REPUBLIC OF THE SUDAN

Ministry of Environment & Physical Development

Higher Council for Environment and Natural Resources

Sudan's First National Communications under the United Nations Framework Convention on Climate Change

Volume I:
Main Communications

February 2003

Acknowledgments

Though not all who have assisted the HCENR in the production of Sudan's first National Communication Report can be acknowledged here, there are many individuals who deserve particular recognition due to their valuable contributions to the preparation of this First National Communications..

His Excellency Major General BSC (Ret.) Eltigani Adam ElTahir, Minister of Environment and Physical Development, has been continuously supportive of all project activities and a major contributor to meetings of the Conference of the Parties. Without his Excellency's unceasing interest, much of the progress of the project would have been impossible.

His Excellency Mohamed Tahir Eila, Minister of Roads and Bridges and ex-Minister of Environment & Tourism provided valuable assistance during the first 18 months of the project. Dr. Babiker Abdalla, Ex-Secretary General of HCENR, provided valuable leadership.

Special thanks also go to members of the project's Technical Committee, as without them much of the project's accomplishments would have been impossible. Thanks are also extended to all stakeholders of the project and in particular the Ministries of Energy and Mining, Agriculture, Health, Finance, the Forests National Corporation, the Meteorological Authority, the Institute of Environmental Studies at the University of Khartoum, the University of Elneileen, the Sudanese Environment Conservation Society, the Industrial Chamber of Commerce and all national experts and resource persons involved. These and many others contributed valuable throughout the course of the project.

Thanks are also extended to Mohamed Ali Omer, Yassin Eisa, Hassan Gaafar, Alla' Moheildin from the Ministry of International Cooperation for their continuous support to the execution of this project. Special thanks are due to the UNDP-Khartoum - in particular Ms. Intisar Ali Salih, A. Abudeik, Amir Baker and Ms. Shamma Mekki for their untiring efforts and continuous support. Thanks should also be extended to our technical support partners, SEI-Boston. Deserving special thanks are Dr. Bill Dougherty and Erika Spanger-Siefried. Without their continuous technical support the project would have been impossible.

Thanks are also extended to the following individuals provided input and guidance to Sudan's National Communications: Charlie Heaps and Michael Lazarus, Stockholm Environment Institute-Boston Center/Tellus Institute, USA: input on greenhouse gas (energy sector) mitigation methods and tools; Willy Makundi, Lawrence Berkeley National Laboratory, USA: input on the greenhouse gas inventory (land use and forestry) and training in mitigation assessment (non-energy); Pim Martens, Maastricht University, Netherlands: input on the malaria assessment; Caxton H. Matarira, Environment & Remote Sensing Institute, Zimbabwe: training in vulnerability and adaptation assessment methods and tools; Steve Meyers, Lawrence Berkeley National Laboratory, USA: input on the greenhouse gas inventory (energy use); Joel Smith and Brian Hurd, Stratus Consulting, USA: input on V&A assessment methods and approaches; and John Stutz, Carrie Gilbert, and Mark Stoughton, Tellus Institute, USA: for their input on the greenhouse gas inventory (solid waste, industrial processes)

We extend our gratitude and great appreciation to Dr. Nadir Mohamed Awad, Secretary-General of the HCENR and our colleagues and the staff of the HCENR and sister projects who participated fully in the implementation of this project.

Many people from UNFCCC - project coordinators from different countries - contributed to this report through experiences sharing information exchange in particular thanks go to Bo Lim and Rebecca Carmen /NCSP for their continuous follow up and technical support.

Last but not least, thanks go the core staff of the project for their untiring efforts. Deserving special recognition are Nagmeldin Goutbi, Environmental Management Specialist, Ms. Balgis Mohd Elhassan, Information Specialist, Ms. Manal Ahmed A. Gabar, Executive Secretary, Ms. Khalda Nour Eldeen & Elghali Atwa, Accountants, and Siddig Mohamed, driver. Anisa Victoria Dougherty assisted in the final copyediting of the Communications.

Ismail Elgizouli
Project Coordinator,
UNDP/GEF Climate Change Enabling Activity Project
Higher Council for Environment and Natural Resources
Khartoum, Sudan
February 2003

Preface

Sudan is concerned about climate change. Our vulnerable ecosystems, on which the vast majority of the population depends, already suffer from recurrent droughts, overuse of marginal lands, and dominance of biomass use for energy. Even small changes in climate will have adverse effects on crop, grassland, and forest production because of the fragility of our production systems. Thus, despite the fact that Sudan contributes an extremely small amount of greenhouse gases to the atmosphere compared to the rest of the world, the impacts of climate change in this largest of African countries, are likely to be disproportionately large.

The Sudanese government and people realize that there is little they can do to prevent global warming. Yet, they also realize that effective measures to address this most pressing threat to the planet need to enlist the cooperation of all countries, North and South, East and West. This is why Sudan has both ratified the Framework Convention, signifying its commitment to the global environment and principals of sustainable development, and has been an active participant in negotiations at the Conference of Parties. It is in this spirit, that Sudan is submitting this first National Communication.

Several organizations and ministries have contributed towards the production of this initial Communication. In Sudan, the Climate Change Team led by Ismail El Gizouli conducted the background studies and prepared the initial draft and further revisions leading to this report. Funding for carrying out the enabling activities to produce the report were provided by the Arab Bureau at the Global Environment Facility. Technical assistance was provided by the Stockholm Environment Institute – Boston Center. On behalf of the Sudanese government, it is an honor for me to express to them all my appreciation and gratitude.

Dr. Nadir Mohammed Awad
Secretary-General,
Higher Council for Environment and Natural Resources
Khartoum, Sudan
February 2003

Contributors

Chapter 1: Sudan's National Circumstances

Ismail Elgizouli *(Project Coordinator)*
Nadir M. Awad, PhD *(Secretary-General, HCENR)*
Nagmeldin Goutbi *(Assistant to the Project Coordinator)*
Balgis M.E.Osman *(Assistant to the Project Coordinator)*
Osman ElToum, PhD
Sayed Darman Kaffi
Fadl Allah E. El Sayem
Elsadig Mahgoub, PhD
Jamal Osman Abu Bakr
Hala M.Salih
Nadia Hassan Omer
Rehab Abdel Mageed
Tawasul Ahmed Kashif

Chapter 2: Greenhouse Inventory

Management and integration:	Ismail Elgizouli
	Nagmeldin Goutbi
	Balgis M.E.Osman
Land use change and Forestry:	ElNour El Siddig, PhD
	Abdel Azzim Yassin, PhD
	Ali Eisa Ahmed
	Rehab Ahmed Hassan
	Nadir Abdel Hamid Mohd
Energy Group:	Hassan Nimir, PhD
	Hassan Wardi, PhD
	Salah Eldin Ali M. Nour
	ElFadil Braima
	ElRabei Mohamed Tahir
Waste:	Dr. Mohammed A. ElRafie
	Dr. Somaia Alsayed
	Ali Osman Elsheikh
	Rehab Omer Karrar
	Imad ElDin Mahgoub
Agriculture:	Dr. Mirghani Ibnoaf
	Asia Adlan
	Aziza El Tayeb
	Maha Mohammed Elwidaa
	Nour Eldin Ahmed Abdalla

Industry:	Adam Musa, PhD
	Faroug Ismail
	Ms. Salwa Elsadik

Chapter 3: Vulnerability and Adaptation Assessment

Development of baseline and climate change scenarios:	Ismail Fadl El Moula Mohammed
	Ahmed M. Abdel karim
	Nourelden Ahmed Abdalla
	Dr. Abdalla Khyar
Agriculture and Forestry:	Izzat Mirghani Taha
	Sayda Mohamed Elhassan Fadul
	Osama Taj Elsir
	Amna Ahmed Hamed
	Nagmeldin Goutbi
	Nadir Abdel Hamid
	Ilham Elsadig Ahmed
	Muna Ahmed Abd- Elmagid
Water resources:	Ismail Fadl Almoula
	Noureldin Ahmed Abdalla
	Tagreed A.Rahim Mohamed
	Nagmeldin Goutbi
	Balgis M.E.Osman
Public health:	Balgis M. E. Osman
	Ahmed A. Alkareem
	Rehab Omer Mohamed
	Salah ElDin Mubarak Elkalifa

Chapter 4: Greenhouse Gas Mitigation Initiatives:

Energy:	Ismail ElGizouli (Study Team Supervisor)
	Balgis M.E.Osman
	Salah A. M. Nour
	Huda AlKhangi
	ElRabie M. Tahir
	Al Fadil Braima
	Faroug Ismail
	Gamal Osman
Non-energy:	Elnour Elsiddig (Study Team Supervisor)
	Nagmeldin Goutbi
	Nada Babiker
	Dunia Khalafalla
	Sawsan Khair Elseed
	Rehab Ahmed Hassan
	Ali Issa

Chapter 5: National Implementation Strategy
Ismail El Gizouli
Nagmeldin Goutbi
Bill Dougherty

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Bcm	billion cubic meters	IPCC	Intergovernmental Panel on Climate Change
BMRC	Bureau of Meteorology Research Centre	ITCZ	Inter-tropical Convergence Zone
CFL	Compact florescent light	km^2	Square kilometer
CH_4	Methane	kV	kilovolt (10^3 volts)
CNS	Comprehensive National Strategy	kTOE	kilotonnes of oil equivalent (10^3 TOE)
CO	Carbon monoxide	kWh	kilowatt-hour (10^3 watt-hours)
CO_2	Carbon dioxide		
COMAP	The Comprehensive Mitigation Assessment Process model	LUCF	Land Use Change and Forestry
CV	Coefficient of variability	LEAP	Long-range Energy Alternatives Planning System model
DSM	Demand Side Management		
EF	Emission Factors		
EIA	Energy Information Agency	LPG	Liquid petroleum gas
FAO	Food and Agriculture Organization	m^2	Square meter
		MEM	Ministry of Energy and Mining
Feddan	0.42 hectares		
FNC	Forest National Corporation	MIASMA	Modeling Framework for the Health Impact Assessment of Man Induced Atmosphere Changes
GCM	General Circulation Model		
GDP	Gross Domestic Product		
GEF	Global Environment Facility		
GFDL	Geophysical Fluid Dynamic Laboratory	MW	Megawatt
		N	North
GHGs	Greenhouse Gases	NCS	National Comprehensive Strategy
Gg	10^9 grams		
GJ	Gigajoules (10^9 Joules)	NCSP	National Communications Support Programme
gm	gram		
GOS	Government of Sudan	NEA	National Energy Administration
GWh	Gigawatt-hours (10^9 Watt-hours)		
		NG	Natural gas
GWP	Global warming potential	NGO	Non-governmental organization
Ha	Hectare (note: 2.37 feddans per hectare)		
		NIT	National Inventory Team
HADCM2	Hadley Centre Unified Model 2	NMVOCs	Non-methane volatile organic compounds
HC	Hydrocarbons	NO_X	Nitrous Oxides
HCENR	Higher Council for Environment and Natural Resources – Sudan	NPV	Net Present Value
		OECD	Organization for the Economic Co-operation and Development
HFCs	Hydrofluorocarbons		

O&M	Operation and maintenance
P	precipitation
PET	potential evapotranspiration
PV	Photovoltaic
R&D	Research and development
Ret.	Retired
RET	Renewable energy technology
RPA	Range and Pasture Administration
S	South
SWDSs	Solid waste disposal sites
SO$_2$	Sulfur Dioxide
SO$_x$	Sulfur Oxides
SEI-B	Stockholm Environment Institute – Boston Center
T	temperature
tC	tones of carbon
TJ	Terajoules
TOE	Tonnes of oil equivalent
tonne	10^3 kilograms
TP	Transmission potential
UN	United Nations
UNDP	United Nations Development Programme (UNDP)
UNFCCC	United Nations Framework Convention on Climate Change
UNITAR	United Nations Institute for Training and Research
V&A	Vulnerability and Adaptation
WSI	Water Satisfaction Index

1 Sudan's National Circumstances

Sudan, the largest country in Africa and the Middle East, is a nation of dynamic social and ecological systems as well as a plethora of accompanying challenges. In this chapter, the country's main characteristics are outlined in an attempt to provide readers with a sense of the context in which Sudan's climate change challenges need to be seen.

1.1 Geographic Profile

Sudan encompasses an area of about 250.6 million hectares, bounded on the east by the Red Sea and on the other sides by nine African nations: Eritrea and Ethiopia to the East, Kenya, Uganda, and the Republic of Congo to the South, the Central African Republic and Chad to the West, and Libya and Egypt to the North. The country is divided administratively into 26 States. It is composed of vast plains interrupted by a few widely separated ranges of hills and mountains. The most important ranges, which attain elevations of over 3,000 meters, are Jebel Marra in the West and the Imatonge in the extreme southeastern part of the country. The Sudan lies within the tropical zone between latitudes 3º and 22º North and longitudes 22º to 38º East.

1.1.1 Land use

Table 1.1 shows land-use in Sudan. Arable land constitutes about one third of the total area of the country, however only 21% of this arable land is actually cultivated. Over 40% of the total area of Sudan consists of pasture and forests. Natural pasture provides grazing land for nearly all livestock. The annual production of animal feed is estimated at 78 million tons of dry matter. Production is subject to fluctuations from one year to another, affected by varying quantities of rainfall and fire hazards. Forests and woodlands are used to meet the population's demand for consumption of wood products, estimated at 16.8 million cubic meters in 1996. Forests are exposed to continuous removal and clearance either for agricultural expansion or for fire wood consumption.

Table 1.1: Land Use in Sudan

Item	Area (000 hectares)
Total area	250,429
Land area	237,443
Area under water	12,986
Arable land	84,034
Cultivated land	17,471
Uncultivated land	66,563
Forest and wood land	64,360
Other	49,569

Source: Administration of Statistics and Information (1995)

1.1.2 Ecosystems

Sudan's landscape consists primarily of gently sloping plain, with the exception of Jebel Marra Massif, Red Sea Hills, Nuba Mountains, and the Imatong Hills. The country is traversed by

9000 km of the Nile River and its tributaries. These have created diversity in soil types; their influence on the hydrologic cycles also influences rainfall. The country's land and water sources can be divided into the five following ecosystems:

- *Arid and semi-arid ecosystems* constitute more than half the area of the country. It is comprised of the following vegetation belts: desert, semi-desert, low rainfall savannah and montane vegetation in the Red Sea hills of Eastern Sudan, and in Jebel Marra and Meidob Hills of Western Sudan. The desert area covers about 700,000 km^2, while the semi-desert area covers 478,000 km^2. Vegetation of the semi-desert area include *Acacia tortilis* and *Maerua crassifolia* desert scrub.

- *Low rainfall savannah on clay* is comprised of the following vegetation belts: *Acacia mellifera*, thorn land, *Acacia seyal*, *Balanites aegyptiaca* and *anogeissus*, and *Combretum hartmannianum* in the savannah woodlands. The total area of low rainfall savannah on clay is about 122,000 km^2.

- *Low rainfall savannah on sand* covers an area of about 83,000 km^2 which has the following vegetation belts: *Acacia senegal*, *Combretum cordofanum, Sclerocarya* and *Anogeissus* spp.

- The *high rainfall* zone covers about 120,000 km^2, and there are about 14,000 km^2 of high rainfall savannah woodland, which was once rainforest.

- The *flood area* covers 85,000 km^2, and *montane vegetation* covers an area of about 2,500 km^2.

1.2   Climatic Profile

1.2.1   Climatic Zones

Sudan is characterized by a wide range of climate variations which vary from desert in the northern part of Sudan, where it seldom rains, through a southward belt of varying summer rainfall, to an almost equatorial type of rain in the extreme southwest, where the dry season is very short. In central Sudan the following division of seasons can be observed; the duration of these seasons vary with latitude[1]:

1.2.1.1   *Winter or Dry Season (December - February)*

- Rainy or monsoon season (June - September),

- Advancing monsoon season (March - May),

- Retreating monsoon season (October - November), and

- This classification might not be applied to the extreme Southern Sudan, where we have two peaks of rainy season.

---

[1] The above classification does not apply to the extreme south of Sudan, where two peaks in the rainy season occur. In the case of Red Sea Hills and the coastal plain, the main rainy season takes place during autumn and winter.

1.2.2   Temperature

Sudan is a tropical country with mean annual temperatures varying between 26°C and 32°C, except for the elevated points of the Imatonge in the extreme south of the country (Negishot 18.1°C), Jebel Marra in the West (Nierteti 22.6°C), and the Red Sea mountains (Erkowit 22.8°C). The hottest areas, based on mean annual temperatures of 32°C, lie within the northern parts of central Sudan, within the geographic triangle of Atbara, Kassala, and Khartoum, decreasing in all directions outside of this triangle, particularly towards the northwest. The highest temperature on record was 49.1°C in June of 1978, at Dongola, and the lowest was -1°C in December of 1961 and January of 1962, at Zalingei (Jebel Marra). The hottest and coldest months vary according to latitude. The hottest month in the extreme south of Sudan is March, while the hottest months at latitude 10°N, 14°N, and 20°N are April, May, and August, respectively. The coldest month in the extreme southern Sudan is August, while at 10° N it is July, and at 12°N, January.

In the extreme north of the country, the weather has changed very little in the region of Lake Nuba, following the construction of the Aswan High Dam. However the mean maximum temperature has dropped by about 2°C at Wadi Hallfa, while the mean minimum temperature has increased by about 1°C during the month of January.

1.2.3   Rainfall

Water has a special role in arid and semi-arid regions like Sudan. Rainfall, which provides much of the available surface water and supports most of the country's agricultural activity, varies significantly from the northern to southern ranges of the country. Annual rainfall in the northern half of Sudan varies from close to zero near the border with Egypt, to about 200 millimeters around the capital Khartoum. Where it rains, the rainy season is limited to two or three months with the rest of the year remaining virtually dry. Moreover, the rain usually comes in isolated showers, which are highly variable in time and location, with a coefficient of variation ranging between 40% and 60%. In the quarter south of the country's center, the annual rainfall rarely exceeds 700 mm. Rains in that quarter are concentrated in less than four months of the year with a coefficient of variation between 20% and 40%. In the southern most quarter, where the annual rainfall exceeds 700 mm, the area is dominated by swamps and inhabited by the tsetse fly, which is hazardous to human and animal life. The erratic nature of rain, and its concentration in such a short season, creates a vulnerable situation, especially for rain-fed agricultural areas. The variation in rainfall is reflected in the following vegetation zones:

- **Desert:** 0 – 75 mm (comprising roughly 36% of Sudan's land area),

- **Semi-desert:** 75 – 300 mm (roughly 20% of land area),

- **Low rainfall savannah:** 300 – 900 mm (roughly 24% of land area),

- **High rainfall savannah:** 900 – 1,500 mm (roughly 12% of land area), and

- **Flood plains and mountain vegetation:** 500 – 2,000 mm (roughly 8% of land area).

Rainfall is influenced by the behavior and nature of the Inter-Tropical Convergence Zones (ITCZ) which itself is controlled by atmospheric pressure over, and near, the African continent. The ITCZ is the zone that separates the dry northerly wind from the moist south to southwesterly winds. It oscillates north and south, following the apparent movement of the sun. South of the ITCZ, the weather is humid with occasional rainfall.

1.2.4 Extreme Events

Drought is one of the most important natural phenomena that Sudan faces. Recurring series of dry years has become a normal phenomena in the Sudano-Sahel region. There are two types of droughts: the first is widespread drought, which is caused by below normal rainfall across the country; the second is localized drought that affects only some parts of the country.

Between 1961 and 1998, episodes of drought have inflicted Sudan with varying severity. This period witnessed two widespread droughts during 1967-1973 and 1980-1984 - the latter being the more severe. The same period witnessed a series of localized droughts during 1987, 1989, 1990, 1991, and 1993, mainly in western Sudan (Kordofan and Darfur) and parts of central Sudan.

A key example of localized drought is that which affected western Sudan (Geneina and Nyala) in 1996. This region reported below normal rainfall while central and eastern Sudan were above normal.

The most vulnerable are the farmers in the traditional rainfed sector of western, central, and eastern Sudan, where severity of drought depends on the variability of rainfall both in amount, distribution and frequency. The most heavily affected are the northern Kordofan and Darfur states.

Drought is threatening the existing cultivation of about 12 million hectare of rainfed, mechanized farming and 6.6 million hectares of traditional rainfed lands. Pastoral and nomadic groups in the semi-arid areas of Sudan are also affected.

Despite the prevalence of drought hazards, floods also affect Sudan. As with drought, two types of floods affect the country: localized floods, caused by exceptionally heavy rainfall, and runoff (flash flood) and widespread floods caused by overflow of the River Nile and its tributaries.

Floods in both forms are highly unpredictable due to the nature of rainfall variability in time and space. The Ministry of Irrigation and Water Resources can monitor the Blue Nile, which is the main cause of the floods, once it enters Sudan territory. However, localized flash floods, which occur during the months of August and September, are associated with above normal rainfall and are more difficult to monitor. In the last 38 years, floods caused by localized heavy rainfall affected parts of central, eastern, and western Sudan during the years 1962-1965, 1978-1979, 1988, 1994, and 1998. Even in northern Sudan there were cases where heavy rain caused localized floods (e.g., October 1999). The most vulnerable groups to both forms of flooding are people who live in low lands and along the riverbanks.

Of the most severe floods recorded for the River Nile (1878, 1946, 1988, 1994 and 1998) three occurred within the past fifteen years.

1.3 Water Resources

1.3.1 Surface Water and Groundwater

Surface and groundwater resources are available in Sudan but are generally shared with neighboring countries. Ten countries, namely Burundi, Democratic Republic of Congo, Eritrea, Ethiopia, Egypt, Kenya, Rwanda, Sudan, Tanzania, and Uganda, share the Nile, which is the dominant surface water supplier. The three main non-Nile streams are also shared with these neighbors. These are the Gash and Baraka, which come from Eritrea, and the Azum, which flows to Chad. Likewise, the Nubian sandstone aquifer is shared with Egypt, Libya, and Chad.

Although 60% of the Nile basin falls within Sudan, the country's share is 22% of the Nile waters according to the 1959 agreement with Egypt. Seasonal streams flow for hours or days during the rainy season. Their flow comes in flushes, which vary considerably in magnitude depending on the nature of the rains. Their total annual flow ranges between 3 and 7 billion cubic meters (bcm), with flow from the Gash, Baraka, and Azum totaling one third of this amount. Sudan's groundwater storage is not yet quantified to a reasonable accuracy. However, annual recharge is estimated to be around 4 bcm. Thus the flow of the seasonal streams and the recharge of groundwater are just under 10 bcm in most years. When this is added to Sudan's share of Nile waters, which is 20.5 bcm, the sum of water resources available to Sudan is estimated at around 30 bcm. As the current population of Sudan is about 30 million, available per capita water is around 1,000 cubic meters. Hence, Sudan is beyond the threshold of water scarcity and is entering the range of water stress.

The possibility exists to increase the Nile yield by, for example, conserving water that evaporates in the southern swamps. However, there are generally environmental and social costs for such actions. Moreover, such savings have to be shared with Egypt, according to the 1959 agreement. Sudan's share of any savings would soon be taken up by the current 2.8% annual increase in population.

1.3.2 Water Demand

Sudan is endowed with vast areas of arable land, totaling 84 million hectares. As potential evaporation and evapotranspiration ranges between 1,000 and 3,000 mm per year, one hectare of seasonal crop requires 12,000 m^3 of water. The 30 bcm available from internal and external water resources would cover 2.5 million hectares, which is 1% of the area of the country and less than 5% of its arable land. If cropping intensity is increased by rotating more than one crop on the same plot, or expanding perennial crops, the area that can be irrigated will shrink. As water is used for purposes other than irrigation, water is bound to be stressed even further.

Despite the situation of water stress, Sudan has been utilizing just over half its available water since the 1970s, mainly because of limited storage facilities. Most of the Nile flow comes from the Blue Nile and Atbara during the flood season from July to October. As this flow is heavily loaded with silt and debris, reservoirs along these rivers are kept at their minimum operating level to bypass the heavily silted water. Filling of the reservoirs usually starts after the flood peak has passed and the flow and silt content have fallen below a certain threshold.

The existing storage facilities hold around 30% of the country's share in the Nile waters. Although some operational measures have been taken, storage in the Roseires and Sennar reservoirs on the Blue Nile, and in Girba on Atbara River, have been gradually reduced by siltation. Efforts are underway to heighten the Roseires dam to more than double its storage – a move that would raise the available storage capacity to around 45% of the country's share. Unfortunately, the heightening process is proceeding at a very low pace due to the current economic hardship and the meager international assistance.

Flow from seasonal streams is variable in quantity, duration, and turbidity. Although storage is restricted by such limitations, it seems to be the most reasonable option for meeting human and animal needs in areas far removed from the Nile. Abstraction of groundwater is costly as most of aquifers are located at depths of 40 to 400 meters. Nevertheless, this is the main source of water in many dry areas away from the Nile.

The current total annual water extracted is about 16 bcm. Around 94% of that total is consumed in the agricultural sector, 5% for human and animal needs, and 1% for industry uses. It is anticipated that these percentages will change considerably in the next 25 years - the shares are expected to be roughly 69% for agriculture, 18% for industrial and hydropower requirements, and 13% for human and animal needs.

1.3.3   Water Quality

Water quality tends to deteriorate during the dry season when flow is low, and during the flood time when sediment concentration is high. Attenuation of water and growth of waterweeds in the swamps and lakes of the White Nile also affect the quality of water. Finally, agricultural chemicals, industrial wastes and urban effluents can make water hazardous when discharged to a low flowing river or stream.

1.4   Population and Demographic Trends

Four national population censuses have been conducted (1955/56,1973,1983 and 1993). The data used in this report is taken primarily from the 1993 census.

1.4.1   Population Growth and Migration

Population has grown from 10.26 million in 1956 to 25.6 million in 1993. At present, the country's population is 30.3 million and its annual growth rate has increased from 1.9% during the 1960s and 1970s, to 2.7% in more recent years.

The population is heterogeneous in terms of culture and socioeconomic characteristics, as manifested in the number of local languages and variable norms and practices. Arabic, however, is the common language among all groups. Gender segregation and imbalance are common in most of the rural populations. In the southern and western regions, women shoulder virtually all of the responsibility of the household, whereas in the Nile Valley men are the breadwinners. Perhaps the most striking difference in regional gender patterns can be seen in education, where enrollment for girls varies greatly, from well over 80% in the capital, Khartoum, to little more than 8% in some regions.

The gender ratio according to the last census (1993) is approximately 103 males to every 100 females. The age distribution reflects a high dependence ratio of 0.96. The number of children under the age of 15 is 11.5 million comprising 45% of the population (6 million are boys and 5.5 million are girls).

Rural-to-urban migration has been steady and high, with urban population growth of 4% between 1983/1995. The urban population has grown from less than one million (854,000) in 1956 to 7.5 million in 1993. The rural population in 1993 constitutes 71% of Sudanese, (11% nomads, 60% rural settlers), whereas the urban population is 29%.

It is predicted that urban populations will double every 26 years. This trend of high rural-urban migration is due mainly to recurring droughts (which are increasing in frequency), major civil conflicts, budget cuts, and declining developmental investment in the rural areas.

Women tend to feel much of this impact. Male migration and displacement (both ecological and political) have increased the number woman-headed households. The national comprehensive strategy (for 1992-2002) acknowledged the need for prioritizing rural issues of rural poverty and exodus.

1.4.2   Population Density

According to the fourth national census (1993), population density per square kilometer is estimated to be 10.2 persons. This figure, however, can be a misleading indicator if population distribution is not considered. In Sudan, a great deal of land is desert, desert-like, or simply non-arable. Therefore, when land area is limited to that which has some potential arability (as done by Modawi *et al.* 1995), measures of population density increase to 31.4 persons/km^2, and go as high as 370 persons/km^2 when considering land presently cultivated. About 35% of the population resides adjacent to the Nile in Khartoum, Gezira, Sennar, Blue Nile, and the White Nile states. This is mainly due to areas being uninhabitable or becoming depopulated with the shrinking nomadic population in the drought-prone north, and the harsh desert conditions from 12°N to 16°N.

Overall, population density in relation to arable land is 63 persons/km^2 but the central region, adjacent to the Nile Valley, is most densely populated compared to traditional rainfed areas.

It is recognized now that the populations of Kordofan, Darfur, Central, and Northern regions were directly hit by drought and desertification in the eighties. This induced the poor and hard-hit inhabitants to move southward or settle around cities and towns. Those displaced people are now facing unemployment, insecurity, hunger, and famine in the newly settled areas. Moreover, the influx of refugees from drought-stricken neighboring countries has complicated the overall situation to an extent that is both intolerable and, sadly, beyond the country's capabilities to address.

The natural resource base and land carrying capacity needed to sustain increasing population growth has not been quantified. However, a few efforts can be quoted, such as the National Forestry Inventory (FNC and FAO, 1995-1996), the National Land Use Map (1996) and the Environment Profile (University of Khartoum, 1982).

1.5   Human Health

Public expenditure on health is only 0.5% of GDP and the total expenditure on health, including private healthcare facilities is 3.3% of GDP.

There is only one doctor for every 11,000 people, of whom 95% are living in urban centers. Access to health services is estimated at 70% in urban areas and only 20% in rural settings. In urban areas, 55% have access to safe water, while this figure is only 10% for the rural population. Similarly, access to sanitation is 89% for urban populations and 60% for those in rural areas.

Although morbidity and mortality are reported to be declining, they are still among the highest in the world. The infant mortality rate is 40 per 1,000 live births. The mortality rate for children under five is 135 per 1,000 live births. The total disability is 14% for urban population and is 18% for rural areas. Life expectancy at birth is 55 years. Factors affecting human health, including social, economic, and environmental factors, are numerous, complex, and compound one another.

1.5.1   Social factors

About 71% of Sudan's population lives in rural settings that face a number of social and environmental problems, such as drought and marginal ecological conditions. These factors can exacerbate public health problems. In addition, they have encouraged migration to cities and the growth of shanty suburbs. Tribal conflicts and civil war have also contributed to rural exodus and urban growth. The crowded and often unsanitary conditions that result can contribute to public health problems.

1.5.2   Economic factors

Economic factors play an important role in human health. Agriculture is the dominant economic activity in the country, practiced either under rainfed or irrigated conditions. Irrigated agriculture can create stagnant conditions that encourage the spread of water-related diseases. Animal husbandry provides livelihoods for a large sector of the society. Diseases related to contact with animals present serious public health problems. Industry in Sudan is still in its infancy and related health problems are limited.

1.5.3   Environmental Factors

The flora and fauna of the country vary from region to region, depending on many factors such as man's activities, the presence of animals, population density, and socioeconomic characteristics. In the northern part of the country, low rainfall, over-cutting, over-cultivation, and over-grazing have led to environmental degradation. In turn, this degradation has led to desertification and more frequent episodes of drought. Which resulted in poverty, malnutrition, and related diseases.

There has been an extensive increase in irrigated areas in central parts of the country. However, this has not been accompanied by a sufficient number of health programs to respond to the health impacts of such agriculture schemes. Environmental sanitation efforts are also insufficient,

particularly in urban slums and rural areas. The most important diseases in Sudan are malaria, malnutrition, respiratory infection, diarrhea, conjunctivitis, bilharzias, tuberculosis, typhoid, hepatitis, and meningitis.

1.5.4   Health services

To improve coverage, the federal Ministry of Health (MOH) is supervising and guiding 26 state-level Ministries of Health in the country. There are 4,491 small health units, 377 health centers and 1,346 dispensaries. A number of these units are administered by a rural hospital for a certain catchment area (the health area) total number of all types of hospitals is 228. However, this system is not complete and services are unevenly distributed with most of the rural areas thinly covered.

1.6   Government Structure

Sudan is governed by a federal system, composed of 26 states. The federal government, according to the 1998 constitution, is responsible for issues of national interest including planning, defense and foreign policy. The state carries out functions and provides services at a regionalized level. States, in turn, are divided into provinces, and each province, according to its size, is divided into local councils. The councils are represented by people committees, in a structure that tries to link grassroots governance to the federal level. Overall, the system divides most responsibilities between the federal government and the states, though some joint responsibilities exist.

1.7   General Economic Profile

Despite substantial resources of rainfed and irrigated arable land, petroleum potential, sizable livestock herds, considerable worker remittances from abroad, and a relatively well-educated portion of the nation's workforce, Sudan's economic potential has yet to be realized. It is still considered one of the least developed countries, with annual per capita income of less than US$400.

Sudan's economic performance during the 1980s was quite poor. The economy suffered major structural imbalances between production and consumption, savings and investment, public revenue and expenditure, and imports and exports. This poor performance was reflected in chronic budget deficits, mounting external debt, declining production and productivity, and spiraling inflationary pressures.

During the 1990s, the economic performance improved somewhat. The federal Economic Salvation Program concentrated on measures to reduce government deficit, restrict imports, promote exports, liberalize prices, and encourage privatization. In response, a real growth rate of 7.8% of Gross Domestic Product (GDP) was achieved between 1992 and 1996, compared to only 1.2% between 1985 and 1991.

The backbone of Sudan's economy is its agricultural sector. It determines, to a great extent, the country's economic performance. During the eighties, agriculture accounted for an average of 41.5% of GDP. In 1997 and 1998 the share was even higher at 47.4% and 48.7%, respectively.

During much of the 1980s, agricultural performance was similarly stable, except in 1984-85 when the country was hit by drought and the agricultural share of GDP dropped to 37.4%.

The proper organization and utilization of agricultural potential is, therefore, of critical importance to Sudan's future. The 7.8% growth of GDP from 1992 to 1996 is attributed mainly to the improvements and developments made in this sector, which directly influenced the level of activities in all other sectors. During the period of 1995-1996, agriculture provided 90% of the raw material for local industries, 80% of export earnings, and income and employment for more than 80% of the population.

The contribution of the industrial and mining sectors to GDP was 14.5% in 1996 and 15% in 1998, with growth rates of 7.2% and 10.2%, respectively. The importance of the industrial sector lies largely in its potential contribution, based on the present under-utilized capacity. At least one third of the manufacturing value-added product comes from traditional small-scale industry. The sector is also a valuable source of employment and income for many Sudanese.

The services sector is relatively large but its contribution to GDP is declining. During the eighties it was quite strong, (at 50% of the GDP) but dropped to 40.5% by 1996, and 37.8% in 1997, with a negative growth rate of -1.1% in 1997. In 1998 the growth rate had increased to 2.0%, although its contribution to GDP has decreased to 36.3% due in part to the increase in the growth of government services, and decreasing inflation.

Inflation was high for most of the 1990s exceeding 120% in 1996 according to government statistics. The high rate inflation clearly impacted the purchasing power of the dinar undercutting modest growth that took place in the 1990s. A medium term program was formulated in 1990 to mobilize internal and external resources available and reform the economic systems and structures. Since then there has been a marked decline with a rate as low as 17% in 1998.

Exchange rates against international currencies continued to plummet throughout the 1990s and up to 1998. In 1990 the Dinar stood at US$0.45 (official rate) and 1.13 for parallel rate. In 1998-2000 the internally free-floating dinar showed a sign of stabilization at 237 Dinar for US $1. Since mid-1999, the Dinar-dollar exchange rate has revolved around the 260 mark.

Table 1.2: Some economic indicators 1990/91-1999

Indicator	1990-91	1991-92	1992-93	1993-94	1994-95	1995	1996	1997	1998	1999
Inflation %	68	121	120	100	116	70	128	44	17	18
Dinar/Dollar Exchange rate	0.45	1.50	10.0	21.5	31.5	83.2	146.0	171.2	237.0	257.0
Parallel rate	1.13	3.00	114.3	33.5	52.5	90.5	179.5	184.0	240.0	257.0

Source: Bank of Sudan

1.8   Agriculture

Although agriculture dominates Sudan's economy, as illustrated earlier, this sector is characterized by a vast agricultural landscape of relatively low productivity. Hence, the long-

term agricultural strategy centers on increasing the productivity of cropland. The annual contribution of agriculture reached nearly 38% during 1985-86. During 1990 and 1991 it had decreased to 29%, but by 1997, the agricultural contribution was up to 47%, due primarily to increased production.

During the early nineties, the economic growth rate went up rapidly, mainly due to the increase in production of the rainfed agriculture and livestock sectors. The share of agriculture in Sudan's foreign trade is almost 80% of total exports. This is mainly in the form of raw materials; the main agricultural commodities exported are cotton, gum arabic, sesame, livestock, groundnut, fruits, and vegetables.

Sudan has benefited from the variation in climate conditions, water resources, and soil types, which have allowed the country to grow a wide variety of perennial crops in different regions.

Agricultural production in Sudan is practiced under several different farming systems, the three main systems being the following:

- **Irrigated Sector:** This sector includes areas irrigated from the Nile and its tributaries, flush-irrigated areas, and irrigated from bore-wells. The total area under this sector is estimated at 4.89million Hectares. This sector is dominated by large national schemes like Gezira, New Halfa and Rahad and sugar factories. The size of tenancies range from 4.20 to 16.8 hectares.

- **Mechanized Rainfed Sector:** This sector covers areas in the central clay plain. Mechanization is practiced in land preparation and threshing. The total area in this sector is estimated at 6.3 million hectares, with average size of holdings of 420 hectares.

- **Traditional Rainfed Sector:** This sector covers all areas under traditional production where non-mechanized agricultural tools are predominantly used. The total cultivated area in this sector is estimated at 8 million hectares.

Sudan enjoys a great diversity in the types of crops produced. The major types are as described below:

- **Sorghum:** The most important annual crop for both domestic food security and the national economy is sorghum. This crop is mainly produced in the rainfed sector, contributing about 80% of the total production of sorghum, while the share of the irrigated sector is around 20%.

- **Gum Arabic:** This tree grows naturally in the rainfed traditional sector and is considered one of the important export crops. Sudan produces about 80% of the total world production.

- **Millet:** This is another important crop, is mainly produced in the traditional rainfed sector.

- **Wheat:** This crop is primarily grown under irrigation in the Gezira scheme, New Halfa, Rahed, Northern states, and White Nile State.

- **Maize:** This is mainly produced and consumed in the southern states.

- **Groundnut:** This crop is produced both in the irrigated and traditional rainfed sectors.

- **Sesame:** This crop is produced in the rainfed sector and mainly for export. Nationally, it is utilized for production of edible oil and the manufacturing of sweets.

- **Sunflower:** This crop is another source of edible oil. Limited quantities are exported.

- **Pulses:** Pulses are mainly grown in the irrigated sector as a winter crop in the northern states, where climatic conditions are more extreme. Broad beans and chickpeas are produced for local consumption while haricot beans are for export.

- **Sugar cane:** Sugar cane is primarily produced under irrigation by five companies in Kennana, Guneid, New Halfa, Asslaya, and West Sennar. The total harvested area is estimated at more than 63 thousand hectares.

- **Assorted Vegetables:** A wide range of types is grown in different regions throughout the country.

- **Perennial crops:** There are several types that are grown in different parts of the country depending on climatic conditions. The most important ones are the citrus, bananas, dates and mangoes.

1.9   Forestry

Forest area in the Sudan was estimated by Jackson and Harrison (1958) to be between 36% and 43% of the total country area. Later in 1990, the forest resource assessment carried out by the FAO indicated that the forest cover had shrunk to 19% of the total country area. This was mainly attributed to expansion of agriculture, building and fuel wood production, and grazing. The most recent forest inventory (1995/1996) conducted for northern Sudan (between latitudes 10º and 16ºN by the Forest National Corporation (FNC), in cooperation with the FAO, estimated forest area at 12% in this part of the country.[2]

The last forest inventory estimated the annual forest harvest (allowable cut) at 11.0 million cubic meters. While the 1994 forest products demand study conducted by the FNC/FAO, estimated the total demand at 16.0 million cubic meters, this clearly indicates the annual loss in the forest capital.

The original forest policy of 1932 stipulated that 15% of the country's area (37.5 million hectares) be reserved as forests, and the current policy (developed in 1986) indicated that a full 20% should be reserved as forest area. However, until 1993, the actual reserved area was only 1.24 million hectares (or 2.94 million feddans, a local unit of area). In that year, a Presidential Directive was issued to finalize the reservation of a vast forest land. As a result, the reserved area has now reached 8.82 million hectares (21 million feddans).

Sudan's comprehensive national economic strategy for 1992 through 2002 states that 25% of the country's area is to be reserved as forest, rangeland and wildlife preserves. In addition to the official efforts to expand the reserved area, the Forests National Corporation (FNC) is encouraging the reservation of community and private forests through legislation and extension work. Thus far, forest areas reserved under this category total about 4,200 hectares.

---

[2] The southern part, with its rich forests, has not been covered by this inventory.

To reduce deforestation, the FNC is planning to put all natural reserved forests under management for sustained production. At present only 116,000 hectares of forest reserves are under management plans, and these are solely plantation forests.

Improved efficiency of charcoal consumption, introduction of energy conservation techniques and promotion of alternative energies are other areas where FNC is exerting great effort to increase efficiency and reduce resource use, in order to save areas from deforestation.

1.10 Industry

With its Ministry of Industry established in 1966, the contribution of the industrial sector to the country's GDP remains small. This clearly reflects the under developed nature of the economy, since development in any country is judged by the level of its industrialization.

The contribution of the industrial sector to the GDP was 14 and 14.9 in 1998 and 1999 respectively, while its growth rate during the same period is 5.7% and 4.3% respectively.

Industry is divided into four main sub sectors, listed below, along with their share of industry's total contribution to GDP:

- **Manufacturing:** 56% of total sectoral contribution to GDP

- **Construction:** 30% of total sectoral contribution to GDP

- **Electricity and petroleum refining:** 15% of total sectoral contribution to GDP

- **Mining and extraction:** 1% of total sectoral contribution to GDP

Sudan's industries are classified using the following International Standard Categories (ISO): food industries, spinning and weaving factories, tobacco products, engineering industries, chemicals and drugs, construction materials, non-metallic mineral products, metallic mineral products, printing, rubber products, tanning, dressing and processing of leather, saw milling and paneling of wood, paper and paper products, and publishing. The electricity consumption by the industrial sector was 200 GWh in 1995 it increased to 468.8 GWh by 1997. The decline in industrial sector activity is attributed to the shortage of electricity, raw materials and spare parts, to limited financial resources, and to a shortage in skilled manpower.

1.11 Energy

In Sudan, like many developing countries, biomass is a primary source of energy. Biomass contributed 78.5% of Sudan's total energy supply in 1995. In that year, 70.5% was in the form of woody fuel and only 8% was non-woody biomass. The other primary energy source is petroleum products, which contribute 19.4% of total energy supply. Hydro electricity contributes a tiny share of total energy supply, at just 2.1%.

Sudan has started oil production in 1992 from small field (Abu Gabra). Oil which presently in production and/or development is huge (approximately 500-900 million barrels). New oil fields are progressively being reported.

A pipeline, 1610 km long and 28 inches in diameter, was established to carry oil from oil fields southwest of Sudan to the exporting harbor in the east, passing through a number of cities and towns including Khartoum.

The present oil production is 200,000 bbl/days. New refining projects were implemented that boost the country's refining capacity by four folds from 25000 bbl/day to more than 100,000 bbl/day. As a result Sudan became oil producing and exporting country in the last two years.

Net energy consumption for 1995 was about 6.3 million Tons of Oil Equivalent (TOE). During that year, total petroleum consumption was 1.35 Million TOE (MTOE). Of this, about 0.63 million TOE (46.25%) of the total was used in transportation, 0.3 million TOE (21.8%) in the electric sector, 0.17 million TOE (12.4%) in manufacturing, .17 million TOE (13%) in agriculture, 0.05 million TOE (3.9%) in depots, 12,775 TOE (1%) in construction, 2,980 TOE (.22%) in mining, and 0.02 million TOE (1.6%) was consumed by households.

Total electricity consumption for 1998 was 1338 GWh, with the household sector consuming the largest share - about 616 GWh (46.0%). About 403 GWh (23.2%) was consumed in the industrial sector, 381 GWh (28.5%) in the service and government sectors, and 30 GWh (2.3%) in agriculture.

The consumption of total biomass in the energy sector in the Northern part of the country reached 13,805,013 m^3 in 1997, composed of 7.44 million m^3 of fuel wood and 6.37 million m^3 of charcoal. Table 1.3 shows the consumption of biomass by sector.

Table 1.3: Consumption of biomass by sector

Sector	Fuel wood (m^3)	Charcoal (m^3)	Total (m^3)	%
Residential	6,148,380	6,070,207	12,218.587	88.5
Industrial	1,050,174	11,673	1,061,847	7.6
Commercial	31,636	283,899	315,535	2.3
Khalwa	209,044	-	209,044	1.6
Total	**7,439,234**	**6,365,779**	**13,805,013**	**100**

Source: National Forests Corporation and FAO, 1994

1.12 Transportation

The transportation sector in Sudan can be divided into five standard modes: air, rail, river/sea, road, and pipeline.

1.12.1 Air Transportation

Air transportation has certain characteristics that make it a preferable mode of travel: in general, it is fast, comfortable and a time saver. As a result, those who can afford to are choosing to travel by air. The Sudan Air Company, which provides all domestic flight service, and a great deal of international, provided statistics which were used in this work - and which support this trend. The level of activity of passenger flights (both domestic and international flights) by Sudan Airways was about 495 million passenger-km in 1987, and about 575 million passenger-

km in 1993. The level of activity of cargo transport (domestically and internationally) was about 3 million ton-km in 1987, and about 28 ton-km in 1993. The energy intensity of cargo transport has improved over time – from 27.14 MJ/tonne/km in 1987 to 7.97 MJ/tonnen-km in 1993, showing high efficiency of energy utilization.

1.12.2 Railway Transport

In Sudan, rail has typically been considered the most efficient transportation mode. The Sudan Railway network is one of the longest among all transportation networks in Africa - the main railway lines cover of nearly 6,000 km. Recently, the system has had to compete with other modes - in particular, road transport. Heavy trucks have taken a large part of rail transport cargo, as they have proven to be faster and able to reach destinations more easily. Also, most passengers now prefer to travel by road and air transport. Rail passenger and freight traffic data are shown in Table 1.4. The table presents the level of activity in Sudan Railways for passengers and freight during the period 1993-1998.

Table 1.4: Rail transport activity

Year	Passenger (10^3)	Pass. Km (10^6)	Freight ton (10^3)	Tonne-Km (10^6)
1993	600.3	231	1400	1575
1994	500.6	119	1761	1585
1995	240.1	96	1902	1713
1996	370.6	154	2059	1616
1997	364.7	176.9	2021.1	1714
1998	240.8	116.8	1931	1518

Source: Osman, 1999

Regarding energy intensity indicators for a specific type of transportation, Table 1.5 presents rail transport energy intensities for passenger and freight for years 1993 to 1998 in units of MJ per passenger-kilometer, and MJ per tonne-kilometer. It is clear that trains were more efficient in 1993 for both passenger and freight energy intensities (only 0.51 MJ/pass-km and 0.18 MJ/tonne-km, respectively), as compared to recent years - especially 1998, where passenger energy intensity had increased to nearly 1.6 MJ/pass-kilometer and freight intensity had increased to nearly 0.3 MJ/tonne-kilometer. The reasons for these increases are related to a combination of factors such as the inability to ensure adequate maintenance of existing facilities, as well as lower passengers and freight transport levels.

Table 1.5: Rail transport energy intensities (*Source: Osman, 1999*)

Year	Passenger (MJ/pass- Km)	Freight (MJ/tonne- Km)
1993	0.51	0.18
1994	1.08	0.19
1995	1.26	0.16
1996	1.35	0.30
1997	1.14	0.28
1998	1.57	0.28

1.12.3 Road Transport

Road transport is the biggest transportation sector, and includes transport between and within cities. Road transport is responsible for about 70% of all transportation activities in the Sudan. It includes many types of vehicles, such as heavy and light trucks, buses, etc. During 1993, the number of passengers moved through this mode was 31.7 million passengers, and the amount of freight shipped was 3.5 million tonnes. In 1998, the number of passengers had grown to 32.6 million, and freight transport totaled 5.2 million tons.

The road transport activities in tonnes-km has increased from 6.5 million tonnes-km in 1993, to 9.9 million tonnes-km in 1998, while the passengers-km increased from 10.9 million passengers-km in 1993, to 11.3 passengers-km in 1998, as shown in Table 1.6.

Table 1.6: Road transport activity

Year	Passengers (10^3)	Pass-km (10^6)	Freight (tons, 10^3)	Tonne-km (10^6)
1993	31655	10936	3462	6512
1994	26990	9324	3579	6732
1995	28339	9791	3499	6582
1996	29758	10281	3422	6437
1997	31245	10794	3347	6296
1998	32590	11259	5240	9857

Source: Osman, 1999

The energy intensity for passenger vehicles has deteriorated from 1.04 MJ/pass-km in 1993, to 1.32 MJ/pass-km in 1998. However, the energy intensity for cargo vehicles has improved from 1.6 MJ/ton km, in 1993 to 1.5 in 1998, as seen in Table 1.7.

Table 1.7: Road transport energy intensities

Year	Passenger (MJ/pass. Km)	Freight (MJ/tonne. Km)
1993	1.04	1.60
1994	1.32	1.74
1995	1.19	1.73
1996	1.32	1.96
1997	1.29	1.94
1998	1.32	1.51

Source: Osman, 1999

1.12.4 River/Sea Transport

River transport in Sudan is limited and has special problems related to the regime of the Nile River and its tributaries. Navigable waters of this system cover about 5,000 kilometers, connecting Kosti in White Nile and Juba in the south and Karima to Dongla in the North.

River transport has two main lines. The line connecting Kosti, Malakal and Juba is the most important, covering 1,436 km. The other, which connects Karima to Dongola, extends 287 km.

In Sudan there are four seaports: Port Sudan, Bashair, Oseef and Osman Digna. Today, these ports accommodate roughly 8 million tonnes of goods. Port Sudan is the main port for the

country, where 80% of the country's ocean transport passes. The port is equipped with 15 docks, and is divided into two sections: the main port serves ships bringing general cargo, and the southern port serves tankers, containers and liquid materials.

In 1997, 160,000 tonnes of exports passed through Port Sudan, while imports totaled 208,000 tonnes. Of passenger travel through Port Sudan, 64% were arriving and 36% departing, in 1994.

1.12.5 Pipe Lines

The imported products pipeline in Sudan is one of the primary modes for oil transportation. Its length is about 815 km, and its capacity is one million metric tons per year. This line is mainly used for transportation of petroleum products: gasoline, kerosene, mogas and avgas. The line includes five main booster stations: Port Sudan, Erkaweet, Haya, Erojer, Atbara, and the terminal station in Shajara.

A new pipeline started operation in 1999, used mainly to export Sudanese oil. It is extended from Heglig in the southern West of Sudan, passing through El Obeid, Khartoum, to the new oil terminal on the Red Sea. Its length is 160 km, with a diameter of 28 inches, and a mean capacity of 400,000 barrels per day.

1.13 Buildings

Buildings in Sudan can be classified into three groups: a) those made of clay and unbaked brick; b) those made of red brick, and c) buildings made of reinforced concrete cement.

Structures made in the first manner (i.e., from clay or unbaked bricks - methods from the Turkish era) also include other construction materials such as bamboo. These comprise about 35% of buildings in Sudan. Buildings made of red brick - a stylistic influence of both the Egyptians and British - comprise most government buildings, and fully half of all construction.

During the last two decades, the third type of construction - reinforced concrete - has greatly increased, as a result of expatriate influences, development and exchange of information. These buildings comprise 15% of all construction. During the hotter months, energy utilization in these buildings is quite high. As a result, 50% of people living in concrete buildings use fans, 35% use air coolers, and 15% use air conditioners. Such ventilation systems are found in only about 40% of all Sudanese building, since all buildings are designed in accordance with wind direction (North - South) and have upper ventilation pores and other specialized designs.

1.14 Waste

The content of household waste in Sudan is roughly estimated to consist of 56% dust and ashes. In Sudan, all solid waste disposal sites are unmanaged. Most are shallow and scattered among residential areas, and few are deep.

Solid waste can be disposed of through landfilling, incineration of waste for energy, or recycling. However, in most cases, open burning takes place, and may, in fact, be the only method used in the Sudan at this time.

Domestic and commercial wastewater is disposed of in open pit latrines - either traditional or ventilated, improved types - and in septic tanks, though these are only found in urban areas. Sewer system exists only in Khartoum and meets the needs of about 0.5% of the population and industrial outputs.

Most industries dispose of their wastewater in open ponds. Disposal and treatment of industrial and municipal wastes can produce emission of important GHGs.

1.15 Education and Research

In Sudan, higher education is offered by university and scientific research institutes. There are about 26 government universities and about 8 private universities and colleges. Private colleges accommodate about 25% of the total capacity of the universities. In 1998, about 33,716 enrolled as first year students - 51.6% males and 48.4% females. The total number of postgraduate students in 1998 were about 1,597, of whom 504 were pursuing doctoral degrees, 1,018 were master candidates, and 75 were postgraduates.

Scientific research centers can be divided into the following categories: universities with institutes and specialized centers, private centers for specialized research, and government ministries and departments.

Organizations operating within these categories conduct research and consultation in the following areas: agriculture, animal resources, industry, public health and medicine, geology, forestry, natural resources and environment, human development, economics, legal and political issues, management issues, social and educational issues, and defense and security.

Primarily four ministries conduct scientific research at the government level:

- **Ministries of Higher Education and Scientific Research:** in charge of national research centers and Universities,

- **Ministry of Science and Technology:** responsible for agricultural research,

- **Ministry of Animal Resources:** which oversees animal research activities, and

- **Ministry of Industry:** which oversees industrial consultants and research institutes.

2 Greenhouse Gas Inventory

2.1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) assessment reports, there is a discernable human influence on the phenomenon of climate change. Human activities in pursuit of development, such as fuel combustion, industrial processing, intensive agriculture, land-use change and forest utilization, have caused a substantial increase in Greenhouse Gas (GHG) emissions into the atmosphere. GHG emissions linked to such activities include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Nitrogen oxides (NO_x), Non-Methane Volatile Organic Compounds (NMVOCs), and carbon monoxide (CO), each of which is known to contribute to the greenhouse effect.

In 1992, the Earth Summit in Brazil adopted the United Nations Framework Convention on Climate Change as a legally binding instrument for international cooperation. The ultimate objective of the UNFCCC is found in Article 2: "...Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." Recognizing the respective capabilities of different nations, the UNFCCC agreed on the principles of common but differentiated responsibilities. Accordingly developed countries are committed to take measures to reduce their levels of GHG emissions, while developing countries are encouraged to undertake a development path that limits the growth of GHG emissions.

Among other commitments, every party to the Convention has an obligation to submit regularly a national inventory of GHG emissions, by source and sink. This will enable the international community to systematically quantify all present day and expected anthropogenic emissions, employing comparable methods to assess the global impacts of such emissions. Sudan signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC) on November 19th, 1993, committing itself to active cooperation with the global community to address the problem of climate change.

Sudan has undertaken, as of 1996, the task of compiling its first inventory of greenhouse gases. These activities, taking place within the Climate Change Enabling Project, will not only create a GHG profile of Sudan, for use in the larger global framework, but will prepare Sudan for compliance with its obligation under the UNFCCC, and assist the nation in formulating climate sensitive development goals and informed mitigation and adaptation policies.

To comply with the requirements of the UNFCCC, the national inventory of GHG in Sudan was conducted using the standardized IPCC/OECD methodology. Following this methodology, GHG emissions have been calculated for most of the source/sink categories identified in the different sectors, namely energy, industry, agriculture, waste management, and land-use change and forestry.

A team of national experts was formed under the Climate Change Enabling Project in the Higher Council for Environment and Natural Resources, to compile the greenhouse gases inventory for Sudan. The team members were drawn largely from those sectors identified as sources and sinks for GHGs, including the Ministries of Energy, Industry, and Agriculture and Animal Resources, the Forests National Corporation, as well as research and climate change-related bodies such as the Environmental Studies Institute, the Meteorological Authority, NGOs, and the private sector.

In addition to basic organizational assistance, this group received training and the materials and tools necessary for the study. The team attended a 1-week training program on GHG inventory methodology, divided into six modules, representing the main source and sink categories specified by the IPCC/OECD. Designed and prepared by UNITAR, the sessions trained participants to identify Sudan's major sources and sinks of greenhouse gases, to calculate the GHGs emitted or absorbed, and to report these findings.

2.2 Methodology and Data Used

2.2.1 Methods

The Sudanese Assessment of Greenhouse Gases Emissions employed the revised IPCC Guidelines (1996). The use of the IPCC/OECD/EIA (Energy Information Administration) methodology contributes toward the international goal of standardizing the system for emissions inventory and reporting, by meeting basic requirements of consistency, comparability, completeness, and transparency.

Following the revised IPCC guidelines, carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (NO_2) were studied. Nitric oxides (NO_x), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOCs), hydro fluorocarbons (HFCs), and carbon monoxide (CO) were also considered. To assess these gases the national inventory covered most of the sources/sink categories identified by the IPCC Guidelines in the energy, industrial processing, agriculture, landuse change and forestry, and waste management sectors.

Initially, the IPCC Beta v1.0 Software was used to calculate emissions from different sources and sinks. Several deficiencies were identified in specific worksheets (e.g. in the agriculture and waste modules). These were later amended and the data was transferred to the new updated version Beta v1.1. Extensive cross checks were conducted for accuracy.

The specific methods related to each sector and associated subsectors are discussed in the relevant sections below.

2.2.2 Data Sources, Coverage, and Reliability

Data on emissions-generating/sequestering activities were collected mainly from secondary sources, such as published research, statistical reports, related studies, publications of the FAO, the Arab Organization for Agricultural, and other international groups, and periodical government reports.

Data was often available in formats that suit government planning purposes, but do not cover all the information required by the IPCC methodology. This highlights a need for reliable

databanks within each sector, to provide complete and standardized information. The data covered 5 years (1993-1997), with 1995 selected as the base year for all sectors.

Emissions and default factors were taken chiefly from IPCC default values and conversion coefficients. This was due to the lack of local factors; despite the fact that, in some cases, these default values do not accurately reflect Sudan's specific, unique conditions. Locally derived default values were used in the landuse change and forestry, waste management, and industrial sectors. In many cases it was necessary to manipulate data to meet the IPCC Guideline requirements. Where actual data was not available, expert staff judgment was relied upon. Such cases include data on savannah are burned and on the area of cultivated organic soils.

2.2.3   *Uncertainties*

Uncertainties are inherent in any estimate of national emissions. Commonly, uncertainties and limitations arise from different interpretations of source/sink categories, use of average values (especially default emission factors), and incomplete scientific understanding of the basic GHG emission and removal processes.

A major objective of the IPCC methodology is to assist national experts in reducing uncertainties to a reasonable minimum. The sector-specific uncertainties encountered by the National Team are elaborated in the following sections.

2.2.4   *Assumptions and Justifications*

A number of assumptions were made in the application of the IPCC/OECD methodology and default data, to the context of Sudan. Similarly, assumptions were made in order to justify the use of locally derived values, intended to represent the explicit local conditions of Sudan. These are described in the following sectoral discussions.

2.3   Energy Sector Inventory

In Sudan, the primary sources of energy are imported oil and hydropower. Energy supply is characterized by an unusually heavy dependence on biomass, which, in 1995, constituted about 80% of total supply, followed by oil 18% and hydro 2%.

Energy consumed during the same year is estimated to be 6 million TOE, 70% (4.2 MTOE) in the form of biomass (firewood, charcoal and agricultural residues), 25% (1.5 MTOE) petroleum products, and only 5% (0.3 MTOE) from electricity. The vast majority of biomass (93%) was consumed by the household sector. The transport sector is entirely dependent on petroleum, accounting for more than 60% of total petroleum product consumption. The electricity sector has an installed generation capacity of 450 MW; 55% is produced from hydro, and 45% from oil-fired generation (thermal). Electricity is mainly consumed by the household and service sectors and, to a much lesser extent, by industry and agriculture. The main economic sectors (agriculture and industry) have a relatively low consumption of conventional – petroleum and electricity – energy.

GHGs emitted from the energy sector are mainly CO_2, CH_4, and NO_x. CO is also emitted but to a lesser degree.

2.3.1 Methodology

Energy data was derived mainly from government ministry and department records. Petroleum data obtained from the Ministry of Energy represents the actual allocation of different petroleum products to the various consuming sectors (industry, agriculture, household, commercial, and services, and transport sectors).

Biomass data was obtained from the National Energy Administration (NEA) and the Forest National Corporation (FNC) (Forestry Products Demand Survey, 1994). Biomass fuel consumption was estimated for the year 1995 based on previous studies and forecasts done by both NEA and FNC. (Data on both petroleum and biomass are considered fully reliable.)

In order to complete the sectoral inventory using available data, it was necessary to make several assumptions. In the transportation sector, for instance, no separate records of bunker fuel exist for types or mode of transport. Thus, estimates were necessary. From previous assessments conducted by the National Energy Administration it was estimated that 90% of fuel allocated annually for river/sea transport is used by Sudan Shipping Lines, which can be considered as as international bunker fuel.[3] Based on an assessment conducted by the National Energy Administration, the bunker aviation fuel was estimated to be about 60% of total jet fuel consumed by Sudan Airways. The figures for lubricants are estimates made by the Ministry of Energy and Mining, which place the total quantity of lubricants consumed at 3% of total petroleum product consumption, for each consuming sector.

A major area of uncertainty exists in the end-use of certain fuels. Diesel fuel, for example, can be switched from the transport to the household or commercial sector, where it is used for electricity generation.

The IPCC methodology and default values were used in estimating energy sector GHG emissions. In addition, two independent approaches were applied. In the *reference approach*, apparent consumption of fuel, by fuel type, is estimated using the following formula:

Apparent consumption (TJ) = Production + Imports – Exports – Stock Change

In the sectoral approach, actual consumption of fuel by-products in each sector is calculated. After estimating actual consumption, the following steps are taken to calculate net CO_2 emissions in the energy sector:

1. Convert country fuel data to energy units (TJ).

2. Select carbon emission factors for each fuel product type and calculate total carbon potentially released from the use of each fuel, in GgC.

3. Estimate the amount of carbon entering long-term storage.

4. Calculate the net carbon released, in GgC, by subtracting sink storage (3) from emissions (2).

---

[3] This was based on the fact that (a) in 1995 there was a massive sea transport from overseas to Port Sudan, largely for transportation of pipeline, oil exploration, and refining equipment; and (b) due to political conflicts and civil war in southern Sudan, river transport trips have been largely reduced.

Table 2.1: Greenhouse gas emissions, 1995: energy sector (Gg)

GHG Source & Sink Categories		CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Total	Reference Approach	4,413						
	Sectoral Approach	4,328	150	1	58	2,104	263	1
Energy Industries		1,027	0	0	3	0	0	0
Manufacturing Industries and Construction		586	0	0	3	41	1	0
Transport		1,923	0	0	18	81	15	0
Other Sectors (commercial, agricultural and residential)		617	63	1	33	1,380	100	0
Others		174	86	0	1	602	146	
Memo Items:								
International Bunkers		194	0	0	5	3	1	0
Biomass		21,936						

5. Calculate carbon not oxidized during combustion to arrive at actual carbon emission.

6. Convert carbon released to full molecular weight of CO_2.

2.3.2   Results

Table 2.1 shows the calculated GHG emissions in the energy sector. It is clear that the discrepancy between the reference and sectoral approaches in estimating carbon dioxide is not significant (4,413 Gg and 4,328 Gg respectively, or less than 2%).

Emissions in the sectoral approach are dominated by the transport sector, followed by the energy industries (electricity generation and oil refinery). In addition, considerable CO is emitted from the commercial, agricultural and residential sectors.

2.4   **Industrial Processes Inventory**

The contribution of the industrial sector to Sudan's GDP is small – about 14.1% in 1995. This reflects the underdeveloped nature of the economy. The industrial sector in Sudan is considered premature, inefficient, capital intensive, highly dependent on imported inputs and dominated by the production of consumer goods.

Only a handful of the industrial activities described by the IPCC methodology are practised in Sudan. These include: cement, lime, soda ash, pulp and paper, and food and beverage production, and halocarbon use. Accordingly, greenhouse gas emissions in this sector are primarily CO_2, NMVOC, HFCs, CO, and SO_2.

2.4.1   Methodology

Data used in this assessment was obtained from reliable, official statistical record sources including the Ministry of National Industry, the Customs Authority, the Civil Defense Authority, Foreign Trade Offices, and various factories.

In this sector, only GHGs emissions from physical and chemical transformation processes were considered. Several limitations and uncertainties were encountered in developing the inventory.

First, annualised data was not consistently available. Secondly, the raw material used in cement may contain amounts of MgO, which warrant the use of different emission factors. This is not reflected in the IPCC Guidelines. Similarly, the IPCC default emissions factor was used to calculate GHG emission from dolomite lime processing. This may not reflect the actual emission values for this sub-sector, since local dolomite lime may contain 20%-50% MgO.

To overcome data constraints, a few assumptions were made. Two local emission factors for the two cement factories were calculated. These were used as a proxy for CO_2 emissions from all cement production. However, an average emission factor was used for Sudan's two cement factories, since the worksheet does not allow for separate annotation of their individual CO2 emissions. IPCC default values were also relied upon, under an assumption of applicability to Sudan's industrial circumstance.

CO_2 is produced during the production of clinker – an intermediate product from which cement is made. Since there are two cement factories in Sudan with different capacities and Emissions Factors (EF), an average EF was calculated based on the percentages of total clinker production of each factory. In addition to cement, calculations of GHG emissions for this sector covered dolomite lime, pulp and paper, food and drink, soda ash use and production, use of miscellaneous mineral products (mainly asphalt for road paving), and consumption of halocarbons and sulfur hexaflouride.

2.4.2 Results

GHG emitted in this sector (as shown in Table 2.2) are mainly CO_2, NMVOC and HFC. CO and SO_2 are also emitted. Not surprisingly, the most important GHG in this sector is CO_2, 97% of which is produced by the cement industry. NMVOC emissions are attributed almost solely to the food industries. Emissions of HFCs are shared between aerosol use, foam blowing and fire extinguishers. Minor quantities of CO and SO_2 are emitted from the pulp and paper industry.

2.5 Agricultural Sector Inventory

Agriculture is the most important sector in Sudan's economy. In 1995, its contribution to the GDP reached more than 45%.

Sudan produces a wide range of crops (including cotton, sorghum, sesame, groundnut, and millet) and livestock (cattle, sheep, goats, camels, donkeys and poultry). Sudan's large animal wealth is estimated at over 110 million heads. Livestock production is done largely under traditional systems. This sub-sector supports 40% of Sudanese people, either fully or partially.

GHG emissions in this sector come from several sources, including crop residues, savannah burning, livestock, and agricultural soils. From these sources, the key GHGs are CH_4, N_2O, NO_x and CO.

Table 2.2: Greenhouse gas emissions, 1995: industrial processes (Gg)

GHG Source & Sink Categories	CO$_2$	NM VOC	HFC P	HFC A
Total	173	11	2	3
Mineral products (cement & lime production)	173	0	0	0
Other production (food & Drink)	0	11	0	0
Consumption of halocarbons and sulphur hexafluoride (foam blowing & fire extinguishers)	0	0	2	3

Notes :
P = Potential emissions based on Tier 1 Approach.
A = Actual emissions based on Tier 2 Approach.
Emissions of CO and SO$_2$ are very small (0.0009 and 0.001 Gg, respectively).

2.5.1 Methodology

Data was collected from several sources and converted to match the IPCC Guidelines worksheets. Data Sources included the Arab Organization for Agriculture (*Statistics Year Book,* a series with annual information on livestock populations, crop production, etc), the Ministry of Agriculture (and several departments within the ministry), national experts' best estimate, and the IPCC Guidelines default values.

Several types of uncertainties were encountered. Again, available domestic data did not fit the IPCC Guidelines format, with variations existing in categories and units. No data were available for Southern Sudan. Default data were relied upon, despite the fact that, in most cases, these are overly generalized and poorly suited to Sudan's national context (e.g., to the heterogeneity of Sudan's ecological zones). Best estimates of national experts were, in cases, relied upon.

To accommodate data limitations, the following assumptions were made. 1995 was used as the base year. Average values for 1994 through 1997 were used, in cases, to arrive at the 1995 values. Despite uncertainties, IPCC defaults values were considered adequate in circumstances where local values were unavailable. Fractions of agricultural residues on the field, and crude IPCC default values were used due to lack of actual data. Since Sudan's soils are known for their poor organic content, the area of cultivated organic soil was estimated as the area of soil with less than 1% organic content.

Calculations of GHG emissions covered a number of source activities, including CH$_4$ (methane) emission from enteric fermentation, manure management, rice cultivation, prescribed burning of savannah, field burning of agricultural residues. N$_2$O and NO$_x$ were calculated from agricultural soil and from savannah and agricultural residue burning. CO emissions were calculated from the latter two alone.

2.5.2 Results

As shown in Table 2.3, GHG emissions from the agriculture sector are dominated by CH$_4$ (1,713 Gg) as shown in the table below. Livestock enteric fermentation – the main source – constitutes about 95% (1,632 Gg) of the total agricultural CH$_4$ emissions.

Table 2.3: Greenhouse gas emissions, 1995: agricultural sector (Gg)

GHG Source & Sink Categories	CH$_4$	N$_2$O	NO$_x$	CO	NHVOC
TOTAL	1,713	30	16	388	0
Enteric Fermentation	1,632	0	0	0	0
Manure Management	62	0	0	0	0
Agricultural Soils	0	30	0	0	0
Prescribed Burning of Savanna	0	0	0	4	0
Field Burning of Agricultural Residues	18	0	16	385	0

2.6 Land Use change and Forestry Inventory

A 1994 demand study of forest products and the 1995/96 National Forestry Inventory indicate that the annual consumption of forest products in Sudan far exceeds the allowable cut. Sixteen million cubic meters of wood product is consumed annually while the annual growth of forests is not more than 11.0 million cubic meters. According to national experts, in 1996, the total volume stocked between latitudes 10ºN - 16ºN had declined to nearly half of its 1983 level. Many factors have contributed to this situation, particularly the high demand for woodfuel (firewood and charcoal), which constitutes more than 70% of total national energy consumption. Agricultural expansion in the absence of proper land-use and forest management planning, has also led to the clearing of vast areas of forest.

Unplanned land-use change, mismanagement, and reduction in the forest stock have caused our forest to become a source of GHG emission rather than GHG sink.

2.6.1 Methodology

Data for this component of the inventory was obtained from recent documents and published reports of Forests National Corporation (FNC) – considered a reliable source – particularly, the Forest Products Demand Survey (1994) and Forest National Inventory (1995/1996). FAO published data and IPCC default data were also used. In addition, national expert opinion was used to fill data gaps in some activities, or to modify and adapt default factors to Sudan's specific circumstances. Data was collected for the 1993 to 1997 period, and converted to suit IPCC guidelines.

In conducting the Land-Use Change and Forestry (LUCF) inventory, three primary sources of uncertainty were encountered. Annual growth rate of urban trees, for one, could only be roughly estimated. Best estimates of national experts were used to fill data gaps in the southern region and for data groups, such as non-forest trees. And in general terms, the IPCC Guidelines definition and specification for source/sink categories, applied to Sudan's conditions and circumstances, introduced uncertainty.

As with each of the sectors, certain assumptions needed to be made for the inventory to take shape. In the case of LUCF, five primary assumptions were made, as listed below:

- In worksheet 5-1, sheet 1 of 3, the category of "Acacia species" was used only for Acacia nilotica. Other Acacia species were entered into the category of "Mixed Hard Wood".

- As *Acacia nilotica* are grown in highly productive site, it has a comparatively higher yield. At the best site, it may reach up to 480 m^3/ha.

- The per capita consumption estimated by FNC (1994) is different from the FAO yearbook figure (0.73 m^3 and 2.0 m^3 respectively). The FNC figure (0.73 m^3) was used, due to its consistency with similar countries in the region.

- The fraction of wood left to decompose was considered negligible due to the scarcity of fuelwood. (In some regions, for example, stumps of cut trees are used for fuelwood).

Calculation of GHG emissions in this sector covered three main activities: change in forest and other woody biomass stocks, forest and grassland conversion, and abandonment of managed lands. GHGs measured include CO_2, CH_4, N_2O, NO_x, and CO.

The annual increment of woody biomass in plantations, logged or otherwise harvested forests, villages, farms, and urban areas (and any other significant stocks of woody biomass), was estimated, not monitored or measured.

All wood harvested for fuelwood, commercial timber and other uses was estimated. Total wood harvested was then subtracted from the annual increment of all woody biomass, to determine the net of GHG in this sector. If this figure is negative (as in Sudan's case) the sector is a net emitter; if it is positive, the sector serves as a sink.

The formula used for calculating Annual Growth Rate (AGR) is as follows:

AGR (tdm/ha) = volume per feddan x 0.42 x 0.5 / rotational age, where:

- Volume per feddan is the total cubic meter volume of trees in one feddan.

- 0.42 is the conversion factor from feddan to hectare.

- 0.5 is the conversion factor from fresh to dry weight.

- Rotational age is the harvest cycle, in years.

2.6.2   Results

As shown in Table 2.4, of the three categories in this sector, two act as sinks, removing 13,138 Gg of CO_2 from the atmosphere (i.e., 9,700 plus 3,438). However, emissions from forest and grassland conversion (28,714 Gg of CO_2) far exceed the total CO_2 removed. The result is net CO_2 emissions of 15,577 Gg. Since this sector represents the only possible sink for Sudan, it can be concluded that Sudan is a net emitter of GHG. Emissions of CO equal about 787 Gg; other emissions are not considered significant.

Table 2.4: Greenhouse gas emissions, 1995: land use (Gg)

GHG Source & Sink categories	CO_2 Emissions	CO_2 Removal	CH_4	N_2O	NO_X	CO
TOTAL	15,577	0	90	1	22	787
Change in forest & other woody Biomass stocks	0	-9,700	0	0	0	0
Forest & Grassland Conversion	28,714	0	90	1	22	787
Abandonment of Managed lands	0	-3,438	0	0	0	0

2.7 Waste Management Inventory

2.7.1 General

In Sudan, Solid Waste Disposal Sites (SWDS) are unmanaged. Most are shallow and scattered amid residential areas, few are deep. In most cases, open burning takes place in SWDSs. This may in fact be the only method currently used in Sudan.

Open pit latrines (traditional and ventilated improved pit latrines), and septic tanks (found only in urban areas) dominate the domestic/commercial wastewater systems in Sudan. The bucket is still used in some towns. Sewer systems exist only in Khartoum and service only about 0.5% of the population, and an equally small percentage of industry. Most industries dispose of their wastewater in open ponds.

Disposal and treatment of industrial and municipal wastes can produce emissions of most of the important GHGs. Solid waste can be disposed of through land-filling, incineration (for energy production) or recycling.

2.7.2 Methodology

Secondary data sources were the main reference for information due to the fact that no organized waste collection and disposal take place. Values for urban populations were taken from the 1998 population sheet of Sudan. A growth rate of 2.7% was used to estimate the previous years' populations. Data on waste production, per capita, per day rate were chosen.

No compiled data exists for either domestic/commercial or industrial wastewater. Accordingly, published academic studies and national experts were consulted. Experts were drawn from the fields of nutrition, public health, waste management, industrial waste systems, tannery and slaughterhouse waste management, edible oil manufacturing, the food and sugar industries, and energy and petroleum, to identify and estimate the amounts and characteristics of sub-sectoral waste.

Wherever default values were used in the waste management inventory – even those derived from neighbouring African countries – the uncertainties are very high. This is very clear in wastewater estimates where loose figures for the whole of Africa have been adopted.

In order to calculate GHGs from different waste sources, separate series of assumptions were made. These are outlined below:

2.7.2.1   Emissions from Solid Waste Disposal Sites

- Only the urban population of Sudan (29% of the total) was considered in the calculation.

- All municipal SWDSs are shallow and unmanaged.

- An old estimate of MSW (0.789 kg/capita/day) was applied since current rates could not be authenticated.

- An approximation of 81.7% is taken as the fraction of MSW disposed of in SWDSs. These are not official figures, and require updating and authentication.

- No figures were available for methane from incineration at SWDSs although it is well known that practices of burning solid waste. 0% is taken until further update.

2.7.2.2   Emissions from Wastewater

- Only the urban population of Sudan is considered (29% of total).

- No authenticated figures were available for degradable organic component removed as sludge from domestic/commercial wastewater, so emissions from this source were placed at 0%, after consultations with experts in this field.

- No figures were available for the percentage of domestic/commercial wastewater or sludge treated by different systems (septic tanks, pit latrines, VIP, etc.). After consultation with local sanitary experts, septic tanks were assumed to comprise 1% of wastewater systems. The figures in the worksheet were generated through such consultation.

- The aerobic sewer system covers only 5% of Khartoum, and is the only established sanitation network in Sudan. The population of Khartoum is estimated to be 17% of Sudan's total. This aerobic sewer is therefore assumed to comprise only about 1% of the national wastewater handling system.

2.7.2.3   Emissions from Human Waste

- The entire population of Sudan was used in this calculation.

- No concrete data were available on open pit latrines. Small, stratified sociological surveys, conducted in a number of areas in Sudan, were used as a base for estimations. The surveys placed the percentage of the population using open pit latrines at 10% (bearing in mind that the urban population of Sudan is 29%).

- To estimate protein consumption, populations were divided into four categories: adult males, adult females, children, and pregnant/lactating females.

- Protein consumption for males is assumed to be 50 gm/day, for females, 45 gm/day, for children, 1.1 gm/kg body weight/day, and for pregnant/lactating females, it is estimated at 80 gm/day.

- For children, average body weight was estimated at 12.8 kg for ages five and under, and 33 kg for ages 6 through 15.

- 20% of married females were assumed to be pregnant or lactating in any given period.

Calculations for 6 years (1993 to 1998) were carried out for methane emissions from solid waste and for nitrous oxide emissions from human waste while wastewater emissions could be estimated only for the years 1993 to 1997 (due to incomplete industrial data for the 1998 production year).

The contents of household waste in Sudan are about 56% dust and ashes. Table 2.5 shows a breakdown of household waste in Sudan for 1984 and 1992. The values could be attributed to the increase in poverty since, according to recent government records, more than 94% of the total population in Sudan is considered to live below the poverty line. Therefore, the Degradable Organic Carbon (DOC) value in the solid waste in Sudan calculated below is very low (see Box 2.1).

Table 2.5: Average Household Waste in Kg

Waste Stream Components	1984	1992
Organic matters	44.70	33.60
Dust & Ashes	37.50	50.75
Paper	4.9	4.43
Plastic	2.6	2.67
Metal & Tins	1.8	2.22
Glass	1.0	1.22
Wood	2.6	1.49
Bones	0.6	0.72
Natural & Artificial Leather	0.3	0.25
Rubber	1.2	1.20
Miscellaneous	1.9	1.40

Box 2.1: Degradable organic carbon in Sudan

The degradable organic carbon (DOC) value in the solid waste in Sudan was calculated as follows:

DOC = 0.4A + 0.17B + 0.15C + 0.3D

```
A = Paper + Textile = 4.43

B = Garden + Nonfood organic=

      Plastic = 2.67
      Bones   = 0.72
      Leather = 0.25
      Rubber  = 1.20
      Total   = 0.25

C = Food waste + Other organic waste
  = 33.60

D = Wood + Straw = 1.49

DOC   = 0.4*4.43 + 0.17*4.84 +
      0.15*33.6+ 0.3*1.49

      = 8.0918
```

The available computer software of IPCC was used for data entry and final worksheet printout. Many assumptions and approximations were required to complete the worksheets. This was due primarily to a lack of data in specific areas.

2.7.3 Results

The results of GHG emitted from different types of waste in Sudan are shown in Table 2.6. Methane is clearly the most important gas; the key waste sources:

- **Methane emissions from SWDSs:** 25 Gg

- **Methane from domestic/commercial wastewater and sludge:** 6 Gg

- **Methane from industrial wastewater and sludge:** 2 Gg

Additional results were included in the

worksheets, such as amount of municipal solid waste of urban populations, and amount and characteristics of industrial wastewater. The GHG category sources are dominated by methane production from solid waste disposal.

Table 2.6: Greenhouse gas emissions, 1995: waste management (Gg)

GHG Source and Sink Categories	CO_2	CH_4	N_2O
TOTAL	0	33	1
Solid waste Disposal on land	0	25	0
Wastewater Handling	0	8	1

2.8 Inventory Results

The results of Sudan's national inventory indicated that the total emissions of GHG, for 1995, amount to 25,752 Gg. Table 2.7 shows the summary emission levels for the national GHG inventory in the year 1995.

The main gas emitted is carbon dioxide (20,077 Gg) which constitutes more the 75% of the 1995 total, followed by carbon monoxide (3,280 Gg), methane (1,985 Gg), small amount of other gases such as NMVOC, NO_x, N_2O, and insignificant amounts of HFCs and SO_2.

Land-use change and forestry, though it should constitute a sink, was found to be the main emitter of CO_2, with 15,577 Gg, or more than 75% of total CO_2 emitted. This fact is indicative of steady reduction in the stocked volume of forest resources in Sudan. Forests could play a vital role in carbon sequestration, if they are consumed at a rate below their annual growth.

In the energy sector, CO_2 emissions from fossil fuel are estimated at 4,328 Gg – about 22% of the CO_2 total. The energy sector emits the major share of CO and NMVOC (3280 Gg and 274 Gg respectively). It is important to note that biomass energy is estimated to emit about 21,936 Gg of CO2, constituting more than 80% of total CO2 emitted in the energy sector, which is consistent with the energy balance of the inventory year.

Emissions from biomass energy are not added to total energy emissions, however, to avoid double counting, biomass is accounted for, instead, in the land-use change and forestry sector. Agriculture is the dominant sector in CH4 emissions, estimated at 1,713 Gg, or more than 86% of total CH4 emissions in Sudan.

Different GHGs are known to contribute differently to the total greenhouse effect.   This contribution is expressed as Global Warming Potential (GWP) – the ratio of GHG radiative forcing (ability to trap infrared radiation) of 1Kg relative to 1Kg of CO_2 over a specified period of time (usually 20, 100 or 500 years – the 100-year GWP was chosen for the Sudan GHG inventory).   Accordingly, GHG can be expressed as CO_2 equivalent.   Table 2.7 shows the assumed GWP values used in calculating GHG emissions in terms of Gg of carbon equivalent.

Carbon dioxide is the most important greenhouse gas, responsible for about 60% of the enhanced greenhouse effect. In 1995, the total global carbon emitted from energy activities was estimated at 6 billion metric tons. Sudan's contribution to this, seen in its level of GHG emissions in Table 2.8, was very modest, even in comparison to many other developing countries. The 1995 per

capita emission of CO_2, as an example, is only 0.003 Gg per person (i.e., 89,220 Gg/28.7 million people).

Table 2.7: Assumed 100-Year GWP of GHG Emissions[4]

GHG	GWP
CO_2	1
CH_4	23
N_2O	296

Table 2.8: Greenhouse gas emissions, 1995 (Gg)

GHG Source & Sink Categories	Total CO₂-equiv	Net CO₂ Emitted	CH₄	N₂O	NOx	CO	NMVOC	SO₄	HFCs P	A
Energy (sectoral approach)	16,706	4,328	150	1	58	2,104	263	1	-	-
Industrial Processes	173	173	0		0	0	11	0	2	3
Agriculture	50,083	0	1,713	30	16	388	0	0	-	-
Land-use change & Forestry	21,184	15,577	90	1	22	787	0	0	-	-
Waste	1,055	0	33	1	0	0	0	0	-	-
Total National Emission and Removals	**89,220**	**20,077**	**1,985**	**33**	**97**	**3,280**	**274**	**1**	**2**	**3**
Memo items:										
International Bankers	**403**	194	0	0	5	3	1	0	0	0
Aviation	**142**	102	0	0	1	0	0	0	0	0
Marine	**262**	93	0	0	4	3	0	0	0	0
CO2 emissions from biomass	**21,936**	21,936	0	0	0	0	0	0	0	0

Notes :
P = Potential emissions based on Tier 1 Approach.
A = Actual emissions based on Tier 2 Approach.

2.9 Conclusions

Permanent observation units have now been established within relevant sectors and institutions, for future updating of Sudan's GHG Inventory. These include the Ministries of Energy, Industry and Agriculture, Forests National Corporation, Khartoum University, the Institute of Environmental Studies, and the Meteorological Authority. A minimum of two people from each sector attended the training program on GHG Inventory and became members on the National Inventory Team (NIT). Ten experts from the research sector (institutions and universities) were also included in the NIT, to assist in supervising the inventory work. Relevant literature, modules of the GHG inventory methodologies, and computer software were provided to all the relevant institutions. Formal Links were established between the institutions and the HCENR.

---

[4] Based on the estimates provided in the IPCC's Third Assessment Report (2001). Indirect effects of NOx and CO not known.

Some of the NIT also attended the Vulnerability and Adaptation Assessment training program, and all members of the team participated in the Mitigation Analysis training.

2.10 Recommendations for Enhancing the Quality of Sudan's GHG Inventory

The importance of embarking on a program to enhance the accuracy of Sudan's national GHG emissions inventory cannot be overstated. A reliable and verifiable greenhouse gas emissions database is a prerequisite for compliance with the Framework Convention, and is vital to Sudan's ability to identify opportunities for mitigating emissions or enhancing sinks. Based on the experience gained in developing the first national greenhouse gas inventory, there are several efforts that should be carried out. They are described below.

In the near-term, the highest priority areas are to strengthen the institutional structure for carrying out future assessments, and to develop emission factors that better represent Sudanese conditions. Specific recommendations are as follows:

- **Institutional strengthening:** While a permanent secretariat has been established within the HCENR to coordinate future updates to the national inventory, it is recommended that a national system be established in order to develop protocols for GHG data collection, monitoring, reporting, and verification. Ongoing capacity building efforts will be needed in methods and tools for ensuring that an inventory updating system is both sustainable and of high quality.

- **Improvement of local factors:** Locally developed GHG emission factors should be used in place of the IPCC default values in future updates to the inventory. Studies should be carried out regarding enteric methane production from livestock, emissions of nitrous oxide from organic soils, assessment of the fraction of agricultural residues burnt on site, and on and off-site burning of cleared vegetation.

In the mid- to long-term, the highest priority is to address the gaps in the data available. Efforts to improve data availability and quality should be principally targeted at the following sectors:

- **Energy:** Conduct surveys to better represent consumption levels particularly for self-generated electricity (commercial and household sectors) biomass use (charcoal and firewood throughout economy), marine and aviation bunker fuels, and new modes of public transport (e.g., Rakshas).

- **Industrial:** Conduct surveys to better represent the production of local industries, and the use of baggasse in industrial facilities.

- **Agriculture:** Collect data on fractions of residue burned in the field and fraction oxidized of agricultural residues.

- **Waste:** Data needs to be collected regarding the amount of solid waste produced and openly dumped in rural areas.

3 Vulnerability and Adaptation Assessment

3.1 Introduction

With an area of about 2.5 million square kilometers, Sudan is the largest country in Africa and the Middle East. It is a country of fragile ecosystems, frequent droughts and, as a result, pressing challenges to address the national priorities of food security, water supply, and public health.

An examination of Sudan's ecological zones indicates that the majority of its land is quite vulnerable to changes in temperature and precipitation (see Chapter 2 for more information). Of its diverse ecological zones more than half the country can be classified as desert or semi-desert, with another quarter, arid savannah. Changes in temperature and rainfall are likely to lead to desertification in some regions, while in the South, the spread of vector-borne diseases is likely. The country's inherent vulnerability may best be captured by the fact that food security in Sudan is mainly determined by rainfall, particularly in rural areas, where 70% of the total population lives. Changes in temperature and precipitation could cause shifts in the precarious distribution of these ecological zones, in the productive capacity of rainfed agriculture, and thus, in the security of the nation's food supply.

In the face of climate change, an assessment of vulnerability and adaptation options is a critical component of Sudan's response. This vulnerability assessment is expected to promote a better understanding of the specific issues faced by Sudan with regard to climate change, by focusing, in particular, on three national priorities: agriculture and forestry, human health (malaria), and water resources. The Kordofan States, located in central and western Sudan, are thought to be particularly vulnerable to these changes and are thus the focus of the assessment. Finally, the results of this work are expected to provide clearer indication of Sudan's public health, food security and resource management challenges, and guidance toward the necessary national strategies and priority areas of intervention, such as prevention and control of land degradation. Adaptation measures are also discussed, though in lesser detail.

3.2 Climate Scenarios

The purpose of a vulnerability and adaptation assessment is to illuminate the potential impacts of climate change on critically important sectors - in the case of Sudan, agriculture, forestry, human health and water - and to assist in identifying adaptation options. This process requires that a picture be created of what the sector of interest might look like in a future without climate change, and that this picture be compared with a parallel vision of what the sector would look like under predicted conditions of climate change. In order for this to be done, two climate scenarios must be created: a baseline scenario, aimed at representing a future *in the absence of climate change* and a climate change scenario, aimed at representing a future under plausible conditions of greenhouse gas concentrations and the resulting changes in climate. This section outlines the steps taken to develop these scenarios for use in Sudan's vulnerability and adaptation assessment.

3.2.1 Overview

Kordofan Region is located in mid-western Sudan between latitudes 9° 30' and 16° 24' North and longitudes 27° to 32° East. Five stations, distributed throughout the region, for which climate records have been kept - El Obeid, En Nahud, Rashad, Kadugli, and Babanusa - were chosen for this study (the map below shows the location of Kordofan in Sudan, as well as the locations of the five stations within the region). The data collected at these stations tells a story of a varied regional climate. Kordofan Region ranges across desert and semi-desert in the North, to moist, sub-humid, and rich savanna in the South (see Volume II, Section 1 for classification of climatic zones). Arid and semi-arid zones make up the largest segment of Kordofan's land area.

The annual rainfall ranges from less than 150 mm in the extreme northern parts of the region to more than 850 mm in the extreme southern parts (see Volume II, Section 1 for rainfall distribution maps). The rainy season varies from one month or less in the North to about five months in the South. Rains generally occur between May and October. Within and between seasons, significant variation in rainfall (both the amount and distribution) is common.[5]

The average daily temperature ranges between 10° and 35° C with an annual variation of 15° C. April, May, and June are the hottest months, December through February, the coldest.[6] The mean maximum temperature varies between 40° and 43° C and the mean minimum temperature varies between 20° and 22° C (see Volume II, Section 1 distribution maps). The prevailing wind direction of the region varies according to the season: northeast in winter and southwest in summer.

The trends and historical patterns described here may persist into the future. However, they may be altered or exaggerated under the pressures of climate change. In order to assess the impact of climate change on the condition and performance of key sectors, it is necessary to create a baseline climate scenarios (a future without climate change), and climate change scenarios. These scenarios can then be used with sector-specific impact models to determine performance of the sector under both baseline and climate change conditions. The difference between these two provides an indication of the vulnerability of the sector to climate change, and the future impacts that might be experienced.

For this study, these scenarios are limited to projections of temperature and precipitation in 2030 and 2060.

3.2.2 Baseline Climate Scenarios

3.2.2.1 Approach

In impact assessment, it is typical to use a period of years of observed meteorological data to define a "current climate baseline". This period of years can be used to calibrate impacts models

---

[5] The trend in rainfall can be seen (Volume II, Section 1) in the deviations of the actual annual rainfall for the period 1961-1998 from average rainfall for baseline for the period 1961-1990. (See figures climate scenario section.)

[6] The trend in temperature can be seen (Volume II, Section 1) in the deviations of annual mean temperature for the period 1961-1998, from the average temperature for baseline for the period 1961-1990. (See figures in climate scenario section.)

and to quantify baseline climate impacts. Thirty-year continuous records of recent climate data have been widely used as future baseline climate scenarios (e.g., Rosenzweig and Parry, 1994). The criteria for this are, first, that a 30-year period is likely to contain wet, dry, warm, and cool periods and is therefore considered to be sufficiently long to define a region's climate. Secondly, the 30-year "normal" period, as defined by the World Meteorological Organization (WMO), is recommended by the Intergovernmental Panel on Climate Change (IPCC) for use as a baseline period (Carter *et al.*, 1994).

The current WMO normal period is 1961-1990. This period is thought to best define current climate because it is recent and of sufficient length. Since the quality and quantity of weather observations tend to improve over time, this period is likely to contain a more extensive network of observing stations and to record more variables than earlier periods. One problem with use of the 1961-1990 period, however, is that the 1980s were, globally, the warmest decade this century (Jones *et al.*, 1994). Therefore, using 1961-1990 as a base period could introduce a warming trend into the baseline, which could bias the results of some impact assessments. This may be the case with Sudan, as the 1980s were period marked by anomalous low rainfall and drought.

Another recent 30-year period, such as 1951- 1980, which has less distinct trends, could perhaps serve Sudan's purposes better. However, climate data for this period were incomplete and thus prevented its use. As the literature warned, earlier periods are more likely to have less comprehensive and poorer quality data and it may, on balance be preferable to use the most recent period (1961-1991).

3.2.2.2   *Methodology*

The selected meteorological parameters are temperature and precipitation. Initially, two potential periods were considered for use as baselines in this study: 1951-1980 and 1961-1990. The first, 1951-1980, was abandoned, due in part to incomplete data and also to remain consistent with the approach of the MAGICC/SCENGEN software, which uses only 1961-1990 as its baseline. Historical climatological records of the period 1961-1990, from the limited number stations that satisfied the necessary criteria (see section 1, Volume II), were used to create baseline scenarios for El Obeid, En Nahud, Rashad, Kadugli, and Babanusa. These were derived on the basis of monthly station averages for the entire 30-year period (e.g., the baseline scenario temperature for January is an average of all January temperatures from 1961-1990).

3.2.3   *Climate Change Scenarios*

3.2.3.1   *Approach*

Two distinct approaches have been applied to the development of climate change scenarios. The first uses three General Circulation Models and climate scenario generating software. The second uses incremental or "synthetic" scenarios, which project a series of future climates based on incremental changes in both temperature and precipitation. Each provides future values for precipitation (P) and temperature (T), albeit through distinctly different means. It is important to note that the first approach is relied upon most heavily, and is the one discussed here (for a full description of the incremental scenario approach, Volume II, Section 1).

3.2.3.2   Methodology

To create scenarios of future climate conditions, the assessment relies on a combination of tools: three General Circulation Models, IPCC emissions scenario (IS92a), scenario generating software (MAGICC/SCENGEN version 2.4), and linear interpolation techniques.   For a complete discussion of these tools, see Section 1, Volume II.

General Circulation Models (GCMs) are mathematical representations of atmosphere, ocean, ice cap, and land surface processes based on physical laws and empirical relations (UNEP, 1998). GCMs used in this impact assessment were selected using the following criteria:

- The scenario should be consistent with the broad range of global warming projections, based on increased atmospheric concentration of greenhouse gases (e.g., 1°C to 3.5°C by 2100 (Houghton *et al.*, 1996), or 1.5°C to 4.5°C for the doubling CO2 concentration (IPCC 1990).

- The scenario should be physically plausible.

- The scenario should estimate a sufficient number of variables on a spatial and temporal scale that allows for impact assessment (Smith and Tirpak, 1989; Viner and Hulme, 1992).

- The scenario should, to a reasonable extent, reflect the potential range of future regional climate change.

This study utilized three of the GCMs provided within MAGIC/SCENGEN software, version 2.4: Hadley Centre Unified Model 2 Transient Ensemble (HADCM2)[7]; Geophysical Fluid Dynamic Laboratory Transient (GFDL)[8]; and Bureau of Meteorology Research Centre (BMRC). These GCMs were used in conjunction with MAGICC/SCENGEN, a scenario generating software (Section 1, Volume II).

Of the IPCC IS92 emissions scenario options within MAGICC/SCENGEN, the 1% per annum increase in CO2 equivalent concentration is best approximated by the IS92a emissions scenario (according to IPCC (1996) calculations). This scenario was used in this study.[9]

The outputs produced by the GCM models, through MAGICC/SCENGEN, are temperature change (in degrees Celsius) and change in precipitation (in millimeters), in the milestone years 2030 and 2060, with respect to the climate baseline (1961-1990). This output is provided for each GCM on a 5° by 5° resolution. Temperature and precipitation changes were ascribed to the station locations through linear interpolation and then added to the historic baseline to arrive at projected levels of temperature and precipitation under the climate change scenario. The figure below illustrates the steps involved in this process.

---

[7] This GCM has been widely used throughout the region.

[8] This model is known to have been used in assessing climate change impacts in Zimbabwe - a nation with climate conditions similar to Sudan.

[9] The greenhouse gas forcing scenarios used by all of the GCM experiments reported on the IPCC DDC are expressed in terms of *equivalent* CO2 concentrations. Most of these experiments use a forcing scenario of 1% per annum increase in equivalent greenhouse gas concentrations.

Figure 3.1: Steps for determining climate change temperature and precipitation

---

Example: El Obeid Station in, 2030

Temperature:

MAGICC/SCENGEN temperature change=1.2°C
Average annual temperature (1961-90)=30.4°C
Average temperature under climate change=31.6°C

Precipitation:

Magicc/Scengen precipitation change=(-5.8%)
Average actual annual precipitation=120 mm
Average precipitation under climate change=113.04=120-(120*.058)

The above calculations were made for each set of GCM outputs, at each station, for both 2030 and 2060. (These are provided in Volume II, Section 1) Figures 3.2 through 3.5 provide a sampling of the output. The climate change temperature and precipitation values generated for each station using the HADCM2 model are presented for both 2030 and 2060.

Figure 3.2: HADCM2 GCM projected average temperature differences at all stations in 2030
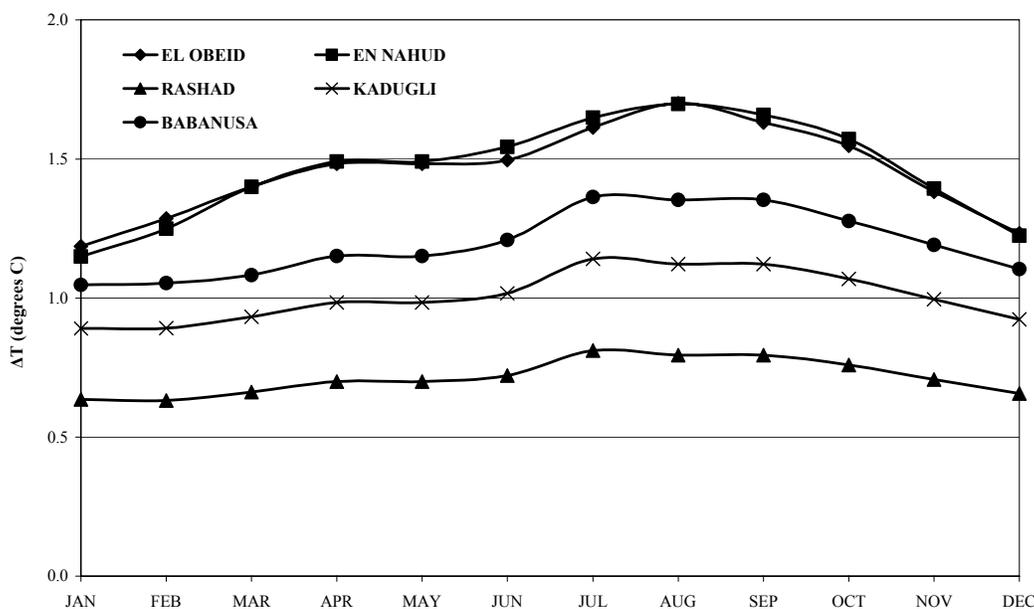
Figure 3.3: HADCM2 GCM projected average temperature differences at all stations in 2060
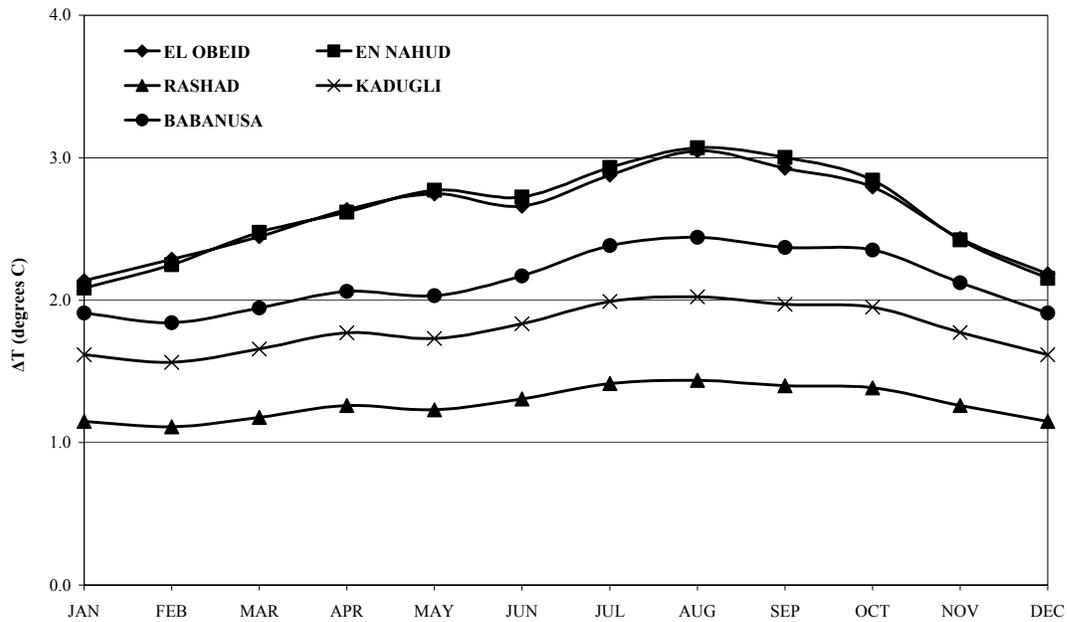
Figure 3.4: HADCM2 GCM projected average precipitation differences at all stations in 2030
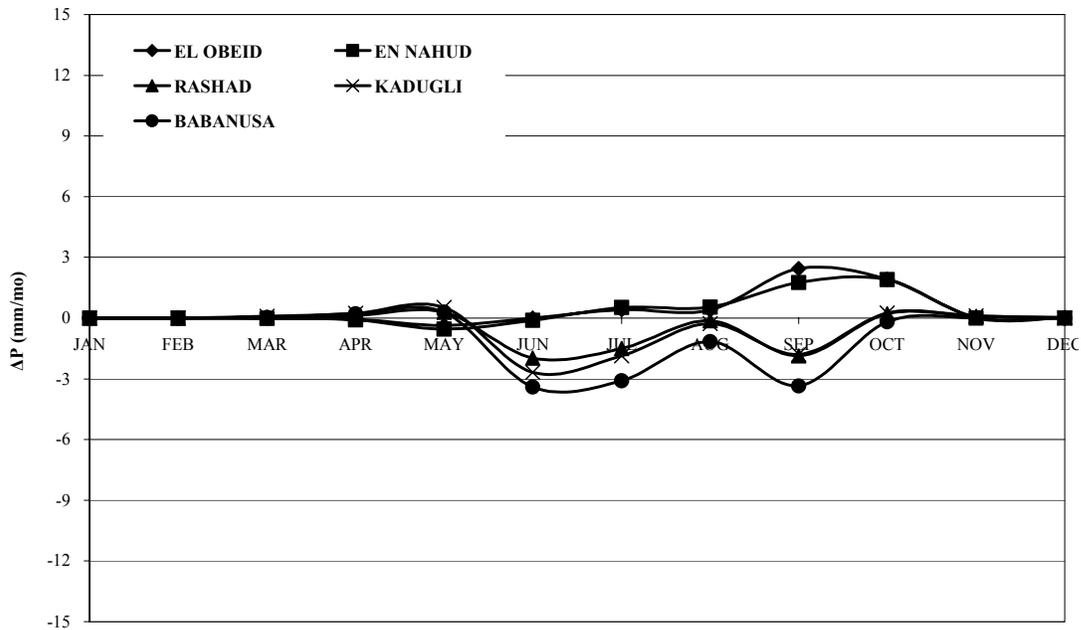
Figure 3.5: HADCM2 GCM projected average precipitation differences at all stations in 2060
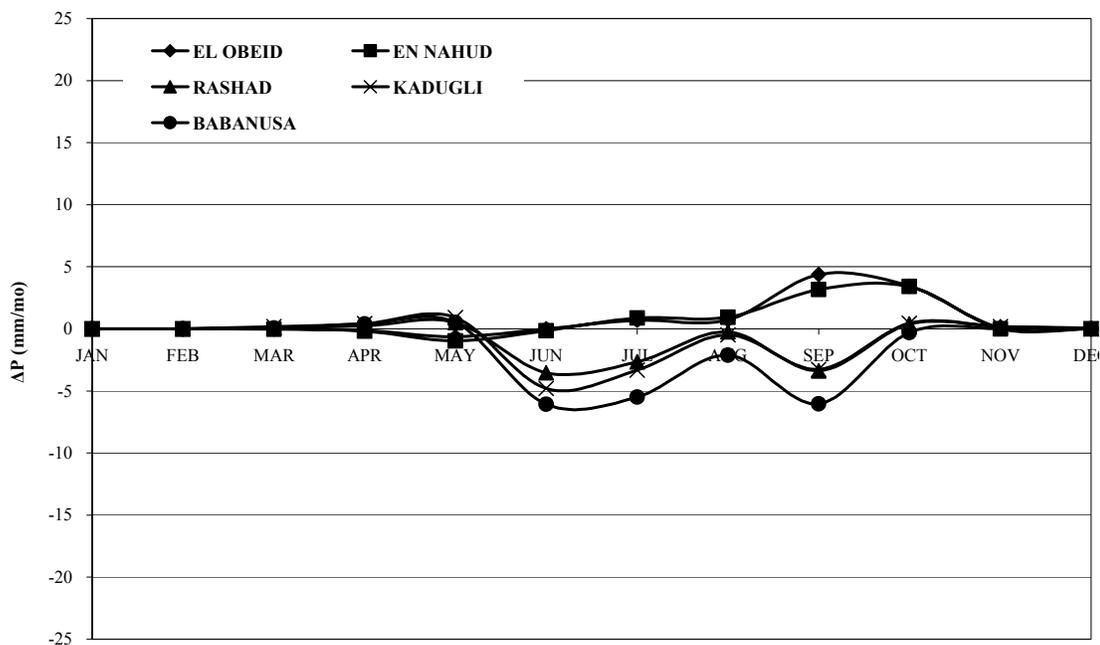
3.3 Agriculture & Forestry

3.3.1 Overview

Sudan's economy is heavily dependent on the agriculture and forestry sectors, which, for the purposes of this study, are considered together as *Agriculture & Forestry*. During the 1990s, the contribution of the sector to Sudan's gross domestic product reached as high as 41.5%. Agriculture provides 90% of the raw material for local industries, and employment and income for more than 80% of the population. In addition, agricultural products are a dominant component of foreign trade, contributing more than 80% of Sudan's exports, primarily in the form of raw materials (gum arabic, oil seeds and cotton). Agriculture and forestry (both natural and planted trees) account for almost all of domestic supply of staple food (sorghum, millet and animal production), and to more than 70% of the national energy consumption, in form of fuel-wood and other biomass sources.

Roughly 90% of cultivated areas depend exclusively on rainfall (a system of farming referred to as the traditional rainfed sector). This is illustrated on Figure 3.6. Quantity and distribution of rain is thus a central determinant of crop success in Sudan, with fluctuation in crop yield attributed almost solely to fluctuation in rainfall. One of Sudan's most pressing concerns as it examines the impact of temperature and rainfall patterns is the security of its agricultural lands. The 1992-2002 National Comprehensive Strategy (NCS) of Sudan, among its main goals, called for food security through horizontal and vertical expansion of crop production – particularly sorghum, millet, wheat, and livestock. The agricultural policy also called for greater environmental balance in the agriculture sector, and for strengthening the role of small farmers -

those who subsist mainly in the traditional rainfed sector. In the context of climate change, the challenges facing each of these objectives are compounded. The small subsistence farmer of the traditional rainfed sector is the most vulnerable to climate change. As such, the Vulnerability and Adaptation (V&A) study has aimed to assess the potential impacts on this segment of Agriculture & Forestry.

Figure 3.6: Agricultural production systems
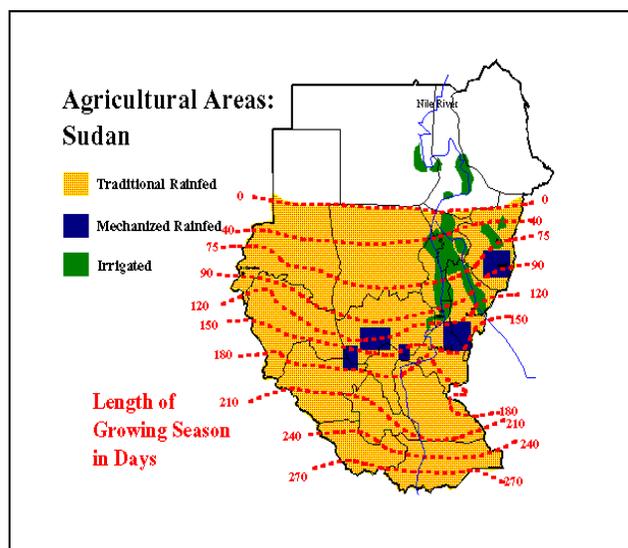
Traditional rainfed Agriculture & Forestry is characterized by small holdings, with most of the operations done by family labor with traditional farming tools. The main food crops grown in the Kordofan Region are millet and sorghum, while groundnut, sesame and gum arabic are the primary cash crops. About 1.7 million households earn their living from this sector, which is why recent droughts (1983-85 and 1990-93) have resulted in such severe food shortages, and in famine among the dependent populations.

In addition to agricultural crops, forest products are extremely important to Sudan, as a source of both energy and exports (Sudan provides 80% of the gum arabic consumed globally). Gum arabic, an ingredient in candy, perfumes, processed food, and pharmaceuticals, is considered a small-scale, rural industry. Those involved are mainly small-scale farmers who tap and produce the gum arabic themselves, while others hire labor. This provides a critical source of income to rural populations during the months of the dry season.

Forests are essential for their vital environmental roles, as well. In Sudan, the most significant of these may be protection from desertification - a process that threatens large areas. The Gum Arabic Belt - a site of diverse Agriculture & Forestry activities that lies within the low rainfall savannah zone (as depicted in figure 3.7) - may be the most important forest in Sudan. The Hashab (gum arabic) tree plays an important role in the traditional rainfed Agriculture & Forestry system. This is recognized by its ability to fix nitrogen and thereby improve soil fertility, providing essential forest products and offering farmers an important source of off-season income. Perhaps most importantly, the Gum Arabic Belt also acts as a natural barrier to desert encroachment (for an in depth look at the sector, see Volume II, Section 2).

Figure 3.7: Sudan's Gum Arabic Belt
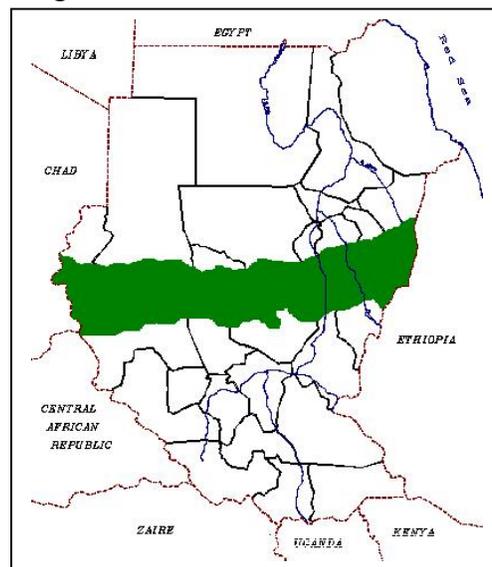
3.3.2   Agriculture & Forestry Assessment Approach

The most vulnerable area with regard to climate change - and the focus of this component of the study - is the large central section of Kordofan, which constitutes 24% of Sudan's total area.   The goal of the Agriculture & Forestry V&A assessment is to identify and gauge the severity of climate change impacts and possible adaptation options of traditional agriculture and gum arabic production in the Kordofan states.

While the adaptation assessment is an ongoing process, the first phase of work has been completed, fulfilling the specific, near-term objective of identifying and assessing the potential impacts of climate change on sorghum, millet and gum arabic production in the Kordofan Region.

As part of future activities, the longer-term objectives of the work are to:

- Identify the possible adaptive responses for reducing adverse effects,

- Inform and advise the policy-making process, and

- Highlight the linkages between Agriculture & Forestry sector impacts and other environmental and socioeconomic consequences of climate change.

3.3.3   Methodology of Agriculture & Forestry Assessment

The methods used for climate change impact assessment are discussed in detail in Section 2 (Agriculture & Forestry) of Volume II. Please refer to this section for more detailed information.

3.3.3.1   Focus

The study's assessment of Agriculture & Forestry impacts considers three key variables: agro climatic zones, crop yield, and gum arabic production - or more specifically, the behavior of each of these in the context of climate change. By using projections of baseline (non-climate change) and climate change conditions, the assessment derives potential impacts on Kordofan's agro climatic zones and on the yield of sorghum, millet and gum arabic produced in these zones (data and calculations are outlined in Volume II, Section 2).

3.3.3.2   Analysis Approach

In its approach, the Sudan study utilizes a combination of existing tools, including expert judgment, analogue methods (historical and spatial trends), GIS techniques (for mapping and

analysis of data on Kordofan states), statistical methods (used to generate crop yield forecasts), and crop impact models (soil water balance models).

The time frames used in the analysis are:

- **Baseline scenario:** According to IPCC recommendations, a normal period of 1961-1990 is used.

- **Climatic change scenario:** Based on a doubling of CO2 emissions (IS92A scenario), milestone years 2030 and 2060 are used (in place of IPCC recommended 2015, 2050 and 2100).

The core assessment tools include:

- **Agro climatic classification scheme**: delineation of an area into zones, based on calculation of moisture index; also known as the Thornthwaite method. The agro climatic classification represents the zone's ability to support different types of vegetation - for these purposes, agricultural crops and gum arabic trees.

- **Soil water balance models:** two models of the Food and Agricultural Organization (FAO) were used calculate values of water satisfaction index for crop monitoring.

- **Water Satisfaction Index**: derived from these FAO tools, WSI is a measure of cumulative water requirements for a given crop. The degree to which the requirements are satisfied in a growing season is used as an indicator of crop conditions and of final yield.

- **Climate change Scenarios**: temperature and precipitation projections for milestone years 2030 and 2060, based on a doubling of CO_2 by the year 2060 (corresponding to a 1% per annum increase of CO_2 emissions). These were generated using:

  - *Approach One:* MAGICC/Scengen software, Version 2.4, with input from the IS92A emissions scenario, and three General Circulation Models (HADCM2, BMRC and GFDL), and

  - *Approach Two:* "Synthetic" vulnerability scenarios (scenarios comprised of assumption-based, incremental temperature and precipitation changes).

Scenarios of climate change were used to test the sensitivity of Kordofan's agro climatic zones, and thus crop yield and gum arabic production, to changes in CO_2 levels. Baseline yield scenarios were established against which predicted crop and gum yield projections were measured. This comparison is intended to help establish the sector's degree of sensitivity and level of vulnerability.

3.3.4   Agriculture & Forestry Vulnerability

The recent droughts, socioeconomic changes, and on-going process of desertification have drastically affected the distribution and condition of tree cover in the Gum Arabic Belt, and agricultural crops in the Kordofan Region, particularly in the sandy areas of North Kordofan and North Darfur. Increased human and animal population, and lower than average rainfall over the last several decades have led to widespread environmental degradation that is clearly reflected in

agriculture crop and gum arabic production. With these processes as a backdrop, crop and gum production is expected to be directly affected by climate change, through changes in temperature and precipitation (as discussed here), as well as indirectly, through increased pests, pathogens, and other pressures.

Potential effects include the following:

- Reduction in ecosystem integrity and resilience, and a decline in biodiversity,

- Decrease in forest area and area under cultivation,

- Decline in crop and gum yield,

- Frequent spells of drought (with impacts such as severe shortages in drinking water),

- Change in the planting dates of annual crops,

- Fungal outbreaks and insect infestations due to changes in temperature and humidity, and

- Increased risk of food shortage and famine.

3.3.4.1   *Impacts of Approach One*

Using the three GCM climate change scenarios to assess the vulnerability of the Agriculture & Forestry sector (sorghum, millet, and gum arabic production), the following specific impacts are found:

- A southward shift in moist agro climatic zones is seen, indicating a shrinking area of crop production.

- Food crop yield for the selected stations showed a decline from baseline yield of between 13% and 82% for sorghum and between 20% and 76% for millet. The exception was Rashad station, where predicted crop yields were roughly equivalent to baseline. Crop yield in the southern part of the region (Kadugli) remained close to historic levels.

- Of the three exposure units, sorghum is most heavily affected.

- Gum arabic yield, region-wide, is predicted to decline between 25% and 30%.

- The most heavily impacted areas for both crops are the northern (El Obeid station), western (En Nahud) and southwestern (Babanusa) parts of the region.   Figure 3.8 shows the crop yield of sorghum in El Obeid and En Nahud stations, indicating a clear decline of sorghum yield in the milestone years.

Figure 3.8: Projected Sorghum Yield El Obeid and En Nahud Stations
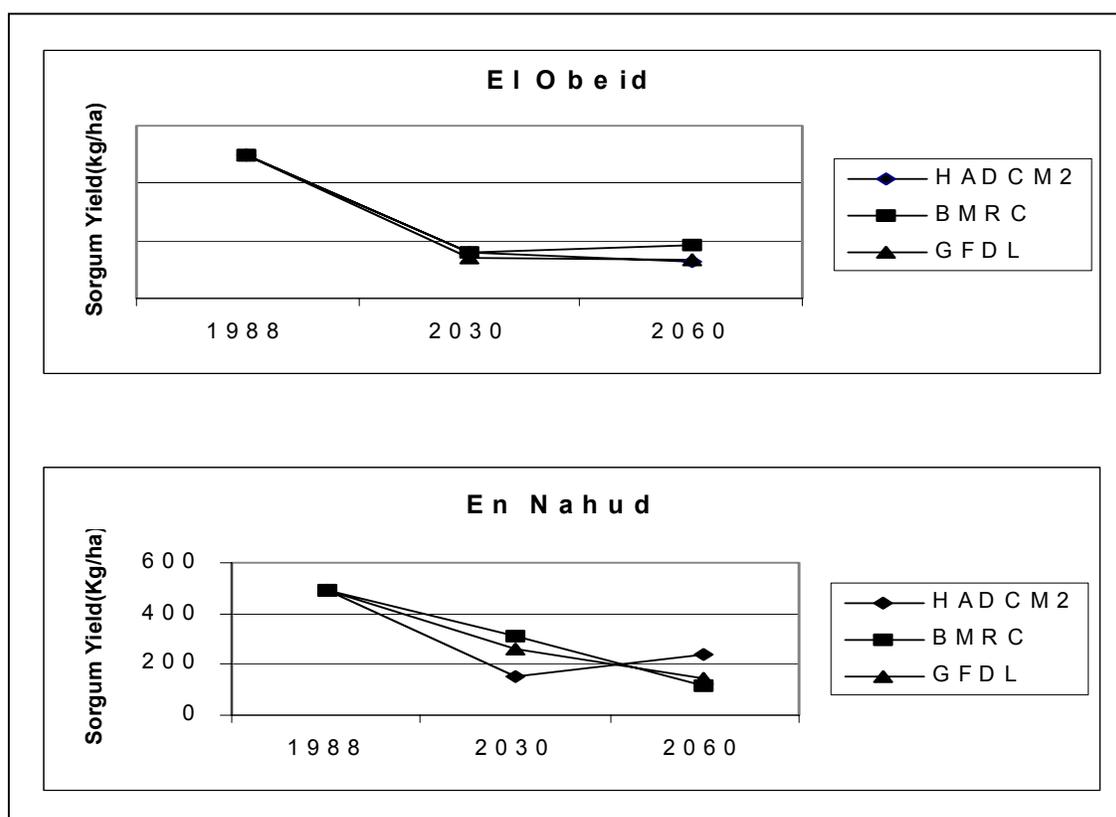
Tables 3.1 through 3.3 show that a decline in sorghum crop yields are predicted for all stations examined. Tables 3.4 through 3.6 show that a decline in millet crop yields is also predicted for all stations examined. The crop yield declines from the historic baseline in year 2030 and worsens in 2060.

3.3.4.2   Impacts of Approach Two

In its second approach - using synthetic (incremental) climate change scenarios - the study finds the following:

- Crop yield for both millet and sorghum drop below baseline and show a general declining trend (except in cases of significant precipitation increase, i.e., 20%).

- With this approach, the northern, western and southwestern parts of the region are found to be highly sensitive to the rise in temperature.

- The production of gum arabic is found to vary, again depending largely on the precipitation increase (e.g., 20%) of the synthetic scenario.

Overall, however, increased temperature, increased evaporation and the resulting reduction in the ability of Hashab trees to utilize water, is expected to lead to decreased production (see Volume II, Section 2 for more information on methods and results).

Table 3.1: Average sorghum yield in the baseline (1961-1990)

Station	Temperature (ºC)	Precipitation (mm)	Im (%)	WSI (%)	Crop yield (kg/ha)
El Obeid	27.3	318	-57	86	495
En Nahud	27.5	335.9	-45	93	631
Rashad	26.8	717.7	-20	100	>748
Kadugli	28.1	633.1	-13	100	>748
Babanusa	28.5	497.3	-28	100	>748

Table 3.2: Projected sorghum yield in 2030

Station	Temperature (ºC)	Precipitation (mm)	Im (%)	WSI (%)	Crop yield (kg/ha)
El Obeid	28.3	328.9	-63	60	150
En Nahud	28.4	347.6	-54	72	285
Rashad	27.2	715.8	-24	100	>748
Kadugli	28.8	630.5	-32	88	533
Babanusa	29.2	489	-45	82	417

Table 3.3: Projected sorghum yield in 2060

Station	Temperature (ºC)	Precipitation (mm)	Im (%)	WSI (%)	Crop yield (kg/ha)
El Obeid	29.1	337.4	-63	59	143
En Nahud	29.2	356.7	-55	71	274
Rashad	27.8	714.3	-31	100	>748
Kadugli	29.4	628.2	-38	86	495
Babanusa	29.8	482.3	-48	80	379

3.3.5   Conclusions

A number of the Agriculture & Forestry sector impacts projected through this work are strikingly negative, suggesting a significant decrease in Kordofan's agricultural productivity and a reduction in its primary cash crop. The results suggest that the Agriculture & Forestry sector - and the nation as a whole - may be hard hit by even modest changes in temperature and precipitation. Given the projected increases in population, desertification and assorted environmental and socioeconomic pressures, these preliminary findings may provide a warning signal to stakeholders and decision-makers and help to sharpen attempts at identifying and implementing adaptation measures.

Table 3.4: Average millet yield in the baseline (1961-1990)

Station	Temperature (ºC)	Precipitation (mm)	Im (%)	WSI (%)	Crop yield (kg/ha)
El Obeid	27.3	318	-57	64	112
En Nahud	27.5	335.9	-45	78	204
Rashad	26.8	717.7	-20	99	433
Kadugli	28.1	633.1	-13	99	433
Babanusa	28.5	497.3	-28	91	343

Table 3.5: Projected millet yield in 2030

Station	Temperature (ºC)	Precipitation (mm)	Im (%)	WSI (%)	Crop yield (kg/ha)
El Obeid	28.3	328.9	-63	53	56
En Nahud	28.4	347.6	-54	60	86
Rashad	27.2	715.8	-24	93	367
Kadugli	28.8	630.5	-32	80	217
Babanusa	29.2	489	-45	71	159

Table 3.6: Projected millet yield in 2060

Station	Temperature (ºC)	Precipitation (mm)	Im (%)	WSI (%)	Crop yield (kg/ha)
El Obeid	29.1	337.4	-63	49	<43
En Nahud	29.2	356.7	-55	59	81
Rashad	27.8	714.3	-31	90	331
Kadugli	29.4	628.2	-38	74	178
Babanusa	29.8	482.3	-48	68	139

3.3.6   Adaptation

The population of Kordofan is expected to double by 2030 alone. In order to prepare to feed this population, measures should be undertaken such as introduction of low water-use crops and adoption of sustainable water resource management policies. This latter action could take the form of seasonal rainfall harvest and water quality control. In building capacity programs, integrated research studies should be implemented between the institutes relevant to these activities.

Since the parallel trends in population growth and deforestation bode ill for the Gum Belt and the Agriculture & Forestry sector in Kordofan, there is a strong need for better policy mechanisms to control unsustainable forest clearing and forest product consumption. In addition, plans must be made for reforestation and afforestation projects, with a primary concentration on Hashab trees in the region.

3.4   Malaria

3.4.1   Overview

Malaria, as the main cause of death and absence from work in Sudan, is the country's most important public health problem. According to government records, it causes 30% of all attendance to health facilities and about 23% of all hospital admissions. Experts believe, however, that the magnitude of the malaria problem in Sudan far exceeds official figures, particularly in rural areas where access to proper health services, and thus epidemiological reporting systems, is very limited (i.e., roughly 20% of rural populations have access).

Malaria causes widespread premature death and suffering. Young children are most severely affected, with one in five childhood deaths in Africa directly attributed to malaria. Mortality is not the only problem; serious long-term neurological disabilities, severe anemia and multiple organ failure are experienced in many countries, as a result of infection. An increase in malaria transmission potential (TP) in Sudan would have broad reaching impacts.

Reports of the World Health Organization (e.g., WHO, 1995a) show a picture of global malaria incidence in which almost 300 million cases of malaria occur each year and over one million people die, with risk particularly high in Sub-Saharan Africa, where about 90% of deaths occur due to malaria. Climate change is expected to exacerbate the current problem.

Various scientific studies based on mathematical models indicated that a global mean annual temperature increase of between 1 and 3° C would enable mosquitoes to extend their range to new geographic areas. According to the Pim Martens (1999), developer of the MIASMA model, the increase in temperature and precipitation associated with future climate change results in a greater potential for malaria epidemics in certain regions of Africa. In 1987, Rwanda for example, experienced increased incidence and distribution of malaria during a period of climatic conditions that is considered typical of predicted climate change (Loevinsohn, 1994)

The sensitivity of malaria to temperature and precipitation is relatively well documented. A growing body of studies has examined the potential influences of global anthropogenic climate change on the distribution of malaria and other vector-borne diseases (e.g., Martens *et. al.*, 1994, 1995a, 1995b, 1997; Matsuoka and Kai, 1994; Martin and Levfebvre, 1995; Jetten *et al.* 1996; Martens, 1996a; Patz *et al.*, 1998). In Sudan, studies from 1999 indicate that temperature determines survival rates of both the vector and parasites, while precipitation directly influences the abundance of breeding sites and vector densities. Some of the effects of climate change on vector-borne diseases are likely to be highly localized in character; others, particularly the effects of rising temperature, are more generalized (Bradley, 1993).

In simplest terms, temperature affects malaria incidence in the following way: higher temperatures shorten the aquatic cycle of the mosquito from 20 to 7 days and reduce the time between emergence and eviposition as well as the time between successive evipositions. With higher temperature the parasite develops faster and can be transmitted to a host carrier earlier in its life cycle. With higher temperatures, the mosquito matures faster, lives longer, and has more frequent blood meals, thus increasing the frequency of potential transmission.

In human populations, malaria can occur on both an endemic and epidemic basis. Endemic malaria recurs continually in a particular region among the small portion of the population that is non-immune (see Figure 3.9). The endemicity of malaria is largely dependent on the mosquito and parasite species, and on local climate, which broadly determines the frequency of transmission. Under very high intensities of transmission, endemic malaria is commonly referred to as stable malaria.

Epidemic malaria occurs when large numbers of non-immunes are exposed to infected vectors. Epidemic areas are subject to regular, rapid increases in malaria incidence, usually related to season and population, whereas in endemic areas, malaria transmission occurs continuously over many successive years. Moderate intensity of transmission, with seasonal fluctuation, is referred to as unstable malaria.

An inverse relationship is observed between endemecity and epidemicity as, in highly endemic areas, adults acquire a degree of immunity through continued exposure and only children and pregnant women are most vulnerable to attack. Conversely, in epidemic areas, most of the population is likely to be non-immune and, thus, at risk of infection in Africa (Ministry of Health, 1998).

Figure 3.9: Endemic zones of malaria
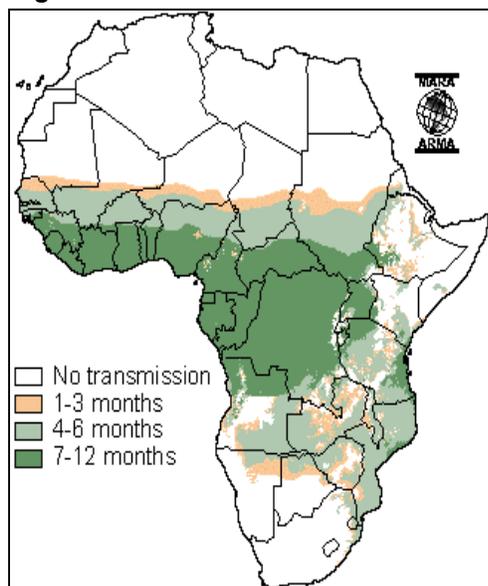
The predominant malaria vector in Sudan is the *Anopheles gambiae* mosquito - an insect found in most African countries and in the whole of Sudan. Of the four parasite species that affect humans, *Plasmodium falciparum* is considered the most virulent, and is the most common in Africa. The risk to Kordofan Region of both *Plasmodium falciparum and Plasmodium vivax* are considered in this assessment.

Malaria is considered endemic throughout the country. In the South, the wet savanna is characterized by stable malaria, while the central and northern parts - poor dry savanna - are characterized by unstable malaria, with epidemic-prone areas. In Sudan, malaria epidemiology can be divided into the strata shown in Table 3.7.

Epidemic prone areas are the strata of unstable malaria (hypo- and meso-endemic zones). This classification suggests that some 26 million people in Sudan are vulnerable to an outbreak of malaria.

In Sudan, as in many countries, socioeconomic factors, in addition to climatic factors, contribute to the determination of malaria-endemic and epidemic areas. For the purposes of this study, such factors have not been taken into complete account - a limitation that will need to be addressed in future analyses.

Table 3.7: Malaria epidemiology in Sudan

Strata	Classification	Annual Parasite Incidence (API) (% of total population)	Number of population	Malaria intensity
Desert Fringe	Hypo endemic	3.8	1,000,000	Unstable
Poor savanna	Mesoendemic	4.8	20,000,000	Unstable
Rich wet savanna	Hyper endemic	1.5	4,000,000	Stable
Urban Malaria	Mesoendemic	0.3	5,000,000	Unstable

3.4.2 Malaria Assessment Objectives

According to a new GIS distribution model, developed for the purposes of converting climate data into a malaria distribution map for sub-Saharan Africa (Craig *et al.*, 1999), the zones most vulnerable to future malaria epidemics due to climate change are likely to be between 4 and 11 degrees latitude, for both the *P. vivax* and *P. falciparum* parasites - a swath which includes Southern Sudan and parts of Kordofan Region.

This analysis focuses on Transmission Potential (TP), in order to provide a "first-cut" indication of when and where malaria epidemics could occur in Sudan, given a change in climate. Kordofan Region is the selected focus of this analysis, largely because of the potential impact of malaria in this area, and also to contribute - together with Agriculture & Forestry and water analyses - to a complete multisectoral assessment of climate change impacts on a single defined region.

The Kordofan states lie in the central part of Sudan, between latitudes 9.5° and 16.4° North, and longitudes 27° and 32° East. The region possesses a diversity of ecological zones, many of which can be categorized as prone to epidemics. This area currently lies on the outer fringe of the malaria endemic regions of Africa. The instability of this area (particularly Northern Kordofan) and, thus, the transmission potential under climate change conditions, is of acute concern.

3.4.3 Methodology of Malaria Assessment

3.4.3.1 Focus

In Sudan, an assessment of climate change impact on malaria incidence is constrained by a lack of reliable epidemiological data. Historic records of disease incidence are incomplete, making it impossible to create a reliable picture of baseline (non-climate change) prevalence of malaria. Thus, it is not possible to compare baseline disease incidence against disease incidence projected in a climate change scenario. As the most significant public health concern in Sudan, however, malaria is a critical area of inquiry, and one that is central to a complete V&A Assessment. To overcome data limitations and facilitate an impact assessment, transmission potential (TP) - as opposed to actual numbers of cases of malaria - is the focus of the analysis.

In simplest terms, transmission potential can be considered a measure of the latent potential for disease outbreak within a particular region. TP, as described by Martens (1998), is a "key summary parameter that is used as a comparative index in estimating the effect on the risk of malaria represented by a change in ambient temperature and precipitation patterns." The results

of the analysis are presented in terms of change in TP, from baseline to the climate change case. The magnitude of the change in TP represents the change in malaria susceptibility of the human population in a given area; higher TP in a given area indicates a higher potential for malaria outbreak.

3.4.3.2 *Analysis Approach*

The modeling tool used in analyzing TP was an Excel spreadsheet model, based entirely on the series of relationships described in Martens *et al.*, 1995, and embodied in the MIASMA model. MIASMA (Modeling framework for the health Impact Assessment of Man Induced Atmospheric Changes) integrates several public health models, each dealing with the health impacts of global atmospheric changes on human populations. The vector-borne disease model within MIASMA is designed to focus on transmission of vector borne diseases related to climate (Martens *et al.*, 1995). Equations for computing transmission potential were used to calculate monthly changes in transmission potential (TP) for the Kordofan Region, for the years 2030 and 2060, relative to the baseline period, 1961-1990. Other major parameters of the analysis are as follows:

- The IPCC's IS92A scenario was used, in which carbon dioxide concentrations in the atmosphere double by the middle of this century

- Five sites within Kordofan were considered for which historical climatological data had been assembled: Rashad, Kadugli, En Nahud, Babanusa and El Obeid.

- Average monthly changes in temperature in the years 2030 and 2060, relative to the historical 1961-1990 baseline period, were determined based on simulation results of three global circulation models: HADCM2, GFDL, and BMRC

- The MAGICC/SCENGEN simulation model was used to obtain temperature changes at the geographic resolution provided by the model. These changes were then linearly interpolated to the latitude and longitude of the five sites within Kordofan.

- All of MIASMA's assumptions and empirically-based constants were assumed as default (i.e., survival potential, incubation period, etc) due to lack of reliable local values.

- The MIASMA equations and assumptions used in the spreadsheet model are described in detail in Volume II, Section 3. The vulnerability to future malaria epidemic outbreaks was calculated as the ratio of the TP with climate change to the TP without climate change.

3.4.4 *Vulnerability to Malaria*

Figures 3.10 and 3.11 show that the potential for climate change induced malaria outbreak is greatest for the regions surrounding El Obeid station, during October and December. However, the maximum tolerable temperature for the two parasites is assumed to be 32°C. Hence, an increase in temperature beyond that is likely to increase mortality. This appears to be true for the period April through July, in both 2030 and 2060, and in all the five stations.

The results also show that at each of the five stations, transmission potential rose above baseline throughout much of the year in both 2030 and 2060, and for both the *P. falciparum* and *P. vivax* parasites (see Figures 3.10 and 3.11). All stations showed seasonal pulses in TP - most notably,

El Obeid, En Nahud and Babanusa during the winter months (December to February), and Rashad and Kadugli during the early and late summer months (June to September). Generally, the situation deteriorated in 2060 compared to 2030. Each of the three GCMs reflected these patterns, are illustrated in the following figures.

Figure 3.10: Projected average increase in the transmission potential of *P. Falciparum* using combined GCM outputs (2030)
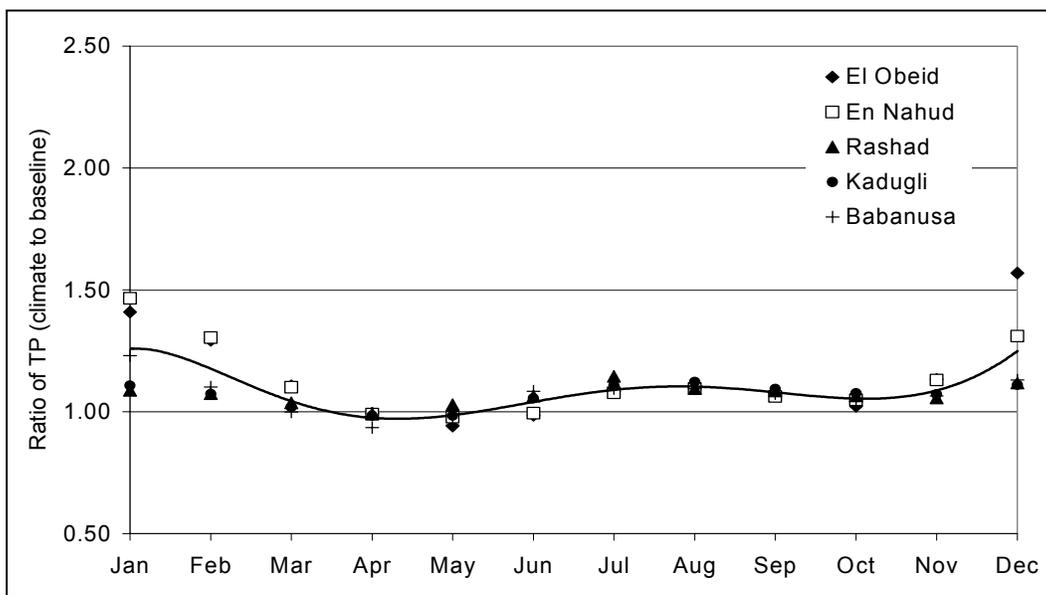
Figure 3.11: Projected average increase in the transmission potential of *P. Falciparum* using combined GCM outputs (2060)
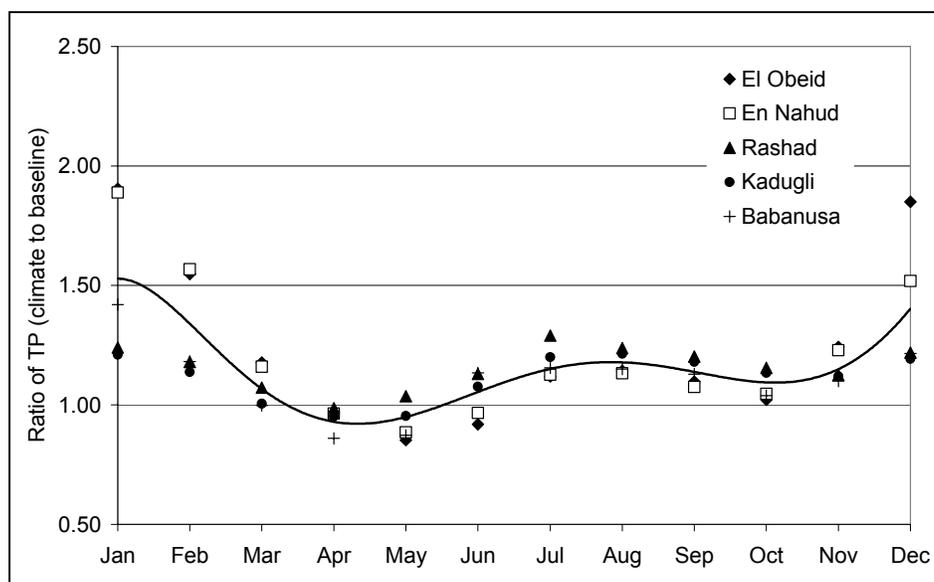
The results of this analysis indicate that Sudan's Kordofan Region will be vulnerable to future climate change-induced outbreaks of malaria. There could be significantly worse malaria problems in these regions during the winter months - November to February - in the absence of effective adaptation measures.

In the months of December and January, the transmission potential of *P. falciparum* with climate change is 75% greater than TP without climate change; Table 3.8 illustrates this pattern, showing the projected increase of *P. falciparum* transmission potential for the region around El Obeid - where the highest increase in TP is seen.

These results, generated by the HADCM2 GCM, show that TP in 2060 is more than double the baseline TP, suggesting a doubling of the potential for malaria outbreak during the months of December and January. The risk in 2030 is only slightly less.

Table 3.8: El Obeid - Projected average transmission potential of *P. Falciparum* using HADCM2 outputs

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline climate	0.18	0.38	0.78	1.00	0.98	1.00	0.88	0.80	0.87	0.96	0.62	0.20
Climate change scenario: 2030	0.28	0.52	0.91	0.98	0.90	0.99	0.99	0.94	0.97	1.00	0.77	0.36
Climate change scenario: 2060	0.39	0.64	0.97	0.92	0.69	0.84	1.02	0.99	1.01	0.98	0.88	0.43
Ratio of climate change baseline: 2030	1.60	1.37	1.16	0.98	0.92	0.99	1.12	1.18	1.12	1.04	1.24	1.80
Ratio of climate change baseline: 2060	2.19	1.68	1.24	0.92	0.70	0.84	1.15	1.24	1.16	1.02	1.41	2.17

The projected decrease in TP in 2030 and 2060 during the May-August period is attributed to the effect of a high increase in temperature during these months. Detailed results for each parasite, at station, during both milestone years appear in Volume II, Section 3.

3.4.5   Conclusions

The projected increase in transmission potential, though not extrapolated into projected numbers of malaria cases, suggests that the changes in temperature and precipitation anticipated under climate change could adversely alter the current distribution and intensity of malaria incidence in Sudan. In addition to the potential human toll, socioeconomic impacts such as the increased burden on the nation's health care system may be significant. Based on such potential impacts, the question of climate change impact on malaria - and the most suitable adaptation options - warrant far greater investigation. Important areas for subsequent research will be the adverse economic impacts of malaria in Sudan (under both baseline and climate change scenarios), as well as the combined effects of climate and socioeconomic factors on malaria incidence.

3.5   Water Resources

3.5.1   Overview

Sudan's current water resources, as well as its ability to harness them, are limited and prone to severe shortage. Annual water availability is provided mostly from surface waters and, to a lesser extent, from groundwater resources (El Toum, 1999). The Nile water basin contributes most of Sudan's available surface water. However, though the Nile transports over 93 billion cubic meters (bcm) of water per year on average, Sudan's share is only 20.5 bcm per year, in accordance with a 1959 water use treaty with Egypt. Beyond the Nile watershed, the total annual flow in seasonal streambeds ranges between 3 and 7 billion cubic meters (bcm) per year in three major rivers - the Gash, Baraka and Azum (El Toum 1999). The water resource situation for remote areas is especially precarious, as flow from seasonal streams is limited in quantity and duration and varies in terms of turbidity. Thus, Sudan's available surface water ranges between 23.5 and 27.5 bcm per year.

With a current population of roughly 30 million, Sudan's available surface water - if fully accessed and utilized - can provide between 920 and 1,050 cubic meters per capita - a level well below the limit of water scarcity and in the range of water's stress as classified by the FAO water stress scale (Raskin *et al*, 1997). Sudan is currently able to utilize only around half of its available water, primarily due to limited water storage capacity.

To supplement surface water, annual groundwater abstraction has grown to roughly 16 bcm. With an annual recharge rate of about 4 bcm (El Toum, 1999), it is clear that Sudan is not harvesting its groundwater resources in a sustainable manner. Ground water withdrawal in Sudan is quite costly, as most aquifers are located at depths between 40 and 400 meters. However, under current trends, reliance on groundwater resources is unlikely to abate. If available surface water is fully utilized by expanding the storage capacity through new technology, investment, and other practical measures, the water available per capita will still only approach the water scarcity level. Moreover, as the structure of water demand evolves from its current dominance by agricultural uses (about 94%) to more intensive future uses in the industrial and residential sectors (together accounting for a future 31% share), water pressures will clearly increase. It is anticipated that the unsustainable nature of groundwater withdrawal will become even more acute.

3.5.2   Kordofan Region Water Resource Profile

Water resources in Kordofan State are highly sensitive to climate variation and fluctuating rainfall. To a large extent, the population of Kordofan is dependent on rainfall to provide water for crops, livestock, and household use. During the last two decades, Western Sudan (Kordofan and Darfur States) has witnessed severe drought that has caused loss of human life, crop failure, and considerable loss of livestock. Meteorological data clearly indicate that recent drought cycles are drier, last longer, cover larger areas, and have shorter non-drought intervals (Sudan Meteorological Authority). For these reasons, water resources in Kordofan are considered a national priority, and an essential component of the vulnerability and adaptation assessment.

The vulnerability of Kordofan Region water resources is the focus of this assessment. In 1993, the population of Kordofan Region was estimated to be 3.6 million. Water resources to meet the needs of these people, and the array of competing demands, consist of groundwater and surface water, both of which are dependent on local rainfall.

Groundwater yield is insufficient to cover the different demands of the region: human, livestock, agriculture, and industry. With an annual groundwater recharge of 1.8 bcm, the "renewable" portion of groundwater is about 500 cubic meters per capita, per year. In 2030, with a projected population in Kordofan of roughly 5.6 million, this level is expected to decrease to between 300-400 cubic meters per capita, per year, and will drop lower still in 2060. Decreases in groundwater recharge as a result of decreased precipitation or increased temperature and evapotranspiration will clearly exacerbate the precarious situation in Kordofan.

Surface water is a necessary supplement to groundwater use in the region. Since Kordofan does not have permanent stream flow, surface water availability is entirely dependent on rainfall, which is sharply constrained by the duration and variability of the rainy season (generally May through October).

The Coefficient of Variability (CV) of rainfall from the historical annual rainfall data (1961-1990) is calculated by using the standard deviation of monthly rainfall and their averages. It is found that rainfall varies by between 15% and 65% in the extreme southern and northern parts of the region respectively. The CV in El Obeid is 32%, En Nahud 30%, Rashad 18%, Kadugli 21%, and Babanusa 24%. This indicates that dependence on rainfall for supply of water is quite risky and that local vulnerability to volatility in precipitation is high.

Annual rainfall in Kordofan Region typically varies between 350 and 850 mm (see Figure 3.12). Peak rainfall occurs between July and August, with the rainy season beginning between May and June, and ending sometime October and November. However, meteorological observations for Sudan over the last several decades show an overall declining trend in rainfall and an increase in the number of dry years (below average rainfall). During the last two decades, Kordofan and other western states (e.g., Darfur) have witnessed a number of periods of severe drought. As the majority of people in the region are farmers, these periods have had serious impacts.

Surface Water consists of rivers and streams with permanent and seasonal flow. In Kordofan, no permanent rivers or streams exist, and thus the region's surface water is supplied entirely by localized rainfall. Kordofan Region has small seasonal streams known as Khors or Wadis (e.g., Khor Abu Habil), which tend to flow mainly during July and August. The flow of these depends on the duration, intensity and total amount of rainfall received. The level of stream flow (and reservoirs) directly reflects rainfall surplus or deficiency, and determines changes in catchment characteristics, such as land-use and vegetation. Khor Abu Habil is the main watercourse in Kordofan Region. It originates in the Nuba Mountains and carries water between July and October. The annual discharge is in the range 132-200 million cubic meters (see Volume II, Section 4 for more information).

Ground Water depth in Kordofan Region varies between 241 and 310 meters (Senden, 1989). The annual groundwater storage in eastern Kordofan (the Umm Ruaba Basin) is 1.7 bcm, and about 0.1 bcm in the Nubian Basin (Nahud basin and the extension of Central Darfur Basin), for

a combined total of 1.8 bcm per year. In this region, as in much of Sudan, groundwater is mainly used for watering animals (an activity of great regional socioeconomic importance) and for human consumption. To a lesser degree, it is also used for supplementary irrigation (i.e., in addition to rainfall), and for cooling systems in the emerging petroleum industry (see Volume II, Section 4 for more information).

Figure 3.12: Average annual precipitation for the five stations
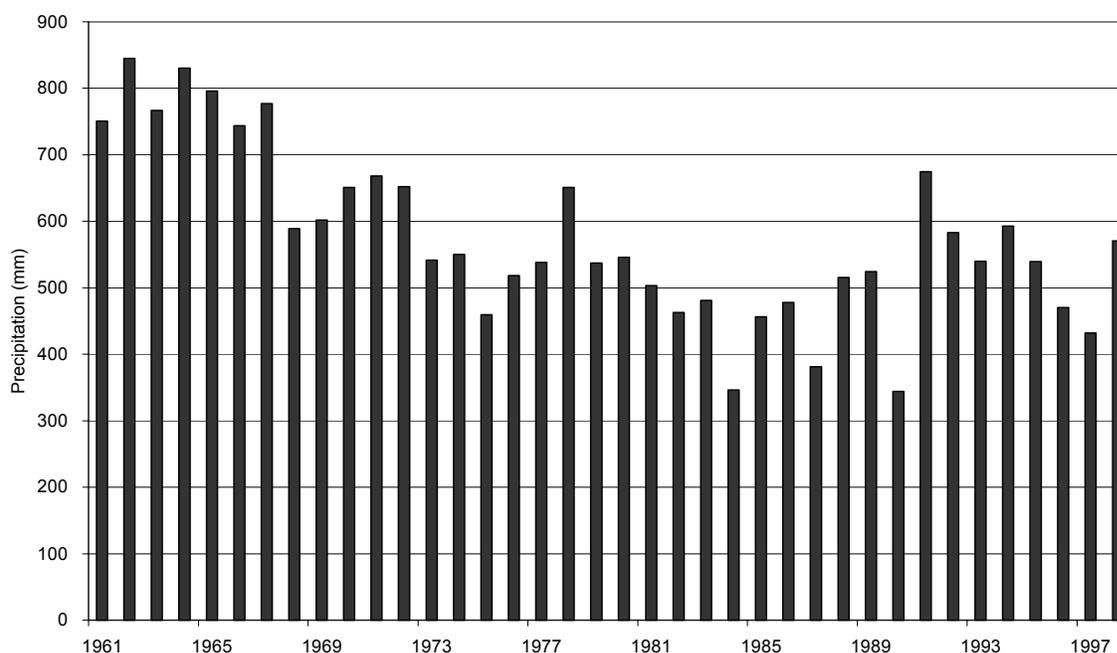
Water in Upper Soil Zones is an important element of the land phase of the hydrologic cycle. Most hydrological activity in this phase takes place in unsaturated zones. In this cycle, the soil acts as a reservoir, from which plants draw moisture to satisfy evapotranspiration requirements. Soil moisture closely influences plant growth and governs water infiltration of soil and, thus, storm runoff.   Soil moisture is an indicator of the water content of soil, which is received from rainfall or from surface water runoff. The correlation between soil moisture and surface water is that, when the soil is fully saturated, part of the excess surface water is evaporated from the soil or transpired by plants and the remainder penetrates downward through the soil. This process of percolation feeds the shallow groundwater while the flow in streambeds helps to feed the deeper groundwater. A deficit in soil moisture is thus caused by a deficit in rainfall. Soil moisture deficit, in turn, means that percolation decreases and that the feeding of shallow groundwater is limited or eliminated.

3.5.3   Water Resource Assessment Objectives

The objective of this study is to assess the vulnerability of Kordofan's water resources to changes in climate. The study aims to serve as a first phase in a complete assessment of the vulnerability of the resource. For this initial assessment, the study focuses only on soil moisture in 2030 and

2060 as an indicator of water stress, determined by changes in available soil moisture under projected temperature and precipitation patterns for the five selected stations (El Obeid, En Nahud, Rashad, Kadugli, and Babanusa).

3.5.4   Methodology of Water Resource Assessment

The temperature and precipitation values derived from the baseline and climate change scenarios have been used to assess soil moisture surplus and deficit. Values of Potential EvapoTranspiration (PET) and precipitation are used as the primary input parameters to the soil water balance model, FAOINDEX. As change in temperature directly affects the values of PET, temperature is a key input to the FAOMET intermediary model (FAOMET calculates PET). Using baseline scenarios for precipitation (see climate scenario section), scenarios are created for baseline soil moisture and water surplus/deficit. For simplicity, historical data (1961-1990) is used to represent conditions in milestone years 2030 and 2060, in the absence of climate change.

By creating scenarios to reflect Kordofan's climate under the projected doubling of atmospheric CO2 and modeling the status of the soil moisture in such conditions, the study was able to compare such projections against the baseline scenarios of historic water resources. Climate change scenarios were generated using three GCMs (HADCM2, BMRC AND GFDL) and the Magicc/Scengen software (See scenario methodology section for more information).

3.5.4.1   Focus

Soil moisture is used as the exposure unit in this study. Kordofan Region is treated as a catchment basin represented by five stations (El Obeid, En Nahud, Rashad, Kadugli and Babanusa). In addition to the limited amount of water received from small rivers (Khors) during the rainy season, rainfall percolates directly into the soil, creating a level of moisture that can be used as an indicator of soil moisture surplus or deficit and an indicator of groundwater recharge.

3.5.4.2   Analysis Approach

Soil receives water either through rainfall or surface water (e.g., stream-flow, runoff, flooding - indirectly, from rainfall as well). This water is evaporated, transpired, or captured in the soil through percolation. The percolation process depends on the type, elevation and saturation of the soil. Fully-saturated soil has reached its maximum holding capacity, and additional (surplus) water will either run off, depending on elevation, or lie stagnant. In this latter case, when there is no place for water to run-off, percolation - the downward movement of water through the soil - will occur, contributing to a certain level of soil moisture. This analysis has focused on soil moisture as a measure of the availability of water for percolation, and thus, the availability of water for groundwater recharge and human extraction.

In this preliminary analysis, the complex linkages between water availability and climatological variation have been simplified to enable the general parameters of potential impacts to be established. The analysis is based on the relationships between core functions of the hydrologic cycle. Water received from precipitation directly affects the moisture content of soil. At high enough levels, however, temperature can operate as a counteracting force, influencing the evaporation rate of water from soil and surface water. Controlled primarily by temperature,

Potential EvapoTranspiration (PET, a combination of evaporation and transpiration) can reduce the influence of precipitation on soil moisture. Thus, while precipitation is the main determinant of the water budget in soil, certain temperature values can exert a significant influence on the hydrologic cycle.

To assess the surplus or deficit of soil moisture under climate change conditions, the analysis relied upon the following resources:

- General circulation Models (GCMs): HADCM2, BMRC and GFDL (IS92A scenario) and MAGICC/SCENGEN v.2.4,

- FAOMET model for calculation of PET,

- FAOINDEX model for calculation of the soil water balance[10], and

- Expert Judgment.

To arrive at specific values of soil moisture, the soil water balance model, FAOINDEX, was used. This model uses Potential EvapoTranspiration (as calculated by the FAOMET model), precipitation (P), soil and surface elevation data to calculate soil moisture content for the area surrounding each station. (The sources of data in this study are the Meteorological Authority, Ministry of Irrigation, and Ministry of Finance.)

The difference between the baseline water holding capacity and the soil moisture values under climate change conditions provide a measure of water surplus or deficit under climate change conditions in 2030 and 2060. These values are measured in millimeters of soil depth. Negative soil moisture values reflect water deficit, and positive values, water surplus. The baseline water holding capacity of the soil is as follows: El Obeid (60 mm), En Nahud (60 mm), Rashad (100 mm), Kadugli (100 mm), and Babanusa (100 mm) (Sudan Meteorological Authority).

In Kordofan, the rainy season generally extends from May to October, thus, to measure soil moisture from one year to the next, FAOINDEX is used to calculate soil moisture in the last dekad of September (the end of the growing season).[11] Using baseline temperature and precipitation values, baseline (non-climate change) soil moisture and water surplus/deficit were calculated. These were used for comparison with soil moisture and water surplus/deficit calculated under climate change temperature and precipitation values for 2030 and 2060. The difference indicates the impact of climate change on this component of the hydrologic cycle, and thus on Kordofan's water resources.

3.5.5   Vulnerability of Water Resources

As illustrated in the following tables, the water deficit in Kordofan is predicted to worsen as a result of climate change in milestone years 2030 and 2060, as compared to the historical baseline (1961-1990). Interestingly, the decline in rainfall is only part of the story; the effect of rising

---

[10] FAOINDEX is similar to the CLIRUN model (Kaczmarek, 1991) and considered an appropriate tool for this preliminary analysis.

[11] The extraction of water by vegetation diminishes by the end of September. The soil moisture content in October (post-rainy season) is the residual of the rainy season.

temperatures and increased PET may have the most significant impact. As mentioned above, higher temperatures can accelerate evaporation to the point where increased PET over shadows the effects of increased precipitation; through the evaporation of surface water, soil moisture can be reduced and thus shallow groundwater recharge and available water diminished. Thus, it is possible for soil moisture to decrease even in the presence of increased precipitation.

The summary tables show the final results obtained from the three GCMs and the FAO impact models. From the results presented in the summary tables 3.9, 3.10, and 3.11, a decline can be seen of between 4 and 25 points in soil moisture in years 2030 and 2060 compared to the historic baseline (monthly values of projected temperature and precipitation are available in Volume II, Section 1).

These results indicate that the situation in El Obeid is critical, since the water deficit (-58 mm) is nearly equivalent to the soil water holding capacity (60 mm). From the values of PET and the resulting soil moisture, it is clear that the effect of the temperature on the results is significant. Though preliminary, such results provide an alarming indication of the potential impact of climate change.

Table 3.9: Estimated water deficit in Kordofan of historical baseline (1961-1990)

STATION	Temp (degrees C)	Precipitation (mm)	PET (mm)	Im (%)	Water deficit (mm)
El Obeid	27.3	318.0	3121	-57	-45
En Nahud	27.5	335.9	2726	-45	-35
Rashad	26.8	717.7	2700	-20	-9
Kadugli	28.1	633.1	2525	-13	-5
Babanusa	28.5	497.3	2692	-28	-24

Table 3.10: Projected water deficit in Kordofan under climate change (2030)

STATION	Temp (degrees C)	Precipitation (mm)	PET (mm)	Im (%)	Water deficit (mm)
El Obeid	28.3	328.9	3400	-63	-55
En Nahud	28.4	347.6	3124	-54	-43
Rashad	27.2	715.8	2825	-24	-15
Kadugli	28.8	630.5	2915	-32	-26
Babanusa	29.2	489	3188	-45	-36

Notes: Results based on average of HADCM2, BMRC, and GFDL GCMs under the IS92A scenario.

Table 3.11: Projected water deficit in Kordofan under climate change (2060)

STATION	Temp (degrees C)	Precipitation (mm)	PET (mm)	Im (%)	Water deficit (mm)
El Obeid	29.1	337.4	3538	-63	-58
En Nahud	29.2	356.7	3213	-55	-44
Rashad	27.8	714.3	2876	-31	-16
Kadugli	29.4	628.2	2965	-38	-27
Babanusa	29.8	482.3	3269	-48	-39

Notes: Results based on average of HADCM2, BMRC, and GFDL GCMs under the IS92A scenario.

3.5.6 Conclusions

These findings, compounded by increased population growth and water demands, imply the following for future water resources in the Kordofan Region:

- Acute water stress could be experienced in the year 2060.

- In order to maintain the same water consumption ratio in 2060 as today, 1.9 additional bcm per year will need to be harvested from rainfall or seasonal stream-flow in 2060, for an annual total of 3.7 bcm.

- In order to maintain the same per capita water consumption in the region, a large-scale water infrastructure development project to tap into remote water resources will be required, at great cost.

3.5.7 Adaptation

There is a need to develop adaptation options to confront the water-scarce future envisioned here. Since groundwater storage capacity is inadequate of meeting people's needs in Kordofan States, other methods of water harvesting and storing must be explored. The harvesting of rainfall water can be accomplished through different methods, traditional and advanced. Sudanese people in areas like Kordofan have developed over time valuable knowledge and techniques for rainfall water harvesting and storing for use during the dry seasons. Examples are numerous, e.g. growing of certain watermelon species and using the hollow stem of the Baobao trees for storing water during rainy season. In the traditional rainfed agriculture the construction of terraces for rainwater harvesting is a common practice, construction of Hafirs and dams is also traditionally practiced in much of Sudan. Most of these old practices been greatly improved in recent times, particularly after the emergence of the drought band desertification problem in the Sahel, which involved financial and technological transfers and encouraged research and development in the region. Improvement of storing capacity and the development of water management systems will be essential to expansion of these sorts of efforts.

In general, several adaptation measures need to be pursued:

- Development of water resource management systems,

- Harvest and storage of permanent and seasonal stream-flow,

- Policies to make water resource management an attractive career and field of investment.

- Public awareness, water pricing and tariffs, incentives for high efficiency and penalties for wasted water,

- Government allocation of water use revenues for water infrastructure development, rehabilitation and equipment maintenance,

- Reduction of water loss through improvements such as water conserving technologies in delivery systems,

- The use of drought resistant, high value crops, and

- Increased water research activities.

3.6   Conclusions of the Assessment

The findings of this first vulnerability assessment give cause for concern for Sudan's security in the face of changing climate. The three sectoral assessments suggest that, under even modest changes in climate, Sudan faces significant threats in terms of food security, export crop production, human health and water availability.

Currently reliant upon ecosystems that are, in many cases, fragile or degraded, the population of Sudan can ill afford the added challenge of increased ecological stress that climate change could bring. In Kordofan Region, the population is projected, by 2030, to be double the 1993 figure, suggesting a marked increase in socioeconomic pressure on food production, water use, health care systems, etc. The need for adaptive measures in the three sectors, and beyond, is urgent. Though preliminary in nature and in need of both refinement and more comprehensive inquiry, these findings can serve as a starting point for the critical work of adaptation assessment.

The Agriculture & Forestry results suggest that, in 2030 and 2060, the humid agro climatic zones shift southward, rendering areas of the North increasingly unsuitable for agriculture. Crop production is predicted to decline by between 15% and 62% for millet and between 29% and 71% for sorghum.

The most vulnerable groups are traditional rainfed farmers and pastoralists. The predicted population increase is inversely proportional to predicted crop production in the region. As a backdrop to this, increased temperature and variability in precipitation, combined with growing socioeconomic pressures are likely to intensify the ongoing process of desertification in the region and beyond. Under such a scenario, the area of arable land as well as the belt gum would decrease, and both local income and food security would drop, exacerbating the recurrent risk of famine.

This assessment suggests, as well, that people in Sudan could be exposed to significantly increased risk of malaria. Sudan currently exists on the outer fringe of Africa's zone of endemic malaria and, in addition to a stable level of disease incidence, is prone to periodic outbreaks. With the assessment tools used here, the risk of transmission potential in Kordofan is seen to rise distinctly. Following clear seasonal patterns, transmission potential jumps at points in 2030 and

2060 to nearly twice the baseline level, increasing the likelihood that the disease will be transmitted from the mosquito host to humans. Should these projections bear similarity to Sudan's future, not only would the overburdened health care system experience extreme stress but the disease would exact a heavy toll on local population.

The availability of water in Sudan, an extremely arid country, is a perennially critical issue. Many areas have no permanent surface water and must rely entirely on seasonal rainfall and groundwater. The risk of reduced groundwater recharge - either through decreased precipitation or increased temperature and evaporation - has grave repercussions for Sudan. In Kordofan Region, the increasing demands of a growing population in turn increase the cost of water extraction (the pumping of water from wells requires continuous financial support). As Kordofan's extraction rate currently exceeds its recharge rate, the system is unsustainable, ecologically and financially. According to the findings presented here, in a matter of years, water availability may be the most critical issue facing Kordofan. The water assessment shows that soil moisture declines under future climate change conditions. Water consumption, population growth, high variation in rainfall and the high rate of evaporation (due to the rise in temperature) are predicted to lead to a situation of water crisis. Of particular note, the results suggest that in the northern parts of the region the soil moisture deficit could be equivalent to the water holding capacity of the soil in 2060 - a situation of extreme water stress.

To address these problems with practical solutions, the government has the responsibility to face these problems jointly with the local community. The risk of water scarcity, for example, makes the development and of water management systems and water storage capacity essential. Policy makers, scientists, and stakeholders must be partners in these adaptation activities and in Sudan's larger response to climate change.

3.7   Areas of Further Inquiry

This report is intended to serve as the first phase in an ongoing process to clarify the risks associated with climate change in Sudan, and to identify options for response. Additional work will be undertaken in the following subsections.

3.7.1   Agriculture & Forestry

The resources and time allocated to the study were tailored to fit the preliminary issues report on V&A, required for the National Communications. As local capacity and expertise in the field were limited, much of the work thus far has been based on analogue (historical and spatial trends) and expert judgment. However, as described here, the team has made use of several sophisticated modeling tools and has laid the foundation for more in depth future inquiry. Drawing on this enhanced capacity, the following are recommendations for future work:

- Similar studies should be undertaken in Darfur and Kassala regions, as they share many characteristics with Kordofan, and may face similar levels of vulnerability.

- The findings of this study should be used as a platform for interaction, research and discussion among the triad of policy makers, scientists and stakeholders.

- The issue of climate change and its potential impacts on the exposure units should be shared and explained within government ministries, in schools and universities, at the local community level, etc., as part of a broad awareness building exercise.

3.7.2   Malaria

The malaria vulnerability assessment has been limited by the lack of available public health data in Sudan. While data on malaria incidence may not be available in the near term, it would be possible in subsequent phases of activity to research and develop local values for use in vector-borne disease modeling. By defining parameters to be more reflective of local conditions, the usefulness and accuracy of malaria vulnerability assessment may be increased.

3.7.3   Water Resources

The assessment of water resources presented here is considered preliminary; subsequent analysis will need to refine the methods in order to better assess the vulnerability of water resources.

Rainfall is the main contributor to the water resources of large parts of Sudan where the traditional and mechanized agriculture are practiced. Meteorological observations of the last several decades show an overall declining trend in rainfall, and an increase in the number of dry years (below average rainfall). During the last two decades, the rainfed areas in western Sudan (Kordofan and Darfur States) have witnessed many periods of drought, severe enough to cause crop failure and significant loss of livestock. The human population in such areas is mainly dependent on rainfed water sources for their livelihoods. Fully assessing the vulnerability of water resources in these areas is considered crucially important among Sudan's national priorities. The results produced in this first phase of work are considered foundational for more comprehensive future investigation.

3.7.4   Adaptation Assessment

Adaptation is an area that will need to be more rigorously explored during subsequent phases of activity. Data has been collected on traditional responses to climate variability, laying the groundwork for this component. For example, studies show that rainfall over most of central Sudan (the primary crop production area), is becoming increasingly variable and is fluctuating considerably around the mean. As mentioned above, food production and security is mainly determined by rainfall. Over recent years, traditional farmers, living under such variable conditions, have developed strategies that allow them to tolerate crop failure in some years and to cope, to an extent, with variability in rainfall. Such "autonomous adjustments" are an important phenomenon, but one that is poorly understood.

Next, technology and research will be closely examined in an attempt to identify possible adaptation options - particularly research into other adaptation experiences in the region. Clearly, identification of adaptation options will pose new challenges in great many sectors. Public health professionals, for instance, will require the analysis of complex interrelated climate variables in order to determine how a population might best respond to increased malaria risk. The process of identifying these options will rely on the complete findings of this phase of work.

3.7.5   *Social and Environmental Baselines*

The impacts of climate change and the impacts of social and environmental baseline processes (i.e., those that will occur in the absence of climate change) may serve to compound one another. In the future, a more in-depth look at these relationships will need to be undertaken in Sudan.

For instance, the Gum Arabic Belt - a typical example of multipurpose forest use in Sudan - is a site of intense, diverse and often conflicting human activities.   These include irrigated agriculture, mechanized rainfed agriculture, forestry, and grazing.   As a result of its numerous uses, the annual consumption rate of woody forest products far exceeds the allowable cut.[12] This social and environmental backdrop may serve to reduce the ecological resilience - and thus adaptability - of Sudan's natural systems to the pressures of climate change, thus enhancing the impacts.   Similarly, changes in precipitation and temperature may cause shifts in vegetation zones, potentially exacerbating baseline environmental processes such as desertification.   In order to account for these effects, additional work will need to be done in the development and use of baseline scenarios.

---

[12] Consumption is approximately 16 million cubic meters annually, while the sustainable cut is approximately 11 million. At present, vast areas of forest cover have been completely cleared, with only scattered, isolated patches of natural forest remaining outside the forest reserves.

4 Greenhouse Gas Mitigation Initiatives

This chapter provides an overview of the initiatives envisioned in both the energy and non-energy sectors to reduce or sequester greenhouse gases. Given the imperative for Sudan to continue in its development trajectory, it is expected that greenhouse gas emissions will increase despite ongoing efforts by the government to promote sustainable development, such as better resource management practices and local environmental protection. While the measures discussed in this chapter will focus on the potential of various technologies and practices, it is clear that to achieve the results laid out in this chapter will also involve a certain number of parallel institutional, regulatory, and financial initiatives. The following discussion lays out viable measures that could be implemented in the near to mid-term in Sudan, first in the energy sector and then in the non-energy sectors, for achieving concrete and enduring greenhouse gas reductions.

4.1 Mitigation Initiatives in the Energy Sector

Sudan's ratification of the UNFCCC commits it to submit National Communications on national programs and measures to respond to climate change. One of the key responses that Sudan can make is to identify a set of appropriate options that can reduce its emissions of greenhouse gases in the energy sector. This first half of the chapter summarizes a national-level analysis of a set of mitigation options in the energy sector and lays out major opportunities for reducing GHG emissions in the energy sector in Sudan.

The period considered in the assessment was from 1995 through the year 2025. Two plans were considered: a "Base Case" assuming business-as-usual assumptions, and a "Mitigation Case", with a set of initiatives described below that have the potential to reduce GHG emissions. The Long range Energy Alternatives Planning System model (LEAP) (SEI-B, 2000) was used to integrate demand and supply mitigation options and calculate GHG emission reductions and associated costs. Additional details concerning methodological and process issues are described Volume II, Section 5.

4.1.1 Ongoing and Future Mitigation Initiatives Considered

In addition to the electric supply sector, five major energy-consuming sectors were considered in the mitigation analysis. They are summarized below together with the measures that were considered in the analysis, a discussion of policies to encourage penetration in the Sudanese economy, and the targets chosen for the mitigation analysis.

Household sector: This sector comprises rural and urban households using energy for cooking, lighting, refrigeration, space cooling, and other domestic end uses. Major GHG mitigation opportunities are as follows:

- **Fuel Switching to LPG in Cooking:** Cooking with biomass fuels is a significant end-use in Sudanese households, both rural and urban. The increased use of LPG can help to reduce pressures on Sudanese biomass stocks that sequester carbon. LPG represents a reliable source of future domestic energy supply as in April 2000; the Khartoum Refinery started production, and has the capability of producing 500 tons/day of LPG.

Steps toward widespread dissemination of this technology are already underway in Sudan. In recent months, the government has implemented a number of policies to encourage the increased use of LPG in the household sector - the price was halved and the fees and customs on LPG stoves were decreased substantially. In addition, the government is encouraging any joint venture that could be established in the field of storage facilities, manufacturing and distribution of LPG cylinders, particularly small size and multi purposes cylinders.

While no major barriers are envisioned for a more widespread use of LPG in the Sudanese household sector, at the present time the distribution capacity is limited. In the year 2025, the use of LPG in the urban non-electric sub sector increases from a 50% share of household cooking in the Base Case to an 85% share in the Mitigation Case. In the rural electric sub-sector, the share of LPG increases from 30% to 67%. In the rural non-electric sub sector, LPG use doubles, from 25% to 50%.

- **Solar Cookers for rural households:** The use of solar cookers for rural households can help to reduce pressures on Sudanese biomass stocks and represents a reliable source of domestic energy. One of the major policy areas of the Ministry of Energy and Mining (MEM) is the dissemination of new and renewable energy technologies particularly in remote and rural areas. This includes the dissemination and promotion of solar energy (photovoltaic and thermal applications) in rural communities for household, educational and hygienic end-uses. The MEM is also conducting training of small entrepreneurs in manufacturing solar boxes for cooking purposes, and is encouraging the manufacture of solar collectors for utilization in community cooking in prisons, camps, etc.

While no major barriers are envisioned for a more widespread use of solar cookers in the Sudanese rural household sector, at the present time the distribution capacity is very limited. In the year 2025, the use of solar cookers in the rural electric sub sector increases from a 0% share of household cooking in the Base Case to a 3% share in the Mitigation Case. In the rural non-electric sub-sector, the use of solar cookers increases from 0% to 5%. Details of the phase-in schedule for this technology are summarized in Volume II, Section 5.

- **Efficient Electric Lighting:** Lighting is a significant end-use in urban Sudanese households. Lighting efficiency measures—including automatic controls for exterior lighting, higher-efficiency fluorescent lighting fixtures, ballasts, lamps, and controls, and particularly compact fluorescent lamps (CFLs) in place of incandescent bulbs—reduce lighting energy and peak power use.

The application of lighting efficiency measures, like other residential sector measures, require the supply of these technologies and the demand for the technologies by consumers to be built up at the same time. Lighting technologies could be a good candidate for in-country joint-venture manufacturing involving Sudanese and foreign firms, supported, for example, with purchase guarantees from the national electric utility. Compact fluorescent bulb and fixture manufacturing ventures have been proposed for and set up in other countries, with good results. In countries such as China, quality control has been identified as a major element in determining the success of adoption of CFLs in the residential sector.

Though compact fluorescent lamps use only a fraction (20 to 25 percent) of the electrical energy and power needed by incandescent bulbs to produce equivalent light output, and last many times longer as well, their high purchase price is a barrier to purchase in many households. A combination of an information campaign to tell households about the energy savings benefits of CFLs, plus some form of financial incentives such as rebates or give-aways are likely to be major components of an efficient lighting program in the Sudanese household sector. Working with lighting manufactures and lighting fixture retailers to make sure that efficient lighting products are made available and are prominently displayed is also important.

The major impediments to implementation of CFL technology in Sudan are likely to be the current low electricity tariffs, the high initial cost of many of the technologies relative to (for example) standard incandescent bulbs, and the current lack of availability in Sudan of the efficient lighting products themselves. In the year 2025, the use of CFLs in the rural electric sub sector increases from a 0% share of lighting in the Base Case to a 25% share of all lighting in the Mitigation Case. In the urban electric sub-sector, the use of CFLs increases from 0% to 50%.

- **Efficient Space Cooling:** Introduce higher-than-standard efficiency evaporative coolers in urban areas as a substitute for air conditioners for achieving reductions in peak power use. This is a very practical and readily acceptable technology for Sudan. Little in the way of incentives or special financing options will be necessary to encourage its penetration in the economy.

  The capability of Sudanese industry to manufacture air coolers is currently limited, so imports would be relied upon in the short term. The combination of low residential electric tariffs (relative to the costs of producing the electricity) and the restricted ability of many households to pay for expensive appliances are key barriers that will need to be considered in program design. In the year 2025, the use of evaporative coolers in the urban electric sub sector increases from a 0% share of cooling technology stock in the Base Case to a 25% share of all cooling technology stock in the Mitigation Case.

Commercial sector: This sector comprises business and governmental establishments using traditional and commercial energy resources in buildings. Major GHG mitigation opportunities are as follows:

- **Efficient Electric Lighting:** Though small relative to other sectors, lighting is a significant end-use by commercial, government, institutional, and religious-sector consumers, the street lighting sector, and both new and existing buildings and installations. Lighting efficiency measures, including fluorescent and compact fluorescent light bulbs, advanced street lighting and traffic signal bulbs, light fixtures, reflectors, and ballasts, and lighting controls such as automatic occupancy sensors and dimmers, will reduce energy use. Also, reducing lighting energy use often has the important side-benefit of reducing air conditioning loads.

  A combination of incentives (such as rebates) to consumers to make the purchase of advanced lighting products less costly, plus equipment supply-side measures such as encouraging vendors to import more efficiency lighting equipment (or joint ventures to

manufacture such equipment in-country) will be necessary. Possibilities for incentive programs to small businesses could include programs with fixed incentives (for example, a set of specific rebates on the purchase of certain types and sizes of bulbs or ballasts) or a "custom" rebate program where the utility's rebate to the consumer is related to the amount of energy or peak saved (or estimated to be saved) by the customer, and to the costs of achieving those savings. For larger-volume consumers such as government buildings, hospitals, or large hotels it will likely be useful to offer a program of "energy efficiency audits" followed up by contacts from the utility or by private contractors to encourage the consumer to undertake some of the identified efficiency improvements, and to offer help (financial and/or design assistance) in making improvements. Marketing of a commercial/institutional lighting program might be done through trade and religious organizations, equipment vendors, and directly to government agencies in Sudan.

As with many of the residential-sector programs, the lack of availability of higher-than-standard efficiency lighting equipment in Sudan will pose a constraint, at least at first, on the type of program identified here. A more serious constraint, in the short run, is likely to be the lack of trained individuals who can identify commercial-sector opportunities (including lighting efficiency opportunities), and of vendors and installers who can implement changes to improve energy efficiency. A concerted program of training of Sudanese personnel to fill these energy service provider roles is an important topic for international and bilateral assistance, in combination with initiatives by Sudanese government agencies. The generic constraints of lower-than cost (or, in the case of the religious sector, no-cost) electric tariffs and the lack, for many businesses and agencies, of the capital to finance efficiency improvements, are elements that will have to be considered in program (and rate) design, just as is the case in the residential sector. In the year 2025, the use of CFLs in the government sub sector increases from a 0% share of lighting stock in the Base Case to a 50% share of all lighting stock in the Mitigation Case. In the non-government sub sector, the use of CFLs increases from 0% to 50%.

- **Efficient Air Conditioning:** Air conditioning a significant and growing end use in Sudan. Higher-than-standard efficiency air conditioning for commercial and institutional consumers, including higher-than-standard efficiency compressors, heat-exchangers, fans, control systems, and other associated equipment has the potential to reduce peak power use.

The goals and possible program approaches for this are similar to those applicable for commercial lighting measures. A combination of fixed and custom rebate programs may be necessary, given the diversity of different types of air conditioning equipment that are likely to be encountered. A program of audits by trained personnel (possibly trained through a follow-up enabling activity project) can be a great aid in identifying cost-effective efficiency upgrades. Equipment vendors will need to be included in the program in some way to ensure that high-efficiency equipment is available in Sudan in a timely manner.

In addition to the general impediments to program implementation identified in the discussion of the commercial lighting program above, it should be noted that, perhaps to an even greater extent than lighting equipment, air conditioning equipment is an integral part of urban buildings. As a consequence, building design plays a pivotal role in broadening or

narrowing the scope of potential energy-efficiency improvements for commercial and institutional air conditioning system. This connection argues for the national electric utility to be active in seeking out and working with architects and engineers that design and build commercial and institutional buildings, as well as the businesses and agencies that employ them.

In the year 2025, the use of high efficiency air conditioners in the government sub sector increases from a 0% share of cooling technology stock in the Base Case to a 50% share of cooling technology stock in the Mitigation Case. In the non-government sub sector, the use of high efficiency air conditioners increases from 0% to 50% of the total cooling technology stock

Transportation sector: This sector comprises on and off road vehicles using commercial energy for transport of passengers and freight. Major GHG mitigation opportunities are as follows:

- **High Efficiency Light Duty Vehicle Fleets:** Current annual passenger travel in Sudan is about 14 billion passenger-kilometers traveled, with nearly 80% in the form of public transportation of various kinds (buses and small vans). Introduce vehicles with higher fuel economy in public and private sector light duty vehicle fleets (i.e., government-owned vehicles, private taxis/courier vehicles).

  The goals and possible program approaches for this initiative would be similar to those applicable other measures. A combination of fixed and custom rebate programs may be necessary, given the diversity of different types of vehicles comprising the vehicle stock. Vehicle dealers will need to be included in the program in some way to ensure that high-fuel economy vehicles are available in Sudan. In combination with, several parallel strategies should be priority areas for government policy: development of transportation infrastructure (roads, telecommunications. etc.), encourage public transport and improve traffic flow, apply speed limits standards and fuel economy standards, encourage importation of technically efficient vehicles. The lack of coordination between Ministries of Energy and Transport and other counterparts could represent a significant barrier to implement the above-mentioned policies and programs. In the year 2025, the use of high efficiency vehicles increases from a 0% share of the total fleet in the Base Case to a 50% share of the fleet in the Mitigation Case for government gasoline/diesel cars, and gasoline/diesel private taxis.

Industrial Sector: Industrial energy use is distributed rather evenly across the sugar, food/oil, and cement sub sectors that account for over 70% of total energy consumed in the industrial sector. Most of the energy consumed in the industrial sector is in the form of residual fuel oil and bagasse for the production of process heat in the sugar industry. Motive power is also used extensively in each of the industrial sub sectors, with the greatest share corresponding to processes involved in the production of cement.

- **Efficient Electric Motors:** With their typically high capacity factor (running time per year), industrial motors are usually prime candidates for highly cost-effective efficiency improvements. This mitigation initiative would introduce higher-than-standard efficiency electric motors, in mostly larger sizes (tens to hundreds of kW), plus motor control systems

such as variable-speed drives, for use in a variety of industrial facilities, including private, semi-private, and ministry-owned factories.

Although it is possible to offer incentives in a program such as this that are tied to rated motor size (offering, for example, a specific rebate per kW of capacity of motors that exceed a threshold efficiency level), given the diversity of motor uses in the Sudanese industrial sector, a motors and drives audit program may be the most effective means of identifying energy efficiency opportunities. Engineers or other audit staff who are trained in assessing industrial motor and drive systems would visit industrial installations, look for opportunities to increase motor and drive (and related) system efficiencies, and report on opportunities to the manager of the facility. The facility manager, working with a utility representative (or contractor) and possibly a mechanical engineer, would then prepare a proposal for efficiency modifications, which the utility would (if the proposal is accepted) help to fund.

As many of the large industrial facilities in Sudan are currently operated by government ministries, it will likely be necessary to work with representatives of other industries to plan the participation of government-owned facilities in an industrial program such as this one, and to work out cost-sharing arrangements for efficiency improvements. For the private industrial sector, a combination of direct contact between the HCENR representative and the energy managers (and/or owners) of industrial facilities, plus distribution of news of the program through trade associations, might be approaches useful in program marketing. As with commercial/institutional electric motors, efficiency standards for locally manufactured and imported electric motors are also an option that Sudan may wish to consider as a means to increase the efficiency of industrial electricity use.

In addition to the generic impediments to demand side management efforts in Sudan (low electricity prices, lack of access to high-efficiency devices, lack of financing), industrial-sector measures like the one discussed here may face roadblocks or delays are a result of a division of authority between those responsible for delivering electricity and those responsible for planning its use in major industries. Coordination between ministries needs to be strengthened substantially if industrial sector programs are to be effective. Specific training of industrial energy managers in both identifying energy efficiency opportunities and in advanced techniques for plant operating and maintenance may pay large dividends in energy savings. Training of a corps of Sudanese engineers familiar with installation of high-efficiency motors and drive systems would also aid the success of industrial motors and drives program, and could be done through and with the cooperation of engineering faculty at Sudanese universities.

In the year 2025, the use of high efficiency electric motors increases from a 0% share of total electric motor stock in the Base Case to a 50% share of electric motor stock in the Mitigation Case for the food, textile, sugar, cement, and other industrial sub sectors. Details of the phase-in schedule for this technology are summarized in Volume II, Section 5.

- **High Efficiency Boilers:** Boilers are usually prime candidates for highly cost-effective efficiency improvements. This mitigation initiative would introduce higher-than-standard

efficiency boilers for use in variety of medium to large industries, including sugar factories, edible oil, refineries, sweets, soap, textile, corrugated board and bakeries.

To implement this program, representatives from each industry, both private and public, need to be trained in energy auditing techniques (e.g., steam measurement). This will help in the choice of actual boilers needed according to known standards. Workshops and training in energy auditing for selected personnel is a must in this sector.

Lack of awareness and training in the field of industrial energy audits is the major barrier in implementing this program. Also coordination is needed between the Ministries of Industry and Energy in giving licenses to different industries without putting energy consumption into consideration. By the year 2025, it is assumed that the average efficiency of the boilers used in the industrial sector will have achieved a 15% improvement relative to the Base Case in that year.

Electric Supply Sector: The assessment of fossil and renewable energy resources is a significant factor in identifying sustainable development paths in the electric sector. Large quantities of natural gas have been discovered on the Red Sea coast and while it is economically unfeasible to invest them currently, this is expected to change around 2010 and later. The availability of natural gas for use in electric generation is assumed. The primary mitigation initiative in the electric sector focuses on incorporating intermittent renewable resources. Advanced fossil technologies (combined cycle and combustion turbines) are also included.

- **Intermittent renewable energy capacity:** This initiative involves adding zero-carbon renewable resources to the electric system (solar thermal and wind turbines). At present, renewable energy has several unique attributes that put it at an advantage when compared to oil-based alternatives. However, in the present electricity planning context in Sudan, these attributes have not as yet been properly valued. Electric planning in Sudan has favored large, dispatchable power sources over decentralized, intermittent options.

  Using intermittent renewable energy technologies represents a departure from business as usual that will require new coordination among different institutional entities. Indeed, one of the key technical issues was how intermittent resources can be integrated in the electric system given system interfacing, stability, and operability concerns. While these issues will require further review for the specific circumstances posed by the Sudanese electric system, it is unlikely that they represent unsolvable technical problems.

  Renewable energy technologies span the range from developmental technologies currently in the prototype development stage, to fully commercialized technologies that have already made significant contributions to national electricity supply in other countries. Given the sizeable Sudanese solar resource potential, solar thermal hybrid systems (that is, with natural gas backup) are an important investment area. Also, as certain parts of the country have sizeable wind regimes that are close to expected future electric load centers; wind turbines were considered suitable in this initial mitigation assessment. For wind, a target of 400 MW by 2025 was chosen. For solar thermal, a total of 300 MW was added with the first units brought on line in 2015.

4.1.2   Impact of Mitigation Initiatives Considered

If implemented, the combined effect of the initiatives discussed above will substantially reduce overall emissions of carbon dioxide and air pollutants in Sudan. Taking the mitigation options across all sectors into account results in a significant reduction in carbon dioxide emissions, as shown in Figure 4.1.[13] For fossil fuel-based emissions, reductions total 7 million tonnes, a 17% reduction by 2025 relative to what emissions would otherwise be. An additional 12 million tonnes from biomass combustion, a 25% reduction 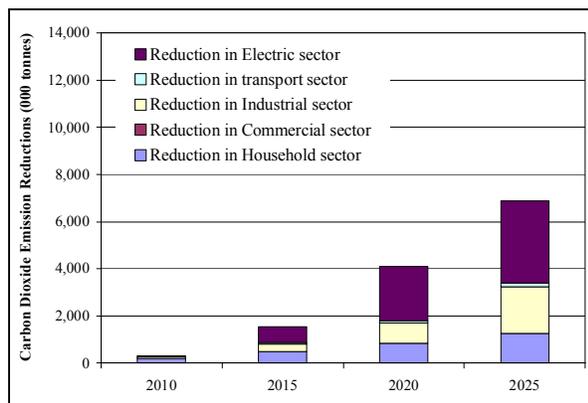by 2025, will also result. Total carbon dioxide emissions and reductions by sector are summarized in Figures 4.2 and 4.3. Detailed carbon reduction results by sector are provided in Volume II, Section 5.

Figure 4.1: CO$_2$ emission reductions
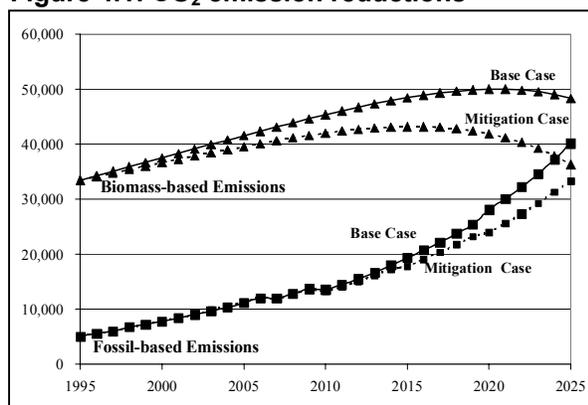
The incremental costs of supply side measures are more than offset by reductions in fuel costs on the demand side. Across all measures (i.e., both on the supply and on the demand side), the benefit-cost ratio is 1.54 indicating that the demand and supply side mitigation plans discussed will result in both reducing costs and reducing GHG emissions, freeing up valuable funds that could be expended on meeting important national development priorities.

Figure 4.2: CO$_2$ emission reductions by sector, fossil-based

4.1.3   Major Challenges and Follow-up

Preparation of this mitigation assessment for Sudan has helped to identify areas where resources will be necessary to develop a more in-depth mitigation assessment effort, where inter-ministerial links for information sharing need to be strengthened, and where institutional capacity and staffing (or sharing of staff for climate change activities) will need to be augmented. In preparing the mitigation assessment, it has also become clear that the implementation of a plan for Sudan will likely require a special organization. Each of these topics is addressed briefly below.

---

[13] Additional details concerning methodological and process issues are described in Volume II, Section 5.

Figure 4.3: CO$_2$ emission reductions by sector, biomass-based
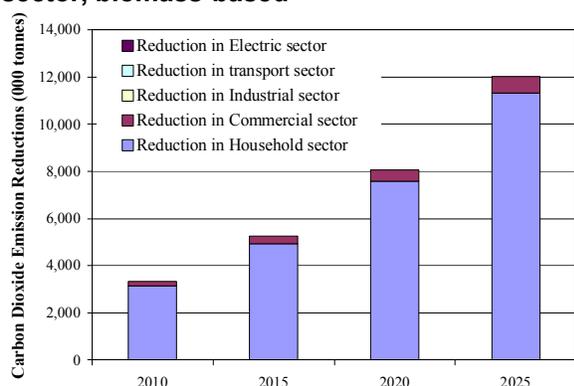
Integration Of Mitigation Options Into National Planning: As many of the elements of a mitigation assessment in Sudan across traditional ministerial boundaries, it is not clear, from an institutional coordination perspective, how all of the various elements of a mitigation plan could be implemented. Providing some clarity as to how the implementation of a mitigation assessment would be organized before the next phase of the process is undertaken would help with coordination of data gathering, as well as, for example, the design of demand side programs and plans.

Training In Energy Efficiency: Throughout the descriptions of Demand Side Management (DSM) programs presented earlier in this chapter, training in a number of different areas has been emphasized as a necessary ingredient to the provision of successful programs. Training of Sudanese professionals and other workers will be required in areas such as:

- Residential, commercial, and industrial energy surveys, including the measurement of appliance and equipment efficiencies,

- Residential, commercial and industrial energy audits,

- The computerized modeling of energy flows in buildings and factories,

- The analysis of DSM measures, plans, and programs,

- Preparing detailed designs for DSM programs, including design of program monitoring and evaluation,

- Implementation of DSM programs,

- The efficient operation and maintenance of building energy systems, including building energy control systems,

- DSM-related billing and metering systems, including load control systems,

- The specification and installation of energy-efficient appliances and equipment, and

- The manufacture of energy-efficient appliances and equipment.

Sudan's colleges, universities, and other educational institutions provide a resource that could be built upon to accomplish training in many of the areas above, although a combination of in-country training and study tours abroad will likely be needed for some of the more advanced and technical topics, particularly in the next few years, as the HCENR "ramps up" (builds) its mitigation assessment efforts.

Assessment Of Local Renewable Resources: The amount of site-specific data on renewable resources is quite limited at this time in Sudan. While a wind atlas has been developed, it provides average values for wind speed and does not contain the type of information (such as seasonality, minimum/maximum speeds, and wind speed height profiles) that would be needed for detailed planning. Additional information on renewable resources such as micro-hydro potential, diffuse solar radiation, and landfill methane would be of value in future GHG mitigation assessments.

Development of Energy Information Networks: Only the most modest and limited surveys of energy end-use in Sudanese homes, businesses, institutions, and industries have been carried out to date. In order to inform many elements of future mitigation assessments, as well as for many other forms of energy planning, it is essential to better understand how energy is used in Sudan. To that end, it will be important to plan and implement a number of comprehensive end-use surveys in a range of different sectors, complemented by a combination of end-use metering and energy audits for larger buildings and for industrial facilities. Arrangements should be made for the data compiled in the surveys to be systematically assembled in a data bank at the HCENR that can be accessible to all ministries who might benefit by using the survey information. A standard general survey approach, such as those used by groups within the UN and the World Bank, should be employed, though customization of the survey instrument and surveying methodology to suit Sudanese conditions will of course be necessary.

4.2   Mitigation Initiatives in the Non-Energy Sector

Another response that Sudan can make under the UNFCCC is to identify a set of appropriate options to sequester carbon in non-energy sectors. In this section, opportunities in the agricultural, forestry, and rangeland sectors will be reviewed that both demonstrate the potential for augmenting national sinks for sequestering carbon emissions, and to contribute to sustainable development priorities. In contrast to energy sector options, which focus on reducing greenhouse gas emissions, non-energy sector mitigation options focus on increasing the carbon sequestered in available land resources.

The assessment covered the land area between latitudes 10° to 22° north (representing about 190 million hectares). Despite their great potential in forestry and rangelands the Southern States were not included in this assessment due to insurmountable data availability problems. As with the energy mitigation assessment, the period considered in this analysis was from 1995 (base year) to 2025. Carbon sequestration potential for the different mitigation options are cumulative values for the period 1995 through 2025. Two plans were considered: a "Base Case" assuming business-as-usual assumptions, and two mitigation cases.

The Comprehensive Mitigation Assessment Process (COMAP) computer model[14] was used to analyze the forestry and rangeland options and to estimate the potential for CO_2 sequestration and the associated cost and benefits. Additional details of the assessment are described in Volume II, Section 6.

---

[14] Developed by W. Makundi and Jayant Sathaye at Lawrence Berkeley National Laboratory in the USA.

4.2.1   Land Use Policy Context

Land is put to a variety of uses in Sudan. Of a total land area between latitudes 10° to 22° North of nearly 190 million hectares, there are nine major land use types as summarized in Table 4.1. As can be seen, nearly 50% is currently classified as desert land, with an additional 24% consisting of scattered trees and shrubs. Only 9% of the land is used for agricultural purposes.

Table 4.1: Land use in Sudan in 1995 (latitudes 10° - 22° N)

	Land use type	Area (Thousand hectares)	% of total
1	Forest land (above 10% crown cover).	7,890	4%
2	Scattered trees & shrubs	44,693	24%
3	Grasslands	20,110	11%
4	Wastelands	15,699	8%
5	Protected land (Sanctuaries and National Parks)	3,352	2%
6	Irrigated & Perennial	3,172	2%
7	Rain-fed Agriculture	14,070	7%
8	Others (Canals, Urban, Dams and Roads …etc.)	519	0%
9	Desert	79,878	42%
	Total	**189,383**	**100%**

Prevailing land tenure systems in Sudan greatly influence the exploitation of natural resources. The 1970 Unregistered Land Act of Sudan stated that all unregistered land (i.e., rangelands and other uncultivated or non-residential lands) is state owned, but local people have rights to its benefits. The current Comprehensive National Strategy (CNS), 1992 – 2002 calls for the reservation of 25% of total country area for forestry, rangelands and wildlife, in addition to the allocation of 5% and 10% of the area of the irrigated and rainfed agricultural schemes respectively for woodlots.

Sustainable land use management faces great challenges in Sudan mainly due to poor policy coordination across sectors (i.e., forestry, agriculture, range and protected lands). Additional factors include the absence of unified legislation, absence of high-resolution land use maps, inadequate consideration of the socio-economic factors, and weak implementation of the existing legislation and policies by the sectors. This land use context has led to serious environmental problems such as overgrazing, over cultivation and reduced land productivity which in turn have led to rural poverty, and rural-urban migration patterns that can not be sustained in the long-term.

In the absence of concerted efforts to address these issues, land degradation is expected to worsen over the next 30 years. Estimates of land use changes in the "Base Case" were made based on several assumptions regarding forest use, land converted to agricultural use, and urban area expansion. A summary of projected changes in land area by type is presented in Figure 4.4. As can be seen in this figure, forested land and trees/shrubs lands are expected to decline, all of which is due to conversion to agricultural purposes.

Figure 4.4: Projected land use change in Sudan, 1995-2025 (latitudes 10° - 22° N)
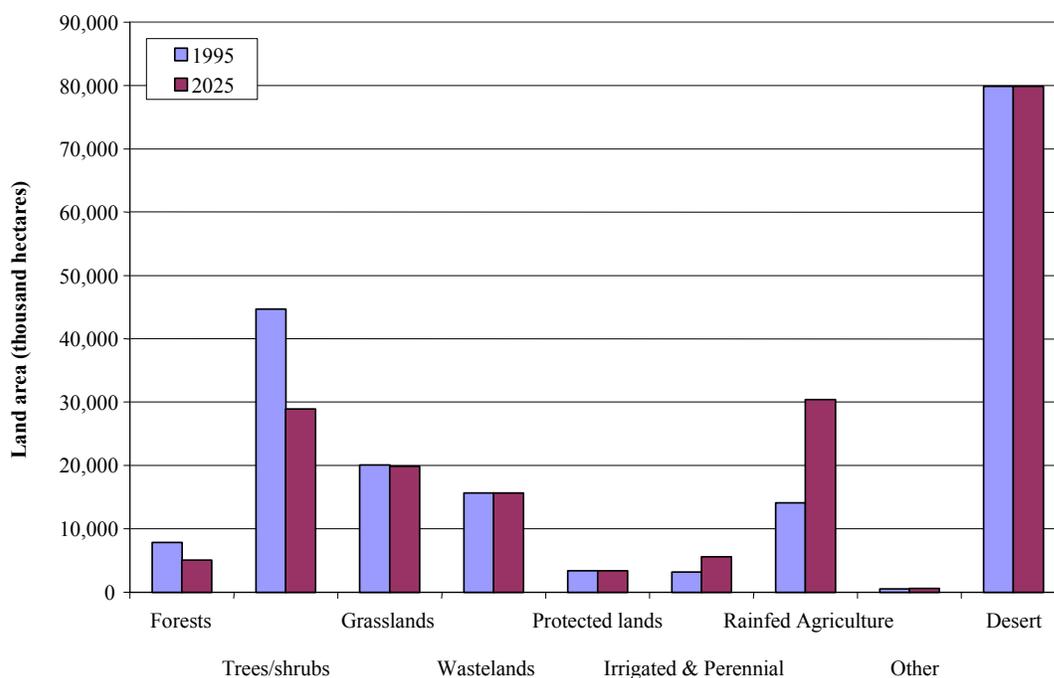
4.2.2   Ongoing and Future Mitigation Initiatives Considered

Two main groups of mitigation options were considered for increasing carbon sequestration and storage. The first group represents *afforestation and rehabilitation* options. These options refer to the afforestation and rehabilitation of wastelands, together with afforestation of 10% of the rain fed land and 5% of the irrigated agricultural land, which are being implemented anyway, as stated in the Comprehensive National Strategy (1992-2002). The second group represents *management* options, which involve a natural resource management approach based on the conservation and rehabilitation of degraded forests and rangelands.

Afforestation and Rehabilitation Options: These options expand the biomass stock on available wastelands and agricultural lands.[15] To determine an appropriate intervention level, it was necessary to first assess national demand for forestry products, particularly woodfuel, and the requirements of national livestock herds for animal fodder. The satisfaction of these needs, together with achieving carbon sequestration targets, was considered an important development priority and a determining factor for the sustainability and the permanence of the carbon stored.

---

[15]   Agricultural land here refer to the 10% and 5% of the rainfed and irrigated agricultural land as specified in the Comprehensive National Strategy (1992-2002)

In species selection, several factors were considered, namely ecological, socioeconomic factors and the interrelationship between the forestry and the rangeland uses. For the most part *Acacia spp* were selected for afforestation of wastelands. Either *Acacia senegal* (Hashab) alone or in mixed forms with *Acacia seyal* (Talih) was also assessed. For irrigated and rain fed agricultural lands, *Eucalyptus spp* and *Acacia spp* were considered respectively. In the rain fed lands, Talih and Hashab were assessed in monoculture or in mixed forms with other *Acacia spp.*

For rangelands, several options were considered including rehabilitation practices, tree planting (mainly fodder trees) and reseeding of associated grass *spp*. A combination of *leguminous spp*, perennial grasses were considered for establishing a form similar to the natural form of scattered trees and shrubs as this combination is considered to be a more productive form of rangeland. For grasslands, three forms were proposed according to the present strategy of the pastoral sector development: open rangeland (i.e., a combination of grass mixture, leguminous and cultivation), grazing reserves & allotment (i.e., grass mixtures, tree and shrubs), and ranching (i.e., grass mixture and cultivation).

Management Options: Improving forests and rangeland management in Sudan is already known to be an urgent need to conserve remaining forest and range areas, improve their stocking density (carbon stock) and hence their productive capacity. Quite apart from carbon sequestration concerns, serious measures should be taken to halt the unsustainable use of these resources. Government options currently under consideration include revision and updating of current policies and legislation, development of sustainable management plans with adequate considerations for relevant stakeholders.

Management strategies should include rehabilitation, reforestation (e.g. enrichment planting), protection, and sustainable utilization measures. Eight million hectares of forest reserves are proposed to be brought under a proper management system during the period of this scenario. For range ecosystem conservation, it is difficult to implement under the open grazing systems practiced in Sudan, unless it is coupled with a strong extension program and suitable corrective measures for range protection and management. Such options may include; proscribe burning, application of range management systems in existing grazing perimeters and protection and management of some grazing region.

4.2.3 Implementation Modalities

Implementing the above mitigation options during the specified period of the scenarios (30 years) will require a coordinated effort across affected ministries, a favorable institutional and legal environment, and adequate technical and financial capacities. Current policies and legislation represent a significant barrier to implementation, particularly on land tenure and land use issues.

Indeed, the security of land tenure arrangements and land use rights are considered to be the most important challenges to sustainable resources use. There are widespread ambiguities and uncertainties in laws governing land tenure and use. Although each sector has its own policy, the absence of integration between these policies, lack of clearly defined mandates and responsibilities, and the piece meal nature of planning and implementation has created numerous problems, such as the expansion of agricultural area on the forest and range land areas.

At present there is a growing recognition within the government and other concerned institutions that these problems pose serious barriers to the implementation of any sustainable development schemes. Some efforts are being made to overcome these shortcomings such as the establishment of the Higher Council for Environment and Natural Resources as a coordination body for policies, legislation and strategic planning in the field of environment and natural resources.

Also, salutary policy and institutional reform is occurring such as the current forest policy and legislation that provides for the establishment of private, community and institutional forests, together with management rights. Unfortunately, these efforts are mostly fragmented, lacking the political recognition and support, and lacking the required technical and financial resource.

4.2.4   Potential of Mitigation Options

Potential carbon uptake and associated costs for each mitigation option, and for each land type is presented in Table 4.2. While these are preliminary results, they nevertheless clearly indicate that afforesting and rehabilitating wastelands and agricultural lands (10% of rainfed and 5% of irrigated), and improving management of degraded forest reserves and rangelands, show great potential for carbon sequestration. Regarding cost effectiveness indicators, almost all the land categories on which the mitigation options are applied have very attractive economics compared to many other countries -- all have very low initial cost and present value of costs per ton of carbon sequestered.

If successfully implemented, the combined effect of the initiatives discussed above will substantially increase the amount of carbon sequestered and stored in Sudan, as indicated by the values of the incremental carbon sequestered per hectare (see Table 4.2) calculated for the number of options applied on the land resources available under the different categories of land use in Sudan.

In addition, these options are expected to have substantial environmental and socio-economic benefits. Environmental benefits may include expanded vegetation cover, increased stock density of forests and rangelands, improved management and utilization of forests and rangelands. These in turn may lead to further benefits on biodiversity conservation, watershed protection, and on combating land degradation and desertification. Socio-economic benefits may include provision of forest products and grazing resources, opportunities for employment, saving in foreign reserves and general economic development.

Finally, carbon credits obtained from LUCF activities may provide opportunities for finance and joint investments.

Table 4.2: Carbon sequestration potential and cost effectiveness of forestry and rangeland GHG mitigation options

Mitigation Scenario	Existing Land Category	Mitigation Land Category	Mitigation Measure	Incremental Carbon Uptake (000 tC/ha)	Initial cost		Present value of costs		NPV of Benefits	
					$/tC	$/ha	$/tC	$/ha	$/tC	$/ha
Afforestation and Rehabilitation	Wasteland	Forest	Hashab	39.6	0.6	23	1.1	44	1.6	63
			Mixed Acacia (60%.Talih)	34.8	0.7	23	1.3	44	1.4	49
			Mixed Acacia (60%.Hashab)	38.8	0.6	23	1.1	44	1.4	54
	Wasteland	Rangeland	Scattered trees & shrubs	39.9	0.2	9	0.7	27	2.9	118
			Ranching	44.6	0.4	16	0.0	0	-0.9	-38
			Open range	33.5	0.3	11	1.2	41	2.3	76
			Grazing reserves	54.2	0.3	14	0.7	40	2.3	125
	Rainfed Agriculture	Rainfed Agriculture	Talih	34.4	0.7	23	7.4	256	3.7	129
			Hashab	42.2	0.5	23	6.1	256	3.2	135
			Mixed Acacia (60%.Talih)	36.5	0.6	23	7.0	256	3.6	130
			Mixed Acacia (60% Hashab)	39.3	0.6	23	6.5	256	3.4	131
	Irrigated Agriculture	Irrigated Agriculture	Eucalyptus	283.6	0.2	50	0.9	259	4.6	1,305
Management	Forest (>20% crown cover)	Forest (>20% crown cover)	Protection, reforestation & sustainable use	70.4	0.1	6	1.2	116	0.2	17
	Rangeland	Rangeland	Application Mgt. System	8.8	0.4	3	6.1	54	1.8	16
			Baga grazing reserve system	8.8	0.4	4	7.4	65	5.4	48

5 Towards A National Implementation Strategy

5.1   Sudan and Climate Change

Sudan's National Strategy to implement the United Nations Framework Convention on Climate Change (UNFCCC) aims at the integration of action to combat climate change and its consequences into national development activities. The development of a national GHG inventory and the assessment of mitigation and adaptation measures fulfill Sudan's commitments to the international community regarding the implementation of the objectives of the UNFCCC and the promotion of sustainable development (Agenda 21). More importantly, the National Implantation Strategy (NIS), as will be discussed in this section, is very much in line with current development priorities such as enhancement of food security, sustainable management of natural resources, improvement of human heath, and poverty alleviation.

The UNFCCC obliged developed nations to reduce levels of their GHG emissions. As a developing country, Sudan is not committed to a GHG emission reduction target. However, under the general commitments of the UNFCCC -- based upon the principal of common but differentiated responsibilities -- all nations, including Sudan, are encouraged to undertake a development path that limits growth of GHG emissions, and which is more sustainable in resource utilization and management.

As described in the previous sections of this National Communications, Sudan conducted a number of studies to assess its contribution to the global emissions of anthropogenic GHG, to assess the vulnerability of the different sectors to the impacts of climate change, to identify its options to mitigate GHG emissions, and to assess capacity building needs to support successful implementation of the UNFCCC. To pursue the main objective of the enabling activities capacity building project, these studies were conducted by national teams consisting of representatives from relevant sectors, supported technically by international and national experts.

The GHG inventory covered a number of sources and sink categories in five sectors namely energy, industrial processes, agriculture, land use change and forestry and waste management. Gases studied include CO_2, CH_4, N_2O, NO_x and NMVOC. The results of the GHG inventory in Sudan indicated that CO_2 is the most important greenhouse gas and represents more than 75% of total GHG emissions in Sudan. The main source categories for CO_2 emission are in the Land Use Change and Forestry (LUCF) and the energy sectors, which together account for more than 97% of total CO_2 emissions in Sudan. Other gases include CH_4 that is emitted mainly from the agricultural sector, and CO and NMVOC, which are emitted mainly from the energy sector.

These results may contain a large degree of uncertainty due to:

- **Data problems:** availability, computability, and accessibility,

- **Methodological problems:** limitation in the definition of sources, sink categories, lack of methods to estimate and manage uncertainties, lack of local emission and other coefficient factors), and

- **Technical capacity problems:** evolving relevant expertise, lack of facilities (computers and software).

Improving the quality of national emission estimates is crucial to the global assessment of the climate change phenomenon. This is why countries, even ones with relatively low emissions like Sudan, are obliged by the UNFCCC to submit regularly their best estimates of GHG emissions by source and removals by sinks, and to report uncertainties associated with these estimates. Sudan's contribution to global emissions of GHG in 1995 is estimated at 89,220 Gg of CO_2 equivalent. Relative to global carbon emissions in 1995 Sudan contributed less than a tenth of 1%, with net CO_2 emissions per capita of 0.7 tonnes.

The study on GHG mitigation opportunities aimed at identifying GHG mitigation options that can both serve national development priorities and contribute to the fulfillment of the general commitments of Framework Convention. Using the results of GHG inventory, the mitigation study focused mainly on the energy and the LUCF sectors as being the dominant areas where GHG emission reductions could be achieved.

In the energy sector a number of mitigation options were identified in five energy-consuming sectors, namely, household, commercial, transportation, industrial and electric supply. The analysis of the options indicated substantial potential for GHG emission reduction and/or avoidance in these sectors. This could be achieved by applying appropriate measures to improve efficiency at end-use and by promoting use of Renewable Energy Technologies (RETs). For the electric supply sector, the assessment of fossil and renewable energy resources is a significant factor in identifying sustainable development path. The primary mitigation initiative in the electric sector should focus on incorporating renewables and advanced fossil technologies.

If implemented, the combined effect of the energy mitigation initiatives will substantially reduce emissions of GHG and air pollutants. The study shows that the incremental costs of supply side measures are more than the offset by reductions in fuel costs on the demand side. Across all measures (supply and demand) the benefit cost ratio was estimated at 1.54, indicating that the demand and supply side mitigation options will result in both reducing national energy expenditures while at the same time reduce GHG emissions.

In the LUCF sector the analysis showed that all options for afforestation and rehabilitation of rangelands are possible for Sudan to both embark on a sustainability path and to contribute to national development priorities. The analysis of these options indicated that all options have a reasonably good potential for carbon uptake. Regarding the cost effectiveness indicators, almost all LUCF options have showed very attractive economics compared to other countries. All have very low initial cost and present value of cost per ton of carbon. Social and environmental aspects have also been weighed in the selection of the options. It is important to note, however, that important limitations were encountered during the analysis of the energy and LUCF mitigation options. Those limitation problems include:

- **Data issues:** availability, accessibility, and reliability of the data. Many assumptions were made to overcome the data availability problems.

- **Technical problems:** lack of adequate resources and institutional capacity, evolving technical capacity.

The third study of the enabling project focused on vulnerability and adaptation (V&A) to climate change. Sudan is particularly concerned with impacts of climate change, as the majority of its

land is quite sensitive to changes in temperature and precipitation. Besides its fragile ecosystems, Sudan has a weak infrastructure and economy. The country's inherent vulnerability may best be captured by the fact that food security in Sudan is mainly determined by rainfall and more than 70% of Sudan population is directly dependant on climate-sensitive resources for their livelihood.

Therefore, the vulnerability and adaptation assessment is considered a critical component of Sudan's response to the phenomenon of climate change and the UNFCCC. The main objective was to uncover the types of challenges that one region in Sudan, Kordofan State, may likely be facing in the not too distant future with regard to food security, water resources, and human health. This will help to inform what are some necessary national strategies and priority areas for intervention and adaptation.

The preliminary findings of this study[16] showed a southward shift of semi-arid areas into temperate agro climatic zones over the next 30 years. The impact of this trend is a shrinking in current crop production area. Also, projected crop yields at selected stations showed a decline from baseline yields ranging between 15% and 62% for millet and between 29% and 71% for sorghum. Of the crops studied, sorghum was found to be the one most adversely impacted. Gum Arabic yields are also predicted to decline region-wide between 25% and 30%.

Regarding water resources in Kordofan State, the study indicated a greater water deficit than in the baseline in the milestone years 2030 and 2060. This is due to a decline in projected rainfall and an increase in PET from temperature rise.

Regarding human health impacts, the study showed that there is likely to be an increase in transmission potential of malaria in 2030 and 2060, particularly in winter. The period and the risk for which the potential for malaria outbreaks will be longer and greater is from October to December. On the other hand, there are expected to be a lower number of cases during the period April-July due to an increase in temperature beyond the maximum tolerance limits of malaria parasites. The projected increase in malaria transmission potential, though not extrapolated into projected number of malaria cases, suggests that anticipated changes in temperature and precipitation due to climate change might alter current distributions and intensity of malaria in Sudan.

The experience learned from conducting the V&A assessment in Sudan reveals a number of limitations and information gaps. These include:

- Limitations with regard to suitability and applicability of models used in generating the climate scenarios and impact models used for assessing the different sectors.

- Limited expertise in modeling, long-term projections and computer model "know-now."

- Climate data limitations regarding meteorological data needed for constructing the baseline scenario, requiring the use of default data.

---

[16] This V&A assessment is considered a Stage I assessment, and deals mainly with first order impacts.

- Data gaps include incomplete historical records of climate, crop productions, disease incidences, etc.

- Agricultural and water resource data gaps: Gum yield per tree, relations between soil moisture, ground water recharge and other factors influencing recharge.

- Future socio-economic changes and their effects on the exposure are not well taken into account due to the lack of relevant expertise and methodological constraints.

- Adaptation measures not well defined and assessed due to lack of relevant expertise and methodological constraints.

5.2   Challenges and Opportunities

As has been discussed in this report, Sudan faces significant challenges related to reducing its annual level of GHG emissions. Over the past few decades, recurrent droughts, chronic food security problems, and regional instability have contributed to population displacement and an ongoing refugee crisis. Agricultural production takes place in vulnerable ecosystems that suffer from expanding desertification in the North where roughly half the population lives. Energy use is dominated by consumption of firewood and charcoal resources that are currently proceeding at unsustainable levels.

In the context of these challenges, increases in temperature and lower precipitation will have a severe impact on the country's ability to develop. This is true even though Sudan's contribution to world carbon emissions in 1995 was negligible, accounting for about less than 0.1% of worldwide emissions. However, the impact of global warming on Sudan's fragile ecosystems is expected to be disproportionately much larger. Consequently, it is imperative that government considers steps, on the one hand, to implement "no-regrets" adaptation options while on the other hand, reduce the growth in GHG emissions. Such steps will contribute to meeting the objectives of the UNFCCC while simultaneously addressing overall development priorities of the country.

Sudan has already taken steps to steer development activities towards a more sustainable path. The current 10-year (1992-2002) Comprehensive National Strategy (GOS, 1991) identified the pursuit of environmental protection as integrally related to goals for increasing population health and prosperity. A number of priority actions outlined in the plan are related, either directly or indirectly, to climate change. These include protection and development of the rural environment for sustainable development, rehabilitation/preservation of ecosystems for sustainable and renewable energy resources, and enhancement of environmental awareness among concerned groups.

Also, in recognition of the importance of environmental protection for sustainable development, the Sudan created the Ministry of Environment and Tourism, now the Ministry of Environment and Physical Development (MEPD), in February 1995, to oversee environmental management, with the task of developing policies that seek to integrate environmental protection into national development strategies. Priorities include raising public awareness, enforcement of environmental law/regulations, data collection, and encouraging the formation of voluntary organizations. The Higher Council for Environment and Natural Resources (HCENR), the key coordinating agency for the preparation of this First National Communication, continues to

remain active as a distinct department within the MEPD. Indeed, the HCENR, since its creation in 1991 by an Act of Legislature, has served as the central government organ coordinating efforts for the sustainable development of natural resources and environmental protection. Patronized by the President of the Republic and chaired by the Minster of MEPD, the Higher Council consists of a number of ministers and has placed special emphasis on addressing acute degradation, resource depletion, and chronic pollution.

However, in spite of the official recognition of the need to address the range of environmental issues facing Sudan, an action plan that focuses on the climate change issues -- and which builds on the results of the studies already completed in inventory development, vulnerability assessment, and mitigation analysis -- needs to be prepared. Underlying such a plan are the following premises:

- The strategy should involve a wide range of Sudan's People. Public input was solicited throughout the term of the enabling project activity and at the end-of-project workshop to help set national greenhouse gas reduction priorities.

- The strategy should recognize Sudan's uniqueness. There are many geographic, climatological, technological, economic, environmental, cultural, and other considerations that must be considered. In particular, Sudan's high dependence on agricultural activities, its intense competition for scarce development resources, and its largely biomass-based energy system should dictate the measures adopted to reduce emissions or enhance sinks.

- The strategy should identify specific mitigation and adaptation measures proposed. Of most value to the formulation of a national strategy are specific measures to pursue. Rather than a listing of vague intentions, the Plan should, as far as possible, outline specific investment areas.

5.3   Objectives

The overall goal of the UNFCCC clearly recognized the need and importance for developing and least developed countries to pursue sustainable development paths. It stated that, the target of stabilizing GHG concentrations in the atmosphere should be achieved within a time frame sufficient to enable the achievement of food security and sustainable development. Article 4 of the commitments is based upon the principal of shared but differentiated responsibilities between developed and developing countries.

The flexible mechanisms of Kyoto Protocol were mainly included to serve the dual objective of helping developed countries achieve their GHG reduction targets cost-effectively, and to help developing countries to pursue sustainable development. This clearly indicates that the participation of developing and least developed countries in global efforts to achieve the objectives of the UNFCCC should be closely linked to national development priorities.

The overall objective of Sudan's national implementation strategy is to promote sustainable development paths that improve Sudan's adaptive capacity and limit its growth in GHG emissions through integration of climate change issues and concerns into national policies, strategies and development plans. Specific objective include:

- To improve scientific knowledge and understanding of climate change and its potential consequences in Sudan,

- To build an enabling environment to integrate climate change issues and concerns into national development (capacity building, institutional infrastructure),

- To raise stakeholder awareness,

- To identify and build synergies with other conventions and agreements (coordination),

- To develop a national climate change adaptation program, and

- To develop a national GHG mitigation program.

5.4   Recommendations for Broad Actions and Programs

5.4.1   Establish a Climate Change Coordination Unit

This unit will be charged with responsibility of supervising and coordinating the implementation of the national strategy and all climate change activities in Sudan. It should be situated within the Higher Council for Environment and Natural Resources with a permanent secretariat office and National Climate Change Committee to be formed from representation of all relevant institutions. The climate change unit should also coordinate sub-regional, regional and international participation of Sudan in various climate change events. Adequate resources, technical and institutional capacities should be provided to this unit to enable it to perform its duties effectively.

5.4.2   Continue to Strengthen institutional infrastructure

It is critical that climate change focal units be identified and established within the related sectors. Adequate technical and institutional capacity should be built within these units. Roles and obligations of focal units should be clearly defined and political commitment and government support for this structure should be obtained. Effective coordination mechanisms should be established to link focal units with climate change coordination unit in the HCENR through regular meetings and web-based networks.

5.4.3   Create a climate change information and database center

This first involves the identification of required data and useful sources. Subsequently, it would involve establishing mechanisms for data collection and reporting, training on methods and techniques of data collection, reporting and management, research to fill data gaps, and the integration of climate change data needs into the normal reporting systems for relevant institutions. The creation and maintenance of a well-designed web-based database will facilitate access to climate change data.

5.4.4   Implement a Strategic Training Program

It will be important to augment the training program of the past three years with targeted training that can best serve to deepen national capability in conducting analyses, as well as equip Sudan

to attract investments in climate change projects. A training strategy should be carried out among key audiences where training can help advance a national consensus for climate change in Sudan. Training courses, workshops, and seminars should be identified and designed to complement the other activities of the HCENR. Training will be an integral part of conducting the HCENR's other activities and should be designed through extensive collaboration with counterparts from government, industry and NGOs.

5.4.5   Strengthen National Consensus for Climate Change Action

An outreach and training program should be developed that supports efforts in building national consensus. The HCENR's outreach component should provide access to national and international climate change information and conduct a series of roundtables, business dialogues and meetings to help foster a better understanding of climate change, stimulate public discussion on key issues, and catalyze project development efforts in Sudan. Information dissemination on national policies, strategies and international cooperation should also be supported through the maintenance of a national climate-related web site as well as through traditional channels such as journals, press and other media. Emphasis should be on the following:

- **Industry Network on Climate Change:** An Industrial Council should be created that will raise awareness among national stakeholders in key sectors about the economic opportunities of GHG emissions reduction projects. Ideally, the Council should support policies and programs for international cooperation on climate change, the use of market mechanisms and encourage voluntary actions to reduce GHG emissions through the implementation of energy efficiency, agroforestry management, and other GHG projects and programs.

- **NGO Network on Climate Change:** Public awareness activities of NGOs in Sudan should be supported by providing climate change specialists as speakers for NGO events, routine newsletters on Sudan's climate change program and activities, access to library and internet resources, and identifying opportunities for joint events.

5.4.6   Improve the Quality the National Inventory of GHGs

It is important that Sudan's national GHG emissions inventory be reliable and up to date. Such as greenhouse gas emissions database is a prerequisite for compliance with the Framework Convention, and is vital to Sudan's ability to identify investment opportunities for mitigating emissions or enhancing sinks. In the near-term, the highest priority areas are to strengthen the institutional structure for carrying out future assessments, and to develop emission factors that better represent Sudanese conditions. In the mid- to long-term, the highest priority areas are to address the gaps in the data available in the energy, industrial, agriculture, and waste sectors.

5.4.7   Implement Cost-Effective Measures in the Energy Sector

In 1995, Sudan consumed over 400 million GJ of energy, which resulted in the emission of 35 million metric tons of carbon dioxide. Biomass energy consumption is responsible for over 80 percent of total carbon dioxide emissions. Investing in energy efficiency is the probably one of the most cost-effective way to reduce carbon dioxide emissions. The National Plan should stimulate the deployment of existing energy-efficient technologies and accelerate the

introduction of better technologies. These programs will cut emissions while improving the quality of life and enhancing productivity

The mitigation analysis has shown that profitable energy efficiency investments exist in the household, commercial, and industrial sectors. These opportunities are currently going unrealized because of information, regulatory, institutional, and other barriers. The following areas are key targets:

- **Government:** The government should lead by example by developing new procurement policies that encourage the use of a) high efficiency compact fluorescent lamps in place of incandescent lamps, b) high efficiency light duty vehicles that reduce fleet fuel consumption, and c) high efficiency air conditioning units and load controllers to reduce peak electric power use.

- **Households:** Sudan should develop policies and incentives for encouraging the switch to the use of LPG in the place of inefficient wood and charcoal stoves in rural and urban areas. Also, the government should encourage the use of efficient stoves and solar cookers in rural areas that have limited access to biomass supplies.

5.4.8   Implement Cost-Effective Measures in the Non-Energy Sector

Expanding biomass stock (forestry and rangeland) into wasteland and agricultural land (10% of rainfed and 5% of irrigated), together with the option of improving management of forest reserves, showed great carbon sequestration potential. These options have attractive cost structures with very low initial capital costs and low net present value per ton of carbon saved. The government should implement some of these programs anyway, as these options are expected to have substantial local environmental and socio-economic benefits. Environmental benefits may include expanded vegetation cover, increased stock density of forests and rangelands, improved management and utilization of forests and rangelands. These in turn may lead to further benefits on biodiversity conservation, watershed protection, and on combating land degradation and desertification. Socio-economic benefits may include provision of forest products and grazing resources, opportunities for employment, saving in foreign reserves, and general economic development.

5.4.9   Implement a Specific Set of Near-term Policies

The above set of recommendation is general in nature. In contrast, there are several near-term policy and program steps that the government of Sudan should take as a follow-up to its First National Communications. They are as follows in the bulleted list below. In addition there are several specific ideas for projects and assessments, as summarized in Table 5.1.

- Develop a unified land use policy and take legislative action as necessary,

- Improve research on diversity and the value of some resources,

- Reform land tenure policy as well as policies on shared responsibilities and benefits among all stakeholders,

- Encourage technology transfer, through incentives and barriers removal,

Table 5.1: List of potential projects and assessments to be considered in the near future

Project Area	Project Type
Observation networks	Detailed natural resources inventory study
	Development of a national land use map
Land Use, forestry, and agriculture	Afforestation and reforestation program for waste degraded lands
	Improvement of timber harvesting techniques
	Rehabilitation & sustainable management practices for degraded rangeland
	Application of proper resources management (existing forest reserves and rangelands sites)
	Application of sustainable agriculture methods
Energy Production and Use	Energy auditing in the industrial sector
	Replacing biomass fuel with higher energy density fuels in sectors of household, bakeries and brick-making industry
	Mini and micro hydro generation of electricity in high-potential areas of Sudan
	Introduction of solar cookers in household and services sectors
	Introduction of new building techniques to improve natural ventilation and air-conditioning in household and commercial buildings
	Energy conservation in the transport sector

- Electricity generation from geothermal resources in Sudan.

- Apply and enforce the Environment Protection Regulation in Petroleum Industry, to minimize pollution,

- Conserve energy and encourage the use of high efficient appliances and equipment,

- Reduce losses in production, transportation and consumption of energy (petroleum products & electricity),

- Switch from the use of traditional fuels (firewood & charcoal) in the household, industry and commercial sectors to more efficient fuels,

- Reform the energy pricing policy in such a way as it encourages the use of more efficient technology,

- Intensify the dissemination of information about renewable energies, particularly solar in remote and rural areas,

- Strengthen energy research in the field of R&D,

- Encourage the introduction of more efficient means of transport, especially mass transport,

- Redesign the construction of roads and rehabilitation of the existing roads in order to reduce annual vehicle miles traveled,

- Allocate financial resources to carry out additional V&A assessments in the Darfur, Kassala, and El Gadaref regions as they share many characteristics with Kordofan and may face similar levels of vulnerability. Include the Northern Region as well as it is particularly vulnerable to climate variations and climate change since the wheat crop cultivated in winter is only feed crop and will be affected by the rise in temperature,

- Strengthen the national database of relevant centers: i.e., increase, rehabilitate, and upgrade the meteorological stations that provide the required data particularly in the most vulnerable areas,

- Use the findings of this study as a platform for promoting discussions among the network of policymakers, scientists and stakeholders,

- Promote awareness of climate change and its potential impacts within government ministries, in schools and universities, and at the local community level, and

- Continue to build and strengthen human capacity (training) indigenous knowledge; the NGOs should be fully involved in such activities.

6 List of References

Chapter 1: Sudan's National Circumstances

Awad, N., ((1999)). *National Environment, Baseline of Vulnerable Sectors*, Khartoum, Sudan.

Centre of Strategic Studies, *Sudan Strategic Reports,* 1996, 1997, 1998, Earth Summit.

Elfaki, J. and Elgizouli, I., (1996). *Energy Utilities and institutions in Africa, (Sudan Case)* AFREPREN, Zedd Books, England.

ElSadig, M., (1999). *Human Health: Baseline of Vulnerable Sectors*, Khartoum, Sudan.

Elshiekh, S., (1999). *Agriculture, Baseline of Vulnerable Sectors,* Khartoum, Sudan.

Government of Sudan, (1991). *Sudan National Report,* submitted at the 1992 Earth Summit at Rio de Janeiro, Brazil.

Government of Sudan, (1993). *Annual Reports and the Fourth National Census,* National Statistics Bureau.

Government of Sudan, (1995). *Handbook of Forestry, Sector Statistics Study,* Administration of Statistics and Information.

Government of Sudan, *Agricultural Statistics and Outlook (Series)* Agricultural Statistics Administration.

Kaffi, S., (1999). *Climatic Data of the Sudan, Baseline of Vulnerable Sectors,* Khartoum, Sudan.

National Forests Corporation and FAO, (1995). *Forestry Products Demand Study*

Osman, E., (1999). *Water Resources, Baseline of Vulnerable Sectors,* Khartoum, Sudan.

Osman, G., (1999). *Energy use in the transport sector,* Proceedings of the Greenhouse Gas Mitigation Workshop, September, Khartoum, Sudan.

World Bank (1993), *Sudan Forestry Sector Review*. Washington, D.C.

Chapter 2: Greenhouse Gas Inventory

NFC and FAO, (1994). *Forestry Products Demand Survey*.

Intergovernmental Panel on Climate Change (IPCC), (1996). *Revised Guidelines for National Greenhouse Gas Inventories*.

Chapter 3: Vulnerability and Adaptation Assessment

Climate Scenarios:

UNEP (United Nations Environment Programme) (1998). *Handbook on Methods of Climate Change Impact Assessments and Adaptation Strategy*.

Jones, P.D. (1994). "Recent warming in global temperature series." *Geophys. Res. Lett.*, 21, 1149-1152.

Agriculture & Forestry:

Barrow, Elaine, Abel Centella, Aston Chipanshi, Mike Hulme, Sarah Raper, Steve Smith, Tom Wigley (2000). *Climate Scenario Generator for Vulnerability & Adaptation Assessments.*

Bayoumi (1996). *General Forests Protection.*

Biswas, B, C. *Agro climatic Classification and Crop Potential.* India.

Census (1995). *Fourth population census of Sudan 1993.* Department Of Statistics.

FAO (1986). *Early Agrometeorological Crop Yield Assessments.*

F.N.C (1995). *Statistic Bureau Census Hand Book.*

GITEC (23 May 1980). *Gum arabic Development.* Final Report. Consult GMBH. Germany.

Gum Arabic Development Final Report (1980).

Kafi, S.D. *Meteorological Authority.* Sudan.

Mirghani, M. (1996). *Time Series of Cereals and Oil Crops (1970-1996).* Ministry of Agriculture and Forestry. Sudan.

Mohamed, M.A. (1996). *Assessment and Mapping of Desertification in Western Sudan, Using Remote Sensing techniques and GIS.* Msc Thesis.

National Forest Inventory (1996).

Save the Children Federation (March 1988). *Baseline Report.* Um Ruwaba District, North Kordofan Province, Sudan.

Sudan Country Report (1999). HCENR

Survey (1995). *Consumption of Forests Products in Sudan.* Forestry National Corporation.

Williams, L. J. and Mendelsel, John (1998). *Evaluating GCM Output with impact models.* USA.

WMA and UNEP. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations.* CGER-1015.

Malaria:

Bradley, D., (1993). *Human Tropical Diseases in a Changing Environment,* in Ciba Foundation Symposium 175, Environmental Change and Human Health, Wiley and Sons.

Carter, T., Parry, M., Harasawa, H., and Nishioka, S., (1994). *IPCC Guidelines for Assessing Climate Change Impacts and Adaptation, IPCC/WMO/UNEP,* Oxford.

Economic Review (1994 - 1995). *General Administration for Macro policies and Program*.

Jetten, T., Martens, W. and Takken, W., (1996). *Model Simulations to Estimate Malaria Risk under Climate Change, Journal of Tropical Medicine and Hygiene, 57(3), 285-297.*

Le Sueur, D., (1991). *A climatic-based distribution model of malaria transmission in Africa. Ph.D. Thesis, University of Natal*.

Maharaj, R., (1995). *A climatic-based distribution model of malaria transmission in Africa. Ph.D. Thesis, University of Natal*.

Making a Difference (1999) *World Health Report*.

Martens, P., (1997) *Modeling the Impacts of Global Warming and Ozone Depletion: An Eco-Epidemiological Approach*

Martens, P., (1998) *Health and Climate Change: Modeling the Impacts of Global Warming and Ozone Depletion,* Earthscan Publications, Ltd.

Martens, P., (1999). *How will climate change affect human health*? American Scientist, 87, November-December, 534-541.

Martens, W., (1996). *Modelling the Effect of GlobalWarming on the Prevalence of Shistosomiasis,* RIVM Report No. 461502010, GLOBO Report Series No. 10, Dutch National Institute of Public Health and the Environment.

Martens, W., Jetten, T., and Focks, D., (1997). *Sensitivity of Malaria, Schistosomiasis, and Dengue to Global Warming.* Climatic Change 35, 145-156.

Martens, W., Jetten, T., Rotmans, J., and Niessen, L., (1995b). *Climate Change and Vector Borne Diseases: A Global Modelling Perspective.* Global Environmental Change 5(3), 195-209.

Martens, W., Niessen, L., Rotmans, J., Jetten, T., and. McMichael, A., (1995a). *Potential Impact of Global Climate Change on Malaria Risk:,* Environmental Health Perspectives,103(5), 458-464.

Martens, W., Rotmans, J., and Niessen, L., (1994). *Climate Change and Malaria Risk: An Integrated Modelling Approach,* RIVM Report No. 461502003, GLOBO Report Series No. 3, Dutch National Institute of Public Health and the Environment.

Martin, P. and Lefebvre, M., (1995). *Malaria and Climate: Sensitivity of Malaria Potential Transmission to Climate,* Ambio, 24(4), 200-207.

Matsouka, Y. and Kai, K., (1994). *An Estimation of Climatic Change Effects on Malaria,* Journal of Global Environment Engineering, 1, 1-15.

McMichael (1997). *Integrated Assessment of Potential Health Impact of Global Environmental Change: Prospects and Limitations*

McMichael and Martens (1995). *The Health Impacts of Global Climate Change: Grappling with Scenarios, predictive models and Multiple Uncertainties.*

McMichael, (1995). *Conceptual and Methodological Challenges in predicting the Health Impacts of Climate Change*

Ministry of Finance and Economic Affairs, (1985). *Desertification and the growth of urban fringe: A case study from Omdurman, Sudan. Ph.D. Thesis, University of Wales.*

Ministry of Health, (1998). *Annual Assessment Report*, Khartoum, Sudan.

Omumbo, (1998). *Mapping Malaria transmission intensity using Geographical Information Systems*

Patz, (1996). *Global Climate Change and emerging infectious disease.*

Smith, J. B., and D.A. Tirpak, (eds.) (1989). *The Potential Effects of Global Climate Change on the United States*. Washington, D.C.: U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation.

Viner D and Hulme M. 1992 *Climate Change Scenarios for the Impacts Community*: *Report of Workshop. 6-7 July 1992*, Climatic Research Unit, Norwich 34pp.

World Health Organization (WHO) (1995a) Annual Report.

Water:

El Toum, O., (1999). *Water Resources in Sudan.* Ministry of Irrigation. Sudan.

El Gizouli, I. and Goutbi, N., (1999). *Sudan Country Report*.

Centre of Strategic Studies, *Sudan Strategic Report,* 1997.

FAO (1986). *Early Agrometeorological Crop Yield Assessment*. Edition 73.

Raskin, P. et al., (1997). *Comprehensive Assessment of the Freshwater Resources of the World,* Tellus Report I7-PR02.

Salama, Ramsis B., (1976). *Groundwater Resources of Sudan.*

World Meteorological Organization (1995). *Long Range Forecasting of Hydrological Aspects of Drought for Tropical and Subtropical Regions*. No.530.

Senden, W., (1989). Water Resources Assessment and Development project in Sudan. Institute of Applied Geoscience, Netherlands.

Balgis, O. E., (1998). *Special Program for Food Security*. Doc1.

Chapter 4: Greenhouse Gas Mitigation Initiatives

Stockholm Environment Institute – Boston Center, (2000). Long range Energy Alternatives Planning System model (LEAP)

Makuni, W. and Sathaye, J., (1995) *Chapter 3: Comprehensive Mitigation Assessment Process (COMAP) – Description and Instruction Manual*, in Economics of Greenhouse Gas Limitations.

Chapter 5: Towards a National Implementation Strategy

Government of Sudan, (1991) *Comprehensive National Strategy (1992-2002)*