CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Anthropogenic (human-induced) forcing and its effect on the climate recently became a global concern. Man's impact on the Earth's climate began during ancient civilizations where forests were burned and cleared for agricultural purposes. However, these interferences were insignificant in comparison to the magnitude of natural fluctuations in climate. It is believed that the impact of the modern human population on climate is much more severe, as outlined by the recent report of the United Nations Framework Convention on Climate Change (UNFCC) (UNFCC; 2003), and scientists believe that anthropogenic forcing may have a significant impact on human live and biodiversity.

Since the start of the industrial revolution (1860), and especially over the previous half-century, it is increasingly recognized that the magnitude of human influence on Earth's environment persistently intensified. Henderson-Seller and McGuffeie (2001) suggested that for the first time in the history of our planet emissions of trace gasses from human activities equal, or even exceed, emissions from natural sources. Human influences, as Jones *et al*. (2003) infers, will continue to change the atmospheric composition throughout the 21st century. Anxieties are now plausibly felt, and extensively uttered about the possible immense of impact on the global climate owing to the enhanced levels of greenhouse gases concentrations on the atmosphere (Fischer *et al.*, 2002). Society adapted according to the conditions of a given climate, and changes in that climate may place significant stress on society (Hewitson, 2004).

Anthropogenic greenhouse warming and possible climate change might result in the shift of climatic zones, the rise in sea levels, more frequent storms, droughts and floods as well as other unprecedented environmental changes. These phenomena might pose challenges to society and might even undermine the existing sustainable utilization of natural resources. They have the potential to influence every sphere of life, as we know it today, if neglected.

Despite their contribution to anthropogenic gas releases are insignificant, developing countries are found to have the most vulnerable populations. Vulnerable populations have limited capacity to protect themselves against and to recover from environmental hazards, and in particular against extreme events such as drought and floods. Those countries that dependent on localized rural agriculture activities as a source for food supply might be most severely affected.

Recognizing that the problem of greenhouse warming is global, the UNFCC entered into force in 1994. The Kyoto Protocol, which sets out more specific, bindings commitments, followed in 1997. The objective of the Convention (Article 2) is the "stabilization of greenhouse gas concentrations in the atmosphere to a level that would prevent potentially dangerous anthropogenic interference with the climate system". Such a level should be achieved within a timeframe sufficient to allow for ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (UNFCC, 2003).

Assessment of vulnerability to greenhouse warming induced climate change is mostly based upon scenarios of future climate. These scenarios are generally derived from projections of climate change undertaken by General Circulation Models (GCMs). Data from present global GCM climate projection simulations are available in fairly coarse spatial resolutions (hundreds of kilometers), and local or regional detail that is needed for impact assessments at a national level is often not captured. A widely applicable approach for adding this detail to global projections is to nest a Regional Climate Model (RCM) with a finer grid resolution within the simulated fields of a global GCM (Jones *et al.,* 2003). This approach is also known as nested climate modelling, and the RCM used is often referred to as a Nested Climate Model (NCM). Knowledge of climate variability on a local or regional spatial scale is important for assessing the impacts of potential future climate change on society. For this reason much attention has been given in recent years to climate simulations using RCMs (see Chapter 3 for details) driven by output from coarser resolution GCMs.

1.2 DRIVING FORCES OF THE CLIMATE AND ATMOSPHERIC MODELLING

The primary processes that drives Earth's climate are the planetary radiation balance between the incidence and emitted solar radiation that governs the difference in energy between low and high latitudes and the effect of Earth's rotational rate on atmospheric and oceanic circulation (Henderson-Seller and McGuffeie, 2001). External (e.g. Milankovitch variations, solar activities and others) and internal (e.g. tectonic, geothermal and anthropogenic) perturbations tend to alter the climate system either positively or negatively (from a human and biodiversity perspective). These perturbations might lead to the warming or cooling of the Earth's surface and atmosphere. It is a known fact that both natural and anthropogenic perturbations caused by variations in the chemical composition of the atmosphere contribute to climate variability and even consistent change. According to present radiation properties and the solar constant the average near-surface temperature of an Earth without an atmosphere would have been in the order of -17^{o}C. In reality an average temperature of approximately +15^{o}C is measured today, meaning that natural greenhouse gasses is responsible for an increase of more than 30 ^{o}C. Greenhouse gases in the atmosphere, such as carbon dioxide (CO_2) and water vapor, lead to positive radiative forcing or warming of the atmosphere, whilst most atmospheric aerosols lead to a negative radiative forcing or cooling of the atmosphere (Henderson-Seller and McGuffeie, 1987).

Any anthropogenic disturbance in climate will be embedded into the more extensive background of natural climate variability that occurs over a wide range in time and space. The ocean-atmosphere El Nińo-Southern Oscillation (ENSO) phenomenon is a typical example of such natural climate variability.

To distinguish between anthropogenic and natural climate variability, it is required that the anthropogenic signal be identified against the background noise of natural climate variability (IPCC WGI, 2001). GCMs are the only tools that can distinguish between the two types of climate variability, meaning that long-term simulations of climate change may be of great value (Bash, 1988). Nevertheless, GCM climate change experiments should not be regarded as future predictions, but should rather be seen as a possible realization of how global climate may evolve in the future when subjected to imposed greenhouse gas forcing (Viner, *et al.,* 1995)

Over the past decades there have been a proliferation of interest at many institutions in modelling the climatic response to increased greenhouse gas concentrations (e.g., Geophysical Fluid Dynamics Laboratory (GFDL), the National Center for Atmospheric Research (NCAR), Goddard Institute for Space Studies (GISS), the United Kingdom Meteorological Office (BMO), Commonwealth Scientific and Industrial Research Organization (CSIRO), Canadian Center for Climate modelling and analysis (CCCMA) and others). All these institutions develop and run sophisticated GCMs, which allowed for an ensemble of climate change scenario simulations that were recently investigated under the umbrella of the IPCC.

Most of these models produced results that agree upon the cooling of the stratosphere, the warming of the troposphere and a global water cycle enhancement under conditions of a doubling in CO_2 concentrations.

1.3 THE NEED FOR RESEARCH OVER ERITREA

The potential of global climate change as a consequence of increased anthropogenic greenhouse gas emission has been recognized as a potential thread to society (Hewitson, 2001). Although Africa, of all the major world regions, has contributed the least to this threat because of its low per capital fossil energy use and hence low greenhouse gas emissions, it is the most vulnerable continent to climate change because widespread poverty and limited capabilities to adapt (Awosika *et a*l., 2001).

In the context of the present debate around international agreements, it is important that uniform assessments be carried out to compare and evaluate national, regional and global impacts of climate change on every vulnerable realm, in general, and on food and agricultural production, in particular. Such quantified impacts of climate change and spatial adaptive polices are the prime drives to mitigate the consequences of climate change (Fischer *et al.*, 2002). As a result, extensive resources are being invested in climate change research by many nations in an effort to understand the potential regional manifestation and impact of such change (Hewitson, 2001).

Eritrea is a relatively young country that gained independence in 1991. It is also regarded as one of the developing African nations that appear to be most vulnerable to climate change and variability because of widespread poverty - presumably as a result of a prolonged war, poor management practices and a lack of expertise. Previous studies have indicated that countries in the Sahelian latitudes are noticeably affected by climate variability (especially droughts) related to the ENSO phenomena. Eritrea is located in the eastern part of the Sahelian latitudes, and is in general regarded as a semi-arid country. Future changes in the climate of this region might influence temperature and moisture prone activities, especially those related to agriculture.

These circumstances have prompted the need to improve current knowledge of the climate of Eritrea. Together with this is a need to assess the future response of climate to a growing change in the chemical composition of the atmosphere as a result of human interferences, and the probable consequences on regional and national scale. This emphasizes the need for more detailed RCM simulations in comparison to the coarse resolution of current GCM simulations (including GCMs used in the IPCC initiative). So far no regional scale climate or climate change scenario simulations have been carried out over the Eritrean region. Even if this could be done, climate model verification will be difficult to perform as a result of a lack of well-documented observations. The research in this dissertation attempts to fill these gaps by introducing simulations of present day as well as possible future climates with a high-resolution RCM over the Eritrean domain.

1.4 OBJECTIVES OF THE RESEARCH

The core objective of the research in this dissertation is to introduce a RCM facility that will facilitate the simulation of present and possible future climate patterns over Eritrea. This is achieved through the following sub-objectives:

OBJECTIVE 1

To develop a regional climate modelling facility for performing climate simulations over Eritrea by implementing the PRECIS RCM system from the Hadley Center of the BMO.

Climate and climate change scenarios simulations are particularly vital for developing countries where economic stresses are likely to increase if significant changes in climate appear. In order to address this need the Hadley Center of the BMO had developed the Providing Regional Climates for Impacts Studies

(PRECIS - pronounced "pray-sea" as in French) RCM system that can run on an affordable, easily available personal computer (PC). The model is an atmospheric and land surface model of limited area and high resolution, which can be run over any part of the globe. Atmospheric dynamics, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and deep soil characteristics are all included. The model equations are solved in spherical polar coordinates, and the latitude-longitude grid is rotated so that the equator lies inside the region of interest in order to obtain a quasi-uniform grid box area throughout the region. Objective 1 intends to introduce the PRECIS RCM to develop a climate simulation facility for Eritrea.

OBJECTIVE 2

To use the PRESIS RCM system in order to perform present day climate model simulations over Eritrea and to verify the simulated climate against the best observational data available.

In an effort to validate model simulations of the standard meteorological variables, i.e., rainfall, temperature, wind patterns and pressure fields, a baseline climate simulation of 30 years (1961-1990) is compared with observational data obtained from the National Center for Environmental Prediction (NCEP) reanalysis dataset, which is available for the period 1948 to 2003. NCEP data with its coarse resolution of $2.5^{o} \times 2.5^{o}$, is probably not the best to use for RCM-scale verification, but as a result of the war and political instability over the past few decades, observational station data over Eritrea is not reliable, and good continues records do not exists. PRECIS RCM results, with the verification analysis in mind, will be used to explain the major driving mechanisms of climate over Eritrea.

OBJECTIVE 3

To determine possible future climate response to different future emission scenarios over the Eritrean region.

Since the industrial revolution that started in 1860, and in particular during the last half-century, it is increasingly recognized that anthropogenic influences on Earth's environment may be significant. The interference may cause that the current atmospheric composition be altered. Objective 3 intend to determine possible future climate responses to the A2 and B2 future emission scenarios (also known as the A2 and B2 Special Report on Emission Scenarios (SRES) scenarios) over the Eritrean region.

1.8 ORGANIZATION OF THE REPORT

Eritrea has experienced intermittent drought, coupled with land degradation and intensifying desertification, provoked by mismanagement practices. These problems pose an additional burden in the strategy to achieve food security and sustainable development. CHAPTER 2 provides a general profile of Eritrea by appraising briefly on the natural geography and the associated resource foundations that include:

(1) climate
(2) landform and drainage systems
(3) soils and geological settings
(4) land use and vegetation cover
(5) agro-ecological zone
(6) the status of agricultural activities.

CHAPTER 3 outlines the fundamentals of atmospheric modelling by putting particular emphasis on RCMs and their capabilities. It also highlights the ultimate driving force beyond RCMs development, and how RCM simulations add value to GCMs fields.

The climate of the eastern section of the Sahelian latitudes is poorly documented and understood. Previous studies mainly concentrated on the western and central parts of these latitudes. CHAPTER 4 describes key features of the observed climate. It offers a full coverage on how recent and present climate system of the region did evolved by focusing on observational patterns and trends. This is done in the context of climate change and variability. CHAPTER 4 also intends to address the mechanisms responsible for, and the origin of persistent droughts that often occur in the sub-Saran latitudes. It appears as if these droughts worsened over the past two decades.

CHAPTER 5 demonstrates possible future climate responses to enhanced greenhouse gases and aerosols over Eritrea. GCM simulations from the most recent Intergovernmental Panel for Climate Change (IPCC) are used to supplement PRECIS RCM climate projections. Both the A2 and B2 SRES scenarios are considered. Inter-model consistency in simulated atmospheric variables is regarded as an important feature in future climate scenario simulations.

At the synoptic scale, modern GCMs can simulate the many processes of the atmosphere to a great degree of accuracy, and are reliable tools. However, computational constraints prevent them from performing detailed climate simulations at the mesoscale. RCM were developed as a computationally feasible alternative to obtain high-resolution climate simulations. Over the past decade many RCM simulations have been performed over various regions of the Earth. Climate simulations by the newly introduced PRECIS RCM system over the Eritrean Sub-Saharan Africa domain are presented in CHAPTER 6. The chapter attempts to offer a comprehensive model description and experimental design. Subsequently, the model's performance in capturing present-day (baseline) climate is both qualitatively and quantitatively verified against observations. Future climate projections by the PRECIS RCM under A2 and B2 SRES scenarios are also discussed.

CHAPTER 7 contains a number of conclusions. The chapter underpins the performance of the PRECIS RCM in simulating present-day and future climates. Opportunities and possibilities of utilizing the latter as input for impact models are also discussed.

The objective measures of skill that have been used to verify the PRECIS RCM performance (CHAPTER 6) are elaborated upon in APPENDIX A. The python code that was developed to manipulate PRECIS RCM output results is presented in APPENDIX B.

CHAPTER 2

GENERAL PROFILE OF ERITREA

2.1 GEOGRAPHICAL LOCATION

Eritrea is located between latitudes 12° 42' N to 18° 2' N and longitudes 36° 30' E to 43° 20' E, in the northeastern part of Africa (Kayouli *et al.,* 2002). Being part of the sub-Saharan Africa, it fits in between Sudan to the north and west, Ethiopia and Djibouti to the south and the Red Sea to the east and northeast (figure. 2.1). The country covers an area of about 124,000 km^2 and has over 350 tiny islands in the Red Sea, over half of which make up the Dahlak Archipelago (America on line service, 2002).

Figure 2.1: Geographical location of Eritrea in north-east Africa, with Sudan to the west and Ethiopia to the South **(**Adapted from: United Nations, 2000)**.**

2.2 HISTORICAL BACKGROUND

Eritrea's strategic location attracted several expansionist powers (UA and MOA, 1998). Starting from the 16th century, Eritrea had fallen under the control or influence of different foreign powers, including the Turks, Egyptians and in modern history by Italy, Britain and Ethiopia (MLWE, 2001). The fall of Eritrea under the full control of Ethiopia in 1962 provoked a long war of liberation that culminated in Eritrean independence in 1991 (CIA, 2002), but left the country in wreck. After seven years of peace and relief, however, the country was again forced to engage in border-war (1998-2001) with its long-time rival, Ethiopia. This imposed war did, by far, cause its reviving economy to collapse again.

2.3 POPULATION

As MLWE (2001) detailed, Eritrea has an estimated population of 3.5 million, growing at a rate of about 3.0 % annually, with an average density of about 28 persons per km^2. More than 80 % of Eritrea's populations live in rural areas. Mainly due to suitability of climate, about two thirds of the population lives in the highlands which has an altitude of higher than 1500 meters Above Mean Sea Level (AMSL). Despite the fact that Eritrea is small in land coverage it hosts diverse ethnic groups. These ethnic groups are divided into nine nationalities namely the Afar, Bilen, Hedarb, Kunama, Nara, Rashaida, Saho, Tigre and Tigrigna. The Tigrigna and Tigre nationalities constitute the majority of the population. Within these nationalities Tigrigna, Tigre and Arabic are widely spoken languages.

2.4 CLIMATE

Eritrea is located in the sub-Saharan latitudes where the Sahelian climate dominates. The eastern boundary of the Sahara desert covers the north-western part of Eritrea where the minimum average annual rainfall is less than 100 mm (figure 2.2). Rainfall gradually increases towards the south-east. There is a concern about the gradual infringement of the Saharan desert from the northwest, which is aggravated by persistent longer drought episodes. From previous studies, different views have been proposed for the possible mechanisms and causes of these dry episodes (see Chapter 4 for details).

In general rainfall is low over Eritrea and significantly varies from year to year (Hurni and Koller, 2002). The central highland receives most rain, but owing to the rugged terrain and thin soil formations that is largely deforested, most of the rain water is channeled away by flash floods. Soil-water infiltration is therefore extremely low. Over lower altitudes infiltration of soil-water is also low because of high evaporation and lower rainfall (GoE, 1995).

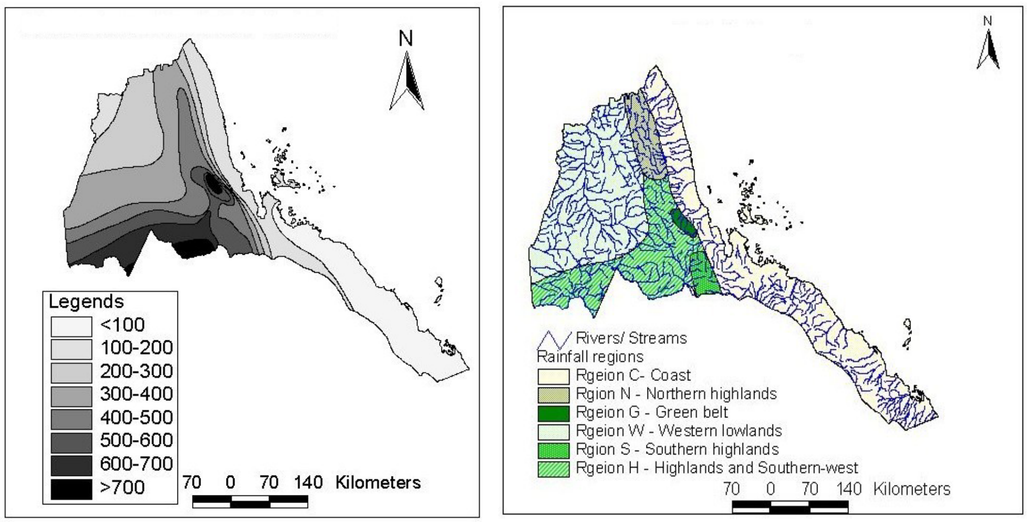

Figure 2.2: Mean annual rainfall totals over Eritrea (left) and rainfall regions of Eritrea (right) based upon rainfall systems and annual distribution as obtained from GIS database of WRD (1997)

Eritrea experiences high temperatures since it is located in the sub-tropical latitudes of the Northern Hemisphere. However, temperatures are highly influenced by local topography that leads to noticeable differences in spatial temperature ranging from a mean annual temperature of 10°C to 34°C (figure 2.3). Temperatures increase toward the eastern and western lowlands, and decreases to a minimum over the central highlands that bisects across the country merdionally.

The wind patterns in Eritrea results from both synoptic and local forcings, but are largely modified by local thermal forcing interacting with atmospheric stratification and topography. Pressure systems due to differential heating and cooling of Asia, Africa and the Indian Ocean are the main forces behind air movement in the Red Sea region (Garbesi *et al.,* 1996). While seasonal wind patterns over Eritrea are caused by the North-east and South-west monsoon, diurnal wind patterns are significantly influenced by local land-sea breezes. When the land mass south and west of Eritrea warms during daytime surface air rises, while cooler, denser air from the Red Sea flows towards Eritrea to replace it. The result is a cyclic diurnal wind speed pattern, with wind speeds peaking during and after the hottest parts of the day and then dying down during the nighttime (Karen, 1998).

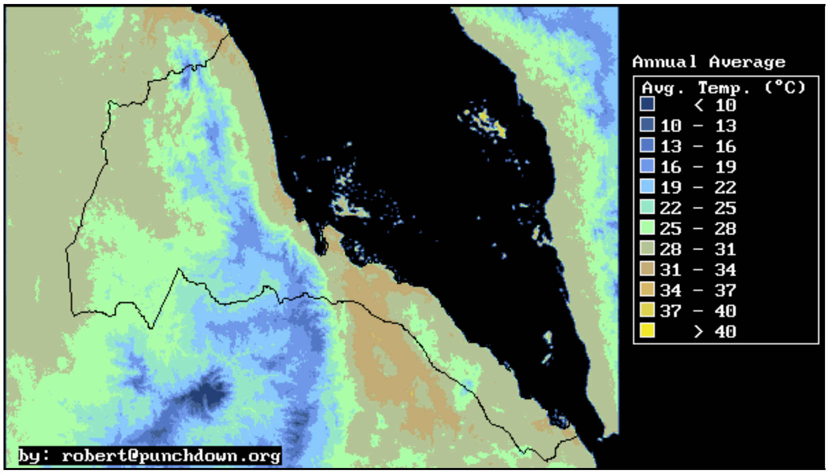

Figure 2.3: Annual average temperature distribution over Eritrea as derived from Advanced High Resolution Radiometer data (from AVHRR channel 5) and correlated with station data (RMSE 1 °C - 3°C) (Source:http://www.punchdown.org/rvb/temps/mapindex.html, 2004/12/20)

2.5 LANDFORM AND DRAINAGE SYSTEM

Topographically, Eritrea is characterized by central highlands that divide the country between its eastern and western low lands (Kayouli *et al.,* 2002). According to MLWE (1997b) the Eritrean landmass is the product of the combined effect of geological and subsequent modification of geomorphologic processes. These processes are responsible for the formation of major physiographic regions:

- The Highland or plateau that is sub-divided into the Central and Southern Plateaus, Upper Anseba, Halhal, Northern, and Eastern Highlands and Mereb Trough.
- The Slopes and Escarpment that includes the Western and Eastern Slopes and Escarpments.
- The Lowlands that includes the Western and Eastern Lowlands.

The drainage system of the country is, more or less the manifestation of its physiographic settings. The genesis and flow direction of the system, apart from its geologic evolution, lies within the circle of these settings. The highlands that divides Eritrea into its Western and Eastern lowlands, defines the flow direction of the rivers. Eritrea, as shown in figure 2.4, has six catchments.

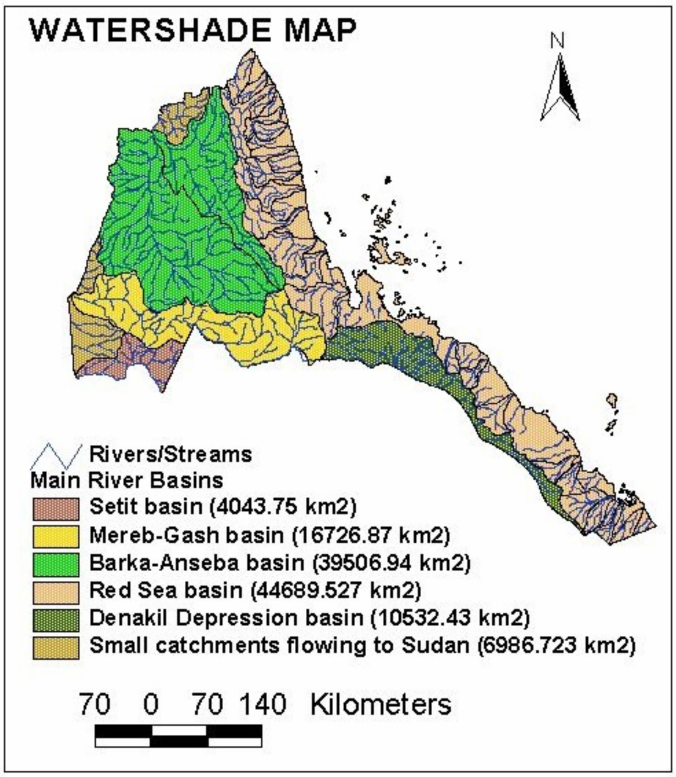

Figure 2.4: Map of Eritrea's surface water resource and drainage patterns as obtained from GIS database of WRD (1997)

On the basis of flow direction and destination FAO (1994) classified Eritrean rivers into three main drainage systems:

- The Mereb-Gash and Tekeze-Setit river systems, draining into the Nile.
- The eastern escarpment and the Barka-Anseba river systems, draining into the Red Sea.

- The river systems of a narrow strip of land along the southeastern border with Ethiopia, draining into the closed Denakil Basin.

The Mereb (upper course of Gash) and Tekezze rivers are found on the border with Ethiopia. As GoE (1995) states, except for the Teckezze Setit, which has a perennial flow, all the other Eritrean river systems are intermittent.

A preliminary assessment indicates that Eritrea is not gifted with appreciable amounts of both surface and ground water resources. The scant rainfall over the Highlands disappears as runoff because of rugged and denuded topographic features and the impermeable nature of the geological formations. Hydrological, climatological, topographical and geological factors, together with human actions of deforestation and war created a chronic shortage of water for human consumption and industrial uses (GoE, 1994).

2.6 SOIL AND GEOLOGY

Soils of Eritrea vary from region to region in terms of texture, fertility and other natural characteristics (Kayouli et al., 2002). So far no known reliable and detailed soil survey has been conducted. Available soil maps are estimated downscaled products from global soil maps or were produced during the colonial time. Diverse soil maps and descriptions are commonly found in literatures. In many cases they lack consistency and are not suitable for application purposes.

As indicated in figure 2.5 leoptosols appear to be the most dominant soil type in Eritrea and covers the Highlands and southern extension of eastern part of the country. Other soil types found in the Highlands are chromic, eutric, calsic cambisols that have a distinctive red-brown color, lithosols, xerosols and fluvisols. In the northern and southern parts of the Red Sea coastal plains, sandy desert soils are most common. In other parts of the country ortho-solonchaks, regosols, and andosols are observed. Soils in the western parts include vertisols and fluvisols.

The geology of Eritrea formed through a process of continuous uplifting and faulting. Eritrean geology is divided into two distinctive regions: (a) the central and northern Highlands and (2) the coastal and low altitude areas. The central and northern Highlands consist of the Pre-Cambrian Basement complex and is known to be one of the oldest formations found in Africa. The western highlands with their typical flat-topped mountains are mostly covered by tertiary basaltic flows. In western Eritrea, the basement complex was covered at a later stage by young quaternary sediments, although local rocky outcrops of the basement complex also occur (Mohr, 1970; Drury et al., 1994 cited in Ogbasighi, 2001:7). The formations along the Red Sea coasts line and the southern Danakil plains are younger and consist of tertiary and quaternary sediments with volcanic rocks. The latter are associated with the Red Sea and the Afar rift system, which cuts through the area from south to north accompanied by many fault lines. During the Tertiary, sandstone and limestone were formed along the eastern coast, where at present lagoons and salt plains are found (Mohr 1961,1987 cited in Ogbasighi, 2001:7).

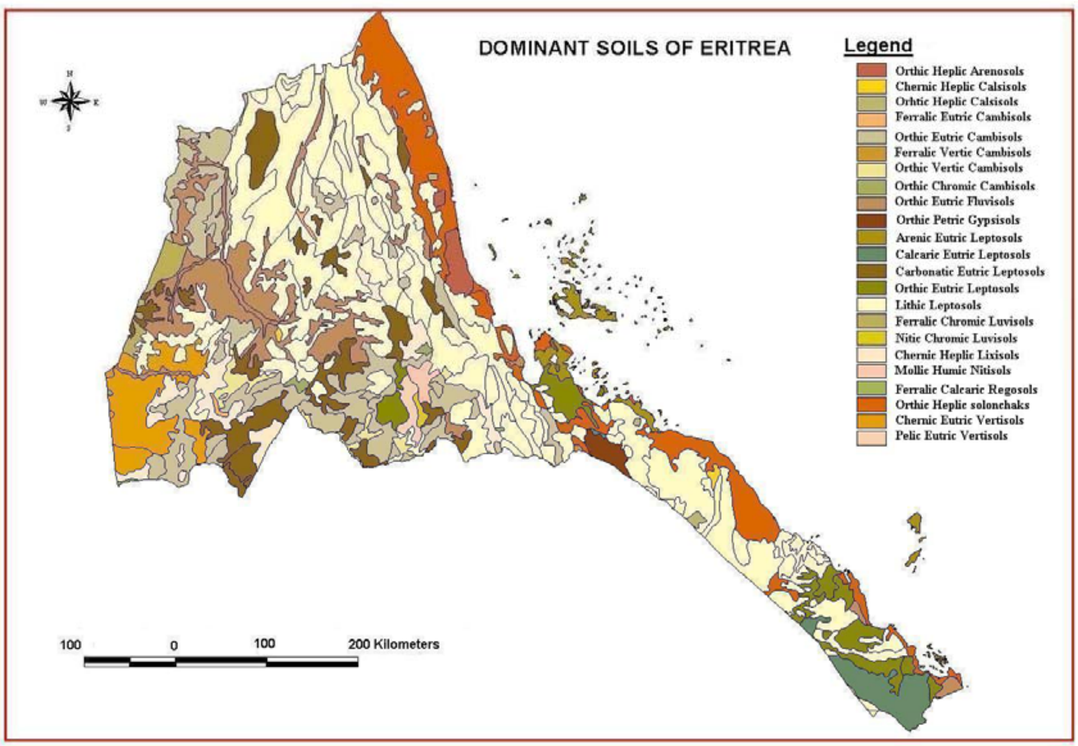

Figure 2.5: A map that exhibits major soil types in Eritrea as obtained from GIS database of FAO (1994)

2.7 LAND USE AND VEGETATION COVER

Since detailed land use studies have not yet been completed in Eritrea, no standard land use classification system exists. As indicated in figure 2.6, the northwestern low altitude region and costal plains are arid zones that are populated by nomadic populations. These areas could also be categorized under pasture zones since they are supporting animal rising activities upon which the nomadic populations depend. Crop zones and pasturelands are mainly found in the central and southern high lands, and southwestern low altitude region.

Vegetation in Eritrea has been subjected to long time mismanagement and over exploitation. Its depletion was associated with the removal of natural vegetation for the expansion of farming, fuel wood, grazing, etc (GoE, 1995). In 1952, Eritrea's forest resources covered an area of 12,525 km^2, i.e., about 11% of Eritrea's surface. This resource has been reduced to a figure of less than one percent at present (MLWE, 1998). Following an international convention (MoA, 2002) the natural forest cover of Eritrea has been classified into six major vegetation types by aggregating the details presented in figure 2.7. These vegetation types include Highland forest, mixed woodlands of acacia and associated species, bush or shrub vegetation, grasslands to wooded grasslands, riverine forest and mangrove.

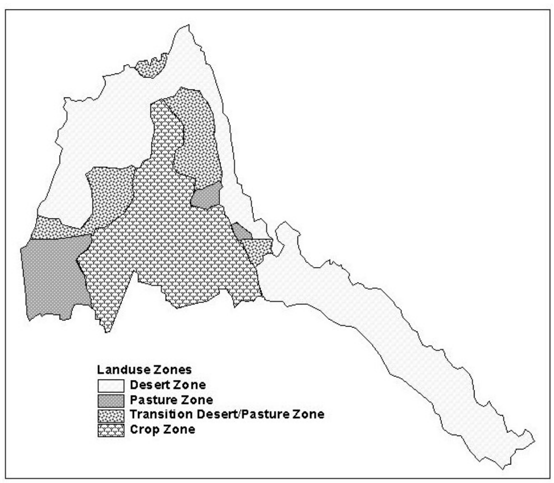

Figure 2.6: The map illustrates major land use zones of Eritrea. It was obtained and digitized from National Center for Earth Resources Observation and Science (EROS) (originally derived from thematic maps and other source material).
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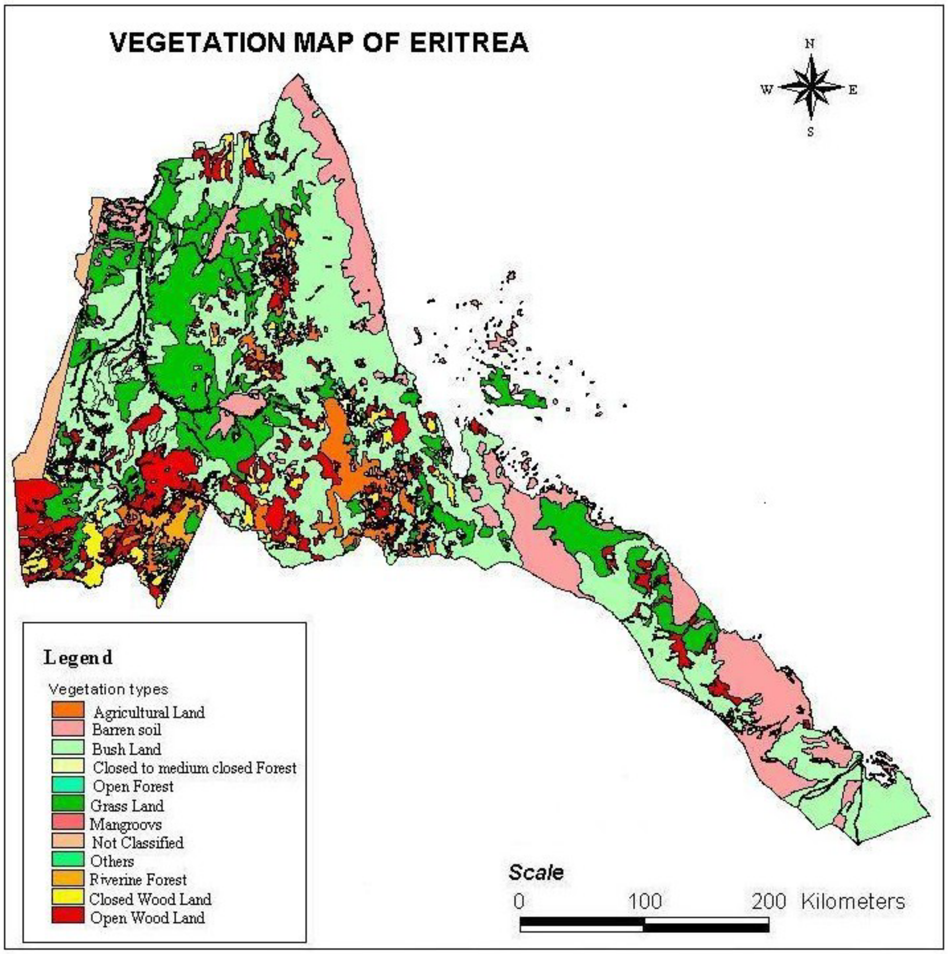

Figure 2.7: A typical vegetation map of Eritrea with 12 vegetation types. (Source: FAO/MOA, 1997)

2.8 AGRO-ECOLOGICAL ZONES

As indicated before, Eritrea is a country with complex landscapes and a variable climate, which result in a wide variety of agro-ecological conditions. As in most other land resource disciplines, no detailed assessment of agro-ecological zones has been completed. Available information was derived from work done in the early 1980s by the Ministry of Agriculture of Ethiopia (e.g., MLWE, 1997a). Although this inventory is not free from limitations (developed from outdated Landsat imagery and aerial photography and without considering inter-annual climate viability) the methodology adopted for its development proved to be sound. The study identified six zones (figure 2.8) on the basis of broad similarities of moisture and temperature regime, natural vegetation cover, soils and land use.

The major zones were each sub-divided into a number of Agro-Ecological Units (AEU) based upon more specific differences of landform, soil type, land cover or land use. Accordingly, 55 AEU were recognized and defined (see MLWE, 1997a).

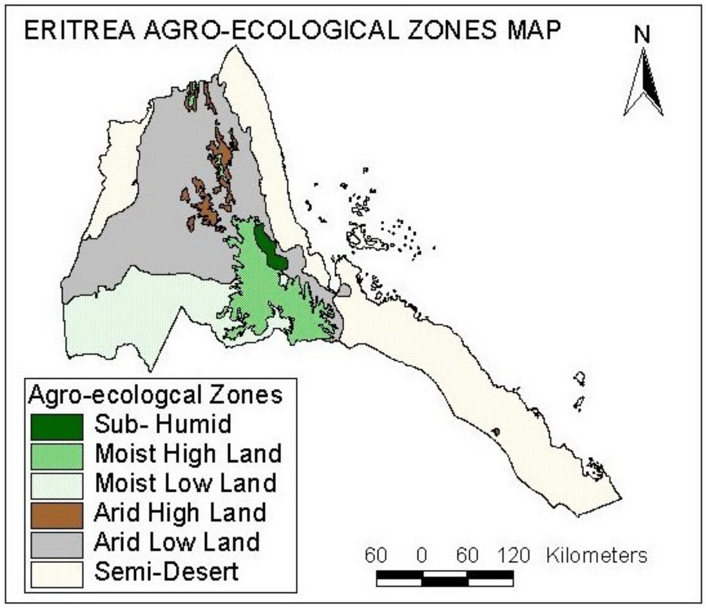

Figure 2.9: A typical agro-ecological map of Eritrea indicating six agro-ecological zones as obtained from GIS database of WRD (1997)

2.9 AGRICULTURAL ACTIVITIES

A large part of Eritrea is unsuitable for agriculture due to climate, soil characteristics or other constraints. There are about 3.2 million hectares of arable land in Eritrea, of which less than 15 percent is normally cultivated. More than 95 percent of the cultivated area is rain-fed (FAO, 2002). Rain-fed agriculture is characterized by low productivity, greatly subsistence and traditional in nature. Modern agricultural inputs such as fertilizers, agro-chemicals and systematic management schemes are often non-existent. This makes Eritrea's agriculture particularly vulnerable for changes in the climate or climate variability.

Eritrean climate, as noted earlier, is characterized by intra-seasonal and inter-annual variability with a high frequency of drought events. Rainfall variability in both magnitude and spatial distribution are the main constraints against the development of rain-fed agricultural activities. What makes the situation particularly venerable is the fact that the majority of the population depends on rain-fed agricultural activities for their livelihood.

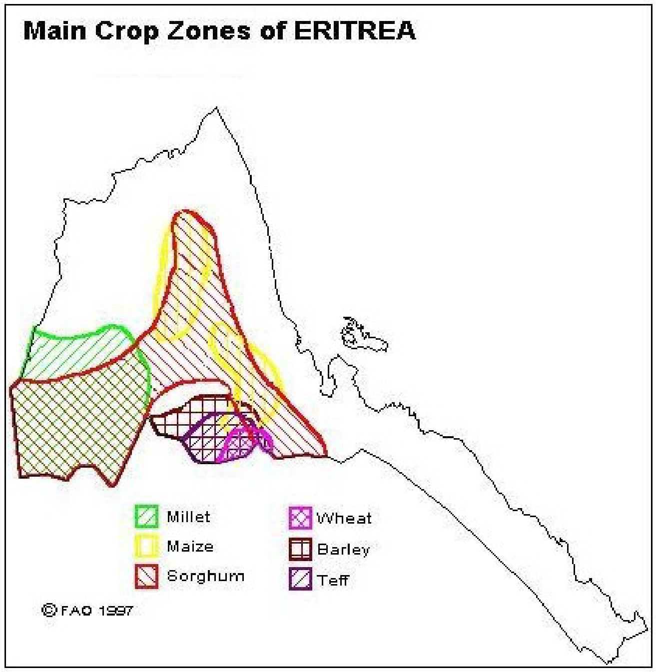

Figure 2.10: Spatial distribution of production zones of the main crops in Eritrea. Major cultivated crops include barely, wheat, African finger millet, taff and maize (Source: FAO, 1997)

The higher rainfall summer season of June-July-August (JJA) is the most suitable for rain-fed agricultural activities. It is during this season that most of the national food production takes place. There is a potential to improve productivity and to minimize risks associated with rain-fed activity by introducing inter-seasonal rainfall predictions, although longer-term changes in climate and climate variability might have a devastating effect on the country's current agriculture activities if more dry spells is anticipated. The major cultivated crops include barely, wheat, African finger millet, taff and maize (figure 2.10).

Potential exists to increase crop production through the expansion of irrigated land (MLWE, 1997b). Proper management of the exiting land and water resource creates additional flexibility to boost agricultural land productivity and sustainability. Currently, irrigation potential is not fully exploited and is still in its early stage. The south-western and north-western regions along major riverbanks, eastern low altitude regions and valley bottoms of the highlands are expected to niche extensive irrigation schemes. Apart from climate awareness, raising agricultural productivity through the use of modern technology and the establishment of irrigation-based commercial farms is a critical component for sustainable future food security.