forestry and animal husbandry to increase yield while conserving and protecting the resource base.
- 12) The proposed resettlements of excess population from both the high and low potential areas to where soil fertility and moisture availability are more reliable and where production is more sustainable could be sanctioned, provided that careful environmental assessment is carried out and the limitations carefully considered. Resettlement should be based on the willingness of people to move, otherwise their essential cooperation in managing the new resource base may not be obtained. Cultural, social, and faith considerations along with the an understanding of land use and environmental elements must be taken into account before indulging in large scale resettlement schemes, because both human and natural factors contribute to the type of land use the new inhabitants are likely to implement. To win the financial and political support of international aid organizations, the fairness of the programme both to the beneficiaries and to the resource base must be apparent and the potential impacts on the environmental resource base must be clearly defined. Mutual trust, among opposing political factions on the matter of saving human life by removing people from drought

and famine prone areas to parts of the country where they can support themselves by conducting sustainable food production, is essential. Similar cooperation and trust must also be sought toward the general protection and rehabilitation of the environmental resources of Ethiopia. The non-partisan findings of this study would serve as a common information source for all parties in achieving these goals.

- 13) Develop large scale wildlife/game ranching and integrate it with livestock species for better utilization of the meager and unreliable resources of the more arid areas. The low productivity UPAs are the only reasonable targets for this form of land use because the demand for food production will dictate more intensive use of the more productive land. .

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ETHIOPIAN PAs

Legend

	KEFFA
	GAMBELA
	ANBABA
	EASTERN HIGHL
	LOWER RPT VAL
	SHAWA
	AGAY
	ASMEBA
	TERAY
	AFAR
	OGADEN
	BIRENTU
	DALLE

500 km

END

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FIN