THE STATE OF ERITREA
MINISTRY OF LAND, WATER AND ENVIRONMENT

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ERITREA'S INITIAL NATIONAL COMMUNICATION

Under the United Nations Framework Convention on Climate Change (UNFCCC)

December 2001
Asmara, Eritrea

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EXECUTIVE SUMMARY

1. Introduction

It is widely agreed today that anthropogenic greenhouse gas (GHG) concentrations in the atmosphere is creating imbalances in the natural cycle of the earth's climate, best known as climate change. Scientific evidence has shown that the earth has been increasingly getting warmer and warmer. Nine of the ten warmest years, for example, have occurred since 1990. The resultant global change of climate has been of major concern to the international community and the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 at the Earth Summit held in Rio de Janeiro, Brazil, was a big step forward in the challenges to mitigate climate change. Today more than 180 States and regional economic integration organizations are Parties to the UNFCCC, under the principle of common but differentiated responsibilities to mitigate climate change.

Eritrea acceded to the UNFCCC on 24 April 1995 to join hands with the international community in the mitigation of climate change. Pursuant to Article 12 of the UNFCCC each Party should communicate information relating to its commitments under the Convention. This national communication has therefore been prepared in this context in accordance with the guidelines of the Non-Annex I Parties for preparing their national communications. The main issues addressed in this report include inventory of GHG, vulnerability and adaptation assessment studies, education and public awareness and systematic observation and research.

2. National Circumstances

Eritrea is located in the Horn of Africa between 12^0 22′ and 18^0 02′ north and between 36^0 26′ and $43^0$13′ east. It is bordering with the Sudan in the west, Ethiopia in the south, Dijibouti in the southeast and with the Red Sea in the east. Eritrea has a total land area of 124,300 km^2 with a coastline of 1900 kilometers. The Eritrean territorial waters are around 120,000 km^2, stretching out to the Red Sea Central Rift. There are around 390 islands in the Eritrean Red Sea zone, the prominent being the Dahelak Archipelago.

The population of Eritrea, which is estimated at $3.5x10^6$, is growing between 2.7 and 3 % annually. Population is unevenly distributed, with settlements highly concentrated in the cooler climates of the central highlands. Eritrea has diverse ethnic groups, which are classified into nine nationalities, namely the Afar, Bilen, Hidarb, Kunama, Nara, Rashaida, Saho, Tigre and Tigryna, with the last two nationalities constituting the majority of the population.

Although Eritrea appears to be small in land area, it has diverse climatic zones, mainly due to its high topographic variations. In physio-graphic terms the country is roughly divided into the Central Highlands (above 2000 m from sea level), the Midlands (1500-2000 m from sea level) and the Lowlands (below 1500 m from sea). The topographic variations have considerable effect on the rainfall pattern of the country. The major rainfall of the Central Highlands and the Western Lowlands takes place during the months of June and September, with much of the rain falling in August. The south- westerly monsoon winds are responsible for the summer rain. The eastern lowland and the escarpments facing these lowlands have rainfall between November and March, which is caused by the northeast continental winds blowing over the Red Sea. Due to orographic effect the escarpments receive high rainfall and since it also gets rain in summer it is the wettest part of Eritrea. Annual rainfall in Eritrea vary from about 100mm in the lowlands to about 700mm in the central highlands, and because of its bi-modal rainfall some places in the escarpment receive more than 700mm of rain annually.

When climate, soil types and other parameters are taken into account Eritrea is divided into six agro-ecological zones, namely, the Moist Highland, Arid Highland, Sub-Humid, Moist Lowland, Arid Lowland and the Semi-Desert. In terms of elevation they range from 100 in the Semi-Desert to 3018 m.a.s.l. in the Moist Highland areas. The variations in mean annual temperature range from 15 ^{0}C in the Moist and Arid Highlands to 32 ^{0}C in the Semi-Desert. Annual precipitation varies from less than 200 mm in the Semi-Desert to 1100 mm in the sub-humid zone.

The Government has been actively working to rehabilitate and reconstruct the economy, which has been very much damaged during the war of independence, which lasted for 30 years (1961-1991). To guide the country's economic activities the Government has formulated in 1994 its economic policy in a Macro-Policy Paper. Based on the economic macro-policy framework the Government pursues a policy of export oriented market economy with the private sector playing the leading role. Moreover, the policy does not make differentiation between domestic and foreign investment. To promote this policy further the Government accords high priority to the construction of infrastructure facilities, such as power generation, transport and communications.

Engaging more than 80 % of the population, agriculture is the main economic stay of the country. Subsistence agriculture, however, is the dominant mode of production and hence the contribution of the agricultural sector to GDP has not been quite significant, which was on average 19 % for the period 1992-1997.

Commercial agriculture is at its early stage and efforts are being made to develop and expand it.

Eritrea has a great potential to sustainably exploit its marine and coastal resources, particularly fisheries. The Eritrean Red Sea zone has the potential to sustainably harvest about 70,000 tones of fish as compared to the current fish catch of around 13,000 tones per year. Its long and pristine coastline of 1900 km also provides a good opportunity for tourism and other economic development activities.

Although the country had a good industrial base in the past, the war had rendered these industries non functional. Moreover, the technologies have become outdated and required considerable investments to replace them. Nonetheless, within a relatively short period of time the Government has made much effort to rehabilitate the industrial sector. Gross out put from the industrial sector almost tripled between 1992. Eritrea's industrial base constitutes medium-and small-scale industries, including food, beverages, textiles and leather.

Mining has good prospects in contributing to the economic development of the country. Some companies have been given concessions in different parts of the country for petroleum, gas and gold explorations. The potential of petroleum and gas is believed to be high.

The energy sector is critical to the development of the other sectors already mentioned above. Hence the Government has focused much attention on this sector. The energy balance for Eritrea is, however, dominated by the use of biomass fuels, accounting more than 70 % of the total energy out put in 1994. The energy balance for 1996 (no similar data existed for 1994) indicated that 77.3 % of the total final energy supply (TFES) was covered by biomass, oil products covered 21.3 %, and the rest was covered from electricity. From the TFES, 77.8 %, 14.9 %, 4.8 % and only 2.4 % was consumed by the household, transport, public and commercial, and the industrial sectors, respectively. Of the total primary energy supply (TPES) biomass accounted for 75.5 % and oil products accounted for 24.5 %. It should be noted that petroleum is the second major source of energy and the only fossil fuel at present in Eritrea.

3. National Inventory of Greenhouse Gases (GHG)

Eritrea's inventory of greenhouse gases (GHG) was conducted using the revised 1996 IPCC guideline. The inventory of GHG emissions by sources and the removals by sinks was carried out, taking 1994 as the base year for Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Carbon Monoxide (CO), Nitrogen Oxides (NO_x) and Non-Methane Volatile Compounds (NMVOCs). CO_2, CH_4 and N_2O are the major GHG emissions in Eritrea as briefly discussed below.

The inventory addressed six sectors, namely, energy, transport, industry, agriculture, land use change and forestry and municipal solid waste.

3.1 Carbon dioxide (CO_2)

Carbon dioxide (CO_2) emissions amounted to 2396 Gg in 1994. The major share of this emission came from LUCF and mainly from burning of fuel wood for energy uses. So it can be argued that LUCF sector in Eritrea was a net contributor of emissions rather than being a sink of $CO_{2.}$

The second major source of CO_2 is from fuel combustion of petroleum products, which amounted to 687.5 Gg of CO_2 in 1994. The major share of this emission is attributed by the road transport and the energy industries, accounting for about 283 and 241 Gg of CO_2 respectively.

3.2 Methane (CH_4)

National methane (CH_4) emission in 1994 is estimated at about 74 Gg. The main source was from agriculture and mainly from enteric fermentation. The energy and waste sectors also contributed small amounts of CH_4 emissions.

3.3 Nitrous Oxide (N_2O)

National emission of N_2O, which came from the energy sector, is not more than 6 Gg. Estimation of N_2O emissions from manure management and from fertilizer applications was found to be negligible.

3.4 Trends of Emissions

The major share of GHG in Eritrea, primarily CO_2, is from LUCF, accounting for about 70 % of the total absolute CO_2 emission in 1994, followed by energy use from fossil fuel combustion accounting 28 % of the total CO_2 emissions. Nonetheless, the IPCC has introduced the notion of global warming potential (GWP), indicating that GHG vary in their GWP. In this respect taking 100 years time horizon for the year 1994 the GWP for CO_2, CH_4 and N_2O is 1, 21 and 310 respectively. The resultant aggregated GHG emission in CO_2 equivalents was thus 7271 Gg. In this context Eritrea's main source of GHG, by sector, was fossil fuel combustion, followed by LUCF and agriculture. By gases $CH_{4,}$ CO2 and N_2O were the main polluting gases, in that order.

3.5 Limitation of the National GHG Inventory

Country specific emission factors and emission ratios are critical for undertaking a national GHG inventory. These values were lacking in Eritrea, and hence IPCC de fault values were adopted to serve a purpose. Lack of time series data was another obstacle to the national inventory of GHG. Relatively speaking the lack of data was more limiting in the agricultural and LUCF sectors than in the energy and industrial processes sectors. In light of this situation the uncertainties could be somewhat high. Future GHG inventory works need to take these issues into consideration.

4. Greenhouse Gas (GHG) Mitigation Options

Greenhouse gas (GHG) mitigation is not a priority for Eritrea, as it is still in its early stage of developing its economy. In the fulfillment of its commitment under the Convention Eritrea's main strategy is therefore adaptation rather than pursuing mitigation options. This is because the primary objective of the country is the realization of food security and the alleviation or eradication of poverty. Nonetheless, if some mitigation options could help promote its sustainable development objectives then Eritrea would exploit such opportunities.

Pursuant to the national inventory of GHG, emissions originate from the burning of biomass related issues, including LUCF, and the consumption of fossil fuel in the energy and transport sectors. It is therefore natural that mitigation options will have to address these sectors if these are to enhance sustainable development issues. In this context the following are some of the potential mitigation options in Eritrea.

- Strengthening further reforestation/afforestation programs, aiming at rehabilitating degraded lands and at the same time solving critical timber and fuel wood supply, as appropriate.
- Expand further the use of closure area system for the regeneration of natural vegetation.
- Strengthen the conservation of natural forest and introduce proper forest management practices, including the establishment of forest reserve areas.
- The introduction and use of energy efficient technologies in the generation of electricity. The Hirghigo Power Plant Project is a good example in this context.
- Introduction of energy efficient devices in cooking, cooling and lighting. These may include the introduction of efficient wood stoves in cooking, introduction of solar cooling devices and increasing lighting efficiency through the use of fluorescent in place of incandescent lamps.

- The development and expansion of renewable energy supply technologies. In this respect many solar PV systems with an average capacity of over 400 kW have been installed in the rural areas.
- The expansion of the use of liquid petroleum gas (LPG) and kerosene. Currently there is an on going program to increase the supply of kerosene and LPG to rural areas and this needs to be strengthened further in the future.
- Formulations of new energy laws, regulations and standards so as to reform and deregulate the energy sector in order to encourage competition and efficiency.
- Introduction of efficient public transport system, particularly in urban centers
- Introduction of regulatory frames that would ban old cars and also encourage the introduction of efficient vehicles using catalysers and the provision of good quality roads and proper traffic planning.

5. Assessment of Vulnerability and Adaptation to Climate Change

By virtue of its geographical location and also because of its least adaptive capacities, Eritrea is one of the most vulnerable countries of the world to the adverse effects of climate. Due to the changing and unpredictable patterns of precipitation, for example, agricultural production, which is the main economic stay of the country, was severely affected in the past. The assessment of vulnerability and adaptation to climate change is somewhat a complex undertaking but, nonetheless, efforts were made to predict some changes of climate using global circulation models (GCM).

Several methods were use in determining the best GCM for Eritrea and theUK89 model was found to be the best predictor. According to this model, the mean annual temperature for Eritrea is expected to rise at the equilibrium level of 2 x CO_2. There will be an increase of temperature and the range between the monthly mean will vary from 29-37 ^{0}C, 28-37 ^{0}C and 18-26 ^{0}C in the coastal plains, the western lowland and in the central highlands respectively. The increase of temperature due to doubling of GHG concentration across the country is expected to rise by 4.1 ^{0}C, well within the IPCC's globally predicted range, i.e. 1.5 to 4.4 ^{0}C for effective doubling of CO_2 over the next century. On the other hand precipitation is expected to vary by a ratio of 0.1 to 0.15.

After formulating these predictions attempts were made to assess vulnerability and adaptation of some selected sectors and to predict changes of climate. The sectors chosen for the assessment were agriculture, water resources, forestry, coastal zone and human health. Given the diverse nature of these sectors, however, assessment focused on some selected components of the sectors, particularly in agriculture, water resources and human health. For example, within the agricultural sector vulnerability and adaptation focused on two crops only, namely sorghum and barley.

6. Policy Measures and Programs in the Context of Climate Change

Policy measures and programs focusing on climate change related issues are still being developed in Eritrea. Nonetheless, there are several national policies and programs that address environmental issues in its broad sense, and these policies and programs have a direct bearing on climate change issues. These policy measures and programs address, among others, poverty reduction, environmental management, land degradation, marine and coastal environment, environmental impact assessment, conservation and sustainable use of biodiversity, and the transport and energy sectors.

The fact that Eritrea is Party to three international environmental treaties (the UNFCCC, the CBD and the CCD) is a testimony of Eritrea's commitment to join hands with the international community in protecting global environment from further degradation. At the national level national action plans have been completed for biodiversity conservation and its sustainable use and also for combating desertification. National action plan for climate change is being developed.

7. Public Awareness, Education and Training

The importance of public awareness, education and training in promoting the implementation process of the Convention need not be over emphasized. In Eritrea the level of knowledge and understanding about climate change issues, however, is somewhat limited, and this remains a challenge to the government at large and to concerned institutions such as the Ministry of Land, Water and Environment in particular, which is Eritrea's National Focal Point for the UNFCCC. It should however, be recognized that many important steps have been taken by Eritrea in the areas of public awareness, education and training with respect to the judicious use of natural resources for a sustainable use, including the following:

- The public was greatly mobilized during the process of preparing the National Environmental Management Plan for Eritrea. That was a good opportunity for the public to be aware about the decreasing trend of natural resources and hence the need to be vigilant for its proper conservation and use.
- Efforts are being made by concerned institutions to disseminate information about climate change issues and its effects through the radio and the written media.

- The preparation of Eritrea's initial national communications was a good opportunity to make many stakeholders aware about climate change issues.
- Various efforts are being made by relevant institutions, such as the Ministry of Education, Ministry of Land, Water and Environment and the University of Asmara in the areas of education and training, both formal and informal, on environment and climate change issues.

8. Research and Systematic Observation

For historical and political reasons research and systematic observation in Eritrea is extremely weak. Since independence in 1991, however, the Government has made considerable efforts to establish varying numbers of meteorological and hydrological stations at selected sites. Nonetheless, the attributes such as the location, distribution and type of instruments in each of these stations in many cases may not satisfy the requirement for a national observation network.

The establishment of an effective national observation system will require a strong institutional set up, development of human resources capacity in technical, scientific, and managerial aspects, and the introduction of state-of-the-art communication and information technology, which is quite limiting in Eritrea. The country therefore seeks in its endeavor financial and technical assistance from bilateral and multilateral sources.

With respect to research on climate change, hardly any thing could be done unless the present levels of human and institutional capacity, physical infrastructure and technology are upgraded. In the short-term the country plans to embark upon data collection and analysis to address the immediate social and economic development planning of the country. While engaged in the short- term program, an enabling environment for long term advanced research on climate change and the environment should be created.

9. Financial and Capacity Needs

Since Eritrea's main objective is attainment of food security and poverty reduction, adaptation measures to climate change should complement this objective. Nonetheless, the country's financial and capacity needs are quite limited and hence will require financial support and technology transfer from developed country Parties to enable Eritrea to fully participate in the implementation process of the Convention.

10. Implementation

A Core Planning Team, drawn from relevant institutions, has been coordinating the implementation process of the Convention. The Department of Environment of the Ministry of Land, Water and Environment, as the National Focal Point of the UNFCCC coordinates national efforts. There are plans to strengthen further the national coordination efforts by establishing a national climate change secretariat under the Department of Environment.

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LIST OF ACRONYMS

ARI	Upper respiratory infection
ASLR	Accelerated sea level rise
CC	Climate change
CTMRE	Chemical Technology, Marine Resources and Environment
DOC	Degradable Organic Carbon
DoE	Department of Environment
EEA	Eritrean Electric authority
FAO	Food and Agriculture Organization
GCM	Global circulation model
GEF	Global environmental facility
GHG	Green House Gases
GWP	Global worming potential
Ha	Hectare
ICS	Inter-connected System
IMC	Integrated management of cases
IPCC	International Panel on Climate Change
LPG	Liquid petroleum gas
MoA	Ministry of Agriculture
MSW	Municipal Solid Waste
NMVOL	Non-Methane Volatile Organic Compounds
OECD	Organization of Economic Cooperation and Development
OPD	Out patient department
ppm	Parts per million
SCS	Self Contained System
TFES	Total Final Energy Supply
Toe	tones of oil equivalent
UNDP	United Nations Developmental Program
UNEP	United Nations Environmental Program
UNFCCC	United Nations Frame Work Convention on Climate Change

FOREWORD

The international community is increasingly being convinced that climate change is adversely affecting every aspect of our life. Our understanding of these adverse effects is getting deeper and deeper as we read the findings of the International Panel of Climate Change (IPCC), and particularly the Third Assessment Report published by the IPCC, which provided more insight into these changes. The UNFCCC and its Kyoto Protocol are excellent opportunities for providing the legal basis to mitigate the adverse effects of climate change.

It is believed that the industrialized countries are to blame for the build up of greenhouse gases in the atmosphere, which is believed to be the main cause of climate change. This build up of greenhouse gases could have also been exacerbated by the massive destruction of forests worldwide, which could have been used as a storehouse for the CO_2 emitted from industrial sources. The Kyoto Protocol, pursuant to Article 4(2) of the UNFCCC, is nothing more than strengthening the commitments of the industrialized countries to reduce their CO_2 emissions. We firmly believe that these commitments will materialize once the Kyoto Protocol enters into force, which is expected to happen after the Second Earth Summit scheduled to take place in Johannesburg South Africa, in September 2002.

Under the principles of common but differentiated responsibilities, all Parities to the Convention have the responsibility to mitigate the adverse effects of climate change. Eritrea took the common responsibility when it became Party to the UNFCCC on 23 July 1995. Eritrea is one of the least emitters of Co_2 but, nonetheless, the victim of the adverse effects of climate change due to the build up of greenhouse gases concentration in the atmosphere. Moreover, it is one of the most vulnerable countries to the adverse effect of climate change mainly due to its low adaptive capacities. The natural resource base of the country including water and land resources, agriculture, forestry, coastal zone and marine resources are very much affected by climate change. The degradation of these resources base is severely undermining the attainment of sustainable development and poverty reduction objectives, which are the prime objectives of Eritrea. Any adaptation strategy to the adverse effects of climate change should therefore aim to substantially contribute to these objectives, which we believe will require considerable mobilization of financial resource from the developed country Parties.

Eritrea's Initial National Communication under the UNFCCC is undoubtedly the first step forward in attempting to reflect Eritrea's efforts in the mitigation of global climate change, as well as providing some reflections of Eritrea's needs and requirements for allowing the country to implement its commitments under the UNFCCC. Pursuant to Article 4(7) of the UNFCCC, full participation of developing country Parties, including Eritrea, will depend on the financial resources and technology transfer requirements provided by developed country parties, which we believe is being delayed from time to time.

The preparation of our Initial National Communication has created some capacities to enable us to do further reporting requirement under the UNFCCC and undertake some assessment work. Nonetheless, continuous effort will have to be made to strengthen these capacities further.

Finally, but not the least, I seize this opportunity to express my appreciation and thankfulness to all institutions and individuals for the hard work and dedication to produce this document.

Woldemicael Ghebremariam, Minister,
Ministry of Land Water and Environment
December, 2001

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The Department of Environment of the Ministry of Land Water and Environment, as the executing agency the implementation of the Climate Change Enabling Activity Project, has the honor and privilege to express its appreciation and gratitude to the following. The list is not meant to indicate any order of priority.

- UNDP/GEF for financing and implementing the Climate Change Enabling Project, which included inventory of a national greenhouse gases, vulnerability and adaptation assessment on key sectors and the preparation of Eritrea's Initial National Communication.

- The National Core Planning Team (NCPT) members for providing guidance and direction to the implementation process of the Enabling Activity Project. It should be noted that the NCPT is basically established to oversee the implementation process of the UNFCCC at the national level and its members are drawn from relevant government institutions, including the Ministry of Land, Water and Environment, the Ministry of Mines and Energy, the Ministry of Agriculture, the Ministry of Trade and Industry, the Ministry of Fisheries and the University of Asmara (Department of Geography). The contribution of some members of the NCPT, particularly Dr. Semere Habtezion, Director, Division of Energy in the Ministry of Mines and Energy and also Mr. Estifanos Bein, Director, Division of Forestry and Wildlife in the Ministry of Agriculture, in reviewing and editing parts of this document is appreciated.

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The contribution of government institutions and particularly the International Cooperation and Macro-Economic Coordination of the Office of the President in reviewing this document is highly appreciated. Furthermore, we take this opportunity to thank various consultants, including the Center for Energy, Environment, Science and Technology (CEEST) from Tanzania and Chemical Technology and Martine Resources Environment (CTMRE) from Eritrea, for their engagement in the climate change studies and in preparing the initial draft report of this document and in reviewing and editing it further.

CHAPTER 1

INTRODUCTION

Scientific evidence has suggested that the build up of man-caused greenhouse gas (GHG) concentrations in the atmosphere, mainly since the start of the industrial revolution, is creating imbalances in the natural cycle of the earth's climate, popularly known as climate change. The Intergovernmental Panel on Climate Change, in its Third Assessment Report (TAR), has stated that under the business as usual scenario, the current mean air temperature of the earth will increase by $1.5\text{-}3.5^0$ C. It is also reported that the warmest year from 1860 to present record occurred in 1998. Nine of the ten warmest years have occurred since 1990, including 1999, 2000 and 2001. The effect of climate change on the social and economic well being of the world has therefore been the concern of international community for some time now. In this respect the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted at the UNCED in 1992 held in Rio de Janeiro, is the result of the efforts of the international community to mitigate the effects of climate change. The prime objective of the UNFCCC, which entered into force on 21 March 1994, is to stabilize the concentrations of anthropogenic greenhouse gas in the atmosphere and hence to mitigate the effects of climate change thereof. More than 180 States and regional economic integration organizations are Parties to the Convention.

Under the principle of common but differentiated responsibilities, and taking into account specific national circumstances, all Parties of the Convention have the commitment to mitigate the effects of climate change (Article 4). Moreover each Party should communicate information related to the implementation of the Convention (Article 12), best known as the national communications.

Eritrea acceded to the UNFCCC on 24 April 1995, and entry into force for Eritrea was 23 July 1995. Since then Eritrea has been actively participating in the UNFCCC process, although it is the victim rather than the cause for global climate change, given the fact that its GHG emission is almost non-existent as compared to many of the industrialized countries. Nonetheless, being a least developing country, it is one of the most vulnerable countries to the adverse effects of climate change, mainly because of its low adaptive capacities. Eritrea has therefore taken a number of steps to fight back the effects of climate change and hence guide its sustainable development planning process. In this connection Eritrea's initial national communication to the UNFCCC, prepared in accordance with the guidelines of the Non-Annex I national communications, is an attempt to report on the over all climate change situations of the country, including the inventory of national GHG, vulnerability and adaptation assessment studies, education and public awareness and systematic observation and research.

CHAPTER 2

NATIONAL CIRCUMSTANCES

2.1. Geographical Setting

Eritrea is located in the Horn of Africa, lying between 12º 22′, and 18º 02′ north and between 36º 26′ and 43º 13′ east. Sudan borders it in the west, Ethiopia in the south and Djibouti in the southeast, and with the Red Sea in the east.

The country has a total land area of 124, 300 km^2, and a coastline of 1900 km. Eritrea's territorial waters in the Red Sea zone are about 120,000 km^2, stretching out to the Red Sea Central Rift, where the maximum depth is several hundred meters. The territorial waters may be divided into a continental shelf region of around 56,000 km^2, and the rest divided into shallow water region (<30 m depth) and deep-water region (>30 m depth).

2.2. Climatic and agro-ecological zones

In simplistic terms the country could roughly be divided into three physio-graphic regions, namely, the central highlands, the midlands and the lowlands. There are two rainfall regimes, summer and winter, whose pattern is affected by these physiographic regions. The summer rains, which are mainly concentrated in July and August, affect the whole central highland and the western lowlands. The southwesterly monsoon winds are responsible for the main rainy season. The winter rains which occur from November to March and which are brought about by the north and northeasterly continental air streams affect the coastal and the eastern and southern escarpments, which is also part of the central highlands. Amount and patterns of rainfall distribution is presented in Fig. 2.1

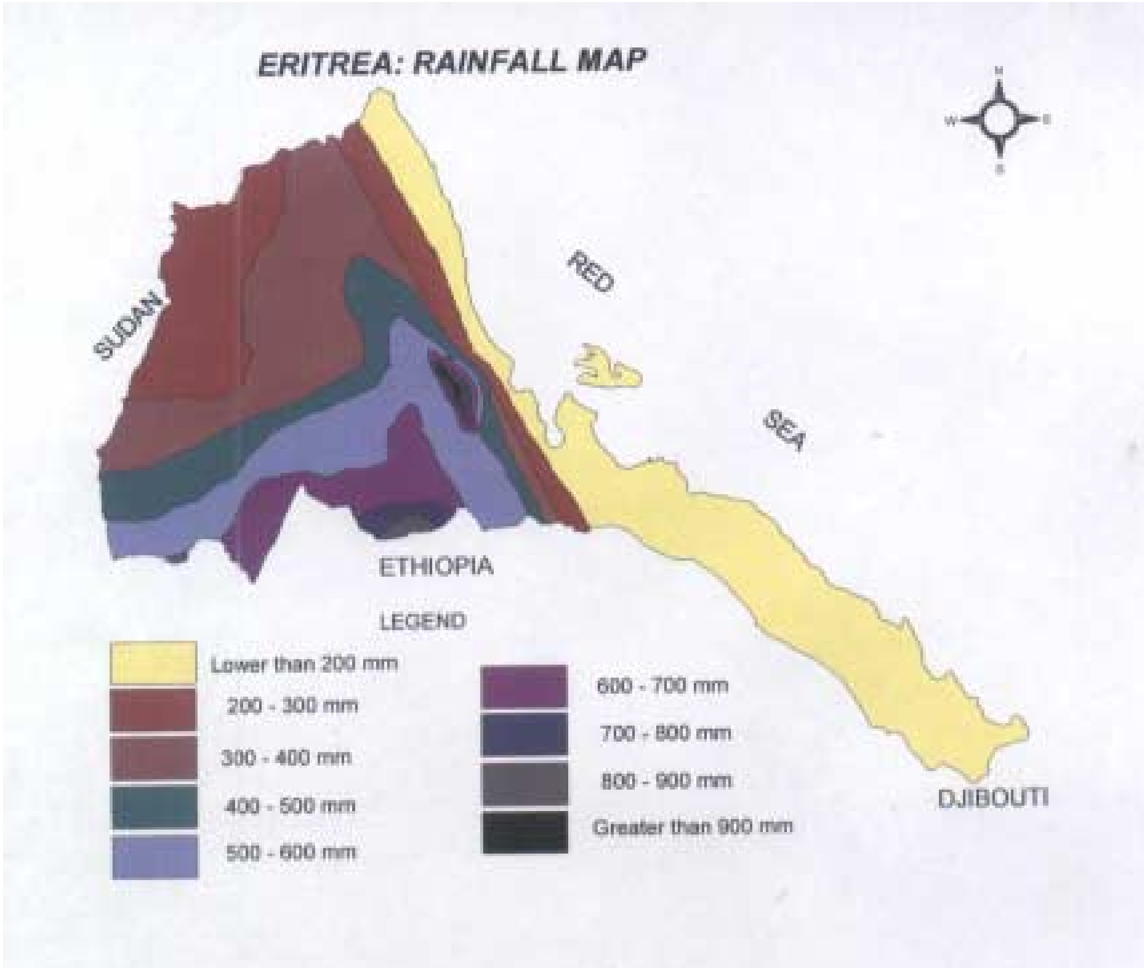

Figure 2.1: Variations in mean annual rainfall of Eritrea

The country has diverse climatic situation ranging from sea level to above 2400 m.a.s.l in the central highlands to temperate sub-humid in isolated micro-catchments within the eastern escarpment. Based on climate and soil parameters six agro-ecological zones exist in the country (Fig.2.2). A summary of these agro-ecological zones is provided in Table 2.1.

Table 2.1 Summary of information on Agro-ecological Zones of Eritrea

Zone	Elevation (m)	Annual rainfall (mm)	Mean annual temperature (°C)
Moist Highland	1600-3018	500-700	15-21
Arid Highland	1600-2820	200-500	15-21
Sub-Humid	600-2625	700-1100	16-27
Moist Lowland	500-1600	500-700	21-28
Arid Lowland	400-1600	200-500	21-29
Semi-Desert	100-1355	<200	24-32

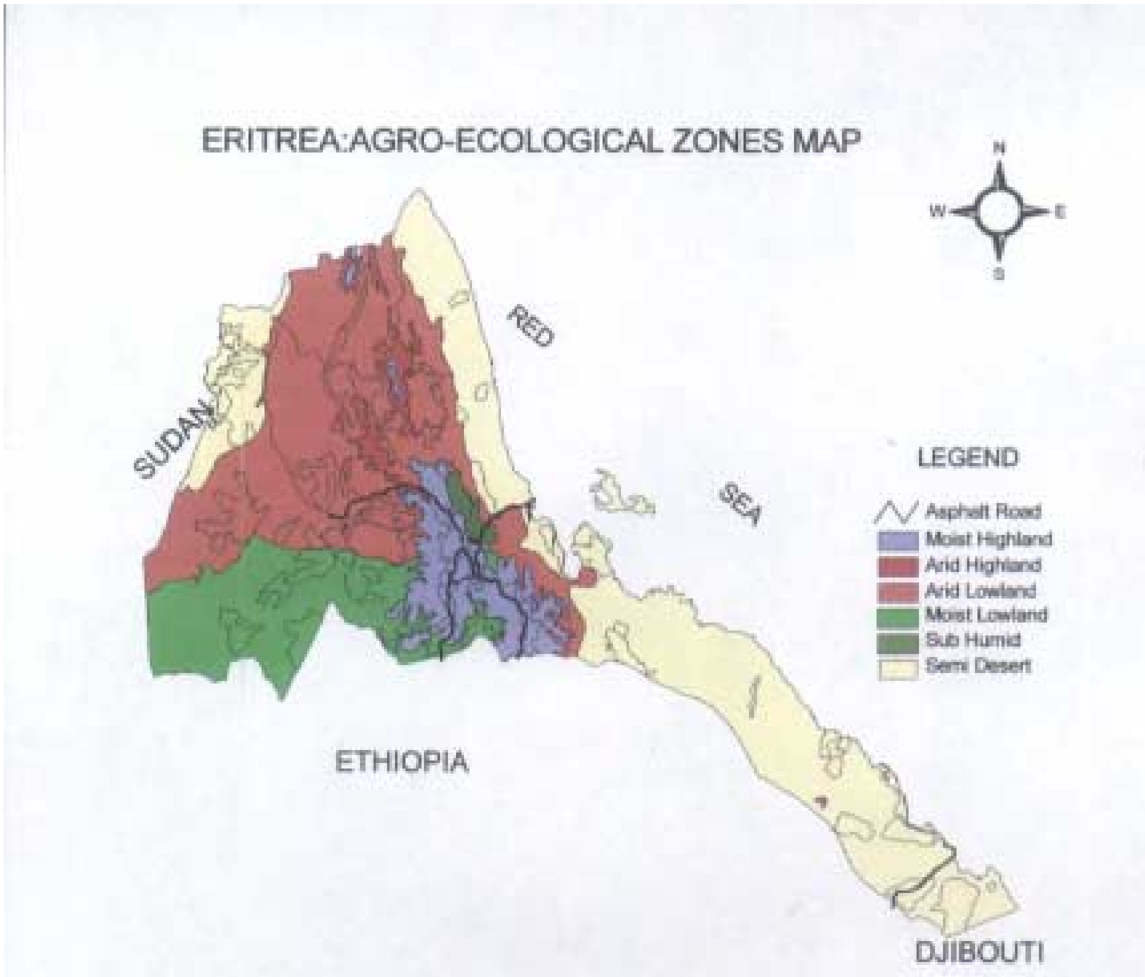

Figure 2.2: Agro-ecological zones of Eritrea

The Moist Highland makes up 7.4% of the total land area of the country. The mild and moist climatic condition coupled with gentle topography and fertile soils have made this zone attractive for settled agriculture under rain -fed conditions. This agro-ecological zone shares 26% of the total annual crop production and 33% of the total cultivated land in the country. On the other hand, the Arid Highland with its relatively smaller amount of rainfall is sparsely populated and cultivated and has a relatively short growing season. This zone covers only 3.4 % of the total land area of the country.

The Sub-Humid Zone, located in the Eastern Escarpment, is a small stretch of land covering only 0.8% of the total land area of the country. This zone gets bi-modal rainfall, one in July-August and the other in November-March. The latter rain is the effect of the winds blowing from the Red Sea and the Indian Ocean to the eastern parts of Eritrea. The remaining forest area of the country, commonly known as the Green Belt Zone, is located in this area. The forest cover ranges from 20% along slopes to 80% in valley bottoms.

The Moist Lowland is located in the southwestern part of Eritrea and particularly in the Upper Mereb Valley, covering an area of about 16.2% of the total land area of the country. This agro-ecological zone has some of the most productive agricultural lands in Eritrea suitable for rain-fed and irrigated agriculture.

The Arid Lowland, occupying a large part of the northwestern lowlands, covers an area of about 34.3 % of the total land area of the country. Nomadic pastoralistsm is the main economic activity in this zone. Due to high evapo-transpiration and limited amount of rainfall crop production hardly exists in this zone.

The Semi-Desert agro-ecological zone occupies a large part of the north-western lowlands and the whole Red Sea coastal plain. This agro-ecological zone makes up 38.8% of the total land area of the country. With mean annual temperature of 24-32 ^{0}C, this zone ranges from hot to very hot climate. In July and August temperatures sometimes reach as high as 48 ^{0}C in many places. Seasonal rivers flowing eastwards are diverted in strategic locations to irrigate agricultural fields, commonly referred to as flood irrigation. Sorghum is a widely cultivated crop in this zone, along with some vegetable production.

2.3. Historical Background

Like all other African countries the formation of Eritrea as a country was the result of European colonialism, which took place at the turn of the 19th century, but its people have a long history that goes back to ancient times. Different peoples had migrated into present-day Eritrea from the Upper Nile Valley, North Africa and later from Southern Arabia over the centuries. These had spread and settled in different parts of the country and intermingled with the inhabitants, slowly giving rise to the present-day linguistic and ethnic composition of the country and spatial distribution of the peoples.

As early as100 to 200 BC, ancient trading posts slowly emerged along the Red Sea Coast and even on the plateau. Important city-states emerged on the Red Sea Coast, including the Port of Adulis and in the central highlands at Kohaito, Tekondae, Metera and Keskese. The presence of ancient settlement ruins, cave paintings, steles and other archaeological artefacts indicate the level of civilization these settlers had reached. The ancient Port City of Adulis was an important centre of ancient civilization with commercial and cultural contacts with the Egyptian, Roman, Persian and Axumite civilizations.

Between the 7th and 13th centuries, new independent political entities of different types also emerged in Eritrea. Starting from the 16th century, however, 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. The Turks, who controlled the coastal areas and parts of the plateau from 1557 to 1872, were replaced by the Egyptians, whose occupation also included the western lowlands. Egypt's rule was, in turn, substituted by Italy by the end of the 19^{th} century during the scramble for Africa.

In 1890, Italy declared Eritrea as its colony. In subsequent years, the Italians demarcated the Eritrean boundaries through treaties with British Sudan, French Djibouti and Ethiopia. During the Italian colonial administration, Eritrea evolved as a single political entity.

After the defeat of the Italians in Second World War, Eritrea was placed under the British military administration. During the British rule (1941-1952), and particularly during the period 1946-48, the Eritrean question, was brought to the attention of the United Nations (UN). First, a commission of inquiry was sent to Eritrea to decide on the future of Eritrea. Nonetheless, since the commission members could not reach an agreement, the Eritrean question was once again brought to the United Nations. In order to annex Eritrea, Ethiopia brought weak historical and cultural arguments and claimed Eritrea as its territory. A five-nation UN Commission of Enquiry was again sent to Eritrea to investigate matters further. Even though the majority of the Eritrean people wanted to be independent, the UN adopted a federal resolution, and pursuant to UN resolution 390(v), Eritrea was federated with Ethiopia. The federal arrangement, which was a sham federation, survived for 12 years (1952-1962), until the Emperor of Ethiopia in 1962 unilaterally abrogated the UN resolution and annexed Eritrea by force. The Eritreans were then faced with the choice of armed struggle for independence, after all means of peaceful settlement was explored, and hence the armed struggle started in 1961.

After 30-year of bitter struggle for independence, the Eritrean people led by the Eritrean People's Liberation Forces (EPLF) liberated the whole country in May 1991. In April 1993, the Eritrean people, under a UN supervised referendum overwhelmingly (99.8%) voted for an independent Eritrea. Eritrea then formally joined the community of nations and became a member of the United Nations on May 28, 1993. It also became a member of the Organization of African Unity (OAU) on 5 June 1993, as the 52^{nd} Member State of the OAU.

2.4. Population

Eritrea has an estimated population of $3.5x10^6$, growing at a rate of about 3 % annually, with an average density of about 28 persons per km^2. More than 80 % of Eritrea's population live in rural areas. Mainly due to suitability of climate about two thirds of the population live in the highlands, which has an altitude above 1500 m.a.s.l.

Despite the fact that Eritrea is small in land area it has diverse ethnic groups. These ethnic groups are divided into nine nationalities, namely, Afar, Bilen, Hedarb, Kunama, Nara, Rashaida, Saho, Tigre and Tigrinya. Tigrinya and Tigre nationalities constitute the majority of the population. Tigrinya, Tigre and Arabic languages are widely spoken languages among the Eritrean population. Eritrea has not yet adopted an official language or languages but it has working languages mainly Tigrinya, Arabic and English.

Eritrea has many of its population in the Diaspora as a result of the 30-year of independence, the majority of whom are in the Sudan and many of these refugees have already started coming back. Resettlement and reintegration of refugees constitutes a very challenging task to the Government.

2.5. Economy

Although Eritrea was once one of the countries with good economic base and prosperous industries, the 30-year liberation war for independence has resulted in the destruction of economic and social infrastructures as well as the loss of skilled manpower. Immediately after independence in 1994, however the Government formulated its economic policy in a Macro-Policy Paper. This policy document encouraged, *inter alia*, private investment in various sectors and the "*establishment of an efficient, outward looking private sector-led market economy, with the government playing a proactive role to stimulate private economic activities…without precluding a well prepared public investment program in strategic sub-sectors"*. Pursuant to this policy the government created opportunities for investments to promote rapid and widely shared economic growth led by the private sector. This has resulted in fast economic growth rate of 7% per year, one of the highest growth rates in Africa. This trend, however, slowed down due to the intensified border conflict with Ethiopia, which started in May 1998.

Agriculture, fisheries, industry, tourism and mining, *inter alia*, play an important role in the economic development of the country. Cognizant of the fact that infrastructure facilities play a crucial role in the development of the above stated sectors, the Government has put much emphasis to develop power generation, transport and communications and the improvement of banking facilities. Some selected physical, economic and social indicators for Eritrea are presented in Table 2.2

Agriculture

Over 80% of Eritrea's population depend for their livelihood on traditional subsistence agriculture, including crop production and livestock husbandry. Eritrea's high variation of climate and topography create favorable conditions for the growth of different cultivated crop plants. Agricultural production, however, is affected by a host of factors including high rainfall variability with recurrent and long drought periods, continuous degradation of the soil, frequent pest outbreaks and lack of research and extension services. Land is almost the sole source of income for a majority of the Eritrean population and its degradation is a serious problem. The annual net soil loss from croplands is estimated at 12 tons/ha, and agricultural production under rain-fed conditions could hardly be determined in any event. Such factors have caused productivity to be less than 0.7 tons/ha for many crops. It is estimated that 16 % of the total land area is arable of which only a quarter is actually cultivated. Agriculture on the average accounted for about 19 % of the GDP for the period 1992-1997, suggesting both its undeveloped nature and its low productivity.

In order to increase the role of the agricultural sector in the growth and development of the country, the idea is to intensify agricultural production in areas of good soil and with reasonable rainfall. Moreover, there are opportunities to construct bigger dams for irrigation purposes in strategic locations but due to technical and financial limitations it was not possible to implement such bigger undertakings. Furthermore, there are also plans to modernize the agricultural sector, through the development of irrigated agriculture, by utilizing underground water resources. Nonetheless, caution should always be exercised in the exploitation of ground water resources, as this capacity is not known accurately. There are clear indications that some wells used for irrigation purposes are getting saline or getting depleted due to over exploitation. Given the long period of time required to replenish ground water, caution is called for planning ambitious irrigation projects. UNEP estimates that about 1400 years is required to replenish depleted aquifers.

Marine and Coastal Resources

The marine and coastal resources, particularly fisheries, are recognized as one of the very important areas, which could have a very crucial role in the economic development of the country. Having 1900 km of coastline, Eritrea has a very high potential not only to exploit its fish and other marine resources but also has an excellent opportunity to develop its tourist industry. The Eritrean Red Sea and coastal beaches remain relatively pristine due to lack of pressure from fishing, tourism and coastal or offshore industrial development.

Eritrea has the potential to sustainably harvest around 70,000 tones of fish annually, but nonetheless the current fish catch is currently known to be around 13,000 metric tones per year. There are plans to expand this rate to higher levels as a means of increasing both local revenue and foreign exchange. Nonetheless, careful planning is required not to exceed exploitation levels beyond its maximum allowable yields. The growing demand for ornamental fish by aquarium market has produced a lucrative market for collectors, and a frenzy hunt for these species that command high price in this market could easily lead to serious stock depletion and even extinction. The use of small nets by many fishermen either due to inadequate control or due to lack of technological options is also something that will require closer monitoring. Experiences in other countries have shown that over fishing has caused the near collapse of certain species, the heavy loss of income, followed by unemployment in the fishing sector.

Since Eritrean Red Sea zone has many endemic marine and coastal species, the conservation of marine and coastal biodiversity for a sustainable use poses a challenge not only for Eritrea but also to the international community. There are about 500 fishes and 44 genera of hard corals recorded by recent surveys and the Eritrean coast is inhabited by up to 5 marine turtles, 8 or more cetaceans and the dugong-almost all of these species are of conservation concern globally. The level of endemism for fish as a whole are around 18 %, but extend to more than 50 % for some fish groups (e.g. butterfly fish). Mangrove trees are also important coastal plants, which contribute to the maintenance of coastal ecology in many ways, including the protection against wave erosion and the provision of soil organic matter formation and act as a wildlife habitat and nursery for many marine species. Timber extraction for various purposes, like fuel wood, construction of boats and over browsing by camels have been the main causes of mangrove degradation.

Mining

Eritrea is also believed to have good potential of minerals including gold, copper, potash, silver, marble, oil and natural gas. Some companies have been given concessions in different parts of the country for petroleum, gas and gold explorations. The potential of gold, petroleum and gas is believed to be high. Mining is believed to have good prospects in contributing to the economic development of the country.

Table 2.2 Important physical, social and economic indicators for Eritrea in 1994.

Item	Indicator
Population (millions)	3.5
Land surface area (‘000 Km^2)	124.3
Territorial water area (‘000 Km^2)	120.0
GDP (US$)	469.6
GDP per capita (US$)	200.00
Share of industry in GDP (%)	16.00
Share of agriculture in GDP (%)	19.0
Share of mining and Quarrying in GDP (%)	1.50
Share of services Sector in GDP (%)	63.5
Arable land (‘000 hac)	2089.00
Land under cultivation (‘000 hac)	362.968
Urban population (% of total population)	17.70
Grazing land (million hectares)	5.985
Other land (million hectares)	4.031
Livestock population : Cattle (millions)	1.927457
Camel ('000)	318.314
Sheep and Goats (millions)	7.5
Forest area (% of the total land area)	0.43
Incidence of poverty (% of population)	69.00
Life expectancy (years)	51.10
Literacy rate (percentage)	75.00

Industry and Trade

The development of industry in Eritrea goes back to the Italian colonial period (1890-1941). During the Italian colonial rule industrial development, coupled with road construction activities, showed a very rapid growth and Eritrea soon became one of the industrial countries in Africa. During the British administration (1941-1952), however, the industrial sector was hampered from the lack of investment and thereafter the imposition of inappropriate economic policy by the Ethiopian administration retarded economic development in general and industrial progress in particular.

Eritrea’s industrial base is made up of primarily small and medium scale industries and the technology remained largely outdated because of neglect and lack of investment during the thirty years war of independence. Efforts made after independence to revive the industrial sector has made it to be one of the important sectors of the national economy both in terms of employment and contribution to GDP. The share of industry in GDP has increased from 12 % in 1992 to 19.5 in 1999.

Table 2.3 illustrates some of the progress made between 1992-1998 and it can be seen that there has been a substantial progress made in the number of enterprises, gross output and value added. For example gross output more than doubled between 1992 and 1998.

Table 2.3 Progress made in the industrial sector, 1992-1998

	1992	1993	1994	1995	1996	1997	1998
Number of establishment (employing more than 10 people)	116	121	131	138	157	205	223
Number of employees	12,748	14,854	14,977	14,198	13,798	15,151	15,424
Gross out put ('000 US$)	58147	71744	81934	107666	128073	145710	153042
Value added to market prices ('000 US$)	36279	37191	38824	54107	53558	57887	56100

Source: Ministry of Trade and Industry, Department of Industry, 2000.

Trade also plays an important role in the economic development of the national economy but progress made in other facilitating sectors, such as transport and communications and banking largely determines the extent to which trade is promoted. In this respect considerable progress has been made to construct and improve land, sea and air transportation facilities and in modernizing the telecommunication services. Moreover, to encourage trade, efforts were made to gradually eliminate tariff and non-tariff barriers and the easing of licensing procedures. The provision of licenses is organized under a "One stop shop" licensing system for ease of investment.

Energy

The energy balance for Eritrea is dominated by the use of biomass fuels (Fig.2.3). The energy balance for 1996 (no similar data exists for 1994) indicated that 77.3% of the Total Final Energy Supply (TFES), amounting to 38,905 TJ, was covered from biomass, 21.3 % from oil products (primarily petroleum) and 1.4 % from electricity. The constituents of biomass were firewood, charcoal, dung, and agricultural residue, accounting for 76 %, 11.6 %, 10.4 % and 2% respectively (Fig. 2.4). The total biomass consumption in 1996 was estimated to be 715,667 tons. Out of the TFES consumed the household, the transport, the public and commercial and the industrial sectors consumed 77.8 %, 14.9 %, 4.8 %, 2.4 % and 0.1 % respectively. Of the Total Primary Energy Supply (TPES), i.e. 51,157 TJ, biomass accounted for 75.5% and oil products 24.5%.

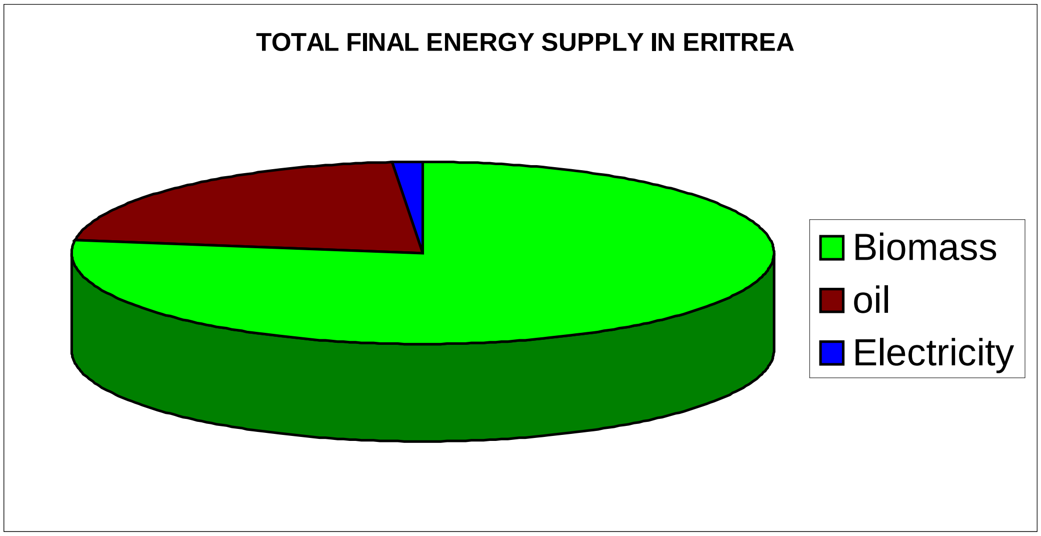

Figure 2 3: Total Final Energy Supply

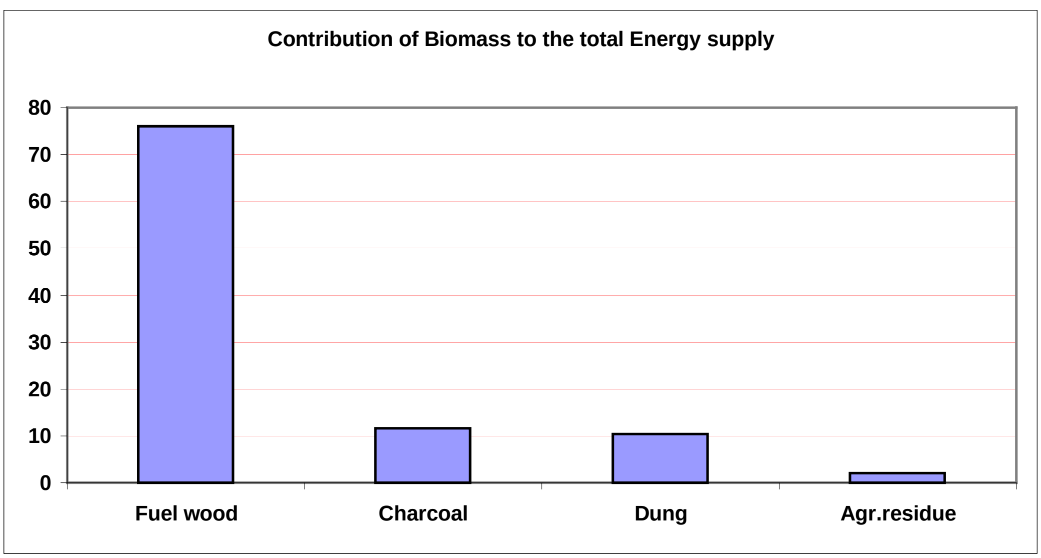

Figure 2.4: Contribution of Biomass to Total Energy

The consumption of petroleum products for electricity purposes has been increasing, which corresponds to an average electricity generation efficiency of 36.7%. Electricity generation capacity has also increased from 35 MW in 1991 to over 150 MW by the end of 2001.

Of the total final supply of oil products amounting to 8297 TJ or 197,119 tones, 70.1% was consumed in the transport sector, 11.1% in house hold, 10.8% in public and commercial, 7.6% in industry and 0.4% in agriculture use. All petroleum requirements of the country is imported.

CHAPTER 3

NATIONAL INVENTORY OF GREENHOUSE GASES (GHG)

3.1 Introduction

Eritrea's inventory of greenhouse gases (GHG) was conducted using the revised 1996 IPCC guideline. The inventory of GHG emissions by sources and the removals by sinks was carried out, taking 1994 as the base year, for Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Carbon Monoxide (CO), Nitrogen Oxides (NO_x) and Non-Methane Volatile Compounds (NMVOCs). CO_2, CH_4 and N_2O are the major GHG emissions in Eritrea. The inventory addressed six sectors, namely, energy, transport, industry, agriculture, land use change and forestry and municipal solid waste.

3.2 Energy Sector

Like most developing countries, Eritrea heavily depends on biomass sources of energy. According to a national energy survey carried out, taking into account 1995 as the base year, the energy balance showed that 77.3 % was from biomass and the rest covered by oil products and electricity, accounting for 21.3 % and 1.4 % respectively[1]. In 1994 the total CO_2 emitted from biomass as source of energy was 2006.3 Gg. To avoid double counting this has been considered as part of the emission from land use change and forestry (LUCF), which will be discussed subsequently.

The heavy dependence on biomass fuel has created a number of problems, including the following:-

- Fuel wood collection and illegal charcoal making aggravates deforestation and associated problems like soil erosion and land degradation.
- Diversion of animal and crop residues to energy use deprives the soil of its organic nutrients sources and reduces its productivity.
- The emission of smoke and other toxic materials from biomass burning in poorly ventilated houses poses health hazards to women and children, and much time and effort is spent on biomass fuel collection as its source dwindles.

[1] Another survey for 1998 by the Department of Energy showed that the dependence of biomass decreased to 65.8 %, oil products and electricity increased to 33.1 % and t0 2.1 respectively.

Nonetheless, efforts are being made by the Government to change this situation. Table 3.1 shows that the share of biomass energy consumption fell by 30 % between 1994 and 1998. This decrease is attributed partly to the introduction of regulations that banned the cutting of live trees for fuel, the prohibition of charcoal making and the growing area coverage of declared closures, which has restrained access to fuel wood. Secondly, these conditions have led to shift to other sources of energy, such as kerosene and LPG. Moreover, research and dissemination activities are underway to increase the efficiency of traditional stoves whenever biomass is used as a source of energy.

Table 3.1 Biomass Energy Consumption 1994-2000 ('000 tons)

Type of Fuel	1994	1995[1]	1996	1997	1998[2]	1999 (estimat)	2000 (estimat)
Fuel wood	1292.4	1334.2	1375.3	1418.2	830.7	855.6	881.2
Charcoal	31.4	32.4	34.5	35.7	18.6	19.2	18.4
Agricultural residues	47.3	48.8	50.3	52.1	90.8	93.5	96.3
Dung	360.0	371.3	382.7	394.4	265.4	273.3	281.8
Total	1733.1	1786.7	1842.8	1900.4	1205.5	1241.6	1277.7

1 Based on the 1995 survey (Lahmeyer, 1997) the figures for 1994,1996 and 1997 were extrapolated.
2 Based on the 1998 survey (Department of Energy, 1998) the figures for 1999 and 2000 were extrapolated.

Petroleum products are the second major source of energy. The consumption of oil products increased from 185,000 tons in 1994 to 205,000 tons in 2000, showing an increase of about 11 %.

As indicated earlier the share of electricity in the energy sector is just around 2%. Between 1992 and 2000 there was an average annual growth rate of 8% for the generation of electricity while consumption increased by 7%. Electricity supply is concentrated in the urban areas and only 2% of the rural population is estimated to have access to electricity. This shows that there is a formidable task required to supply modern energy to the rural areas, although per capita electricity consumption grew from 16 kWh in 1991 to about 50 kWh in 2000. The Government is making considerable effort to promote alternative sources of energy to rural areas, e.g. by promoting the use of cost effective renewable energy technologies (RETs). To date some RETs, like photovoltaic for example, have been introduced mostly limited to some welfare-focused applications like powering remote schools, health centers and village water pumps. Up to now about 500 kW solar PV systems have been installed. The potentials of other renewable energy resources like modern bio-fuels, geothermal, micro-, mini-, and small hydropower are not conclusively studied and developed.

The dominant mode of transport in Eritrea is road transport, and in terms of energy consumption the road transport is the highest consumer of fuel products. Between 1993 and 1997 the consumption of petroleum products increased by 10% per year. This is attributed mainly to the increase of vehicles by an average of about 23 % annually between 1992-1998. In 1994 the total CO_2 emitted from the road transport was about 283 Gg.

Emission of GHG from the energy sector was estimated on a mass balance basis using information of the amount of carbon content of the fuels consumed. Total CO_2 emissions from the combustion of fuel oil products, excluding international bunkers, was 687.5 Gg in 1994, as shown in Table 3.1, indicating per capita CO_2 emissions of 0.21 tons/year.

Of the total 1994 GHG emissions from fossil fuel combustion, the transport sector accounts for 41 %, energy industry 35 %, public and commercial 10 % and the manufacturing and the residential sectors each account for 7 %, as shown in Fig. 3.1

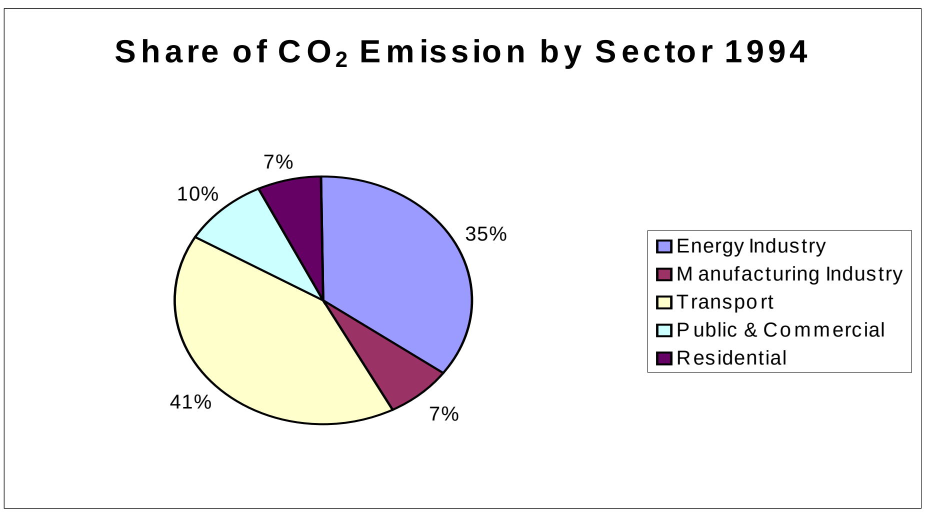

Figure 3.1: Share of CO_2 Emissions by Sectors, 1994

A comparison of CO_2 emission from fossil fuel combustion between the sector approach, and the reference approach, for the period 1994-2000, is provided in Table 3.2 and in Table 3.3. From 1994-1997 the reference approach was greater than the sector approach. This is due to the statistical difference between crude imported, refined and consumed amount of refined oil. Since 1998, however, Eritrea imported only refined oil products and whatever imported was assumed to be consumed, and hence both the reference approach and sector approach converged towards each other, as shown in Tables 3.2 and 3.3.

Table 3.2 CO_2 Emissions (Gg) from fossil fuel Combustion 1994-2000 (Sector approach)

Year	1994	1995	1996	1997	1998	1999	2000
Energy industry	240.90	250.42	258.01	160.96	127.07	138.09	140.73
Manufacturing industry	49.83	54.32	46.78	49.16	36.56	44.38	36.63
Transport	282.92	326.29	365.12	354.39	222.07	203.33	198.74
Public & commercial	66.31	62.57	91.56	97.88	128.34	162.77	155.29
Residential	47.54	58.42	66.37	69.86	62.06	66.68	68.88
Total	687.50	752.02	827.84	732.24	576.11	615.26	600.27

Table 3.3 Comparison of the reference and sectoral approaches of CO_2 emissions (Gg)

Year	1994	1995	1996	1997	1998	1999	2000
Reference approach	741.91	829.49	919.27	793.07	584.81	617.16	601.54
Sectoral approach	687.50	752.02	827.84	732.24	576.11	615.26	600.27

3.3 Industrial Processes

Modern industrial sector in Eritrea is just emerging. Most of the existing industries are small to medium scale manufacturing industries, including food, beverages, tobacco, textile, leather, wood and printing. These industries collectively account for about 7% of the oil products and around 40% of all electricity consumption in 1994. The total CO_2 emitted from industrial processes was estimated at 32.3 Gg in 1994.

3.4 Agriculture

Agriculture is the primary economic stay of the country involving more than 80% of the population. Eritrea is home to a wide variety of crops and livestock, including sorghum, barley, wheat, taff, chickpea, millet, cattle, sheep, goat, camel, donkey and poultry.

In the agricultural sector attempts were made to estimate GHG emissions in 1994 as follows:

CH_4 emission from enteric fermentation of livestock and manure management in 1994 was estimated to be 65 Gg, i.e. about 63 Gg for enteric fermentation and 2 Gg for manure management. N_2O emissions from manure management were estimated to be 0.00034Gg in 1994, which is negligible and hence was not included in this report.

The N_2O emission from agricultural soils in 1994 was estimated to be 0.0193 Gg. These include direct N_2O emissions from agricultural fields, grazing animals and indirect N_2O emissions from atmospheric deposition of NH_3 and NO_2 and leading/run off. N_2O emissions from agricultural fields are mostly from nitrogen fertilizers and mineralized cultivated soils.

With respect to prescribed burning of savannas the non-CO_2 emissions are mainly CH_4 and NO_x, being 0.45 and 0.2 Gg respectively for 1994. Savannah burning frequently occurs during the dry season in the western lowlands and about 65,612 ha of arid savannah land had been burnt in 1994.

In the Eritrean context burning of agricultural residues in the field is almost non-existent, mainly because agricultural residues are used for animal feed and fuel. Thus non- CO_2 emission from burning of agricultural residues has been ignored.

3.5 Land Use Change and Forestry (LUCF)

According to FAO report (FAO, 1997) of the total land area of the country 0.8 % was covered by forest, 11.3 % was woodland, 63.8 % bush land and grassland, and 1.6% was covered by riverine and mangrove forests. The land covered by bushes and grasses, however, has to be taken cautiously, mainly because during the long dry season die away and a vast tract of land is exposed to wind erosion as well as to soil erosion at the beginning of the rainy season. Although agricultural activities and/or other types of land use occupy probably around 20 %, the rate of conversion of forestland into agricultural land or any land use change has not been properly documented. Nonetheless, attempts were made to assemble different sources of information in order to estimate changes of land use and forestry, and the consequential CO_2 emissions and removal by sinks.

Due to information limitations only two sub-sectors, namely, (1) changes in forest and other woody bio-mass stocks and (2) grassland and forest conversions to agricultural fields are treated for estimating CO_2 emissions and removals by sinks for 1994, as summarized in Table 3.4.

From Table 3.4 it can be argued that the LUCF sector in Eritrea was a net contributor of emission to the atmosphere rather than being a sink of CO_2. This was the situation of 1994, when the forest cover of Eritrea was believed to be less than 1% of the total land area of the country. Nonetheless, the current forest cover of the country is believed to be improving and is estimated to be 2.4 % of the total land area of the country. In light of this situation one may be optimistic that the LUCF, as it stands now, could be a sink of CO_2 rather than being a source of emission to the atmosphere.

Table 3.4 CO_2 Emissions and removals from LUCF (Gg) -1994

	CO_2 (Gg)		
Activity	Removals	Emissions	Balance
1. Annual growth increment (removals	-1073.12		
2. Annual harvests, including fuel wood gathering		+2730	
3. Annual emissions from changes in forest and other woody biomass stocks		+19.31	
4. Total annual emissions from land use change and forestry			+1676
Total	-1073.12	2749.31	1676

3.6 Solid Municipal Waste

In the waste sector only methane emissions from the partially managed municipal solid waste (MSW) disposal site from the City of Asmara has been estimated. All other cities in the country have open dumps and thus CH_4 emission is negligible. The annual generation of solid waste, the fraction of solid waste- land filled and the estimated CH_4 thereof are presented in Table 3.5. It is estimated that food wastes, paper, plastic and textiles constitute most of the MSW, accounting for about 52 %, 13 % and 6 % of the MSW respectively.

It should be noted that the Asmara landfill site has been approximated to fulfill 70 % of the requirements of a sanitary landfill (or 100 % anaerobic decomposition). This is to say that 30 % of the municipal waste in Asmara is open to aerobic decomposition where the emission is CO_2 and not CH_4.

Table 3.5 Annual Municipal Solid Waste (MSW) Generated, Fraction of MSW Land Filled ("000 tons), and CH_4 Emissions from Asmara Landfill, 1994-2000.

Year	Annual MSW Generated	Fraction of MSW Land filled	Total CH_4 Emission (Gg) from Annual MSW Generated	Fraction of CH_4 Emission (Gg) from Land filled MSW
1994	79.3	47.6	3.67	2.57
1995	83.8	50.3	3.87	2.71
1996	88.6	62.0	4.77	3.34
1997	95.0	76.0	5.85	4.10
1998	102.6	82.1	6.32	4.42
1999	110.8	88.8	6.82	4.77
2000	119.7	95.8	7.38	5.17

Table 3.6 Summary Report for National GHG Inventories (Gg)-1994

GREENHOUSE GAS SOURCE	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
Total National Emissions	2396.1	73.8	6.02	0.3	126.55	13.6
1. Energy	SUTKR	SKO	SKM	MKN	NNQKS	NPKS
A. Fuel Combustion (Sectoral Approach)						
1. Energy Industries	OQMKV	MKM	MKS	MKM	MKVR	MKMO
2.Manufacturing Industries	QVKU	MKM	MKN	MKM	MKMN	M
3. Road Transport	OUOKV	MKM	PKM	MKM	TKRN	NKQR
4. Public and commercial	SSKP	MKO	MKO	MKM	PKTN	MKPU
5.Residential	QTKR	SKM	OKN	MKN	NMPKPT	NNKTU
B. Fugitive Emissions from Fuels	0	0		0	0	
1. Solid Fuels		0				
2. Oil and Natural Gas		0		0	0	

2. Industrial Processes	32.3	0	0	0	0	3
A. Mineral Products	32.34				0	3
B. Chemical Industry	0					
C. Metal Production	0					
D. Other Production	0			0	0	0
3. Solvent and Other Product Use	N.E	N.E	N.E	N.E	N.E	N.E
4. Agriculture	N.O	65.00	0.02		11.9	
A. Enteric Fermentation		63.00				
B. Manure Management		2.00				
C. Rice Cultivation		N.O				
D. Agricultural Soils		N.A	0.02			
E. Prescribed Burning of Savannas		0.45		0.2	11.9	
F. Field Burning of Agricultural Residues		N.E				
5. Land-Use Change & Forestry (LUCF)	1676.3	0.00	0.00	0.00		0.00
A. Changes in Forest and Other Woody Biomass Stocks	1657					
B. Forest and Grassland Conversion	19.3					
C. Abandonment of Managed Lands	N.A					
6. Waste		2.57	0	0	0	0
A. Solid Waste Disposal on Land		2.57				
B. Wastewater Handling		0	0			
C. Waste Incineration						
CO_2 Emissions from Woody Biomass	2006.3					

Note: N.A- Not available
N.E- Not Estimated
N.O- Not occurring

3.7 Trends of Emissions

The absolute emissions of GHG from the various sectors, taking 1994, as the base year, are provided in Table 3.7. It can be seen from Table 3.7 that the major share of GHG, primarily $CO_{2,}$ is from LUCF, accounting for about 70 % of the total absolute CO_2 emissions. This is followed by energy use from fuel combustion, which accounts for 29 % of the total absolute emission of CO_2.

It is a commonly acknowledged fact that GHG differ in their capacities to trapping heat in the atmosphere and hence in their warming potential to global warming (GWP). For example NO_2 is much more effective than CH_4.

The aggregated GHG emissions for Eritrea using the IPCC 1995 GWP factors in 100 years horizon for the year 1994, is presented in Table 3.7, taking the GWP for CO_2, CH_4 and N_2O to be 1, 21 and 310 respectively. The resultant GHG emissions in Eritrea therefore amounted to 7271 Gg CO_2 equivalent in 1994. In this context Eritrea's source of GHG emission, by sector, mainly comes from fossil fuel combustion, LUCF and agriculture, accounting for about 57 %, 23 % and 18.8 % respectively of total CO_2 equivalents. When viewed by gases, CH_4, CO_2 and NO_2 are the main pollutants, accounting for 41.4 %, 33 % and 25.6 % respectively.

Table 3.7 Emissions / Removals in Absolute Values (Gg) and Aggregated Emissions in CO_2 Equivalent Emissions (Gg)-1994

GHG Sources	Emissions in Absolute Values (Gg)			CO_2- Equivalent Emissions				%
	CO2	CH_4	N_2O	CO_2	CH_4	N_2O	Aggregated Emissions	
Fuel Combustion	688	76	6	688	1596	1860	4144	57
Industrial process	32	-	-	32	-	-	32	0.4
Agriculture	-	65	-	-	1365	-	1365	18.8
Total emissions from LUCF	1676	-	-	1676	-	-	1676	23
Waste		2.57	-		54	-	54	0.7
Total Emission	2396	144	6	2396	3015	1860	7271	
%				33	41.4	25.6	100	99.9

3.8 Limitations of the GHG Inventory

One of the limitations of the GHG inventory was lack of country-specific emission factors and emission ratios. Hence in the absence of such national established values, IPCC factors and emission rations, sought to be relevant to our situation, were adopted. The adoption of such *de fault* values has its limitations and may not fully reflect the objective realities of the country. It is therefore strongly advised that future endeavors of national inventory of GHG emission consider the development of national emission factors and emission rations. It should also be noted that lack of data was much more limiting in the agricultural and LUCF sectors than in the energy and industrial process sectors.

CHAPTER 4

GREENHOUSE GAS (GHG) MITIGATION OPTIONS

4.1. Overview

Eritrea being a developing country and also a member of the least developed countries (LDCs) of the world, the achievement of food security and poverty reduction and/or alleviation remain the preoccupation of the country. For this reason Government policies reflect these concerns at all times. As can be seen from Eritrea's inventory of GHG emissions, the country is among the least emitters of GHG and therefore Eritrea has been the victim of the consequences of the adverse effects of climate change caused by the build up of GHG in the atmosphere. In pursuance of fulfilling its commitments under the Convention the strategy to be adopted therefore is adaptation rather than mitigation options. Nonetheless, whenever any mitigation option is found to promote its sustainable development objectives it will be explored.

Emissions in Eritrea mainly originate from LUCF and the consumption of fossil fuel in the energy and the transport sectors. Mitigation options would then focus on these sectors for promoting sustainable development objectives of the country.

4.2. Mitigation Options in the Forestry Sector

Land degradation including deforestation, loss of biodiversity and habitat loss still remain the most serious environmental problems in the country. The scale of impact of land degradation on the social and economic well being on the Eritrean population is incalculable. Since the majority of the Eritrean population depends on biomass fuel as source of energy, shortage of fuel wood, for example, is one of the most visible problems. For enhancing sustainable agricultural production, while at the same time solving critical environmental problems of land degradation, the following options are being pursued by Eritrea:

1. **Afforestation:** Afforestation activities in deforested lands constitute a very important element in the overall national programs and activities of relevant government institutions, such as the Ministry of Agriculture, the Ministry of Local Government and the Ministry of Land Water and Environment. Since 1991, more than 56 million seedlings of different species have been planted in deforested lands, covering an area of more than 16,000 ha of land. The major problem encountered in tree planting is lack of rainfall, which greatly affects survival rate and establishment of newly planted tree seedlings. The emphasis

of tree planting is now based on indigenous tree species rather than on exotic species, as was the case in the past with eucalyptus species.

2. **Soil and Water Conservation Activities**: Deforestation, burning of grassland, rampant soil and water erosion, are leading to ecological degradation and habitat loss. This phenomenon drastically affects the soils capacity to store carbon, and in effect undermining sustainable agricultural production. The overriding objectives of the country, i.e. the achievement of food security and poverty reduction could not be achieved unless the problem of land degradation is solved. Cognizant of this fact the Government is making considerable efforts to mobilize its meager resources to tackle this problem. In this connection, high school students have regularly been mobilized to undertake terracing activities during summer since 1994. Under this program more than 75,772 km of terraces have been built for soil and water conservation purposes. These include cropland and hillside terracing. Figure 4.1 is an example that illustrates the various soil and water conservation and tree planting activities being carried out in the country.

Figure 4.1: Typical example of terracing for soil and water conservation and tree planting activities.

3. **Expansion of Closure System:** Although a closure system is a traditional way of land recovery, it is now widely introduced and practiced in the country as a means of fighting land degradation. The closure system is usually divided into temporary and permanent closures. The temporary closure system is more of traditional and is practiced by many villages in the central highlands for preserving grass for their cattle during the dry season. It is the permanent type of closure, which is now practiced. Under the permanent type of closure a land is delineated and is excluded from any human or animal activities for an extended period of years, usually more than 10 years, for allowing the regeneration of natural vegetation. This system has proven to be not only cost-effective but also is very productive in terms of restoring degraded ecosystems. Currently there are more than 200,000.00 ha of land brought under the closure system. In many closure areas it is encouraging to see the re growth of natural vegetation and the coming back of some wildlife species, which were believed to be lost forever.

4. **Protection of Existing Natural Forest**: Eritrea's remaining thick forest area is mainly located in the Eastern Escarpment overlooking the coastal plains of the country. This area gets bimodal rainfall, i.e. June to September and November to March. Moreover, there are riverine and mangrove forests, which are under threat of deforestation for agricultural expansion. As has been indicated earlier Eritrea's current forest area is estimated to constitute only about 2.4 % of the total land area of the country. To protect the remaining forests, efforts are being made to develop management plans. Thus far "The Management Plan of Riverine Forest of the Western Lowland" has been prepared and efforts are being made to develop forest management plan for the "Green Belt Integrated and Sustainable Forest Resource Management". Capacity limitations, including financial and legal, remain one of the major bottlenecks to prepare and implement such management plans.

4.3. Mitigation Options in the Energy Sector

Mitigation options in the energy sector may be viewed in terms of short- and long strategies. Over the short term period energy efficiency improvements and the use of small- scale renewable energy alternatives will be pursued, while in the long-term efforts will be made to introduce new power supply and advanced renewable technologies. In this respect the mitigation options that may be pursued are summarized under Table 4.1.

In the pursuance of increasing energy efficiency and the introduction of sustainable energy supply it is worth mentioning some of the activities and achievements, which in practice Eritrea is making in its mitigation efforts.

1. **Increasing Energy Efficiency**: The Eritrean Electric Authority (EEA) has made considerable progress in its efforts to increase the electricity generation capacity. It has increased the capacity from 35 MW in 1991 to over 70 MW by the end of 1996. With the commissioning of the Hirgigo Power Supply Project the capacity has been boosted by a further 84 MW by the end of 2001. The new generation facility is to consume around 170 grams of heavy fuel oil per kWh of electricity generated as compared to the average consumption of around 220 grams of diesel or light fuel oil. If we estimate the generation for 2002 to be around 300 GWh, the new generation facility will reduce CO_2 emissions by around 45,000 tones in that year.

To make the power systems more efficient and to promote energy conservation measures, feasibility studies of major projects to rehabilitate the old transmission and distribution systems in Asmara and Massawa have been finalized. The Massawa project has already entered in the implementation process while that of Asmara will start some time in 2002. When finalized, the current technical losses of 20% in transmission and distribution system will be reduced by at least 50% of the current loss. Assuming that oil fired stations produce about 0.7 ton of CO_2/MWh generated, this reduction in technical loses implies CO_2 abatement of 21,000 tons/year.

2. **Increasing Efficiency of Traditional Stoves**: To tackle the prevalent household energy problems, a program to disseminate improved traditional wood-stoves has been launched and the supply and distribution of kerosene and LPG has been expanded. Note that the improved stoves have around 21% efficiencies as demonstrated experimentally, while the traditional stoves are less than 10% efficient. Simple calculations made suggest that the CO_2 reduction potential per improved stove is 0.6 tons per year.

3. **Renewable Energy Sources**:

   (a) Wind Energy: National wind and solar energy assessment study is in progress from 25 stations installed for this purpose. Feasibility study of wind energy applications has been finalized in the southern coastal areas of Eritrea. A project document for Wind Park to feed the Port City of Asseb grid and many decentralized stand alone or wind hybrid systems in the small towns and villages in the area have been prepared. Fund soliciting is also in progress.

   (b) Solar PV: Many solar PV systems with an aggregate capacity of over 500 kW have been installed in the rural areas. Among these installations are 25 for health centers, 60 water pumps, 70 school lights and power supply, general communication purposes, light houses and powering remote offices. Around

1.6 ton of CO_2 is abated for each kW of renewable energy technologies (RETs) installed.

It should be noted that in connection with the above improvements in energy efficiency and the introduction of sustainable energy supplies there is an Energy Research and Training Center under the Ministry of Energy and Mines of the State of Eritrea. This Center was established in 1996 with the purpose to undertake research activities on renewable energy resources and technologies and improvement of traditional cooking stoves. Moreover, the Center is also involved in the installations, repair and maintenance of (RETs), training of technicians and extension activities.

For proper management of energy resources, formulation of energy laws and regulations and setting up of standards are critical, in which case Eritrea is making all the necessary efforts for their establishment. Moreover, the Government intends to reform and deregulate the sector and avoid any form of subsidy. This is believed to encourage competition and efficient use of energy, promote private investment and ensure public safety.

Table 4.1 Summary of Mitigation Options in the Energy Service Sector (for residential and commercial purposes)

Activity	Mitigation Option
Cooking	Introduction of bio-digesters, solar heaters, electric heaters Introduction of energy efficient devices e.g. wood stoves Energy switch to sources with lower GHG emission factors e.g. electricity
Cooling	Introduction of solar cooling devices Maximization of ventilation in newly built houses Introduce energy efficient cooling devices Switch to coolers that use energy sources with lower GHG emission factors Introduction of efficient refrigerators
Light	Lighting efficiency improvements through the use of fluorescent in place of incandescent lamps, Introduction of solar panels for light energy generation and storage when ever possible

4.4. Mitigation Options in the Transport Sector

At the global level the transport sector is a major contributor to the GHG concentrations in the atmosphere, accounting for about 20-25% of global GHG emissions. In the Eritrean context the transport sector also constitutes a major source of $C0_2$ emissions, accounting for 41 % from fossil fuel combustion in 1994.

The existing taxation policy of Eritrea gives due emphasis to the public transport sector. Public buses, for example are imported with a minimal tax, and the use of non-motorized transport system, such as bicycles, is encouraged. Roads in bigger cities, such as Asmara, for example, are being constructed taking into account bicycles. Moreover, to further strengthen its policies on land transport the Government has issued in 2000 a Land Transport Proclamation, Proclamation No.111/2000, whose objectives are the development and establishment of the land transport system in the country with adequate standards and safety requirements.

Development of mitigation policies and measures over the long-term period in the transport sector may include the following.

- Introduction of efficient public transport sector system, particularly in urban areas.
- Introduction of efficient vehicles using catalyzers and the provision of good quality roads and proper traffic planning.
- Introduction of regulatory frames that would ban old and outdated cars.
- Encourage the use of non-motorized transport systems, such as bicycles.
- Introduction of proper urban planning mechanisms.

CHAPTER 5

ASSESSMENT OF VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

5.1 Introduction

Eritrea is among the most vulnerable group of countries to the adverse effects of climate change, mainly because of its least adaptive capacities. It is believed that all sectors are potentially affected by the impacts of climate change but it appears that the agricultural sector is the most visible one to have been impacted by climate variability, mainly due to extreme changes, both in space and time, in weather patterns particularly in precipitation. Due to financial and technical limitations the vulnerability and adaptation assessment focused on five sectors only, namely, agriculture, water resources, forestry, coastal zone and human health. It should be noted that due to the complex nature of these sectors vulnerability studies considered only a small segment of each of these sectors. The establishment of scenarios and the choice of best global circulation model (GCM), from among the various GCMs, was a necessary condition for undertaking the vulnerability assessments.

5.2 Choice of Best Global Circulation Model (GCM) for Eritrea and the Construction of Scenarios

Several methods were used to determine the best predicting GCM for Eritrea. The methods used were (a) Isoline Method, where isotherms and isohyets constructed from model 1xCO_2 outputs on Eritrea base maps were verified on the ground with those drawn using observed data. From these isoline maps a visual and expert judgments were used to eliminate unrealistic Global Circulation Models, (b) Graphical Method, where graphs of 1xCO_2 mean monthly variables predicted by the various Global Circulation Models were superposed over graphs prepared using observed data, and using visual and expert judgment GCMs whose predictions were too far away from reality could be singled out and (c) Taxonomic Distance Method: A more objective method than the two above was the calculation of root mean square differences between actual (observed) and model predicted 1x CO_2 data sets. The model that came up with the lowest root mean square difference value was regarded as the best predictor of the given variable. UK89 model has the lowest root mean square difference than the other models, namely, CCCM, GISS and Gfd3, as illustrated in Fig 5.1 (a) and (b) below.

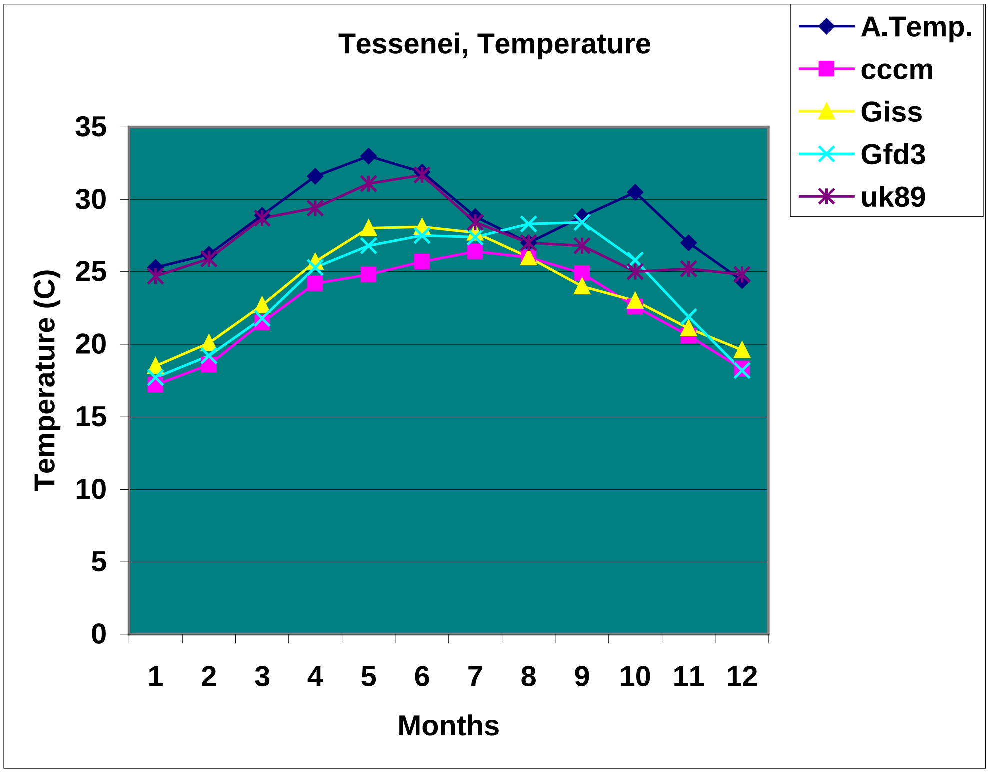

Figure 5.1: (a) Mean monthly temperature from Global Circulation Models and observed data at Tessenei

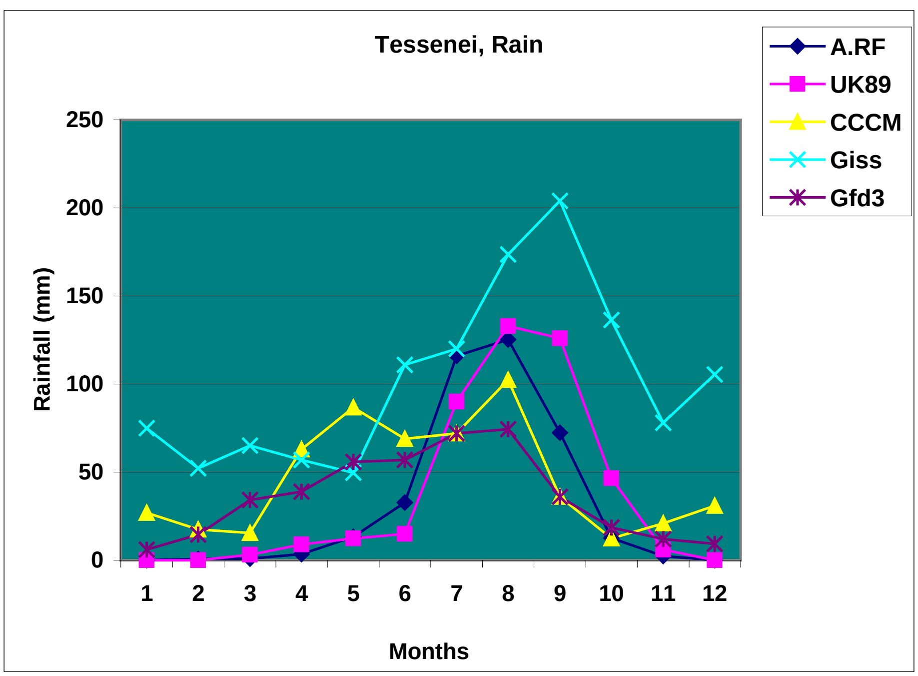

Figure 5.1 (b): Mean monthly rainfall from Global Circulation Models and observed data at Tessenei

The climatic baseline period for Eritrea used in this study was (1935-1964). The period 1935-1964 was good for at least three main reasons. These are:

(1) It fairly represents the present day or recent average climate in Eritrea.
(2) It is sufficient in duration as it includes a number of significant weather anomalies such as severe droughts.
(3) Data covered a wide range of agro-ecological zones of Eritrea.

Temporal data gaps were filled in by means of linear regression models and correlating data sets of adjoining meteorological stations. For example, temperature data gaps at the Port City of Asseb were filled in after inputting Massawa Port temperatures in the regression model. In this gap filling work, only models that had correlation coefficients higher than 60 % were used.

Four Global Circulation Models, namely, UK89, GFD3, CCCM, and GISS were tested to see how close they predict the $1XCO_2$ against the measured meteorological data. These Models were applied to 7 stations in Eritrea, namely, Asmara, Adi keyh and Mendefera (located in the Moist Highland-above 1600 m.a.s.l), Akordet and Tessenei (located in the Arid Lowland-below 1600 m.a.s.l), and Massawa and Assab (located in the Semi-Desert-100-1355 m.a.s.l).

Out of the 7 stations, which have relatively reliable temperature and precipitation data, 5 stations, (Akordet, Tessenei, Masswa, Asseb and Mendefera) gave UK89 as the best estimator, and 2 stations (Asmara and Adi keyh) gave CCCM as their best estimators. Thus, UK89 was taken as the best model for vulnerability assessment. From this finding it could be argued that the UK89 model has good application in elevations lower than 1600 m.a.s.l and the CCCM higher for elevations than 1600 m.a.s.l.

Table 5.1 is an example of how $1xCO_2$ and $2xCO_2$ temperatures, rainfall and solar radiation data from UK89 model for the town of Tessenei have been analysed. The differences and ratios indicated in Table 5.1 were used as adjustment statistics. To get the GCM scenarios for specific sites, the adjustment statistics were combined with observed climate data for the baseline period. For temperature, the adjustment statistics were added to the historical baseline data. For rainfall the historical monthly-observed data at a particular weather station was multiplied by the monthly adjustment statistic for the appropriate grid box. The adjustment statistics for each month were applied to the corresponding months for thirty years i.e. 1935-1964. These calculations yielded a 30-year climate scenario for the given site under $2xCO_2$ conditions and served as an input to the vulnerability assessment of the selected sectors for the study. The day-to-day pattern of temperature change is maintained, but the average monthly temperature becomes 3.6 ^{0}C higher.

The UK89 model showed that at the equilibrium level of $2xCO_2$, the mean annual temperature for Eritrea is expected to rise. The coastal plains will experience an increase in temperature and the range between the monthly means will vary from 29 to 37 ^{0}C. The western lowlands will also experience an increase in temperature and the range between the monthly means will vary between 28 and 37 ^{0}C. The northern, central, southern and eastern highlands will have a range of 18-26 ^{0}C. On the other hand rainfall is expected to vary by a ratio 0.1 to 0.15. The temperature increase due to a doubling of GHG concentrations across the country is 4.1^{0}C, well within the IPCC's, Third Assessment Report globally predicted range, i.e. the Earth's mean surface temperature is projected to warm by 1.4 to 5.8 ^{0}C by the end of the 21st century, with land areas warming more than the oceans.

Table 5.1 UK89 generated climate variables at Tessenei

Monthly temperature (^{0}C)				Precipitation (mm day^{-1}			Solar Radiation (W/M**2)		
Month	$1xCO_2$	$2xCO_2$	Diff.	$1xCO_2$	$2xCO_2$	$2xCO_2$ $1/xCO_2$ ratio	$1xCO_2$	$2xCO_2$	$2xCO_2 1/xC0_2$ ratio
1	24.6	28.2	3.59	0.0	0.0	0.07	263	262	1.00
2	25.8	28.8	3.04	0.0	0.1	3.95	293	286	0.98
3	28.5	32.1	3.59	0.1	0.0	0.37	318	318	1.00
4	29.3	34.6	5.33	0.5	0.2	0.37	324	320	0.99
5	30.8	35.2	4.39	0.6	0.2	0.30	331	334	1.01
6	31.4	34.0	2.60	0.6	2.5	3.85	329	306	0.93
7	28.3	30.6	2.30	2.9	3.9	1.35	281	281	1.00
8	27.1	31.3	4.22	4.4	3.4	0.78	255	280	1.10
9	26.7	31.4	4.71	4.3	4.7	1.10	242	259	1.07
10	25.0	30.0	5.01	1.4	1.3	0.89	257	267	1.04
11	25.1	30.0	4.90	0.2	0.0	0.17	254	260	1.02
12	24.7	29.1	4.39	0.0	0.1	5.00	253	245	0.97

Nonetheless, these findings have to taken very cautiously. This is because the models are too general and have limited practical application in areas of high topographic variation such as Eritrea, since climate is very much determined by altitude. For example in the case of Asmara City, located at an altitude of around 2300 meters above sea level, the $1xCO_2$ temperature has a root mean square average deviation of 8 from the actual observed temperature. This indicates that there is significant altitude factor, which is mostly 1^0C for every 200 meters change in altitude.

5.3. Vulnerability and Adaptation Assessment of the Agriculture Sector

5.3.1 Overview

In Eritrea, the agricultural sector engages more than 80% of the work force of the country. Most of the rural communities live on subsistence agriculture, mainly crop and livestock production. Agricultural production ranges from nomadic pastoral system to small scale irrigated horticultural production. Three main agricultural production systems are recognised: settled agricultural system, agro-pastoral and pastoral system. The population, however, is predominantly settled agricultural. Pure livestock and crop production without livestock is rare, as production depends on animal traction.

Owing to its ecological diversity, Eritrea produces a wide-range of cereals, vegetables, pulses, fiber crops, etc. Subsistence farmers in the highlands, *inter alia*, grow sorghum, millets, barley, wheat, legumes and taff (*Eragrostis teff),* while in the lowlands the main crops grown are sorghum and millets. Sorghum is the main crop in the country and accounts for about 46% of the total cereal production in the country. Next to sorghum are pearl millet and barley, accounting for about 16% and 15% of the total production, respectively. Eritrea is also famous for the production of tropical fruits like lemon, orange and bananas, which are also widely grown in the country. Moreover, Eritrea once used to be famous for the export of vegetables.

In the past, commercial agriculture played a significant role in the economy of the country, which included cotton production as well as large scale irrigated production of fruits and vegetables mainly for export. However, war and recurrent drought retarded progress in commercial agricultural production. During the war, for instance, most of the agricultural infrastructure, including irrigation structures, was destroyed and the agro- industry dismantled.

The livestock sector is an important component of the agricultural sector in Eritrea. It is estimated that about 40% of these animals live in the highlands and the remaining in the lowlands. In the highlands, livestock have greatly contributed to land degradation mainly because of lack of mobility during the dry season. Grazing is open and depends on the seasonal availability of grass. Ecological problems associated with the livestock sector include overgrazing and soil erosion. During the rainy season, most parts of the highlands are cultivated and animals lack enough space for grazing. Consequently, in localized areas especially around water holes and routes, overgrazing causes soil degradation.

In Eritrea rainfall is the limiting factor affecting many facets of the agricultural system, including the crops to be grown, the livestock to be reared, the farming system practiced and the sequence and timing of operations. Rainfall is not only erratic and torrential but it is so variable within and between years that it highly affects agricultural production systems. Moreover, rainfall is also variable in distribution both in space and time. It is commonly observed that the frequency of the variability of these events has been increasing during the last forty years or so, and consequentially agricultural production has been decreasing from time to time. Drought has been hitting the country every 5-7 years in the past, with adverse effects on crop production, and between 1972 and 1987 there were three catastrophic droughts. These observed events are believed to have come as a result of some weather changes, which could possibly be the effects of human induced changes of climate. It is there fore obvious that the agricultural sector, which occupies a central place in the economy of the country, is highly vulnerable to the adverse effects of climate change.

The assessment of vulnerability of the agricultural sector to the adverse effects of climate change is technically quite complex and costly, and equally so is the assessment of adaptation to climate change. It should, however, be understood that over the years farmers have developed adaptation strategies to cope with the ever changing events of weather, and these need to be recognized and assessed carefully, if meaningful adaptation strategies are ever to be developed over the long time period.

Given the complex nature and wider scope of the agricultural sector, attempts were made to demonstrate the vulnerability of the agricultural sector by selecting two important crops, namely sorghum and barley, which are widely cultivated in the country under rain fed conditions. Out of the total land area under cereal cultivation, the percentage share of land for the period 1992-96 was 43 % sorghum and about 13 % barley. Other important crops like pearl millet, taff, finger millet, maize and wheat constituted 14.8%, 8.8%, 7.8%, 6.6% and 6.0% respectively. Sorghum is cultivated, mainly in the lowlands and the midlands, and to a lesser degree, in the cooler highlands. Due to its resistance to drought, it is the crop *par excellence* for the dry areas (300-400mm of precipitation annually). In the cooler highlands, barley dominates, being more tolerant to drought and diseases than most highland crops and more productive under adverse conditions.

Both sorghum and barley grains are used for human consumption and the straw is used to feed livestock. Yield levels for both crops are low. The yield of barley in Eritrea is 0.8 t/ha compared to the world average of about 2.2 t/ha. The yield of sorghum is 0.8-1.2 t/ha. The low yield levels are attributed to the fact that the landraces have not yet been improved and more importantly soil fertility and labor productivity are extremely low.

5.3.2 Vulnerability Assessment of Sorghum and Barley to Climate Change

A. Vulnerability Assessment

To assess the potential sensitivity and vulnerability of agriculture to the adverse effects of climate change, two crops, namely, sorghum and barley and three growing sites for these crops were selected. The sites selected were Asmara, located in the moist highland agro-ecological zone, for simulating the impact of climate change on barley production, and Tessenei and Akordat, both located in the arid lowland agro-ecologic zone, for simulating the impact of climate change on sorghum production.

The Decision Support System for Agro-technology Transfer Version 3 (DSSAT 3) and the CERES-Barley and CERES-Sorghum models were used for undertaking vulnerability assessment. CERES integrates growth models with crop, weather, soil data and application for risk analysis and weather generation. Data on weather, soil and management practices for the study were obtained locally. Daily rainfall, maximum and minimum air temperature and solar radiation, for each study area, for the period 1935-64, were obtained from the Department of Civil Aviation of the Ministry of Transport and Communications. To fill missing data the DSSAT Utility Program "*weatherman*" was used. Soil and crop management data were obtained from the Department of Agricultural Research and Human Resources Development (DARHRD) of the Ministry of Agriculture.

The assessment involved comparison of growth and yield parameters i.e. days to anthesis, days to maturity, biomass dry matter weight and grain dry matter weight. Other parameters include seasonal water balance parameters (rainfall, evapo-transpiration, runoff, extractable water and drainage), and seasonal nitrogen (N) utilisation parameters (N uptake, soil inorganic N and N leaching) for different GCMs.

(a) Potential Impacts of Climate Change on Barley Production at Asmara.

The potential impacts of climate change scenarios on growth duration, biomass yields and grain yield of barley, under current management practices is shown in Table 5.2. According to the GCMs simulation of future scenarios under climate change, growth duration and biological yield of barley are projected to decrease both under rain fed and irrigated conditions.

The GCM scenarios also predicted an adverse water balance under climate change with seasonal rainfall. In this case, evapo-transpiration and extractable water are projected to decrease and runoff increases. GCM estimates of nitrogen (N) utilization predicted N leaching to increase while N uptake and soil inorganic N to decrease.

Reduction in total biomass and grain dry matter weight is presumed to be due to increase in temperature, which shortens the growing period of barley. Partly, it may be due to the predicted moisture and nutrient (N) stress. It may thus be inferred that the full effects of climate change on barley production will exceed the immediate benefits of increased atmospheric CO_2 concentrations.

Table 5.2 Predicted % changes to anthesis, maturity, and biomass and grain yield of barley compared to baseline under different climate change scenarios at Asmara.

Parameter	Condition	Baseline	CCCM %	GFDL %	UK89 %
Days to anthesis	Rain fed	74.0	-4.1	-1.4	-18.9
	Irrigated	67.0	9.0	-14.9	-23.9
Days to maturity	Rain fed	120.0	0.8	-15.8	-34.8
	Irrigated	112.0	-6.3	-16.9	-17.9
Biomass yield (kg/ha)	Rain fed	791.0	-40.7	-22.1	4.7
	Irrigated	1093.0	-45.1	-16.1	-16.2
Grain yield (kg/ha)	Rain fed	357.0	-56.0	-34.2	-54.6
	Irrigated	510.0	-56.3	-27.3	-41.1

(b) Potential Impacts of Climate Change on Sorghum Production at Tessenei

The GCM scenarios invariably predicted increase in the length of the growing period of the crop, which results in the increase of biological yield of sorghum both under rain fed and irrigated conditions (Table 5.3). The GCM further predicted rainfall and extractable water to decrease; whereas soil inorganic N and N uptake to increase with a simultaneous decrease in N leaching. Surprisingly, the growth duration and biological yield of sorghum are projected to increase in the wake of adverse water balance- a phenomenon inconceivable under normal climate. Thus is has to be inferred that the positive effects of atmospheric CO_2 concentration will exceed the adverse effects of climate change. In addition, the rise in temperature under climate change may not have negative impact on the growth of sorghum as opposed to that of barley.

(c) Potential Impacts of climate change on sorghum Production at Akordet.

The GCM scenarios predicted increase in the growth duration and biological yield of sorghum both under rainfed and irrigated conditions (Table 5.4). Rainfall and extractable water are projected to decrease while evapo-transpiration and drainage are to increase. In respect of N utilisation, the rate of N uptake is projected to increase while N leaching is projected to decrease. Interestingly, the predicted changes at Akordet correspond somewhat to those of Tessenei, presumably because the sites in question are located in adjacent ecological zones. A typical sorghum field in the Gash Barka area is illustrated in Figure 5.2.

Table 5.3 Predicted % changes to anthesis, maturity, and biomass and grain yield of sorghum compared to baseline under different climate change scenarios at Tessenei.

Parameter	Condition	Baseline	CCCM %	GFDL (%)	UK89 (%)
Days to anthesis	Rainfed	78.3	0.0	-0.13	-0.3
	Irrigated	76.4	-1.3	-1.2	-1.3
Days to maturity	Rainfed	92.5	2.8	8.0	4.0
	Irrigated	93.8	21.3	9.3	20.3
Biomass yield (kg/ha)	Rainfed	4966.0	23.2	34.4	10.8
	Irrigated	7116.0	62.5	27.8	97.2
Grain yield (kg/ha)	Rainfed	588.0	40.1	74.5	10.8
	Irrigated	1108.0	131.0	47.7	138.9

Table 5.4 Predicted changes in days to anthesis, days to maturity, biomass yield and grain yield of sorghum compared to baseline under different climate change scenarios at Akordet.

Parameter	Condition	Baseline	CCCM %	GFDL %	UK89 %
Days to anthesis	Rain fed	78.3	0.0	-0.13	-0.3
	Irrigated	76.4	-1.3	-1.2	-1.3
Days to maturity	Rain fed	92.5	2.8	8.0	4.0
	Irrigated	93.8	21.3	9.3	20.3
Biomass yield kg/ha	Rain fed	4966.0	23.2	34.4	10.8
	Irrigated	7116.0	62.5	27.8	97.2
Grain yield kg/ha	Rain fed	588.0	40.1	74.5	10.8
	Irrigated	1108.0	131.0	47.7	138.9

Figure 5.2: Typical local sorghum field in Gash-Barka

B. Adaptation Options in the Agricultural Sector

The GCM scenarios showed that the projected climate change conditions are likely to impact crops and the natural resources base. The models predict that the productivity of barley is projected to fall below baseline level due to the predicted warmer temperatures, adverse water and nutrient balance. Consequently those parts of Eritrea where barley is extensively grown are likely to experience production shortfalls. On the other hand, sorghum production is likely to experience significant improvement under conditions of climate change i.e. warmer temperatures and increased nutrient (N) utilization. Thus, the sorghum growing parts of Eritrea are likely to witness increased productivity. In the face of the impending climate change, Eritrea must prepare itself for the opportunities and challenges that lie ahead. That is to make the most of potential positive impacts of climate change, on the one hand; and to devise and implement strategies to minimize its negative impacts, on the other. A broad-based approach is essential to this end, integrating the following essential components:

1. A policy framework to combat climate change-induced problems coupled with appropriate institutions to translate policy objectives into concrete action;
2. Protection and sustainable use of natural resource base on which agriculture depends;

3. Improvement of existing crops, technologies and traditional knowledge systems;
4. Education and mobilization of the public for effective participation in the fight against the potential negative impacts of climate change;
5. Construction of a comprehensive information system along with an early warning system;
6. Linkage with regional and international networks involved in climate change studies; and
7. Setting up a co-ordination mechanism to enable stakeholders i.e. policy makers, development planners, scientists, rural communities and farmers to participate constructively in the efforts to adapt to climate change.

Since, the traditional farming skills that exist today in Eritrea have been developed over the past generations, the farming communities have over the years developed traditional crop production to suit the ever -changing climatic situation. Some of the local and traditional knowledge include crop rotation, use of early and late season crops and cultivars, fragmented land-holding systems and mixed cropping and inter-cropping. Crop rotation is practiced to improve soil fertility and to avoid the risk of disease and pests. To adjust crops to the unpredictable rainfall occurrence and high variability in the start of growing season, farmers always have early and late season crops and cultivars at their disposal. The fragmented land holding system in Eritrea also plays a key role in maintaining the diversity of crops and cultivars that exist today and avoid the risk of crop failure. Mixed cropping and inter-cropping are practiced to increase crop yield by using the land and climatic resource efficiently while maintaining the productivity of the land. Such traditional farming skills have enabled past generations to cope with the changing climatic conditions and are still being practiced by farmers. Therefore, traditional farming systems should be studied carefully and improved so that they may be employed as the best tools for tackling the impact of future climate change on crop production and other agricultural activities in Eritrea.

5.4 Vulnerability and Adaptation Assessment of the Water Sector

5.4.1 Overview

Eritrea lies in the Sahelian belt, which is characterized by frequent and prolonged droughts. The country has suffered from major prolonged droughts since 1965, the latest drought being in 1993. It is observed that drought has been repeating itself every 5-7 years.

Extreme altitude variations, ranging from sea level to over 265m above sea level, continental pressure changes and other factors determine the climate of Eritrea. Most parts of Eritrea receive uni-modal rainfall and the rainy season extends form

June to September, although there are small rains that start in April/May. Rainfall increases from north to the south of the country, varying from around 200mm in the North Western Low Lands to around 650mm in the Southern part of the Central Highlands.

The south -westerly winds, flowing from the Atlantic Ocean, are responsible for the rainy season from June to September. The northeasterly winds passing over the Red Sea pick up moisture and deliver some precipitation along the coastal plains of the Red Sea. While advancing eastwards, however, they encounter steep escarpment and because of orographic effects produce abundant rainfall. The eastern and southern escarpments facing the coastal areas have therefore a bi-modal rainfall.

It is generally observed that weather patterns in Eritrea started changing greatly since some time in the 60's. Moreover, farmers observe that the duration of the rainy season has been narrowing for the last two or three decades, and this is resulting in the spatial and temporal availability of water resources through out the regions of the country, although these observations need to be substantiated by detailed studies. These observations are in agreement with the general belief that climate change is affecting the global hydrologic cycle in general and precipitation and runoff in particular.

As a result of these changes arid and semi-arid regions of the world, including countries like Eritrea, are projected to be more vulnerable to the adverse effects of climate change than others. In Eritrea there is nothing

much more limiting than water. Rainfall is erratic and torrential and quickly forms heavy floods with little chance of penetrating into the ground. Perennial streams hardly exist and there are no lakes, and River Setit is the only perennial river. The potential of underground water resources is still not clearly studied and documented. Moreover, meteorological and hydrological information, which is critical for any water resource development activity, is at its early stage of development.

Meteorological data collection started during the Italian colonial period (1890-1941), and before the 1930's more than 20 meteorological stations were operating throughout the country. At the time of independence (1991), however, only two stations were operational. Time series of hydrological and weather data gaps have therefore made water studies difficult. Currently there are around 160 weather stations distributed through out the regions of the country (see Fig.5.3).
The water potential of Eritrea could be studied based upon the river basins that exist in the country. There are six drainage basins (Fig.5.3), namely, (1) Setit, (2) Mereb Gash, (3) Barka-Anseba, (4) Red Sea, (5) Danakil Depression and (6) small

catchments flowing to the Sudan. The Mereb and Setit Rivers make a boundary line between Eritrea and Ethiopia in the southern and southwestern part of the country respectively. The Setit, Mereb-Gash, Barka and Anseba Rivers flow to the Sudan. Eritrean rivers are all seasonal, except the Setit River, which is part of the Nile basin. Very little has been done in the past to harness and utilize these rivers for developing irrigated agriculture and other infrastructure services.

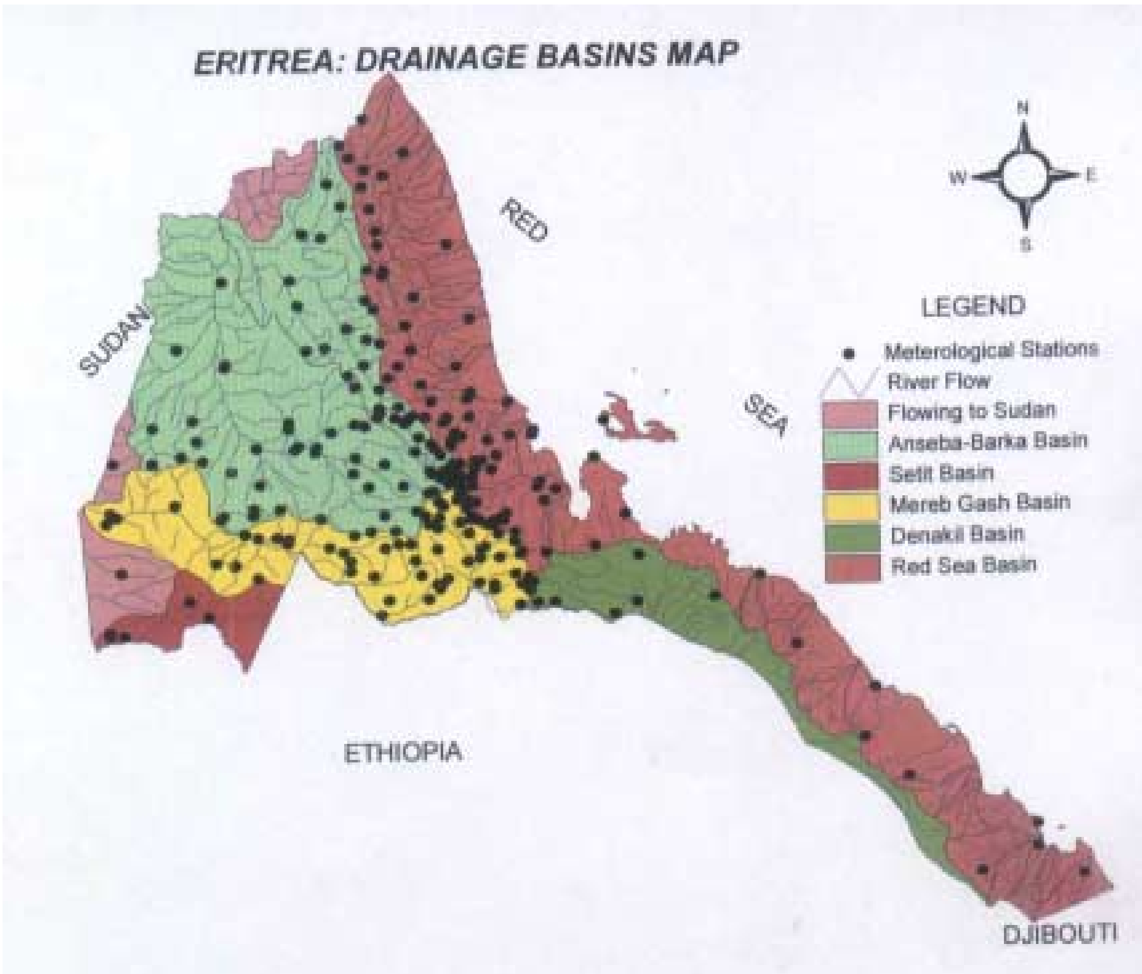

Figure 5.3: Watershed regions of Eritrea: Note that the Mereb-Gash Basin, which is the focus of the study, is shaded yellow.

5.4.2 Vulnerability Assessment

The Mereb-Gash basin was selected for the vulnerability assessment of the water sector, mainly because of the availability of discharge data in this basin and more importantly this basin probably has the highest potential for agricultural activities, both for rain-fed and irrigated agriculture, than the other river basins. Although the scenario period for all the other sectors studied was 30 years (1935-1964), the water study was limited to only 11 years (1943-1953), mainly due to lack of discharge and other meteorological data. The Mereb-Gash basin covers an area of 16,726.87 km^2 starting from the southern part of the highlands to the lowland bordering the Sudan. The Mereb-Gash basin is an ephemeral system, with significant surface flows only during the months of July, August and September.

In the process of vulnerability assessment, the water balance model has been used to determine rainfall/ runoff relationships. Water balance has two modeling components: the water balance component and the calculation of Potential Evaporation using Priestly Taylor method. In areas where there is availability of stream flow and climate data, a monthly lumped integral model or water balance approach is recommended. The water balance model needed to be calibrated and validated with historical data prior to using it to simulate the runoff under different climatic scenarios.

Discharge data for the period of 1943-1948 and 1949-1953 were used to calibrate and validate the model respectively. No significant differences were detected, however, between the calibration and validation with respect to their correlation coefficients values, as shown in Table 5.5. Thus, the model performance was believed to be adequate for the purpose of this study and hence it was accepted for further analysis. The results of the observed versus the modeled discharge for the calibration and validation of the Mereb-Gash basin are also shown in Fig.5.4 and Fig.5.5, respectively. Discharge data from only two stations (Magauda and Tendelai) from the whole of Gash-Barka basin were taken, as there is no data available from other places for the selected period.

Table 5.5 Statistical values for calibration and validation of discharge data

	Correlation	*Average error*
Calibration	0.95	0.035
Validation	0.98	0.025

After adjustments were made to both temperature and rainfall data, using the UK89 GCM, the climate change scenario of $2xCO_{2,}$ showed that, on average, temperature will increase by about 4 ^{0}C and precipitation will also show some increase, as shown in Table 5.6

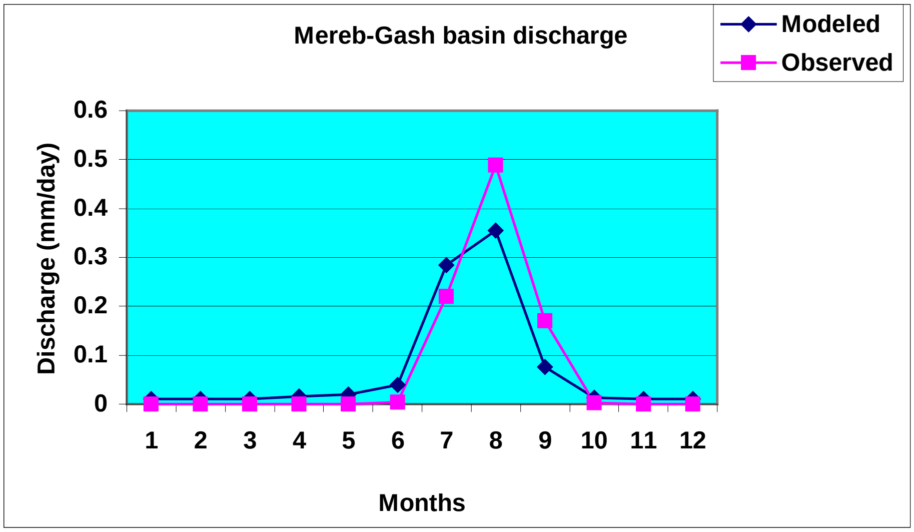

Figure 5.4: Observed and Modeled Discharge Data for Calibration of Mereb-Gash basin

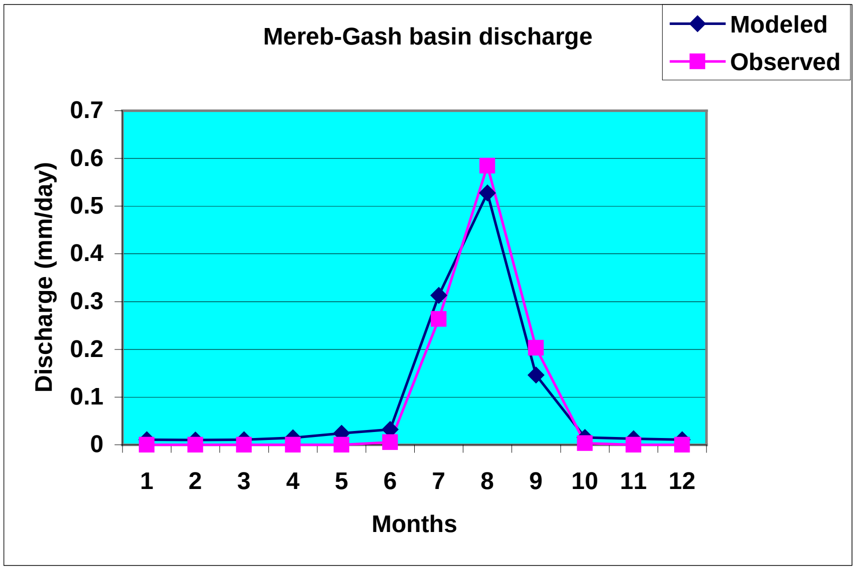

Figure 5.5: Observed and Modeled Discharge Data for Validation of Mereb-Gash Basin

Furthermore, Table 5.6 and Fig.5.6 show the observed and modeled runoff after temperature and precipitation data were adjusted using the UK89 GCM. The 2xCO_2 scenario showed that there would be a decrease of 29.5 % of runoff in the modeled as opposed to observed data. The main reason for the decrease could be attributed to the expected increase in temperature, which in turn results in increased evapo-transpiration. It should be reminded that the effect of different water demanding activities such as irrigation, urbanization, etc, on runoff was not taken into account in the vulnerability study.

Table 5.6 UK89 Climate Scenario for Temperature, Rainfall and for Observed and Modeled Runoff

Month	Temperature (°C)	Rainfall ratio	Runoff mm/day	
			Observed	Modeled
January	3.24	0.090	0.000	0.000
February	3.02	2.067	0.000	0.000
March	4.05	0.346	0.000	0.000
April	5.51	0.355	0.000	0.000
May	5.01	0.356	0.000	0.000
June	4.12	1.826	0.005	0.008
July	2.80	1.791	0.263	0.407
August	3.84	0.958	0.584	0.290
September	4.54	1.136	0.203	0.039
October	4.49	1.510	0.003	0.000
November	4.09	0.594	0.000	0.000
December	4.20	5.000	0.000	0.002
Annual			1.060	0.747

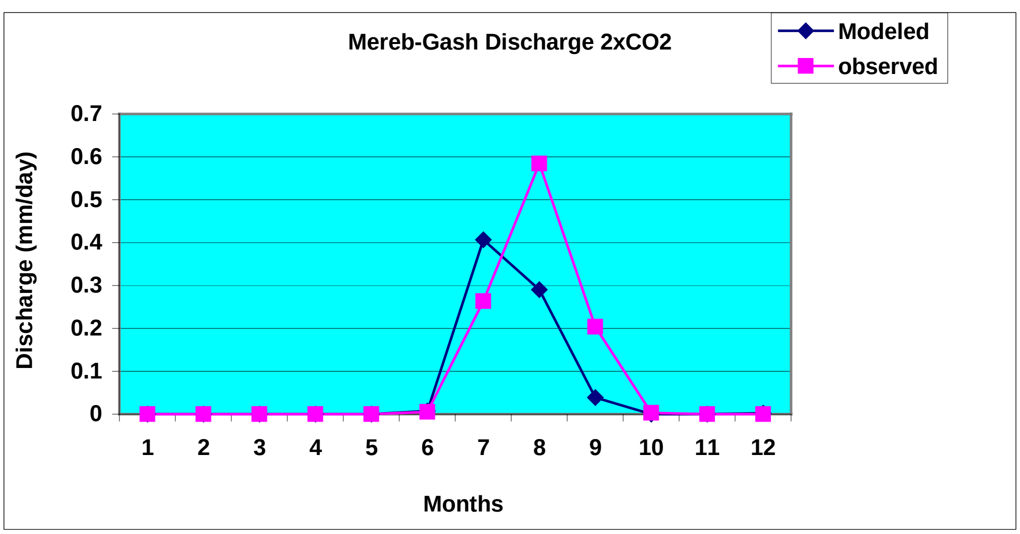

Figure 5.6: Observed and modeled runoff after temperature and precipitation adjustments.

5.4.3 Adaptation Options in the Water Sector

Given the fact that water has always been one of the most scarce natural resources, perhaps the scarcest resource in the country, farming communities have tried to develop coping mechanisms to deal with shortage of water, including for agricultural and domestic purposes. Such mechanisms are, *inter alia*, the construction of terraces for soil and water conservation and the construction of small earthen dams. Moreover, farmers over the generations have always tried to develop drought resistant varieties (be it crops or animals) to cope up with cyclic drought conditions. These adaptive strategies, which the farming communities have developed in the past, are still being pursued and developed using modern knowledge and techniques. In this respect the following adaptations options are quite important to resolve and mitigate water shortage problems that may exist in the country.

1. The construction of dams and check-dams has been one of the major engagements of the Government since independence in 1991. Between 1992-1999 more than 75 concrete and earthen dams were constructed, as shown in Fig.5.7. Moreover, more than 1000 km long check- dams were also constructed to protect these dams from silt accumulation. These dams vary in water holding capacities from 0.3 million m^3 to 0.5 million m^3. Many of these dams are being used for small- scale vegetable production, as shown in Fig.5.8. The construction of dams is equally important in the Gash-Barka basin if sustainable human settlement and agricultural production is to take place.

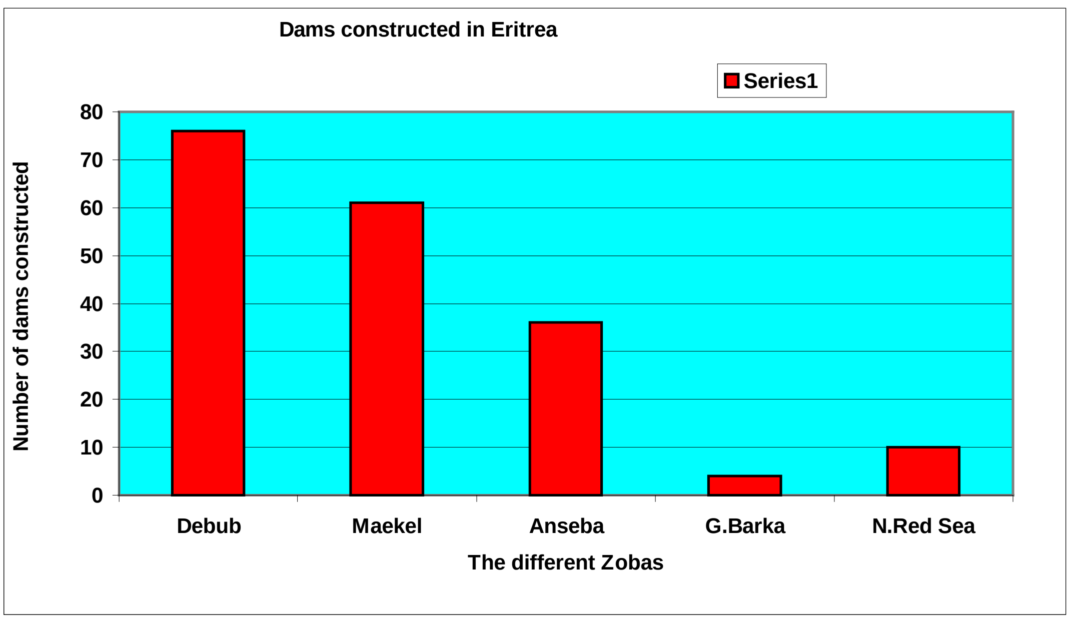

Figure 5.7: Dams Constructed 1992-1999

Figure 5.8: Dam Site at one village (Embaderho) in the Central Highlands

2. Undertake assessment studies of the underground water potential of Eritrea, including water irrigation potential of the major river basins, including that of Gash-Barka River basin.

3. Establish and strengthen a national meteorological and hydrological information system.

4. Develop a national disaster management strategy to mitigate the adverse impacts of periodic droughts. This has to do with early warning system that has to be coordinated by concerned institutions, such as the Ministry of Land Water and Environment, the Ministry of Agriculture, the Ministry of Transport and Communications, the Ministry of Fisheries, etc.

5. The current water management practices are not commensurate with the existing water shortage of the country. Water tariff is only practiced in major cities, and there is no progressive water tariff charge in use. Moreover, there is no policy to levy tariff on irrigation water. The absence of such policy measures allows investors to exploit and consume lavishly too much water.

Such uncontrolled exploitation of scarce water resources not only depletes scarce water resources, but also leads to salinity hazards. Uncontrolled exploitation of underground water resources, for example, exists in the Gash-Barka region and there are clear indications that underground water resources is getting saline and hence becoming unproductive for irrigation purposes. It is therefore timely that cost effective water management policies, including pricing policy, be introduced as early as possible. Moreover a national water law must be put in place to regulate and manage the sustainable use of water resources.

5.5 Vulnerability and Adaptation Assessment of the Forestry Sector

5.5.1 Overview

The major vegetation types in Eritrea are the highland forest, riverine forest, closed and open woodland, mangroves, shrub and bush-land. Because of the exploitative management strategy followed by the successive colonial administrators, the forest area of the country has been reduced from 30% in 1900's to about 2.4% now. The conversion of forests and woodlands into agriculture, fire wood collection and overgrazing also exacerbated the situation. El Nino related drought of early 1970s, 1982-85, and in the 1990s have also caused massive plant losses.

Biodiversity has suffered in the hands of past generations. Plant communities have been greatly altered with impoverishment of local species. Wildlife has been devastated through loss of habitat and hunting. The remaining closed to medium closed and open forests are restricted to the eastern escarpment and in some river basins. Despite the continuous destruction of forest, however, Eritrea has a rich floristic composition owing to the diversified climatic conditions and differences in altitude and soil, which need to be protected.

The effects of deforestation are evident. There is shortage of construction poles and fuel-wood supply in the country. Deforestation on steep lands has increased the sediment loads of rivers, reservoirs and canals. Exposed soils, particularly following mechanical clearing, are subject to erosion, compaction and crusting.

The low occurring natural forests still remain very important resource to rural communities by providing fuel wood, construction materials, medicines, forage and shelter. However, despite various efforts at conservation, the destruction of this natural vegetation continues unabated.

Alarmed by such precarious state of the environment, the Government of the State of Eritrea introduced a number of control measures. For example, law forbids cutting live trees, hunting of wild animals, and charcoal making. In parallel, the government has mobilized rural population and students to construct hillside terraces and plant seedlings. It also encouraged area closures of degraded hills and woodlands for natural regeneration. Planting trees along roads and homestead is also widely encouraged.

Efforts are underway to undertake forestry research activities to promote forestry management. The Department of Agricultural Research and Human Resources Development in the Ministry of Agriculture has this mandate and is in the process of intensifying applied research and dissemination of its findings. There has also been continuous improvement in the provision of quality seeds to the forest services and other users. Seeds have been dispatched strictly on the basis of provenances.

5.5.2. Assessment of Impacts of Climate Change on Forestry

The impacts of global climate change on future forest distribution was evaluated with an integrated approach using the Holdridge life zone classification, Gap model and three general circulation Models (GCMs) i.e., the Geographical Fluid Dynamics Laboratory (GFDL), Canadian Climate Change (CCCM) and the United Kingdom Meteorological Office (UKMO).

Holdridge life zone classification is a climate classification model, which relates the distribution of major ecosystem complexes to climate variables like bio-temperature, mean annual precipitation, and the potential evapo-transpiration to precipitation ratio. Based on the Holdridge's classification schemes, the country was divided into potential forest cover zones for current and future climate change scenarios. The forest Gap model, on the other hand, was used for the prediction of the plant species composition, vegetation structure, and associated productivity phenomena, as well as standing biomass through time. The model was used to track the temporal response of vegetation to changing environmental conditions under climate change scenarios that were developed earlier. Tree species and site data for the eastern escarpments (Semienawi and Debubawi Keyh Bahri) were used to parameterize the model. The parameters from which the optimal growth function is derived are maximum age, maximum diameter, and maximum height. The environmental response to light is described by the shade tolerance of a given species, while growing degree-days at base temperature of 0 ºC is used to track the response to temperature, and the maximum and minimum degree-day values define the northern and southern boundaries of the geographic distribution of a species.

Precipitation and temperature are the two key factors in the productivity and distribution of land vegetation. Whereas the former affects soil processes in a given ecosystem the latter affects the biochemical and physiological processes. Because of harsh climatic conditions and periodic droughts, the current climatic conditions in Eritrea limit the scope for the regeneration of biodiversity. An assessment of the impact of climate change on the forestry sector, therefore, needs to incorporate these two important elements.

The result of the Holdridge Life Zone classification model was compared across the three GCM scenarios (CCCM, UKMO, and GFDL). Neither of the GCMs, however, has predicted life zone, which corresponds to those created under current climate. Under the current climate scenarios, a bigger portion of the country is tropical desert bush followed by tropical thorn woodlands (Figure 5.9).

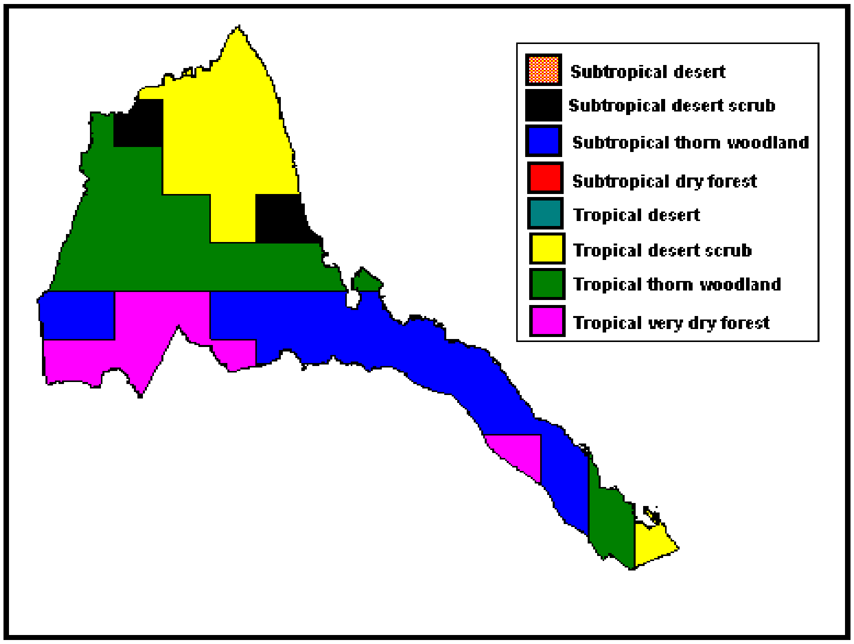

Figure 5.9: Current forest types that has been generated by the combination of GFD3, CCCM and UKMO models

Under climate change, the country would have more diverse bio-climatic zones. Tropical thorn (Grasslands/Wooded Grasslands) woodland would dominate a large portion of the central highlands, the eastern and western escarpment, and central part of the western lowland. The southern zone of the central highlands, south-western lowlands and higher altitudes of the eastern lowlands would be dominated by the tropical very dry forest (Open and closed/medium closed woodlands). The northern portion of the country would be dominated by tropical desert scrub (bush lands / scrublands). There would be also pockets of other types of bio-climatic zones as shown in Figure 5.10. The projected shift in forest distribution is attributable to either future increase or decrease in precipitation and an increase in ambient temperature.

The results generated by these models, however, have to be taken cautiously. The model predictions are almost opposite the present forest cover and this has resulted in the expression of serious reservations about these models by concerned experts.

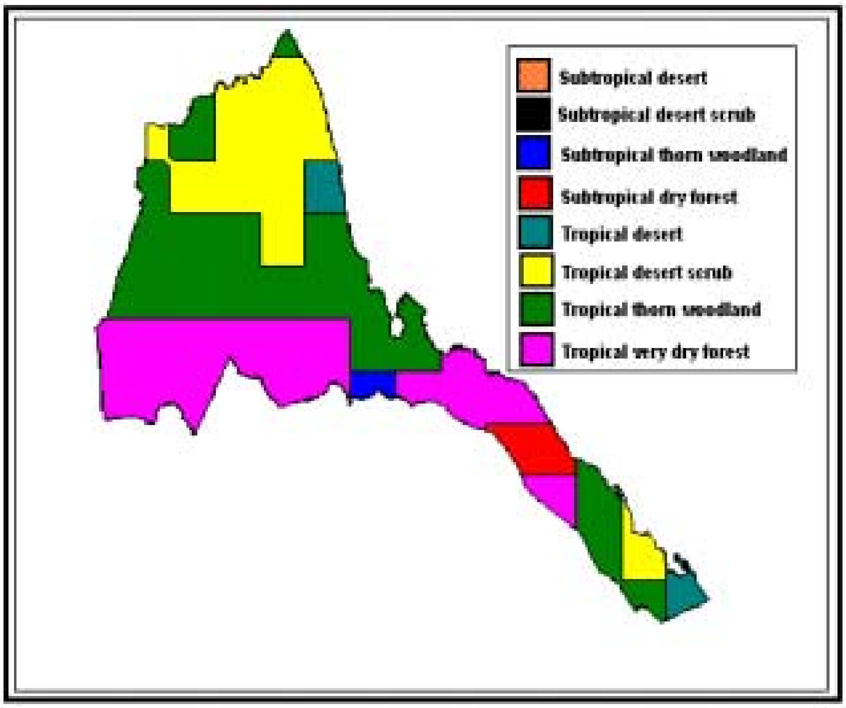

Figure 5.10: Forest types under 2xCO_2 that have been projected by the combination of the three GCMs.

Some assumptions and limitations of the approach used to determine the effects of climate change on forests are:

1. According to Hordridge's model, the bio-temperature values are set at a base temperature of 0ºC. This value is much lower than 25ºC recommended for Eritrea. This means that Holdridge's Classification will tend to exaggerate levels of aridity under climate change scenario.
2. The Holdridge model is an abstraction of the actual vegetation pattern i.e. the classification is not based on the actual distribution of vegetation instead on some climatic factors.
3. Current global circulation models intended to develop future climate change scenarios are limited in their use for predicting possible changes in ecosystem and species distribution. This is because they have low spatial

resolution i.e. their ability to reproduce reliable major climate anomalies such as El Nino and tropical storms to confidently predict inter- and intra-annual rainfall distribution patterns is limited.

The summary of Forest Gap model analysis, for the various tree species, under climatic change scenario is shown in Table 5.7. This Table shows that warmer conditions would have a positive impact, though not significant on the diameters of all the species considered. The largest impact would occur when the plants are 20-40% of their maturity life. Climate change also had a positive impact on the biomass production of most of the tree species throughout their life span.

Table 5.7 Performance of various three species under climate change

Species	Number of years to maturity	Maximum diameter At maturity, Current climate (cm)	Performance under climate change		
			Incremental diameter at full maturity (cm)	Maximum incremental diameter (cm)	Year of maximum incremental diameter
Juniperus procera	60	75.546	0.738	1.259	23
Olea africana	50	58.333	0.321	1.167	21
Anogeisus leiocarpus	50	65.346	0.569	1.307	25

Improved biomass production would mean that more fuel-wood supply would be available to the rural areas. Improved tree performance is likely to positively contribute to soil stabilization, provision of organic nutrients to the soil and improvement of biodiversity.

5.5.3 Adaptations Options in the Forestry Sector

Adaptation measures should include sustainable utilization of the land resources for various uses. It requires the protection and rehabilitation of the existing forest and woodlands as well as controlling to achieve sustainable harvesting. Rehabilitation and improvement of past forest and woodland sites through forestation using site appropriate species would be highly needed if economic and social benefits of the forest are to be realized. Increasing the local wood supply through the establishment of wood lots or the incorporation of trees into the farming systems; reduce wood energy need through either greater efficiency of wood energy conversion and utilization or substitution of wood fuels by alternative energy sources.

Efforts should be made to reduce tree clearing and land use changes particularly on steep terrain. Instead, through the application of modern forestry practices, the farming communities should be supported to benefit from the non-timber forest products and made to appreciate the economic benefits of forests. Identify and manage areas of important populations of trees and shrub species, potential forest migration or decline specially buffer zones along the banks of major rivers of the country.

Some of the adaptation measures that need to be implemented to alleviate the adverse environmental effects of deforestation are described as follows.

1. The deforested sites should be rehabilitated and improved through afforestation, enrichment planting, and area closure to realize economic and social benefits from the forests. Not much attention has been paid so far to select suitable tree species for planting. Some species are fast growing and provide natural products and are also adapted to a wide range of climatic conditions. In species selection, survival rate under adverse conditions, resistance to browsing and grazing damage should be considered. Tree species like *Acacia etbaica* and *Eucalyptus cladocalyx* have already proven their wide adaptability to a wide range of ecological conditions within the highlands, although there is also a concern that the Eucalyptus species is a heavy user of water. *Acacia polyacantha* and *Eucalyptus camaldulensis* in the midlands and *Acacia senegal* and *Acacia tortilis* also demonstrated their wide adaptability in the lowlands. Selection of species that have considerable power of acclimatizxation and species with a wide genetic diversity for planting may act as adaptation option to climate change.

2. Integration of multipurpose tree and shrub species in the agricultural land to provide fuel wood and poles as well as for land stabilization, soil improvement, shelter and silvipasture. Efforts should also be made to stabilize farmland through either biological or physical measures to reduce soil erosion.

3. Re-establishment of wild life habitats in selected areas such as Buri Peninsula and Hawakil Bay for the conservation of terrestrial wild life in those areas.

4. Design of fuel wood collection management practice within the productive capacity limits of the forests and woodlands,

5. Introduce comprehensive rehabilitation and protection plans for the Mount Bizen and Semienawi Bahri forest area to meet the fuel wood and fodder

requirements of rural and urban communities and to reduce silt down stream. Among the elements of management proposals are:

- Development of management planning for the entire area including forest inventory, delineation of land use components;
- Undertake enrichment planting, reforestation of grasslands and avoid grazing and illegal exploitation,
- Assign trained forest guards to patrol forests;
- Establishment of permanent plots to identify proper silvicultural treatments for rehabilitation of the forest and yields forecast.

6. Provide incentives to promote community involvement in forestry conservation programs. Moreover, encourage private reforestation schemes and ensure that all trees planted are the property of the individuals who planted and cared them, without prejudice to any law introduced from time to time regulating or limiting of felling or destruction of privately owned trees.

7. Replacement of thatched roofs for traditional houses known as H*udmo and Agudo* by corrugated iron sheets to reduce the consumption of construction poles. It has been reported that at least 100 live trees have to be cut to construct a traditional house (*Hudmo)* in the central highland.

8. Introduce proper land use planning. Demarcate and designate forest areas and discourage other types of land use. To overcome land use changes proper resource management plan should be drawn and overall land use map of the country should be prepared.

9. Encourage school wood-lot programs and wood-burning stove improvement in the country.

10. Introduction of a national reforestation schemes to create a well- managed fuel wood plantation for each village, the reforestation work to be carried out by the villagers themselves.

11. Delineate certain forest areas within the Green Belt for the conservation of forest genetic resources, encouraging natural regeneration through closure etc. Eritrea being one of the major centers of origin/diversity of many plant species, has an immense wealth of genetic diversity. This plant genetic resource is vital to the economic, social and environmental development. However, the endowment of genetic resources is threatened by irretrievable loss of biodiversity as a result of, *inter alia*, resource mismanagement and environmental degradation leading to genetic erosion. The situation, therefore, requires an urgent national action plan to ensure the conservation of genetic

resources and to develop rational systems for their development and sustainable use.

12. Reduction of wood energy demand through greater efficiency of wood energy conversion and utilization or substitution of wood fuels by alternative energy sources. Heating efficiency of traditional open stoves is hardly more than 10 – 15%, and smoke -generated as a result of the burning of fuel wood within household premises is injurious especially to women. Efforts are now being made to improve the traditional stoves and in effect improved stoves are 21 % more efficient as compared to traditional stoves, as reported by the Research and Training division of the Ministry of Mines and Energy.

13. In the highlands, there is scarcity of forage and fodder because of deforestation and degradation of grazing areas. The farmers will have to adapt to a lower number of livestock to cope up with the carrying capacity of the pastures or make provision for stall-feeding. Some of them may even have to give up this profession to avoid depletion of the pasture and to prevent land degradation.

5.6 Vulnerability and Adaptation Assessment of Coastal Environments

5.6.1 Overview

The total Eritrean coastline runs for 1900 km, stretching from Ras Kasar in the Sudanse boarder in the north to Ras Dumera in the Djibouti border in the south. There are over 300 big and small islands in the Eritrean Red Sea. Low-lying sandy, rocky, continental and volcanic rocks that contain isolated patches of mangroves and palm trees exist along the coastal areas.

The Red Sea, , is a semi-enclosed water body with two outlets, one with the Indian Ocean through Bab El Mendeb and the other with the Red Sea through the Suez Canal. The Southern Monsoons, the dry climate of Central Asia, the Saharan desert and the North Mediterranean climate largely influence it.

High density, high salinity and high transparency water characterize the Red Sea area. This is mainly due to the absence of significant fresh water input having no major rivers draining into it, and has low precipitation and high evaporation. This situation has resulted in the evolution of unique types of flora and fauna. The distribution of nutrients in the Red Sea is similar to the open oceans and it is higher in the southern end compared to the northern part. Dissolved oxygen is similar to the open oceans and is largely affected by temperature.

Sea surface temperature shows seasonal variations. From November to March, it ranges from 25 ^{0}C to 28 ^{0}C and during May to October it ranges from 29 ^{0}C to 32

^{0}C. During summer, i.e. July and August, the coastal area is characterised by high temperature and humidity. Rainfall is very small, localized and irregular.

The southern Red Sea is characterised by relatively weak currents and small tides. The prevailing waves are not strong with heights ranging from 1-2 meters in the months of January to March. From October to April, the wave directions move towards the east and southeast, while from May to September it is towards south, northwest and north. On shallow coastal areas currents are more influenced by underlying topography.

Since fresh water availability is critical in determining urbanization in the coastal areas, the Eritrean coastline is characterised by very low population density. The population of the coastal areas is estimated to be about 100,000 population, of which 90% reside in the port cities of Massawa and Assab. The major economic activities include port activities, fishing, tourism and trade. At some strategic locations, where flood irrigation is practiced, crop production mainly sorghum and some vegetables are produced, while rearing of animals, mainly camel, goat and some cattle is also an important economic activity.

5.6.2 Impact of Climate Change on Sea Level Rise

The Port City of Massawa was selected to demonstrate the effect of climate change on sea level rise. The Port of Massawa is located almost at sea level and is one of the two ports situated along the Eritrean Red Sea coast. It is formed of different islands, namely Tewalet, Gerar and Green Island. The first two islands are connected to the mainland of Edaga by a landfill bridge (Fig 5.11).

According to the UK89 model, the average increase of temperature, due to doubling of GHG concentrations (2xCO_2 scenario) will be about 4.1 ^{0}C. Taking this situation into account vulnerability analysis has shown that the various parts of Massawa are vulnerable to 0.5 –1.0 meter sea level rise. This poses a potential threat, given the fact that most parts of Masswa are situated ranging from below sea level up to 1.0 m above sea level. Attempts were made to estimate the economic losses that would result if sea level rise of 0.5 m and 1.0 m were to happen in the two main areas of Massawa, namely, Edaga and Tewalet areas. A 0.5 m increase of sea level rise would result in the submerging of infrastructure and other valuable economic installations. This loss has been estimated to be about USD 242,750,000.00 at Edaga area and USD 14,080,000.00 at Tewalet area.

The increase of temperature could also affect the local flora and fauna of the coastal areas. Ecologically, a slight increase in temperature negatively affects the biological equilibrium of marine life. For instance, as corals are very sensitive to slight environmental stress, a slight increase in temperature could cause irreversible damages. Moreover, fluctuations in temperature cause stress on corals by affecting the energy producing algae (Zoozantelle). Increase or decrease in temperature beyond the critical point also impairs proper metabolic activities of invertebrates, particularly fish. Furthermore, increase in temperature also reduces the dissolved oxygen in water, which affects the metabolic efficiency of marine organisms.

Figure 5.11: An overview of the port city of Massawa.

5.6.3 Adaptation Options in the Coastal Areas

The following adaptations options are considered important for mitigating the adverse effects of climate change along the coastal areas.

1. In the coastal areas, various adaptive strategies may be employed, including the retreat, accommodation and protection methods, to mitigate the effects of hurricanes and sea level rise in the coastal areas. Depending on the capacities and specific situations of coastal areas, however, one approach may be better than another. For a sustainable protection of the coastal areas from the adverse effects of climate change the protection approach appears to be feasible for Eritrea. In this connection attempts were made to estimate the prevention costs that may arise due to sea level rise. The construction of walls (steel or concrete) along the entire length

2. of the coastline, up to 25 km to the hinterland where economic activities are being carried out, would cost in the range of USD 50 –500 million, depending on the type of construction materials chosen. Such walls may reach up to 2 meters in height. This appears worth constructing given the potential damage of sea level rise on the economic activities of coastal areas.

3. The development of an integrated coastal zone management plan (ICZMP) needs to be considered, taking into account short- and long-range concerns of climate change. The coastal zone management plan will have to address, *inter alia*, coastal erosion, pollution, and habitat destruction.

4. Coastal vegetation, particularly mangroves could stabilize shorelines and prevents wave erosion. The mangroves provide habitat for wildlife and nursery for many marine species. The destruction of coastal vegetation could thus lead to undesirable imbalances in the coastal ecology. It is therefore extremely important that mapping and evaluation of mangroves and other coastal vegetation is considered in the ICZMP. Efforts are being made by the government to create wetland for mangrove plantations.

5. The discharge of heated water from the cooling systems of power generation plants along urban settlements, a good example being the Hirgigo Power Plant in Massawa, should be properly managed. The water should be cooled before reaching the marine environment. If possible, the water should be circulated to minimize damage to marine life and coastal vegetation, particularly mangroves.

6. The development of appropriate institutional and technical capacities for the establishment of a comprehensive ecological, oceanographic and metrological information system is essential for developing a visionary adaptive strategy of coastal areas. This capacity is now lacking and future coastal adaptation strategies should consider this matter seriously.

5.7 Vulnerability and Adaptation Assessment of Human Health

5.7.1 Overview

In Eritrea there are several climate-related diseases, and the major health problems are communicable and nutritional disorders. The poor water quality and inadequate water supply, lack of sanitation and hygiene are the main reasons for the high prevalence of the preventable communicable diseases. These diseases include diarrhea, malaria, acute respiratory infections (ARI), tuberculosis, eye infections, skin infections etc. These diseases constitute over 50% of all the registered cases in the country. The main causes of ill health in Eritrea include poor environmental sanitation, inadequate and unsafe water supply and poor housing conditions, which might also include the effect of climate change.

5.7.2 Assessment of Impacts of Climate Change on Human Health

An attempt was made to study the impacts of climate change on human health. In conducting the study, first baseline assessment was carried out and secondly some selected sites were used to show the relations between climate change and some other diseases particularly malaria.

The result of the baseline assessment showed that during the past five years i.e. 1995-1999, malaria, ARI, diarrhea, skin and eye infections, tuberculosis and malnutrition were the most common diseases seen at OPDs. Similarly the most common cause of deaths among inpatients in 1999 were ARI (12.7%), diarrhea (10.2%), malnutrition (9.9%) HIV/AIDS (8.9%), malaria (8.5%) and tuberculosis (7.1%). Among these diseases the most important climate related diseases are malaria, ARI, diarrhea and malnutrition.

A total of 13 study sites were selected representing three agro-ecological zones, namely Moist Lowland, Arid Lowland, Sub-Humid and Semi Desert, taking into account accessibility, magnitude of the diseases to be studied, and availability of health facilities with the necessary data for analysis. The results of the specific selected study sites showed that Malaria is an endemic health problem in these areas, becoming an epidemic at times. It affects all age groups but is more serious age group 5 years and above. Over 90% of the malaria cases in Eritrea is *Plasmodium falcipurum* and the main vector is the *Anopheles gambiae*. The highest risk areas of malaria are observed in western and southwestern lowlands while the lowest is in the central

highlands. Malaria is thus the major health problem in Eritrea as it has appeared in more than 10% of all OPD cases almost once every year. Analysis made in the 13 selected study sites has shown that incidence of malaria is higher at lower altitudes with high rainfall. In the majority of cases the period from September to January has the highest incidence of malaria.

The climate change scenario has revealed that there would be a significant increase in temperature and slight increase in rainfall in Eritrea. These environmental conditions may favor the development of Anopheles vectors and hence would have profound effect on the incidence and prevalence of malaria. The appearance of malaria at altitudes close to 2000 meters is a new phenomenon in the country. With increasing temperatures, the malaria altitude belt is likely to increase. The empirical analysis has showed that for each increase in unit of rainfall and temperature there will be increase of malaria cases in the country. Moreover, this could be compounded with the already high incidence and prevalence of diarrhea, ARI and malnutrition.

5.7.3 Adaptation Options in the Health Sector

Adaptation options to mitigate and control the main climate related disease, namely, Malaria, Diarrhea, ARI and Malnutrition, may be treated under three control mechanisms, as follows:

(a) Environmental control option

As far as environmental control is concerned it is anticipated that, among others, improved sanitation, better housing conditions, adequate and safe water supply, avoidance of breeding sites would reduce the incidence and prevalence of the four diseases specified above. To be effective the above-recommended activities need to be integrated with other economic interventions. The measures for eradicating the breeding sites include drainage, filling of holes, water level management, and clearing/burning of refuse found around households. To eliminate poodles, water drainage and/or filling can be done. However, if this cannot be undertaken, the surface water should be kept as clean as possible to avoid breeding of larvae and pupae.

It should be noted that without improved environmental sanitation, better housing condition, adequate and safe water supply, avoidance of breeding sites could not be easily implemented. Hence, these issues should be integrated with other economic activities such as agriculture. In this regard, these should be viewed as complementary to other integrated control strategies rather than replacing other methods.

(b) Biological Control Options

While applying biological control (e.g. in malaria reduction of vector density and parasite rate, improving human immunity and preventing drug(s) resistance) an integrated measure should be applied. This is because of the fact that the four diseases (malaria, diarrhea, ARI and malnutrition) are interrelated. Hence, as a strategy, Integrated Management of Child Illness (IMCI) program of the Ministry of Health (MoH) should to be applied.

A child attending at a clinic with one of the above diseases requires to be fully assessed so as not to miss an opportunity of being treated for the rest of the diseases. The MoH is carrying integrated management of cases (particularly for children) under the IMCI program. Some other biological controls that need to be integrated with other sectors (e.g. agriculture, water sector etc.) activities are microbial insecticides, introducing exotic natural enemies, genetic manipulations etc.

Chemotherapy: Follow up of drug resistance, mainly in the treatment of malaria is a very important measure. In the case of diarrhea, avoiding dehydration by providing Oral Rehydration Solution (ORS), which prevents deaths, is an important mitigation measure. Since diarrhea is a health problem with high recurrent rate (5 episodes per year per child), it is important to provide households with ORS for self-treatment. This would highly reduce mortality rate in children less than 5 years, and it could be integrated into the provision of prophylaxis for malaria and rehabilitation and nutrition centers.

(c) Socio-economic control measures

The socio-economic control measures include strengthening the health systems, (e.g. providing policies, guidelines and resources), taking precautions in initiating economic activities (such as building dams, ponds), pre- planning of immigration, urbanization and educating target groups.

To reduce the high incidence of the health problems an integrated approach of strengthening the health system should be initiated, which includes precautions in initiating economic activities such as building dams, ponds etc, particularly in the area of agriculture and forestry, preplanning of immigration and urbanization and educating target groups.

To smoothly undertake an integrated management of the climate related childhood diseases (malaria, diarrhea, ARI and malnutrition) there is a need of strengthening of the health systems by providing all the necessary resources (human, material, financial and others), guidelines, supportive supervisions, maintenance of trained personnel and clear policies, among others. The management of the above childhood diseases would include not only treatment of cases but also preventive measures such as provision of immunization against the vaccine preventable diseases.

Research Activities

Specific research activities on the following aspects would enhance adaptive capabilities. These would include:

- Research on the vector types, density and patterns of distribution, particularly that of malaria are important. The relationship between altitude, rainfall, temperature and socio-economic aspects of malaria should also be studied.

- Introduction of surveillance systems of health problems, not only the four diseases discussed above, but others like schistosomiasis should also be studied.

- Vector borne diseases and other climate related diseases (e.g. meningitis, cholera etc.) know no boundaries and could spread outside the country very easily if situations are favorable for them. It is therefore important to collaborate with neighboring countries in the control of the spread of such types of diseases.

- Assessment should be made about the cost effectiveness of mitigation measures such as the use of treated mosquito bed nets used for the control of malaria.

- Risk assessment should be carried out for new introductions of drug and chemical treatments.

CHAPTER 6

POLICY MEASURES IN THE CONTEXT OF CLIMATE CHANGE

6.1 Introduction

Although climate change is believed to have affected many aspects of social and economic life at global, regional and country levels since the start of the industrial revolution, the formulation of global and national policies to mitigate the adverse effects of climate change is probably less that 10 years old. Eritrea formally joined global efforts to mitigate climate change when it acceded to the UNFCCC on 25 March 1995. Although the environmental policies and measures constituted thus far many not have specifically addressed climate change as such, these policies, in one way or the other, touch upon climate change issues. In this respect the following are some of the major policy measures taken by the Government.

6.2 Poverty Reduction

Economic development and poverty reduction remain the central goal of the Government of Eritrea, as enshrined in the *Constitution*, through a strategy initially articulated in its Macro-Policy Paper of 1994 and also in its *National Economic Policy Framework and Program* presented in 1998. One of the main elements of this strategy is the investment in rural infrastructure, the development of agriculture and fisheries and the proper management of natural resources, including management of pastures and animal resources and the protection of the environment. In the second half of 2001 Eritrea has also come up with the" *Transitional Economic Growth and Poverty Reduction Strategy*" (PRS), covering the period 2001-2005. The PRS follows a two-pronged approach in its effort to achieve economic growth and poverty reduction. Firstly, for the immediate period 2001-2002 two of the main challenges are to address the immediate needs for humanitarian assistance and the restoration of a stable macroeconomic framework. Secondly, for the medium-term period 2003-2005 the emphasis, among others, will be the development of new export markets, increasing agricultural productivity, achievement of macroeconomic stability and the development of sound financial system.

6.3 Environmental Policy Measures

Since war and recurrent drought caused immense damage to the environment, the government accords environmental issues among the top priorities. In this respect the first measure taken was to formulate macro policy measures, which was elaborated in a Macro-Policy Paper of 1994. Environmental issues constituted a major part of this Policy Paper and a special chapter is devoted to providing policy guidance to environmental protection, including policy guidance on the introduction and development of impact assessment, the conservation of biological resources and the prevention of pollution from wastes. The *Eritrean Constitution* has also emphasized, in the interest of present and future generations, the need of ensuring the management of natural resources in a balanced and sustainable manner.

To implement these environmental policy measures the Government has taken several important steps. To begin with, in 1995 an interim secretariat was established to prepare a National Environmental Plan for Eritrea (NEMP-E) and after an extensive national consultation process among the Eritrean population, the NEMP-E was adopted and published by the Government. Following the adoption and publication of the NEMP-E, the Government established the Eritrean Environmental Agency, as an autonomous body under the umbrella of the Ministry of Local Government. In a Government's restructuring process that took place in 1997, however, the Agency became the Department of Environment under the Ministry of Land, Water and Environment. The Department of Environment is entrusted with the development and elaboration of national policies, programs and strategies on the environment. The proper conservation and utilization of environmental resources cannot be achieved by the activities of one government institution alone, as the issue is complex and vast in scope. In recognition of this, various line ministries and other government institutions address environmental management issues within their portfolios. For example the Ministry of Agriculture addresses environmental issues related to agricultural activities and the Ministry of Trade and Industry addresses issues specific to trade and industry, etc. The Department of Environment, therefore, plays a coordinating role among the various institutions, including the NGOs.

In implementing the NEMP-E several steps have been taken, which the following are important in the context of climate change issues.

6.4 Land Degradation

As has been indicated earlier, forests currently cover only about 2.4 % of the total land area of the country. The loss of forests and vegetation cover means, among others, considerable loss of soil and water through runoff and the loss of habitat to various wildlife populations. The loss of soil and water, which is chronic, has also been the main cause of low soil fertility and hence less agricultural production. The protection of forests and vegetation cover from further depletion and the rehabilitation of degraded lands has therefore been of major concern to the people and Government of Eritrea. Hence a national Forestry and Wildlife Law has been drafted and is waiting approval by the Government. In the absence of such a law, however, the people and the Government of Eritrea have made significant achievements. So far protection of forest and wildlife depend on ad hoc directives and guidance but nonetheless, very efficient and productive system. For example, charcoal making has been banned since 1995 and the cutting of live trees is prohibited unless the concerned village authorities give the permission to do so. Moreover, many forest reserve areas have been identified and any human and animal activities are prohibited from such areas.

In the broader efforts to combat land degradation at the global and regional levels, Eritrea has ratified the Convention to Combat Desertification (CCD) in August 1996. In order to combat land degradation in an integrated manner at the national level, a National Action Plan (NAP) has also been prepared recently and its implementation process is underway.

6.5 The Conservation and Sustainable Use of Biodiversity

Biodiversity resources are critical to increasing food production and to achieving food security in Eritrea. Framing of crops and livestock is an age old practice in Eritrea and the country has diverse endemic crops and livestock. Eritrea acceded to the Convention of Biological Diversity (CBD) on 11 September 1995 to join hands with international community in the conservation and sustainable use of biodiversity. As part of its international obligation and more importantly to meet its development objectives, Eritrea has now put in place its National Biodiversity Strategy and Action Plan (NBSAP). There are capacity limitations to implement the NBSAP but efforts are being made to overcome these gaps through multilateral and bilateral agreements.

6.6 Marine and Coastal Environment

The Red Sea marine and coastal resources are important in fulfilling Eritrea's food and transport requirements and in generating jobs and economic revenue, for example, through fishing and tourism. The Eritrean marine and coastal ecosystems harbor important biodiversity resources, including coral reefs, sea grasses and macro-algae inter-tidily and mangroves and other coastal vegetation sub-tidily. These habitat are often regarded as critical and collectively they:

- Provide diversity at ecosystem, species and genetic levels;
- Provide a habitat and shelter for many species;
- Represent the feeding, breeding or nesting areas for marine and other animals.

In recognition of this potential Eritrea is making an increasing commitment to marine environmental protection and management. For example, in 1998 the Government has initiated a Marine and Coastal Biodiversity Conservation Project in partnership with UNDP/GEF, one of whose aims is the establishment of marine protected areas. Laws have also been promulgated to strengthen these efforts.

6.7 The Development and Introduction of Environmental Impact Assessment Procedures and Guidelines

Pursuant to the policy guidance provided by the Macro-Policy Paper of 1994, and further articulated in the NEMP-E, the Government took the initiative to develop a National Environmental Assessment Procedures and Guidelines (NEAPG), with the financial assistance from the World Bank. The NEAPG was made public in 1999, and, through the application of certain procedures, is intended to determine the potential negative environmental consequences of all development projects. Moreover, the NEAPG is a tool for integrating environmental issues into a planning process.

6.8 Energy and Transport

The energy and transport sectors are critical to the economic growth and development of Eritrea and hence the Government has made considerable effort to develop these sectors.

As has been indicated earlier biomass and imported petroleum products are by far the most important energy sources in the country. The use of biomass resources as the main source of energy does not appear to be sustainable, given the fact that biomass resources are dwindling and also there are many competing needs for it. So the Government, through Ministry of Energy and Mines, has a policy of exploiting the potential of renewable energy sources, including hydro, solar, wind power and geothermal. Recent studies indicated that the potential for developing geothermal energy is significant. Continuous efforts are also being made to ensure that energy is priced at full cost to encourage development of new energy sources, promote efficient energy conservation and to protect the environment.

In the power sector the new Hirghigo Power Plant has boosted total electricity production from 70 MW in 1996 to more than 150 MW by the end of 2001. Efforts are also being made to supply electricity to rural areas at affordable cost from the national grid using low cost technologies and operational procedures as demand grows. For remote villages and communities, renewable energy for electricity, such as PV solar systems, is being pursued. Ways and means to involve the private sector in the supply and expansion of electricity, particularly in the PV solar systems is being explored. The extension of electricity to rural areas will have not only important impact on poverty reduction but also will have a positive impact on the conservation of biomass resources, and hence protecting the land from further degradation.

In brief the main energy policies and strategies of the Government may be summarized as follows:

- Promotion of economically and environmentally sound energy sector development using appropriate technology of energy production, conservation and usage optimization;
- Implementation of appropriate energy pricing structures to avoid all forms of subsidy;
- Diversification of energy sources to reduce the strategic dependence on the dwindling biomass energy resources and imported oil through the promotion of private capital participation in hydrocarbon exploration and developing renewable energy resources potential;
- Modernizing and expansion of power generation and distribution systems and creation of an enabling condition for private sector in energy development and marketing; and
- Developing human capacity through training and establishment of institutional and legal framework so as to competently manage the sector.

In land transport, the Government firmly believes that an efficient transport system is critical to achieving intended development objectives. In the past, both roads and railway lines that existed in Eritrea were among the most improved transport systems in East Africa. Nonetheless, the 30-year war of independence had resulted in total collapse of the transport system and had required massive investment to rehabilitate them.

To revive the land transport system the Government has issued a proclamation (Proclamation No.111/2000), whose main thrust is the development of an efficient public transport system. This is reflected in Eritrea's taxation policy whereby public transport vehicles have nominal tax as compared to privately imported vehicles, which is relatively very high. Since economic activity depends on the smooth and proper networking of roads for the delivery of goods and services, the construction of smooth roads and connecting them to important economic sites has been one of the priority areas of the Government. The re-construction of railway lines, after having been completely destroyed during the liberation war, is progressing using entirely local resources and skills.

Furthermore, Eritrea is considering for regulating the importation of older motorized vehicles, in view if the fact that older vehicles are more polluting to the environment. A proclamation will soon be proclaimed in this connection.

CHAPTER 7

PUBLIC AWARENESS, EDUCATION AND TRAINING

7.1 Introduction

Pursuant to Articles 4 and 6 of the UNFCCC, the importance of public awareness, education and training are well recognized in the mitigation of the adverse effects of climate change and Parties to the Convention are requested to take appropriate measures in this regard. The following are efforts made by Eritrea in the areas of public awareness, education and training, which in one way or the other are related to mitigating the effects of climate change and to the protection of the environment at large.

7.2 Public awareness

Eritrea is located in one of the most vulnerable regions of the world to the adverse effects of climate a change and the adaptive strategies that have to be developed to counteract these effects are complex and wide in scope. The level of knowledge about these issues may be poorly understood by the general public, which remains a challenge to the government at large and to the concerned institutions in particular, such as the Ministry of Land, Water and Environment, which is spearheading the climate change issues in the country. So far Eritrea has made considerable progress in raising public awareness, but nonetheless many challenges still remain ahead.

The following are some of the major steps taken in public awareness activities:

- In the process of preparing the National Environmental Management Plan for Eritrea (NEMP-E) there was extensive consultation among the Eritrean population about the protection and judicious use of environmental resources, including the adaptive measures, which have to be taken to cope up with the declining resource base of the country.
- Selected written materials about climate change issues and its adverse effects are being prepared for broadcast by radio and newspapers. The Ministry of Land, Water and Environment and the Ministry of Education have been active in this respect.
- The preparation of Eritrea's initial national communication was a good opportunity for increasing awareness about climate change issues to many stakeholders. It gave opportunities for organizing workshops and the dissemination of written materials to concerned institutions about the issue of climate change.

7.3 Education and Training

Education and training, both formal and informal, are critical to the protection of environmental resources for a sustainable use. During the last few years environmental issues have gained considerable attention by the training institutions of the country, particularly the Ministry of Education and the University of Asmara.

Formally the Ministry of Education recognizes the importance of including environmental education in the national educational system. Thus far efforts were made to elaborate environmental education at the secondary school and teacher training institutes. More work is being expended to further define and elaborate environmental education in the national education system. This is being done in collaboration with concerned institutions, such as the Ministry of Education, the Ministry of Land, Water and Environment, the Ministry of Agriculture and the University of Asmara. Informally the Ministry of Education has also a regular radio program for adults about the protection of the environment for sustainable use. This is part of the national program to increase the level of awareness of the general public about the management of natural resources.

The University of Asmara is also putting emphasis in the inclusion of environmental issues under the various degree programs of the faculties of the University. The College of Agriculture and Aquatic Sciences (CAAS), for example, has opened a new department, namely the Department of Land Resources and Environment, which will cater for addressing environmental issues in CAAS. Moreover, the Department of Geography has courses on climate issues and other related courses. The Ministry of Land, Water and Environment and the University of Asmara are in the process of discussing the issue of institutionalizing environmental issues in the University, by establishing a separate environmental institute in the University at diploma or certificate level as appropriate.

CHAPTER 8

RESEARCH AND SYSTEMATIC OBSERVATION

8.1 Systematic Observation in Eritrea

As opposed to most developing countries, Eritrea has passed through successive colonial powers. One of the legacies of Eritrea's colonial history is that, Eritrea inherited neither well-developed infrastructure nor the institutional framework for systematic data collection and documentation of climate, natural resources and the environment. Few and fragmented data on climate and natural resource were collected during the Italian colonial era. These limited and uncoordinated efforts were sporadic in time and space with limited scope to satisfy small-scale resource exploitation activities at that time. Nonetheless, they generated climatic records of varying lengths for a few locations of the country. Yet these records have gaps that pose serious questions regarding their reliability. Because of this the quality of these database and the infrastructures that generated them were inadequate to lay the foundation for a national climate observation system.

Since independence in 1991, the of the Ministry of Transport and Communications (Civil Aviation Department), the Ministry of Land, Water and Environment (Water Resources Department), and the Ministry of Agriculture have each established many of meteorological stations at selected sites. These stations were put in place to generate data needed for the respective institutions. Most of the attributes such as the location, distribution, and type of instruments used in each of these stations do not satisfy the requirements for a national observation network. Consequently data sharing among the three institutions need to be improved in terms of standardization and exchange of database.

The meteorological stations put in place, doubtless put a firm foundation for future network. The establishment of an efficient and effective national climate and resource information system requires planning, management and co-ordination. The responsibility of such a system will be to create a national meteorological center in the country.

Climate change is relatively a long process and comparatively not well understood. It takes time and resources to systematically record it and understand its consequence. To this end a continuous monitoring and the collection of up to date and reliable information will have be gathered for analyses and follow up. In this case, the national meteorological agency will have to concentrate on important indicators that provide information on climate change. The crucial climate change indicators that will be monitored include temperature, rainfall, relative humidity, solar radiation, wind speed and direction, discharge rate, cloud cover, evapo-transpiration, dissolved oxygen and tides etc.

Water resources conditions and coastal environments are to a large degree controlled by climatic conditions and changes thereof. Thus, variations in hydrological cycle and sea level positions reflect not only the magnitude and severity of causative climatic changes, but also provide a measure of the impact of such changes on the hydrological cycle. In its nascent stage, hydrometric data collection is encouraging. To study the national water resources and irrigation potential, the Water Resources Department has established several hydrometric stations in the major watersheds. At each station, stream flow, water quality and sediment yield has been automatically monitored since 1997. Additional monitoring sites will be identified for similar observations to cover national network coverage of water resources assessment.

To date, there is no coastal zone monitoring system in the country. The Water Resources Department is preparing an initiative for a national groundwater-monitoring program, in addition to the on-going surface water- monitoring program. Much of the limited hydro-meteorological data collection activities in Eritrea rely on field equipment with a capability for automatic data recording. Such data are physically transferred to the office with the help of downloading computer facility. Nevertheless, the country needs to introduce technology for the acquisition of real-time data and computerized systems to facilitate access to national, regional and international databases.

The type and amount of data analyses presently carried out by the various ministries need to be standardized to meet the demands of the users. The limited data processing and analyses carried out by the various agencies are supported with state-of-the-art software. In the future, data collections and dissemination of raw and processed data should be carried out using modern communication technology such as Internet facilities. The country can, with proper planning and investment levels, take advantage of the latest information technology to establish and operate a national observation system. This effort is believed to save time, effort and resources. The requirements and potential difficulties of such an undertaking to poor nations like Eritrea cannot be underestimated.

The establishment of an efficient observation system that supports national development planning entails important requirements, which must be, satisfied *a priori*. These include:

- Establishment of a strong and effective institution to manage a national observation system;

- Development of human resources capacity in technical, scientific and managerial aspects;
- Introduction of state-of-the-art communication and information technology; and
- Investment to satisfactory levels of capital to support these and related efforts.

In spite of financial difficulties, Eritrea is committed to meet these national requirements. To these end the country seeks technical and financial assistance in its endeavours from bilateral, multilateral and international organisations. The country also aspires to be a member of regional and international climate agencies. This would help the country to integrate and participate in their observation networks and joint programs.

8.2 Research on Climate Change

Research is one of the top priorities of the Government of the State of Eritrea. To strengthen its research capability, the government has embarked upon a national human resources development program to train young scholars in various disciplines. To this end, there are short and long-term research programs in line with the availability of human resources. In the short term, it is anticipated that research should focus on applied type of research mainly focusing on data collection and monitoring on climate related issue. In the long-term, however, it should be necessary to embark in high-level research on climate change and the environment.

In the meantime, the present levels of human and institutional capacity, physical infrastructure and technology as well as existing information should be upgraded. In the short-term, the country would be embarking in data collection and analyses to address the immediate social and economic development planning of the country. These efforts would support:

- Development of tentative policy guidelines;
- Formulation of natural resources management strategies;
- Protection and preservation of the environment;
- Mitigation of natural hazards and to set up an early warning system; and
- Establishment and design criteria for hydraulic structures.

While engaged in these short-term efforts, the country should undertake the long-term task of creating the enabling environment for advanced research on climate and the environment by building the capacities and capabilities outlined in the preceding section.

CHAPTER 9

FINANCIAL AND CAPACITY NEEDS

Pursuant to Article 4.7 of the Convention, the full participation of developing country Parties, including Eritrea, in implementing the Convention will depend on the financial resources and technology transfer requirements provided by developed country Parties. As has been indicated earlier Eritrea is one of the most vulnerable countries of the world, mainly because of its geographical location and more importantly because of its low adaptive capacities to the adverse effects of climate change. The main preoccupation of Eritrea is to achieve a satisfactory level of food security and poverty reduction. All adaptation strategies to climate change should therefore fit in with this objective. This is quite a complex undertaking requiring a whole range of issues including financial, institutional, technical and human resource capacities, which is extremely lacking in Eritrea. The following are some of the important capacity gaps (not listed according to priority) to be addressed for allowing Eritrea to implement its commitments under the UNFCCC.

1. Strengthen the national focal point and the national climate change secretariat. A national core planning team, drawn from relevant institutions, has already been established, but it should be strengthened, *inter alia*, in terms of networking of information, acquisition of equipment and in information technology.

2. Support to preventive measures, including planning preparedness of disaster relating to climate change, such as droughts and floods in areas prone to weather.

3. Financial and technical assistance, including training, to develop national climate and resource information systems. These include

    - Climate and meteorology, water resources and hydrology (monitoring and estimation of rainfall distributions and the impacts on surface runoff, soil moisture and ground water infiltration and recharge);

    - ecology and agriculture (monitoring vegetation, land use changes, agricultural production, rangelands and forest/bushland);
    - energy resources (estimation, monitoring and forecasting solar energy resources, wind energy resources, biomass resources and domestic energy demand);

- marine resources (monitor and estimate Red Sea winds, currents, sea surface temperatures and sea level rise).

4. Financial and technical support for undertaking research and development about the use of sustainable energy resources, including solar and wind energy and also in the areas of energy efficiency and conservation.

5. Financial and technical support to undertake assessment for short and long term adaptation programs on agriculture (including crop and livestock production), land management, water resources, coastal zone and fisheries, infrastructure development, human health, energy and transport. Some of the adaptation programs for agriculture, water resources, forestry, coastal zone and human health have already been identified and included in this report (Chapter 5) but more work needs to be done in the future.

CHAPTER 10

IMPLEMENTATION

The implementation process of the UNFCCC in Eritrea is based on broad participation of all relevant stakeholders, including line ministries, the University of Asmara, the private sector, civil societies and non-governmental organizations. The Ministry of Land, Water and Environment, represented by the Department of Environment, the National Focal Point for the UNFCCC, coordinates national efforts. In this respect a national steering committee, known as the National Core Planning Team has been established to coordinate and harmonize national efforts in the process of implementing the Convention. The preparation of Eritrea's initial national communication was a good opportunity for documenting Eritrea's experience in the implementation process of the Convention.

For an effective and smooth implementation of the Convention in the country it is intended in the future to establish a strong National Climate Change Secretariat (CCS), which will be housed in the Department of Environment. The CCS, among other things, will provide information to all stakeholders and under the guidance of the Department of Environment and the Core Planning Team monitor the implementation process of the Convention. Its establishment and sustainable functioning will, however, largely depend on external funding.